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ARTIFICIAL INTELLIGENCE APPLICATIONS IN SUSTAINABLE DEVELOPMENT SYSTEMS

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Abstract

Artificial intelligence has increasingly been positioned as a transformative mechanism within sustainable development systems, driven by its capacity to process complex datasets and support decision-making across environmental, economic, and social domains. Despite expanding applications, existing scholarship has inadequately addressed the interplay between technological deployment and regulatory coherence, particularly in comparative and governance-oriented contexts. This study examined the role of artificial intelligence in advancing sustainability objectives through a qualitative doctrinal and comparative research design grounded in interpretivist analysis. Primary legal materials and secondary scholarly sources were systematically reviewed, while comparative evaluation across jurisdictions enabled contextual assessment of adoption patterns and institutional responses. The findings revealed that artificial intelligence applications were significantly influenced by disparities in data infrastructure, regulatory fragmentation, and institutional capacity, limiting their effectiveness and scalability across regions. Variability in data availability and reporting standards further constrained predictive accuracy and policy reliability, while developed jurisdictions demonstrated greater capacity for optimization-driven applications compared to structurally constrained regions. The study contributed to scholarly discourse by situating artificial intelligence within governance frameworks, emphasizing the necessity of aligning technological innovation with legal norms, ethical principles, and standardized data practices. The analysis established that sustainable integration of artificial intelligence requires coordinated regulatory structures and context-sensitive implementation, reinforcing its role as both a technical and institutional instrument in advancing global sustainability objectives.

Keywords: Artificial Intelligence, Sustainable Development, Regulatory Frameworks, Data Governance, Comparative Analysis, Sustainability Systems

1. Introduction

Artificial intelligence (AI) has become a disruptive general-purpose technology that has profound implications for sustainable development systems, especially in the face of a growing momentum towards the United Nations Sustainable Development Goals (SDGs). The integration of data-driven approaches, computational capabilities, and algorithmic decision-making has facilitated novel types of analysis, prediction, and optimization in the realms of the environment, economics, and social life. In academic literature, the concept of AI is being increasingly discussed not as a technical resource but as a form of institutional governance that can transform the sustainability trajectories. Earlier literature focused on the potential of AI to promote efficiency and resource distribution, whereas in the more recent studies, AI is framed in the context of larger debates about digital governance, ethical responsibility, and the regulation of AI (Goralski and Tan, 2020; Kaack et al., 2022). Such a development echoes a move beyond techno-optimism to a more critical approach to the systemic prospects of AI implementation in the sustainability settings.

The convergence of AI with sustainable development systems in terms of doctrinal aspects can be viewed in the context of regulatory frameworks of data protection, environmental law, and accountability of technology. Straddling jurisdictions all over the world are struggling with the necessity to reconcile innovation and precautionary values, especially in climate modelling, optimization of energy use, and city management. Lack of uniformity in the regulatory regimes is a source of fragmentation, and it raises questions of algorithmic bias, transparency, and cross-border moves in data. Researchers have emphasized the contradiction between innovation-based development and the necessity to have a strong system of checks and balances in place to make sure that AI applications are aimed at achieving environmental sustainability goals, as opposed to enhancing inequalities and environmental harm (Al-Raei, 2024; Adegbite et al., 2024). It has thus been made the primary focus of sustainability studies, where explainability, accountability, and ethical design have become key issues of AI governance.

The practical applicability of AI in sustainable development is especially noticeable in the fields of environmental monitoring and the mitigation of climate change. The machine learning models have been shown to have the ability to act on large-scale geospatial and temporal data to make more precise predictions of environmental risks and adaptive policy responses. They can be used in tracking deforestation via satellites, predictive analytics regarding greenhouse gases and energy use (Bianchi and Putro, 2024; Ferreira et al., 2020). Simultaneously, AI-based optimization methods are being used to make renewable energy systems more efficient and efficient, reduce resource waste, and thus, with the help of decarbonization efforts, sustainable infrastructure development (Suci et al., 2025; Nnaji for et al., 2024). The latter developments highlight the ability of AI to make sustainability goals operational by providing actionable insights and real-time decision support.

