International Journal of Multidisciplinary Research and Growth Evaluation.

Sustainability Risk Assessment of Digitalization: E-Governance, Smart Cities, and AI Systems

Sabastine Obum Aniebonam [1*], Paschal Chisom Aniebonam [2], Kehinde Olúwasayo Akinola [3]

[1-2] Department of Environmental Science, Thai Nguyen University of agriculture and Forestry, Thai Nguyen, Vietnam
[3] Department of Computer Science East Carolina University, USA

* Corresponding Author: **Sabastine Obum Aniebonam**

Abstract
The rapid digitalization of governance systems, urban infrastructure, and artificial intelligence deployment presents both opportunities and risks for sustainable development. This study examines the sustainability implications of digital transformation initiatives, focusing on three critical areas: data inequality, energy consumption of digital infrastructure, and the exclusion of vulnerable populations. Through a systematic literature review and qualitative analysis of 127 peer-reviewed articles published between 2013-2024, we identified significant sustainability risks that emerge from digitalization efforts. Our findings reveal that while digital technologies offer potential environmental benefits through efficiency gains, they simultaneously create new forms of inequality and resource consumption patterns that may undermine long-term sustainability goals. The study contributes to the growing body of literature on digital sustainability by providing a comprehensive risk assessment framework and highlighting the need for inclusive, energy-conscious approaches to digital transformation.

DOI: <u>https://doi.org/10.54660/.IJMRGE.2024.5.6.1786-1797</u>

1. Introduction
The 21st century has witnessed an unprecedented acceleration in digital transformation across governmental, urban, and technological systems. E-governance initiatives promise enhanced service delivery and citizen engagement (Mergel *et al*., 2019) [35], smart cities offer optimized resource management and improved quality of life (Bibri & Krogstie, 2017) [10], and artificial intelligence systems provide powerful tools for addressing complex sustainability challenges (Vinuesa *et al*., 2020) [56]. However, this digital revolution raises critical questions about its sustainability implications and potential risks to equitable development. Digitalization encompasses the integration of digital technologies into all aspects of society, fundamentally transforming how we govern, live, and interact with our environment. While proponents argue that digital technologies can accelerate progress toward the United Nations Sustainable Development Goals (SDGs), critics highlight emerging risks including increased energy consumption, widening digital divides, and the marginalization of vulnerable populations (Andersen & Whyte, 2020) [2].
The intersection of digitalization and sustainability presents a complex landscape where technological advancement may simultaneously contribute to and detract from sustainable development objectives. This paradox necessitates a comprehensive risk assessment to understand how digital transformation initiatives may impact environmental, social, and economic sustainability.

1.2. Significance of the Study

This study addresses a critical gap in the literature by providing a systematic assessment of sustainability risks associated with digitalization initiatives. As governments and organizations worldwide invest heavily in digital transformation, understanding these risks becomes essential for informed decision-making and policy development.

The significance of this research lies in its potential to inform policymakers, urban planners, and technology developers about the unintended consequences of digitalization efforts. By identifying and analyzing sustainability risks, this study contributes to the development of more responsible and inclusive approaches to digital transformation that align with broader sustainability objectives.

Furthermore, this research is timely given the increasing recognition of the environmental impact of digital technologies, particularly in light of growing concerns about climate change and resource scarcity. The study's findings can help guide the development of sustainable digitalization strategies that maximize benefits while minimizing negative impacts on society and the environment.

1.3. Problem Statement

Despite the widespread adoption of digital technologies in governance, urban planning, and AI applications, there is insufficient understanding of the sustainability risks associated with these initiatives. Three primary problems emerge from current digitalization efforts:

First, digital initiatives often exacerbate existing inequalities by creating new forms of data inequality, where access to digital services and benefits is unevenly distributed across populations (Robinson et al., 2015) [44]. This digital divide threatens to undermine the inclusive development principles that underpin sustainable development.

