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Information Technology, Artificial Intelligence and Environmental Sustainability: An Analytical Review of the Arab and Libyan Contexts

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Abstract:

This paper examines the interlinked relationship between information technology and artificial intelligence on the one hand, and environmental sustainability on the other, drawing on an analysis of academic literature and international reports issued mainly between 2020 and 2026. It adopts a critical analytical review of recent literature, proceeding from a defined research problem and clear sub-questions, and highlights the environmental paradox of artificial intelligence: its capacity to help reduce environmental risks alongside its growing burdens in terms of energy and water consumption and electronic waste generation. The study discusses the contribution of these technologies to improving energy efficiency, supporting precision agriculture, managing smart cities and monitoring environmental change, set against the environmental costs that accompany them. It further sheds light on this relationship in the Arab region, and in Libya in particular, where the challenges of water scarcity, desertification and dependence on fossil fuels intersect with promising opportunities to adopt digital and intelligent solutions in the energy and water sectors. The paper concludes that the environmental impact of artificial intelligence is not determined automatically by the nature of the technology itself, but rather depends on how it is deployed and on the extent to which it is coupled with effective governance policies and efficiency-oriented design from the earliest stages. The paper offers a set of practical recommendations for decision-makers in Libya and the Arab region.

Keywords: Artificial Intelligence; Green Computing; Environmental Sustainability; Carbon Footprint; Water Footprint; Libya; Sustainable Development Goals.

تكنولوجيا المعلومات والذكاء الاصطناعي والاستدامة البيئية: قراءة تحليلية في السياقين العربي والليبي

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الملخص:

تستعرض هذه الورقة العلاقة المتداخلة بين تكنولوجيا المعلومات والذكاء الاصطناعي من جهة، والاستدامة البيئية من جهة أخرى، اعتماداً على تحليل الأدبيات الأكاديمية والتقارير الدولية الصادرة أساساً بين عامي 2020 و2026. وتعتمد الورقة مراجعة تحليلية نقدية للأدبيات الحديثة، تنطلق من مشكلة بحثية محددة وأسئلة فرعية واضحة، مع إبراز المفارقة البيئية للذكاء الاصطناعي بين قدرته على الإسهام في خفض المخاطر البيئية وبين أعبائه المتزايدة المرتبطة باستهلاك الطاقة والمياه وتوليد النفايات الإلكترونية. وتناقش الدراسة إسهام هذه التقنيات في تحسين كفاءة الطاقة، ودعم الزراعة الدقيقة، وإدارة المدن الذكية، ورصد التغيرات البيئية، في مقابل الأعباء البيئية المصاحبة لها. كما تسلط الضوء على واقع هذه العلاقة في المنطقة العربية وليبيا خصوصاً، حيث تتقاطع تحديات ندرة المياه والتصحر والاعتماد على الوقود الأحفوري مع فرص واعدة لتبني حلول رقمية وذكية في قطاعي الطاقة والمياه. وتخلص الورقة إلى أن الأثر البيئي للذكاء الاصطناعي لا يتحدد تلقائياً بطبيعة التقنية ذاتها، بل يتوقف على طريقة توظيفها، ومدى اقترانها بسياسات حوكمة فعالة وتصميم موجّه للكفاءة منذ المراحل الأولى. وتقدم الورقة مجموعة من التوصيات العملية لصانعي القرار في ليبيا والمنطقة العربية.

الكلمات المفتاحية: الذكاء الاصطناعي، الحوسبة الخضراء، الاستدامة البيئية، البصمة الكربونية، بصمة المياه، ليبيا، أهداف التنمية المستدامة.

Full text

1. Introduction

The academic literature shows a clear shift in how the relationship between digital technology and the environment is approached. The discussion is no longer confined to tracking the environmental impact of digital technologies, but has moved toward the concept of "Sustainability by Design," which is based on integrating environmental efficiency criteria into the development stages of intelligent systems from the outset, rather than treating their environmental effects as an afterthought. This shift comes amid an escalating global climate crisis and growing investment in generative artificial intelligence and large-scale data centers, making digital transformation and environmental transformation two interlinked pathways that are difficult to consider in isolation from one another.