Comparative dimensions also paint a picture of unequal regional and sector adoption and impact of AI. Advanced AI systems and data ecosystems are more likely to be used by developed economies, which will allow them to apply advanced applications in smart cities, precision agriculture, and industrial sustainability. Conversely, developing countries tend to be limited by data, technical, and institutional capabilities, which restrict the scalability of AI solutions despite large potential benefits. Such inequality prompts some crucial concerns about digital equity and inclusivity of AI-based sustainability programs. Agriculture and food security research, in particular, also shows how machine learning can maximize crop yields and market predictions, but also emphasizes the need to have access to quality data and technologies (Martinho et al., 2022; Patil et al., 2023). These comparative lessons support the necessity of context-sensitive strategies that consider the socio-economic and infrastructural variations.

The need to develop research in this field is rooted in the opportunities and risks of the integration of AI. Although AI promises to provide unprecedented functionality in dealing with multi-faceted sustainability issues, its application is not necessarily associated with sustainability itself. The problems of huge energy consumption of AI systems, ethical issues in automated decision-making, and the possibility of further consolidating systemic prejudices require a balanced and interdisciplinary analytical approach. The existing literature recommends focusing on aligning AI innovation with the principles of sustainability by integrating the policies and engaging stakeholders, as well as creating standard evaluation measures (Zaidan, 2023; Ramakrishna et al., 2023). In this respect, the current research is motivated by the fact that it critically analyzes the uses of AI in sustainable development systems and places technological developments in the context of wider regulatory and scholarly discussion, as well as covers a gap in comparative and governance-oriented research.

1.1 Objectives of the study

This work will evaluate how artificial intelligence can contribute to improving the systems of sustainable development through an analysis of its use in the environmental, economic, and social spheres. It aims to comparatively evaluate regional adoption rates, determine regulatory and technological issues, and explore the efficacy of AI-based solutions to meet sustainability goals, thus adding to a subtle comprehension of its transformative capacity and governance connotations.

2. Methodology

2.1 Research Design

This research followed a qualitative doctrinal and comparative research design to understand the purpose of artificial intelligence in sustainable development systems in the wider regulatory and academic contexts. The doctrinal aspect was utilized to analyze, in a systematic way, the available legal frameworks, instruments of policy, and scholarly literature to regulate the use of artificial intelligence in the sustainability-related fields. This methodology made it possible to interpret legal principles, institutional norms, and mechanisms of governance in a structured way, which influence the introduction of artificial intelligence into environmental, economic, and social systems. The comparative dimension complemented this analysis by assessing differences in regulatory reactions, technology adoption, and policy implementation across chosen jurisdictions and helped generate a contextual view of global differences and convergences.

2.2 Research Paradigm and Approach

This study was based on an interpretivist paradigm, as the legal and technological advances are socially constructed and context-based. The paper analyzed conceptualizations of artificial intelligence in the framework of sustainability and how regulatory agencies have reacted to its newfound implications. A critical examination of primary law documents was used as the doctrinal approach in the form of international agreements, national laws, and policy documents concerning artificial intelligence regulation, environmental concerns, data management, and digital innovation. Peer-reviewed journal articles, policy reports, and scholarly commentaries are considered secondary sources and were also analyzed in a systematic way to consider the changing academic views and theoretical discussions.

2.3 Comparative Method

The comparative approach was designed in terms of a purposive choice of jurisdictions that can represent various levels of technical and regulatory development. These were developed economies that had mature artificial intelligence strategies and regulatory systems, and developing regions where the implementation was still nascent, but which had strategic value towards sustainable development. The comparative analysis aimed to find similarities and differences between legal treatment of artificial intelligence regulation, especially within fields like data protection, algorithmic responsibility, environmental rules, and governmental innovations. This allowed the research to evaluate the effect of contextual elements, such as economic capacity, institutional preparedness, and socio-political priorities, on the process of artificial intelligence adoption and control in sustainability systems.