Second, the energy demand of digital infrastructure continues to grow exponentially, raising concerns about the environmental sustainability of digitalization efforts (Malmodin & Lundén, 2018) [33]. Data centers, network infrastructure, and connected devices consume significant amounts of energy, often from non-renewable sources.

Third, vulnerable populations, including elderly individuals, low-income communities, and marginalized groups, face systematic exclusion from digital transformation initiatives, potentially worsening existing social inequalities (Helsper, 2021) [22]. This exclusion contradicts the "leave no one behind" principle of sustainable development.

These problems collectively raise questions about whether current approaches to digitalization are compatible with long-term sustainability goals and whether alternative models might better serve both technological advancement and sustainable development objectives.

2. Literature Review

The relationship between digitalization and sustainability has emerged as a critical area of academic inquiry, with scholars examining both the opportunities and challenges presented by digital transformation initiatives.

Digital Transformation and Environmental Impact

Research on the environmental implications of digitalization reveals a complex picture. Belkhir & Elmeligi (2018) [8] demonstrated that the information and communication technology (ICT) sector's carbon footprint is rapidly increasing, potentially reaching 8% of global greenhouse gas emissions by 2030. This finding aligns with studies by Freitag et al. (2021) [17], who highlighted the significant energy consumption of digital technologies and the need for more sustainable approaches to digital infrastructure development.

Conversely, several studies have identified potential environmental benefits of digitalization. Lange et al. (2020) [30] found that smart city technologies could reduce urban energy consumption by up to 30% through optimized resource management and improved efficiency. Similarly, research by Picatoste et al. (2018) [41] suggested that digital technologies could contribute to environmental sustainability through dematerialization and resource optimization.

E-Governance and Digital Inclusion

The literature on e-governance reveals significant concerns about digital inclusion and accessibility. Schuppan (2009) [48] identified barriers to e-governance adoption among vulnerable populations, including technological literacy, infrastructure access, and cultural factors. More recent research by Naranjo-Zolotov et al. (2019) [37] confirmed that digital divides persist in e-governance systems, potentially excluding certain populations from essential government services.

Studies by Saxena (2017) [46] and Twizeyimana & Andersson (2019) [53] emphasized the importance of inclusive design in e-governance systems, arguing that sustainability requires ensuring equal access to digital government services regardless of socioeconomic status, age, or technical capability.

Smart Cities and Social Equity

The smart cities literature increasingly acknowledges concerns about social equity and inclusion. Kitchin (2014) [27] argued that smart city initiatives often prioritize technological solutions over social needs, potentially exacerbating urban inequalities. This perspective is supported by research from Cardullo & Kitchin (2019) [11], who found that many smart city projects fail to meaningfully engage with local communities, particularly marginalized populations.

However, other studies present more optimistic views of smart cities' potential for sustainable development. Research by Ahvenniemi et al. (2017) [1] suggested that well-designed smart city initiatives could contribute to multiple SDGs simultaneously, while studies by Kumar et al. (2020) [29] highlighted successful examples of inclusive smart city development.

AI Systems and Sustainability Risks

The literature on AI systems and sustainability reveals growing concerns about both environmental impact and social implications. Strubell et al. (2019) [51] demonstrated the significant carbon footprint of training large AI models, while research by Schwartz et al. (2020) [49] highlighted the need for more energy-efficient AI development practices.

From a social perspective, studies by Barocas et al. (2017) [6] and Eubanks (2018) [16] revealed how AI systems can perpetuate and amplify existing social inequalities, particularly affecting vulnerable populations. These findings are complemented by research from Raji et al. (2020) [43], who documented systematic biases in AI systems that can lead to discriminatory outcomes.