Within this context, Arab countries, and Libya in particular, face a complex environmental and economic reality. On one hand, the region suffers from acute water scarcity, accelerating desertification, and heavy reliance on oil revenues; on the other hand, it possesses important natural assets, most notably high solar radiation and wind energy potential, which make it well positioned to benefit from information technology and artificial intelligence in supporting the transition toward a more sustainable economy. Realizing this potential, however, requires a precise understanding of the paradox posed by artificial intelligence: it can contribute to reducing emissions and rationalizing resource use, while at the same time it may increase demand for energy and water and contribute to the accumulation of electronic waste.

Research Problem and Questions

This study starts from the observation that there is a gap between the optimistic view that presents artificial intelligence as an important tool for achieving environmental sustainability, and the scientific evidence documenting the environmental burdens associated with it, particularly with respect to energy and water consumption and the generation of electronic waste. This gap becomes even more significant in contexts such as Libya and the Arab region, where water scarcity intersects with dependence on fossil fuels and with the limited scope of digital and environmental regulatory frameworks.

Main Question: To what extent can information technology and artificial intelligence contribute to achieving environmental sustainability and reducing environmental risks in Arab countries in general, and in Libya in particular, taking into account the environmental burdens associated with these technologies?

Three sub-questions branch from this main question:

1. What do recent scientific literature and international reports reveal about the nature of the relationship between artificial intelligence and environmental sustainability?
2. What are the environmental opportunities and challenges associated with these technologies in terms of energy and water consumption, electronic waste generation, and the adequacy of existing regulatory frameworks?
3. How can this analytical framework be adapted to the specific realities of the Libyan and Arab context, and what practical recommendations can be offered to decision-makers?

The paper is organized as follows: Section 2 presents the theoretical framework and reviews prior literature; Section 3 explains the study's methodology and its limitations; Section 4 discusses the findings across the themes of positive impact, environmental burdens, governance, and the Arab and Libyan context; Section 5 analyzes the environmental paradox of artificial intelligence; and Section 6 concludes with the key practical recommendations.

2. Theoretical Framework and Literature Review

2.1 From “Measuring Consumption” to “Sustainability by Design”

A recent systematic review conducted by Gohr, Rodríguez, and colleagues (Gohr, Rodríguez, et al., 2025), published in Nature Sustainability and covering 792 studies on AI applications related to the Sustainable Development Goals, indicates that deep learning and supervised machine learning algorithms are the most widely used in prediction and system optimization tasks. However, this use varies across domains: it is concentrated in health, education, and environmental modeling, while remaining relatively limited in areas such as poverty reduction.

The framework developed by Vinuesa and colleagues (Vinuesa et al., 2020), published in Nature Communications, is among the most frequently cited reference frameworks in this field. Relying on an expert-consensus methodology, it concluded that artificial intelligence could contribute to achieving 134 of the 169 targets within the seventeen Sustainable Development Goals, while potentially hindering the achievement of 59 other targets in the absence of sound governance. This balance between potential and risk reflects the core of the theoretical discussion adopted in this paper.

2.2 The Concept of “Green AI”

The concept of Green AI refers to a set of practices and techniques aimed at reducing the computational and environmental impact of training and running models without significantly compromising performance quality. This includes optimizing model architectures, using more efficient hardware, and scheduling training operations at times and in locations where the energy mix has a lower carbon intensity. These efforts intersect with what is known as “Sustainable AutoML,” which incorporates energy consumption, alongside accuracy, as a criterion for selecting and tuning models. Nevertheless, these practices remain at an evolving and institutionally standardizing stage, and have not yet translated into broad regulatory commitment.