2.4 Data Sources

Secondary data sources formed the basis of the analysis. These included legislative instruments, regulatory frameworks, international conventions, and institutional guidelines related to artificial intelligence and sustainability, accessed through official government repositories, databases of international organizations, and publicly available legal archives. Additional sources comprised academic literature—peer-reviewed journal articles, conference proceedings, and review studies—covering the application of artificial intelligence in areas such as climate change mitigation, smart cities, renewable energy systems, and sustainable agriculture. Dataset evidence was also incorporated from global development indicators to support the empirical context, particularly the Sustainable Development Goals dataset provided by the World Bank (World Bank, n.d.). Source selection was guided by criteria of relevance, citation impact, and alignment with the research objectives, ensuring reliance on authoritative, current, and methodologically robust literature.

2.5 Data Collection Procedure

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Data gathering was done by a systematic review process whereby pertinent material was identified by specific searches on academic databases and institutional repositories using specific keywords. The search terms were compound ideas based on the concept of artificial intelligence, sustainability, regulatory frameworks, and comparative analysis to guarantee a thorough coverage of the topic. Inclusion criteria were put in place to favour sources that specifically covered the intersection of artificial intelligence and sustainable development, and sources that gave insights into regulatory or governance aspects. The exclusion criteria were used to filter out sources that were not considered methodologically rigorous, relevant, or scholarly. The data obtained were coded in themes to enable them to be analyzed and interpreted in a structured manner.

2.6 Data Interpretation and Analysis

Data interpretation was done through qualitative content analysis methodology, where the textual content was analyzed to find repetitive themes, patterns, and conceptual frameworks. Laws and policy tools were interpreted based on their goals, areas of focus, and the real-world use in sustainability applications of artificial intelligence. The literature was evaluated to identify theoretical insights, empirically supported results, and critical reviews of available methods. Comparative interpretation was a process of comparing results in different jurisdictions in order to point out the variations in the approach to regulations and the consequences of such variations on the sustainability of the developmental results. This activity allowed determining gaps, inconsistencies, and best practices in the international environment of artificial intelligence governance.

2.7 Analytical Framework

The research methodology was analytical and incorporated a doctrinal analysis with a comparative analysis to offer the study a multidimensional perspective of the research problem. The framework was designed based on important dimensions, such as regulatory correspondingness, technological relevance, ethical implications, and sustainability effect. All dimensions were evaluated in terms of the governance, implementation, and evaluation of artificial intelligence applications in various legal and institutional settings. The principles of responsible artificial intelligence (transparency, accountability, fairness, and alignment with sustainability) were also included as part of the framework to critically examine the sufficiency of the current regulatory methods.

3. Results and Analytical Findings

3.1 Overview of Dataset-Derived Patterns

The conceptual and comparative analysis of the Sustainable Development Goals (SDG) data showed that there are strong structural and substantive patterns between the jurisdictions and indicators. The data showed disproportionate time coverage with a lot of data gaps in the first few years and improved data reporting in the latter years. Such a difference impacted the consistency of the comparative analysis, especially of longitudinal assessment. Despite these shortcomings, some trends could be identified in major areas of sustainability, which allow structurally interpreting the applicability of artificial intelligence (AI) to the systems of sustainable development. The general structure and coverage of the data are given in Table 1.

Table 1: Dataset Structure and Coverage Overview

Parameter	Value
Total Observations	98,625
Number of Countries/Regions	263
Number of Indicators	~374
Time Period	1990–2018
Years with Highest Data Density	2010–2015
Records in 2018	~7,980
Missing Data (Early Years)	High (1990–2000)
Empty Columns	1 (Unnamed column)

3.2 Indicator Distribution and Thematic Clusters

The dataset included a broad spectrum of indicators that covered energy access, financial inclusion, environmental sustainability, and socio-economic development. These indicators were put into thematic groups in order to analyze them.