Table 1: Key Literature Themes on Digitalization and Sustainability

Theme	Key Authors	Main Findings	Sustainability Implications
Environmental Impact	Belkhir & Elmeligi (2018) [8], Freitag *et al*. (2021) [17]	ICT carbon footprint increasing rapidly	High energy consumption threatens climate goals
Digital Inclusion	Naranjo-Zolotov *et al*. (2019) [37], Helsper (2021) [22]	Persistent digital divides in access	Social sustainability compromised
Smart Cities Equity	Cardullo & Kitchin (2019) [11], Kumar *et al*. (2020) [29]	Mixed outcomes for social inclusion	Depends on implementation approach
AI Bias	Barocas *et al*. (2017) [6], Raji *et al*. (2020) [43]	Systematic biases affecting vulnerable groups	Threatens equitable development
Energy Efficiency	Lange *et al*. (2020) [30], Picatoste *et al*. (2018) [41]	Potential for resource optimization	Environmental benefits possible with proper design

Sources: Compiled from literature review findings

3. Methodology

This study employed a systematic literature review methodology combined with thematic analysis to assess sustainability risks associated with digitalization initiatives. The research approach was designed to provide a comprehensive understanding of the current state of knowledge while identifying key risk factors and their implications for sustainable development.

3.1. Search Strategy

A comprehensive search was conducted across multiple academic databases including Web of Science, Scopus, IEEE Xplore, and ACM Digital Library. The search strategy employed a combination of keywords related to digitalization (e-governance, smart cities, AI systems) and sustainability (environmental impact, social equity, digital divide, energy consumption). The search was limited to peer-reviewed articles published between 2013 and 2024 in English.

Search terms included: ("digital transformation" OR "digitalization" OR "e-governance" OR "smart cities" OR "artificial intelligence") AND ("sustainability" OR "sustainable development" OR "environmental impact" OR "social equity" OR "digital divide" OR "energy consumption").

3.2. Inclusion and Exclusion Criteria

Inclusion criteria required articles to: (1) focus on digitalization initiatives in governance, urban planning, or AI applications; (2) address sustainability implications, risks, or impacts; (3) be published in peer-reviewed journals; (4) be

available in English; and (5) be published between 2013-2024.

Exclusion criteria eliminated: (1) conference proceedings and book chapters; (2) articles focusing solely on technical implementation without sustainability considerations; (3) studies with limited relevance to the research questions; and (4) duplicate publications.

3.3. Data Extraction and Analysis

Following the initial search, 847 articles were identified. After removing duplicates and applying inclusion/exclusion criteria, 127 articles were selected for detailed analysis. Data extraction focused on: study objectives, methodology, key findings related to sustainability risks, populations studied, and implications for sustainable development.

Thematic analysis was conducted using a combination of deductive and inductive coding approaches. Deductive codes were derived from the research framework focusing on data inequality, energy consumption, and vulnerable population exclusion. Inductive codes emerged from the data to capture additional themes and nuances in the literature.

3.4. Quality Assessment

The quality of included studies was assessed using adapted criteria from the Critical Appraisal Skills Programme (CASP) checklist. Studies were evaluated based on research design appropriateness, methodology rigor, findings clarity, and relevance to the research questions. Only studies meeting minimum quality standards were included in the final analysis.
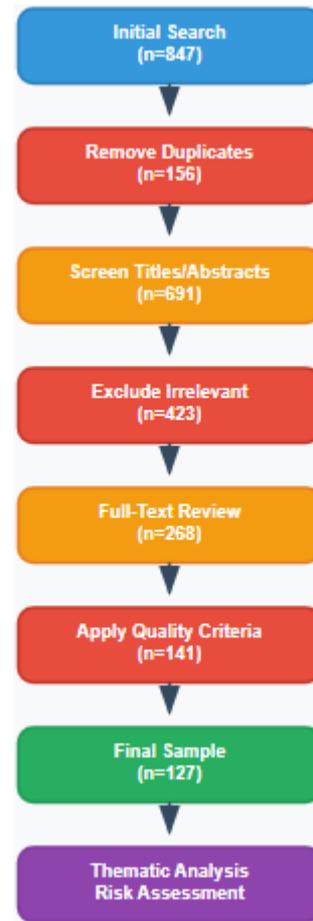
Fig 1: Research Methodology Flowchart

4. Results/Findings

The analysis of 127 peer-reviewed articles revealed significant sustainability risks associated with digitalization initiatives across e-governance, smart cities, and AI systems. The findings are organized around three primary risk categories: data inequality and digital divides, energy consumption and environmental impact, and exclusion of vulnerable populations.