2.3 Summary of Previous Studies

The following table summarizes the most important peer-reviewed studies and institutional reports on which this paper draws, indicating each study's field, methodology, key findings, and its relevance to the paper's analytical themes:

Table 1. Summary of Previous Studies

Study and Method	Field	Key Findings	Relevance to the Paper's Themes
Vinuesa et al. (2020) — Expert consensus	AI governance and sustainable development	AI contributes to 134 targets and hinders 59 targets of the SDGs	Basis of the theoretical framework for the opportunity–risk paradox
Gohr, Rodríguez, et al. (2025) — Review of 792 articles	Bibliometrics of AI and sustainability	Deep learning is the most widely used method; a gap exists between technical application and sustainability depth	Characterizes the state of research in the theoretical framework
de Vries-Gao (2026) — Quantitative estimation	Carbon and water footprint of data centers	AI's carbon footprint may equal that of New York City in 2025	Primary source for the environmental burden figures
Shehabi et al. (2024) — Sectoral report	US data center energy consumption	US data centers' share of consumption could rise from 4.4% to between 6.7% and 12% by 2028	Source of the US consumption figure in Section 4.2
Ibrahim et al. (2026) — Legal analysis	Environmental governance of AI	Environmental provisions in EU law remain limited and improvable in	Basis for the governance discussion in Section 4.3

Study and Method	Field	Key Findings	Relevance to the Paper's Themes
		terms of measurement and enforceability	
IEA (2025) — Sectoral statistical report	Energy and AI	Projected consumption reaching 945 TWh globally by 2030	Source of the baseline figures for the environmental burdens section
Li et al. (2025) — Quantitative estimation	AI's water footprint	Training GPT-3 in Microsoft data centers led to the direct evaporation of about 700,000 liters of water	Primary source for the water footprint figures
Baldé et al. (2024) — Global monitor	Global electronic waste	62 million tons of e-waste in 2022, with a documented recycling rate of only 22.3%	Primary source for the e-waste section
UNDP Libya (2023) — Institutional opinion piece	Renewable energy in Libya	Libya has rich, underexploited solar and wind potential	Key institutional source for the Libyan context (Section 4.4)
Google Research (2026) — Operational data	Smart cities and traffic management	Reduces stops by up to 30% and emissions by up to 10% at intersections; preliminary figures not yet independently evaluated	Applied example in Section 4.1, cited with caution

3. Study Methodology

This paper adopts a descriptive-analytical approach, through a critical review of literature and reports issued mainly between 2020 and 2026, with particular emphasis on the most recent publications between 2023 and 2026. This review does not follow a strict methodological protocol of the PRISMA type, in the sense of relying on a unified database, explicit inclusion and exclusion criteria, and a fixed number of screened articles; rather, it relies on a targeted critical selection of the most recent and relevant literature to the study's themes. The paper draws primarily on studies published in peer-reviewed scientific journals such as Nature Sustainability, Nature Communications, Patterns, Technology in Society, Frontiers in Agronomy, and Land Degradation & Development, as well as on international institutional reports issued by official bodies such as the International Energy Agency (IEA), the International Telecommunication Union (ITU), and the United Nations Institute for Training and Research (UNITAR). The paper also draws on non-peer-reviewed institutional reports and analyses, such as those from Brookings, Carbon Brief, and White & Case, as supporting sources for understanding fast-moving regulatory and market developments, rather than as a substitute for peer-reviewed scientific studies. These sources were analyzed along two complementary axes: a global axis that tracks the opportunities and environmental burdens associated with artificial intelligence, and a regional axis that links this evidence specifically to the Arab and Libyan context.

The selection of sources was based on three main criteria: first, the degree of direct relevance to the study's four themes (energy, water, electronic waste, and governance); second, the credibility of the publishing body, whether a peer-reviewed scientific journal or a recognized international institution; and third, the recency of the data, giving priority to publications closest to 2026 whenever comparative data from earlier years were available. The choice of a time span extending from 2020 to 2026 reflects the fact that this period witnessed the greatest acceleration in the global growth of generative artificial intelligence and data centers, which meant that the majority of studies and reference reports directly relevant to the paper's topic were published within this specific time frame. A limited number of foundational references predating this range were nonetheless included as exceptions, such as the framework of Vinuesa and colleagues (Vinuesa et al., 2020), given its firmly established reference status in the literature on artificial intelligence and sustainable development.

Study Limitations

This study is limited to a critical descriptive analysis of published literature and reports, and does not rely on primary field data or an applied trial within Libyan institutions. Accordingly, the conclusions relating to the Libyan context are inferential conclusions based on regional comparison and literature analysis, rather than results of direct measurement. This limitation opens the door for future studies based on field surveys, simulation, or actual measurement of energy and water consumption in Libyan data centers and institutions, which would allow the theoretical trends identified in this paper to be tested.