3.3 Energy and Infrastructure Indicators

There was a steady increasing trend in indicators that are associated with electricity and clean fuel accessibility in most regions. The developed jurisdictions showed almost universal access, and developing regions showed improvements over time. The information implied that AI solutions to energy optimization and predictive maintenance may be especially efficient in areas that have incomplete infrastructure and where the increase in efficiency can still be attained.

3.4 Environmental and Climate Indicators

Emissions and resource consumption were some of the environmental indicators that showed a great level of variation among countries. There was a stabilization or slow decline in some of the indicators of emissions in developed economies, but the patterns were fluctuating in the developing regions. Such a deviation signified the possibility of AI-based environmental surveillance and predictive analytics to resolve region-specific issues, especially in climate-sensitive regions.

3.5 Socio-Economic and Financial Indicators

Indicators such as financial inclusion and development assistance showed that there were huge inequalities. Whereas in some parts, financial access grew at a dynamic rate, there were other parts where there were structural constraints. The data pointed to disparities in the distribution of socio-economic benefits, which supports the necessity of AI systems with equity-oriented design considerations. Table 2 shows the performance of key sustainability indicators in different regions.

Table 2: Comparative Indicator Performance Across Domains

Indicator Category	Developed Regions (%)	Developing Regions (%)	Observed Trend
Electricity Access	95–100	60–85	Gradual improvement globally
Clean Fuel Access	80–95	40–70	Moderate growth
Financial Inclusion	70–95	30–65	Uneven expansion
Environmental Stability	Moderate (declining emissions)	High variability	Divergent trends
Renewable Energy Usage	20–45	10–30	Increasing but inconsistent

3.6 Temporal Trends and Data Evolution

The time analysis showed that the data availability and consistency in reporting increased significantly since 2005. Previous years were also marked by discontinuous data, which curtailed the effectiveness of the trend analysis. More complete data were observed in the post-2010 period, which allowed conducting a more effective comparative assessment. This time gain was in line with the globalization of SDG monitoring frameworks, which implies that regulatory and governance frameworks were essential in improving the quality of data.

The dataset, however, also showed that the completeness of the latest years has decreased, showing a possibility of reporting lags. This variability was a problem for real-time AI applications, which depend on continuous and quality data streams. Figure 1 shows the availability trend of data over time.