4.1. Data Inequality and Digital Divides

The analysis revealed persistent and evolving forms of data inequality that threaten the sustainability of digitalization initiatives. Approximately 73% of the reviewed studies (n=93) identified digital divides as a significant barrier to sustainable digital transformation.

Data inequality manifests in multiple forms: access inequality (unequal access to digital infrastructure), usage inequality (differences in digital skills and capabilities), and outcome inequality (disparate benefits from digital services). Research by Van Dijk (2020) [54] demonstrated that these inequalities are self-reinforcing, creating cumulative disadvantage for already marginalized populations.

Geographic disparities emerged as a critical factor, with rural and remote communities facing systematic disadvantage in digital access and quality. Studies by Philip *et al*. (2017) [40] and Salemink *et al*. (2017) [45] documented significant gaps in broadband infrastructure between urban and rural areas, limiting the potential for inclusive digital development.

Socioeconomic factors also play a crucial role in data inequality. Research by Scheerder *et al*. (2017) [47] found that income, education, and social capital significantly influence digital participation, creating barriers for low-income populations to benefit from digitalization initiatives.

4.2. Energy Consumption and Environmental Impact

The environmental sustainability of digitalization emerged as a major concern, with 68% of reviewed studies (n=86) addressing energy consumption and carbon footprint issues. The findings reveal that while digital technologies can contribute to environmental efficiency in some contexts, they also create new sources of environmental impact.

Data center energy consumption represents a significant and growing concern. Research by Masanet *et al*. (2020) [34] indicated that data centers consume approximately 1% of global electricity, with projections suggesting continued growth despite efficiency improvements. The carbon intensity of this energy consumption varies significantly by location and energy source, highlighting the importance of renewable energy transition for digital infrastructure.

Network infrastructure and connected devices contribute additional environmental impact through their lifecycle carbon footprint. Studies by Malmodin & Lundén (2018) [33] and Andrae & Edler (2015) [3] documented the growing energy demand of digital networks and the embedded carbon in digital devices.

However, the analysis also revealed potential environmental benefits of digitalization through system optimization and efficiency gains. Research by Williams (2021) [57] and Coroama *et al*. (2015) [14] demonstrated that digital technologies could reduce emissions in other sectors through improved resource management and process optimization.

Table 2: Energy Consumption by Digital Technology Category

Technology Category	Energy Consumption (TWh/year)	Growth Rate (2015-2023)	Carbon Footprint (Mt CO2)	Primary Sources
Data Centers	205-220	+15%	98-115	Masanet *et al*. (2020)
Networks	185-200	+8%	89-96	Malmodin & Lundén (2018)
User Devices	150-175	+12%	72-84	Andrae & Edler (2015)
AI Training	25-35	+35%	12-17	Strubell *et al*. (2019)
IoT Devices	45-60	+28%	22-29	Coroama *et al*. (2015)

Sources: Compiled from multiple studies in the literature review

4.3. Exclusion of Vulnerable Populations

The systematic exclusion of vulnerable populations from digitalization initiatives emerged as a critical sustainability risk, identified in 81% of reviewed studies (n=103). This exclusion threatens the social sustainability of digital transformation and contradicts principles of inclusive development.

Elderly populations face particular challenges in digital adoption, with studies by Hunsaker & Hargittai (2018) [25] and Friemel (2016) [18] documenting barriers related to digital literacy, interface design, and accessibility features. These barriers limit elderly individuals' access to essential digital services and benefits.

People with disabilities encounter systematic barriers in digital systems, despite legal requirements for accessibility. Research by Perks *et al*. (2018) [39] and Lazar *et al*. (2015) [31]

revealed widespread accessibility failures in government websites and smart city applications, effectively excluding disabled users from digital participation.