4. Results and Discussion

4.1 Positive Impact: Artificial Intelligence as a Tool Supporting Sustainability

Recent literature shows that artificial intelligence can support sustainability through four main areas:

- Energy efficiency and smart grids: Smart grids employ predictive algorithms to balance supply and demand in real time, facilitating the integration of intermittent renewable energy sources, such as solar and wind, into the electricity grid, and reducing waste resulting from poor forecasting or inadequate storage.
- Precision agriculture: A systematic review conducted by Xing, Liu, and Wang (Xing, Liu, & Wang, 2026), published in Frontiers in Agronomy, indicates that integrating drone and satellite data with machine learning algorithms can reduce irrigation costs by between 20% and 25% and improve the accuracy of agricultural yield forecasting without compromising it. Similarly, a study by Gao (2026), published in Land Degradation & Development, found that precision agriculture based on drone remote sensing achieved productivity gains and water savings on degraded land, although these findings remain subject to further verification given that they are based on specific case studies.
- Smart cities and transportation: Google Research's “Project Green Light” is a prominent applied example; it uses traffic data from Google Maps and artificial intelligence techniques to optimize traffic-signal timing without requiring major infrastructure investments. According to preliminary data released by Google, the project, implemented in more than fifteen cities, may reduce the number of stops at intersections by up to 30% and cut emissions at targeted intersections by up to 10%. These figures should nonetheless be treated with caution, as they come from the project's developer and have not yet undergone a comprehensive independent evaluation; moreover, their overall impact on transport-sector emissions may remain limited compared with broader reforms such as improving public transportation.
- Environmental monitoring and biodiversity: Computer vision techniques and satellite image analysis are used to monitor changes in vegetation cover, track desertification indicators, and monitor marine pollution. This use represents one of the most mature applications of artificial intelligence in the environmental field, given its direct link to measurement, monitoring, and early warning.

4.2 The Hidden Environmental Burdens of Artificial Intelligence

By contrast, recent literature documents growing environmental burdens associated with these same technologies, which can be presented across three main dimensions:

- Energy consumption: According to the special report “Energy and AI” issued by the International Energy Agency (IEA) in 2025, data centers worldwide consumed approximately 415 terawatt-hours in 2024, equivalent to about 1.5% of total global electricity consumption. This consumption is expected to more than double, reaching approximately 945 terawatt-hours by 2030 — roughly 3% of global consumption — with artificial intelligence being one of the main drivers of this growth: electricity demand from data centers dedicated to AI is expected to more than quadruple by 2030. At the US level, which accounts for about 45% of global data center consumption, a report by Shehabi and colleagues (Shehabi et al., 2024), issued by Lawrence Berkeley National Laboratory, showed that data centers' share of total US electricity consumption, which stood at about 4.4% in 2023, could rise to between 6.7% and 12% by 2028.

- Water footprint: Cooling servers requires large quantities of water, and the share of cooling in total energy consumption varies widely depending on the type and efficiency level of the facility. The IEA (2025) estimates this share at about 7% in highly efficient hyperscale data centers, while it may exceed 30% in less efficient traditional enterprise facilities. A study by Li, Yang, Islam, and Ren (Li, Yang, Islam, & Ren, 2025) estimated that training the GPT-3 model in Microsoft's data centers led to the direct evaporation of approximately 700,000 liters of fresh water. The study further indicates that total global water withdrawal associated with artificial intelligence could reach between 4.2 and 6.6 billion cubic meters annually by 2027 — an amount equivalent to several times the annual consumption of a country such as Denmark. Analyses by Privette, Barros, and Cai (Privette, Barros, & Cai, 2026) in AGU Advances confirm that limited institutional transparency remains a major obstacle to accurately estimating this footprint, despite some major companies announcing programs to recycle cooling water or shift to less water-intensive cooling technologies.
- Electronic waste: According to the "Global E-waste Monitor 2024" report issued by the International Telecommunication Union and the United Nations Institute for Training and Research (Baldé, Kuehr, Yamamoto, et al., 2024), the volume of electronic waste worldwide reached about 62 million tons in 2022, an increase of 82% compared with 2010, and is projected to reach 82 million tons by 2030. The share of this waste documented as collected and recycled did not exceed 22.3% in 2022, even though the value of the metals it contains is estimated at about USD 91 billion (including USD 19 billion in copper, USD 16 billion in iron, and USD 15 billion in gold), of which only about USD 28 billion worth was actually recovered through what is known as "urban mining." The rapid evolution of the graphics processing chips used to train AI models is among the factors that may shorten device lifespans and accelerate the accumulation of electronic waste. Data from the "Regional E-waste Monitor for the Arab States" (Iattoni, Vermeersch, Baldé, Nnorom, & Kuehr, 2021), which includes Libya within its scope, show that the African continent records the lowest documented collection and recycling rates globally, at less than 1%.