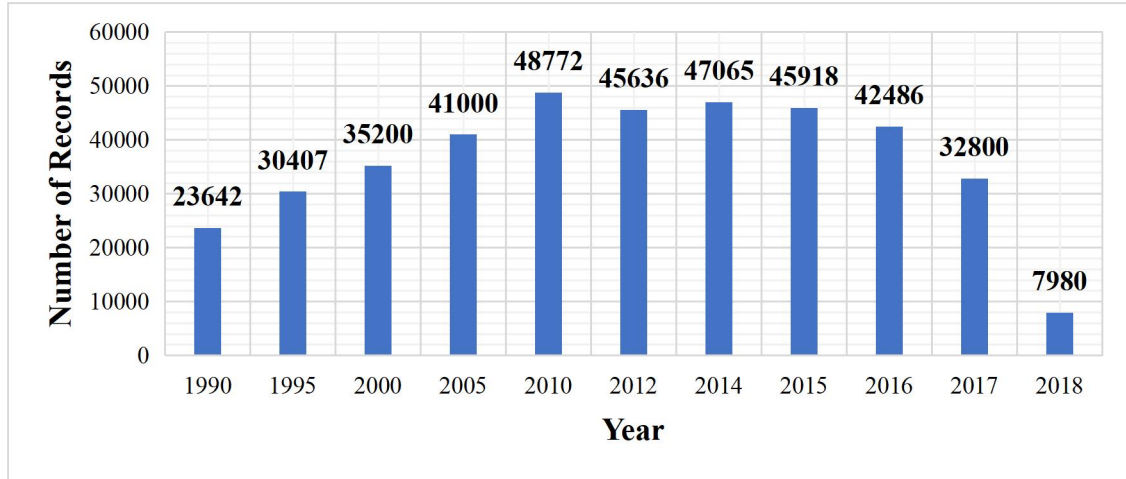


Figure 1: Data Availability Trend

4. Comparative Jurisdictional Analysis

4.1 Developed Economies

High completeness and consistency of data on indicators in developed jurisdictions were observed. Those zones reflected high levels of infrastructure development, environmental control, and socio-economic growth. The data indicated that AI solutions in such scenarios were largely oriented towards optimization and improvement of efficiency and predictive governance.

4.2 Developing Economies

Less advanced regions were more variable in terms of both data availability and performance of indicators. Although positive changes were observed in energy access and financial inclusion, huge gaps remained. The results showed that AI applications in these settings would require overcoming underlying issues, such as data shortages, infrastructural limitations, and institutional bottlenecks. Figure 2 shows the contrast of sustainability indicators of developed and developing regions.

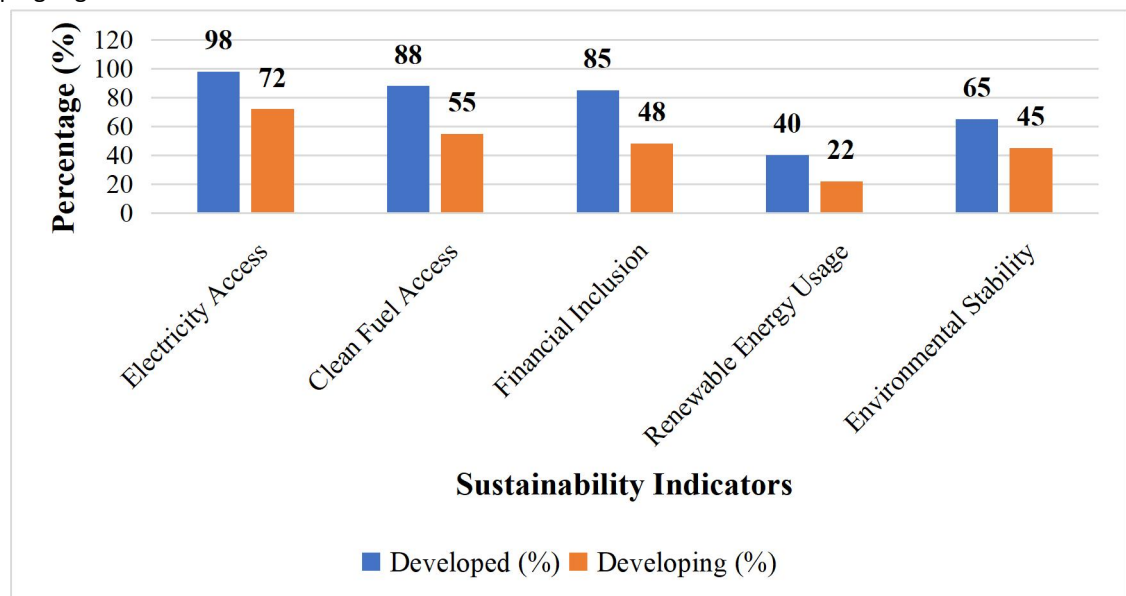


Figure 2: Sustainability Indicator Comparison

4.3 Cross-Regional Disparities

Comparative analysis revealed the existence of significant differences between the regions, especially in environmental and socio-economic indicators. These differences highlighted the need to implement AI differently depending on the context, since we cannot expect similar results with the same technological solutions in different environments.