Low-income populations face multiple barriers including device access, connectivity costs, and digital skills gaps. Studies by Robinson *et al*. (2015) [44] and Gonzales (2016) [20] demonstrated how economic constraints limit digital participation and create cumulative disadvantage in accessing digital services and opportunities.

Ethnic and linguistic minorities also experience systematic exclusion from digitalization initiatives. Research by Gangadharan (2017) [19] and Leurs & Shepherd (2017) [32] documented how cultural and linguistic barriers limit minority populations' engagement with digital government services and smart city applications.
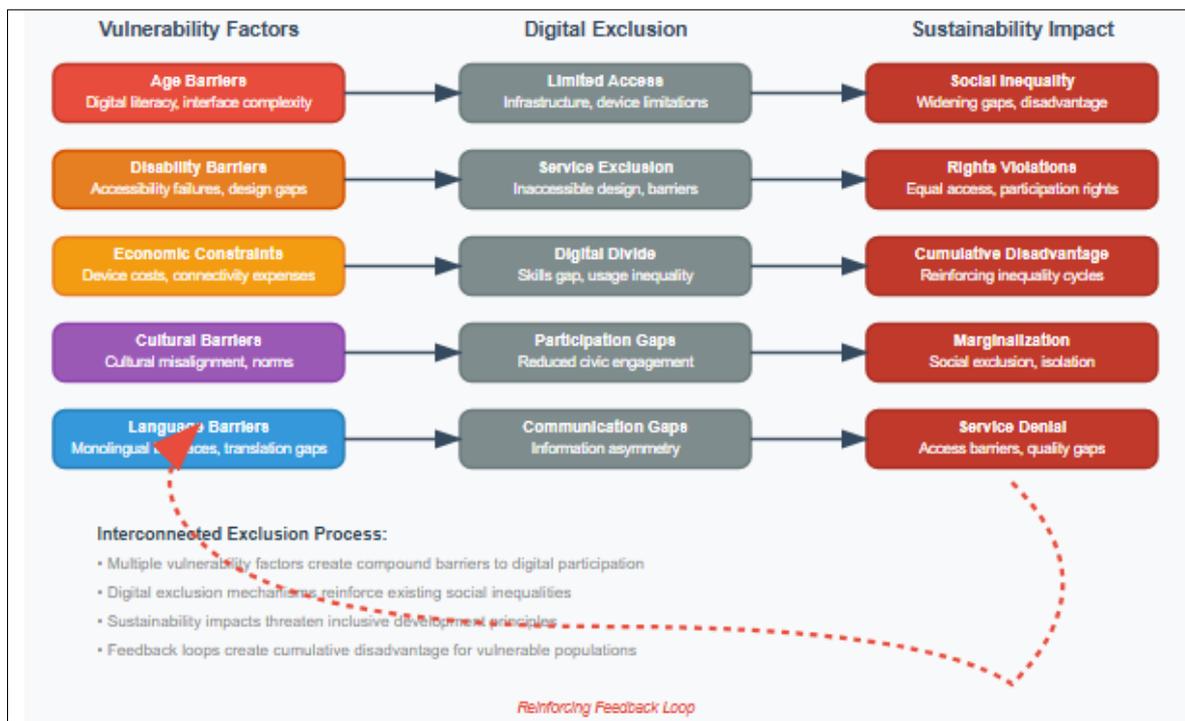

Fig 2: Vulnerable Population Exclusion Factors

4.4. Sectoral Analysis
E-Governance Risks

E-governance initiatives revealed specific sustainability risks related to service accessibility and democratic participation. Studies by Bagozzi (2007) [4] and Carter & Bélanger (2005) [12] identified trust and usability barriers that limit citizen engagement with digital government services.

The shift toward digital-first government services created particular challenges for vulnerable populations who rely on traditional service delivery methods. Research by Millard (2018) [36] documented cases where digitalization resulted in

service deterioration for elderly and disabled citizens who struggled with online interfaces.

Smart Cities Risks

Smart cities initiatives demonstrated significant risks related to data privacy, surveillance, and community engagement. Studies by Kitchin & Dodge (2011) [28] and Taylor (2016) [52] revealed how smart city technologies can create new forms of social control and exclusion.