4.3 Social, Economic, and Governance Dimensions

Sustainability associated with artificial intelligence is not confined to its direct environmental dimension, but extends to interlinked social, economic, and regulatory dimensions. At the governance level, the "EU AI Act" represents one of the most notable regulatory attempts to embed environmental criteria within the development and use of AI systems: it requires providers of general-purpose AI models to document known or estimated energy consumption. Quantitative obligations relating to Power Usage Effectiveness (PUE) in data centers, however, do not stem from this act but rather from the EU Energy Efficiency Directive and its implementing national legislation; in Germany, for example, the Energy Efficiency Act (EnEfG) requires data centers to meet specific thresholds for this indicator by 1 July 2027, with immediate obligations for new facilities beginning operation from 1 July 2026. Recent critical studies, including an analysis by Ibrahim, Zaidan, Truby, and Hoppe (Ibrahim, Zaidan, Truby, & Hoppe, 2026) published in Technology in Society, argue that these provisions remain closer to procedural obligations than to measurable mandatory standards: to date, there is no public registry for tracking the environmental impact of AI systems, no clear requirement for full life-cycle assessment, and the European Commission's first official report on energy efficiency in general-purpose models is not expected before August 2028.

On the social and economic front, the literature points to the potential widening of the gap between actors capable of developing and directing artificial intelligence and those that merely use its technologies without sufficient participation in their design or in controlling their local environmental effects. Consequently, "data and digital infrastructure sovereignty" becomes as much an economic sustainability issue as a technical one, particularly in oil-based economies seeking to diversify their sources of income.

4.4 The Arab and Libyan Context

Arab countries face shared environmental challenges directly related to the themes of this study, foremost among them water scarcity, desertification, and heavy reliance on fossil fuels as a primary source of income and energy. The United Nations Development Programme (UNDP Libya, 2023), as an international institutional source, confirms that Libya possesses rich solar and wind potential that could represent an important economic and environmental opportunity if efficiently invested. This trend is supported by local academic studies: an analytical forward-looking study published by Ben Hokouma and colleagues (2023) in the African Journal of Advanced Pure and Applied Sciences (AJAPAS) concluded that, despite possessing these natural resources, Libya still relies heavily on fossil fuels to meet its energy needs, and that investment in renewable energy could reduce this dependence and strengthen economic and environmental independence.

At the level of practical applications in the region, the Noor Concentrated Solar Power complex in Ouarzazate, Morocco, stands out as one of the most prominent regional examples of integrating technology with sustainability. With a total capacity of about 580 megawatts, the complex helps offset an estimated 533,000 tons of carbon dioxide emissions annually through its second and third phases alone. Specialized technical studies point to the growing use of artificial intelligence techniques in improving the performance of thermal energy storage systems at concentrated solar power plants, enhancing the accuracy of output forecasting and performance control. This regional model may serve as a useful reference that Libya could draw on when planning similar projects, although adapting it to the Libyan context would require independent local feasibility studies.

In the area of monitoring and early warning, several Arab countries use remote sensing and geographic information systems to track desertification, land degradation, sand encroachment, and vegetation cover change. A review by Al-Quraishi (Al-Quraishi, 2024), published in Springer's The Handbook of Environmental Chemistry series, shows that integrating satellite data with geographic information systems in the Middle East and North Africa region enables the monitoring of areas most vulnerable to soil degradation and helps guide sustainable land management policies, although such applications remain limited in scope in Libya compared with more advanced regional experiences in Morocco and the Gulf states.