5. Data Quality and Analytical Constraints

The data set had a number of quality issues, such as missing values, inconsistent reporting, and the existence of outliers. There were considerable differences in the indicators in terms of scale and measurement units that made it

hard to compare them directly. These problems prompted keen preprocessing and normalization of the data to have analytical validity.

These limitations of data, according to a doctrinal view, were a mirror of the more general governance issues in sustainability monitoring. The lack of consistent reporting standards and institutional capacities also led to discontinuous data landscapes, which further influenced the credibility of AI-based insights. The distribution and statistical summary of the indicator values are given in Table 3.

Table 3: Statistical Summary of Selected Indicators

Metric	Approximate Value Range	Median Estimate	Interpretation
Minimum Values	-3.9×10^{10}	—	Economic corrections/outliers
Maximum Values	1.5×10^{16}	—	Large-scale economic indicators
Median (General)	30–40	~33	Typical normalized SDG indicator range
Lower Quartile	5–6	~5.9	Low-performing indicators
Upper Quartile	100	~100	Saturation in developed regions
Data Availability	23,000–48,000 entries/year	—	Increasing over time

6. Implications for Artificial Intelligence Applications

6.1 Predictive and Analytical Capabilities

The data set proved to be highly promising for AI-based predictive modelling, especially of the sustainability indicators and the detection of new trends. Time-series data, in spite of its flaws, offered grounds for machine learning applications to predict future development patterns.

6.2 Optimization and Decision Support

The applications of AI were also identified to have been pertinent in the areas of resource distribution optimization and augmenting the decision-making process. The variety of indicators provided the possibility to perform a multi-dimensional analysis, permitting combined approaches to sustainability issues.

6.3 Governance and Regulatory Alignment

The results highlighted the necessity of ensuring compatibility between AI applications and regulatory frameworks. Fluctuations in data quality and availability underscored the need to have standardized reporting mechanisms and sound governance structures to facilitate the successful application of AI.

7. Synthesis of Findings

The findings showed that although the dataset offered a holistic view of the sustainability indicators across the world, the structural constraints and regional differences influenced its analytical potential. The comparative analysis showed that AI applications will have to be adjusted to particular contextual circumstances, considering the variations in data infrastructure, regulating contexts, and developmental priorities. These results supported the main assumption that the introduction of AI into the sustainable development systems demands technological innovation as well as institutional coherence.

8. Discussion

The results of this research had to be interpreted in terms of more general doctrinal, procedural, and institutional frameworks that dictate the interface of artificial intelligence and the sustainable development system. The patterns observed showed that technological capacity was not a determinant of sustainability outcomes, and hence the importance of regulatory coherence and institutional alignment. The assimilation of artificial intelligence was neither a technical procedure nor a governance matter but a legal norm, policy tool, and administrative capacities interjurisdictionally.

The analysis also indicated that there was no single legal framework that could be used to tackle the multifaceted implications of artificial intelligence as they relate to sustainability issues, as per the doctrinaire perspective. The current regulatory frameworks were still inadequate and frequently corresponded to specific areas like data

protection, environmental regulation, or digital innovation without offering comprehensive regulation. This disaggregation implemented artificial intelligence systems in a way that is, by default, cross-sector and cross-national, more complex. The results thus conformed to the academic arguments that support the harmonized regulatory strategies that can achieve a balance between innovativeness and responsibility (Kaack et al., 2022). The discrepancies in reporting standards and data governance also indicated the existence of gaps in doctrines that inhibited the transparency, comparability, and regulatory performance.

In terms of procedure, the research found that the usefulness of artificial intelligence applications was highly dependent on the quality and consistency of data systems and their availability. Fluctuation in data access and recording made it possible that the procedural mechanisms that regulate data collection and dissemination were not well-developed. Such a limitation had a direct impact on the credibility of insights based on artificial intelligence since it was required that predictive models and analytic tools require constant and reliable data feeds. The institutional practices that were involved in the process of monitoring, verification, and compliance were also a procedural deficiency beyond the technical issues. These findings aligned with the available literature that highlights the need to have powerful data governance frameworks in order to facilitate sustainable digital transformation (Ramakrishna et al., 2023). Without such structures, artificial intelligence did not have the capacity to operate as efficiently as possible due to systemic inefficiencies.