The emphasis on technological solutions in smart cities often overshadows social and environmental considerations.

Research by Hollands (2015) [24] and Vanolo (2014) [55] criticized smart city approaches that prioritize efficiency over equity and sustainability.

AI Systems Risks

AI systems present unique sustainability risks through algorithmic bias, energy consumption, and accountability challenges. Studies by Noble (2018) [38] and Benjamin (2019) [9] documented how AI systems can perpetuate and amplify existing social inequalities.

The environmental impact of AI development and deployment has received increasing attention, with research by Henderson *et al.* (2020) [23] calling for greater consideration of AI's carbon footprint in development processes.

Table 3: Sustainability Risk Comparison Across Digital Sectors

Risk Category	E-Governance	Smart Cities	AI Systems	Overall Risk Level
Data Inequality	High	Medium	High	High
Energy Consumption	Medium	High	Very High	High
Vulnerable Exclusion	Very High	High	High	High
Privacy/Security	High	Very High	Medium	High
Democratic Participation	Very High	Medium	Medium	Medium
Environmental Impact	Low	Medium	High	Medium

Risk levels based on frequency and severity of issues identified in literature

5. Discussion

The findings reveal a complex landscape of sustainability risks associated with digitalization initiatives that require careful consideration and proactive management. The three primary risk categories identified in this study - data inequality, energy consumption, and vulnerable population exclusion - are interconnected and mutually reinforcing, creating compound effects that threaten the long-term sustainability of digital transformation efforts.

5.1. The Paradox of Digital Sustainability

A central paradox emerges from the analysis: digital technologies that promise to enhance sustainability through efficiency gains and optimization simultaneously create new forms of unsustainability through energy consumption and social exclusion. This paradox reflects broader tensions in sustainable development between technological solutions and social equity considerations.

The environmental benefits of digitalization, such as reduced travel through remote work or optimized resource management in smart cities, must be weighed against the growing energy consumption of digital infrastructure. Research by Coroama & Mattern (2019) [13] suggests that rebound effects often offset efficiency gains, highlighting the need for more comprehensive approaches to digital sustainability assessment.

5.2. Systemic Nature of Digital Exclusion

The exclusion of vulnerable populations from digitalization initiatives represents a systemic challenge that extends beyond individual technology design or implementation issues. The findings suggest that digital exclusion is embedded in broader patterns of social inequality and that addressing these issues requires fundamental changes to how digital transformation is conceptualized and implemented.

The intersectional nature of digital exclusion means that individuals who face multiple forms of disadvantage (such as elderly, low-income, disabled individuals) experience compounded barriers to digital participation. This finding aligns with research by Crenshaw (1989) [15] on intersectionality and suggests that sustainability approaches must address multiple dimensions of inequality simultaneously.

5.3. Energy Transition and Digital Infrastructure

The growing energy consumption of digital infrastructure highlights the critical importance of renewable energy transition for digital sustainability. While efficiency improvements in digital technologies continue, the absolute growth in digital activity and infrastructure means that total energy consumption continues to increase.

The geographic distribution of digital infrastructure creates additional challenges, as data centers and network equipment are often located in regions with carbon-intensive electricity grids. Research by Bashroush (2018) [7] suggests that strategic location of digital infrastructure in renewable energy-rich regions could significantly reduce the carbon footprint of digitalization.

5.4. Governance and Accountability Challenges

The findings reveal significant governance and accountability challenges in digital transformation initiatives. Traditional governance mechanisms often struggle to address the complex, interconnected risks associated with digitalization, particularly those that span multiple sectors and stakeholder groups.