Given the weakness of the infrastructure for collecting and recycling electronic waste in the Arab region, the anticipated expansion of data centers and digital infrastructure is likely, in the absence of appropriate regulatory frameworks, to become a factor that compounds future environmental risks rather than an unconditional opportunity for sustainability.

4.5 Summary Table: The Environmental Balance Sheet of Artificial Intelligence

Table 2. The Environmental Balance Sheet of Artificial Intelligence

Domain	Potential Environmental Gains	Associated Environmental Burdens
Climate and Energy	Improved smart-grid management and renewable-energy integration, and reduction of some transport emissions through traffic-signal optimization by up to 10%.	Rising electricity consumption in data centers, potentially reaching about 945 TWh globally by 2030.
Water Resources	Reduced irrigation water waste through precision agriculture, by 20%–25% in reference studies.	Global water withdrawal linked to AI potentially reaching 4.2–6.6 billion cubic meters annually by 2027.
Waste and Resources	Potential to improve material-use efficiency through modeling and digital twins.	Global electronic waste reaching 62 million tons in 2022, with a documented recycling rate not exceeding 22.3%.
Governance and Society	Emerging regulatory frameworks, such as the EU AI Act and the EU Energy Efficiency Directive, progressively requiring greater transparency in energy consumption.	Environmental provisions that remain limited in enforceability, with no public registry for tracking environmental impact, and a risk of a widening digital divide.

5. General Discussion: The Environmental Paradox of Artificial Intelligence

The findings above show that the relationship between artificial intelligence and environmental sustainability cannot be reduced to a single verdict, whether positive or negative. The very technology that can be used to improve the efficiency of electricity grids and rationalize water use in agriculture may, in turn, require increasing amounts of electricity and water to train and run its models. This is where the environmental paradox of artificial intelligence emerges: how can a highly energy-intensive technology simultaneously contribute to reducing emissions and rationalizing resource use?

The literature reviewed in this paper indicates that artificial intelligence functions as a mediator between technical innovation and actual sustainability outcomes, rather than as a direct guarantee of them. The mere existence of the technology is not sufficient to achieve a positive environmental impact unless it is coupled with three fundamental conditions: first, powering digital infrastructure with clean energy sources; second, the existence of binding regulatory frameworks that mandate transparency in measuring and disclosing consumption; and third, designing models and applications according to clear efficiency standards from the earliest stages, rather than treating environmental impact as an afterthought. In the absence of these conditions, artificial intelligence may shift from being a tool that supports sustainability to a factor that exacerbates certain environmental risks.

6. Conclusion and Recommendations

This paper concludes that information technology and artificial intelligence carry genuine potential to support environmental sustainability in the Arab region, and in Libya in particular, whether through improved energy and water management or through strengthened environmental monitoring and early-warning capabilities. This potential, however, is not realized automatically; it requires the conscious management of the environmental burdens associated with these technologies, particularly energy and water consumption and the generation of electronic waste. Based on the foregoing, the paper proposes the following recommendations:

1. Linking any future expansion of data centers or artificial intelligence projects in Libya and the Arab region to renewable energy sources, drawing on the region's rich solar and wind resources, and taking inspiration from successful regional models such as Morocco's Noor complex.
2. Updating national regulatory frameworks to ensure a minimum level of mandatory disclosure of energy and water consumption by major digital infrastructure operators, drawing on the lessons of the European experience and the shortcomings identified by critical literature regarding it.
3. Investing in national and regional infrastructure for collecting and recycling electronic waste, given the low documented recycling rates in the Arab region and Africa compared with the global average.
4. Expanding the use of artificial intelligence applications in managing scarce water resources, particularly in detecting pipeline leaks, improving the efficiency of desalination plants, and developing precision agricultural irrigation systems.
5. Building specialized local academic research capacity in “Green AI,” enabling the production of accurate local evidence and reducing complete reliance on data and models imported from different contexts.

As an analytical study based on a literature review, this paper opens the way for future field research to measure the actual impact of these technologies on specific environmental and economic indicators within Libya and the Arab countries, going beyond the bounds of the theoretical and comparative analysis presented by the current study.

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