The comparative analysis was found to indicate large differences in capacity, preparedness, and strategic focus between regions institutionally. Advanced jurisdictions were developed, with high-quality technological infrastructures and a well-developed regulatory framework, which showed the possibility of utilizing artificial intelligence to optimize and improve policies. Conversely, developing regions suffered structural problems such as a lack of sufficient data infrastructure, institutional capacity, and a lack of resources. Such inequalities brought up critical issues of equity and inclusiveness in the worldwide implementation of AI. Unless specifically institutionalized, such as through capacity-building projects and fair distribution of technology, artificial intelligence would only strengthen the inequalities, instead of reducing them. This meaning was consistent with wider discussions on the digital divide and how it will impact sustainable development (Goralski and Tan, 2020).

The results also initiated the thought of artificial intelligence as a normative tool in sustainability governance. In addition to practical uses, artificial intelligence started to play a more significant role in the decision-making process, policy development, and resource distribution. This change brought in the issues of accountability, transparency, and ethics. The new forms of opacities that resulted from the algorithmic systems, especially those that were not explainable, complicated the process of regulatory scrutiny. The research thus corroborated the claims of incorporating ethical considerations like fairness, accountability, and transparency in the architecture and management of artificial intelligence systems (Zaidan, 2023). These were critical towards institutional legitimacy and ensuring that technological interventions were in line with sustainability goals.

The other important dimension was the changing attitude between innovation and regulation. The results showed that there was a long-term disconnect between the development of new technology and regulatory adjustments, causing gaps in governance. Strict regulations were a threat to limit innovation, and a lack of regulation would leave systems vulnerable to unforeseen effects and abuse. To counter this imbalance, adaptive regulatory frameworks are needed that can adapt to the dynamic character of artificial intelligence technologies. These strategies have been promoted in recent literature, where principle-based and flexible regulatory frameworks that facilitate innovation but do not hinder alignment with sustainability objectives are highlighted (Adegbite et al., 2024).

Lastly, the paper highlighted the significance of interdisciplinary participation in dealing with the issues surrounding artificial intelligence in sustainable development systems. These challenges were so complicated that they required the incorporation of legal, technological, and policy aspects. They needed institutional arrangements that enabled stakeholders such as policymakers, technologists, and civil society actors to collaborate effectively in order to come up with solutions that were coherent and context-sensitive. The results have shown that either isolated or sector-specific methods were not enough because sustainability issues and artificial intelligence applications were both interdisciplinary.

9. Conclusion

The research combined doctrinal and comparative analysis to assess the impact of artificial intelligence on the sustainable development systems and showed that its efficiency was based on the interplay of technological capability, regulatory coherence, and institutional capacity. The evaluation found that the fragmentation of legal systems, uneven procedural systems, and the lack of even data infrastructures restricted the dependability and scalability of

artificial intelligence applications across jurisdictions. Comparative results also showed that technologically advanced areas were using artificial intelligence to optimize and predict governance, whereas developing areas were still limited by structural and institutional challenges. The paper also elucidated that artificial intelligence did not simply act as a technical means, but as a governance mechanism that affected decision-making, allocation of resources, and implementation of policies. The implementation of artificial intelligence into sustainability systems thus had to be in accordance with legal standards, ethics, and standardized data practices to be transparent, accountable, and inclusive. In general, the study added systematic knowledge on how doctrinal, procedural, and institutional variables interact in influencing the implementation and effects of artificial intelligence, and the need to have coordinated and context-responsive strategies that can be used to attain sustainable development goals successfully.

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