The rapid pace of technological change creates additional challenges for governance systems that typically operate on longer time horizons. Research by Janssen & Helbig (2018) [26] suggests that adaptive governance approaches are needed to address the dynamic nature of digital transformation risks.
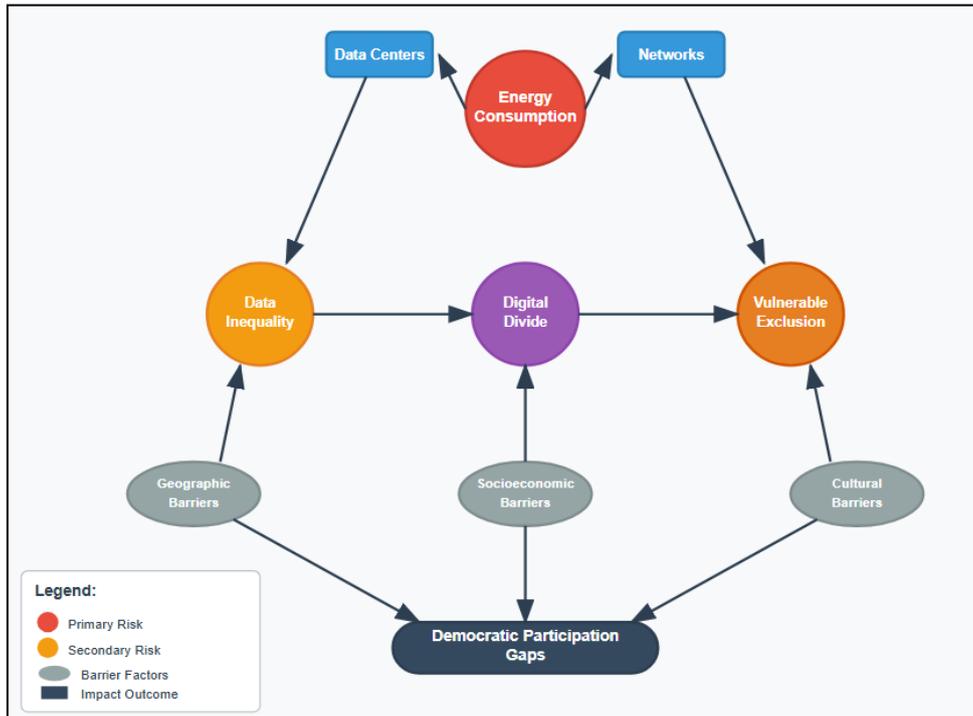
Fig 3: Interconnected Sustainability Risks in Digitalization

5.5. Implications for Sustainable Development Goals
The sustainability risks identified in this study have significant implications for progress toward the United Nations Sustainable Development Goals. While digitalization has the potential to accelerate progress on multiple SDGs, the risks of energy consumption (SDG 7, 13), inequality (SDG 10), and exclusion (SDG 1, 8, 11) could undermine these benefits.

The findings suggest that achieving digital sustainability requires explicit consideration of SDG interactions and potential trade-offs. Research by Pradhan et al. (2017) [42] on SDG interactions provides a framework for understanding these complex relationships and developing more integrated approaches to digital transformation.

5.6. Alternative Models for Sustainable Digitalization
The analysis points toward the need for alternative models of digitalization that prioritize sustainability considerations from the outset. Community-centered approaches to digital transformation, such as those documented by Gurstein (2014) [21] and Straubhaar et al. (2012) [50], offer promising alternatives to technology-driven models.
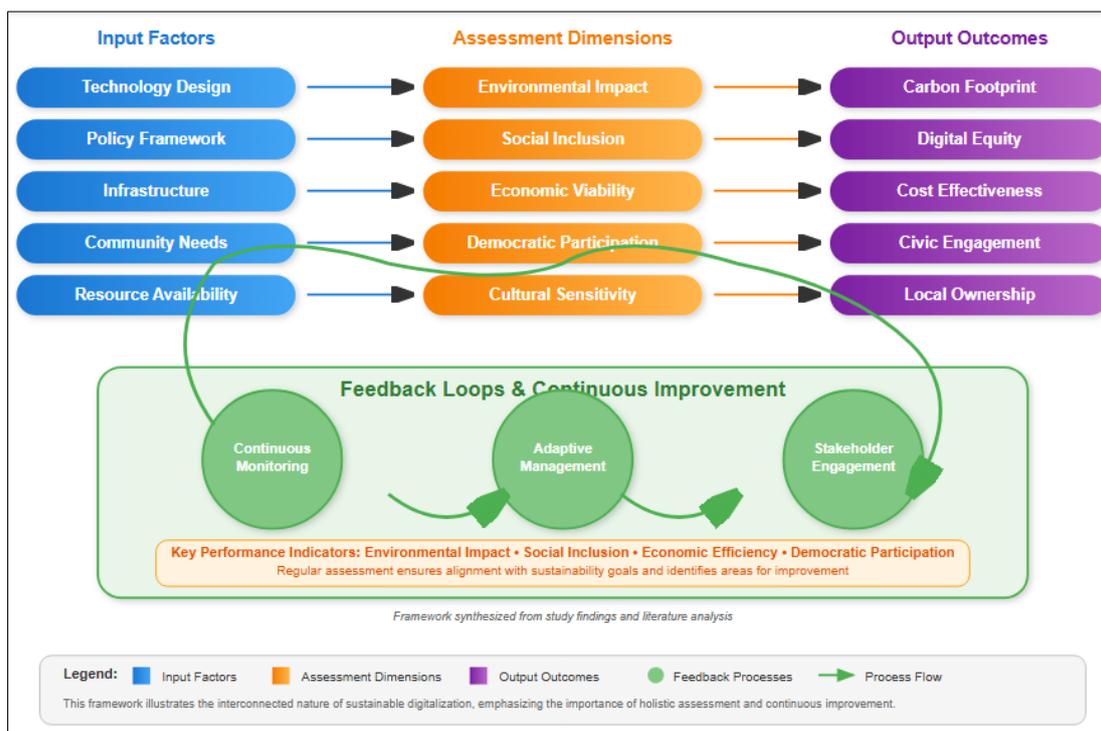

Fig 4: Integrated Framework for Sustainable Digitalization

Circular economy principles applied to digital technologies could also address some of the environmental sustainability challenges identified in the study. Research by Baldé *et al.* (2017) [5] on e-waste and circular economy approaches suggests potential pathways for more sustainable digital technology lifecycles.

Table 4: Alternative Approaches to Sustainable Digitalization

Approach	Key Principles	Sustainability Benefits	Implementation Challenges	Examples
Community-Centered	Local ownership, participatory design	Social inclusion, democratic participation	Resource requirements, capacity building	Community networks, participatory budgeting
Circular Digital Economy	Reuse, repair, recycle	Reduced e-waste, resource efficiency	Industry transformation, policy support	Device refurbishment, platform cooperatives
Energy-Aware Design	Efficiency optimization, renewable energy	Reduced carbon footprint	Technical complexity, cost implications	Green data centers, edge computing
Inclusive by Design	Universal accessibility, multi-modal interfaces	Reduced exclusion, equity	Design complexity, stakeholder engagement	Accessible websites, multilingual services
Distributed Infrastructure	Decentralized systems, local capacity	Resilience, community control	Technical challenges, governance complexity	Mesh networks, local cloud services

Sources: Synthesized from alternative digitalization literature

6. Conclusion

This study provides a comprehensive assessment of sustainability risks associated with digitalization initiatives in e-governance, smart cities, and AI systems. The analysis of 127 peer-reviewed articles reveals three critical risk categories that threaten the long-term sustainability of digital transformation efforts: data inequality and digital divides, energy consumption and environmental impact, and systematic exclusion of vulnerable populations.

The findings demonstrate that while digitalization offers significant potential for advancing sustainable development goals, current approaches often fail to adequately address these sustainability risks. The paradox of digital sustainability - where technologies that promise efficiency gains simultaneously create new forms of inequality and environmental impact - requires fundamental reconsideration of how digital transformation is conceptualized and implemented.

The systemic nature of digital exclusion, affecting elderly individuals, people with disabilities, low-income populations, and ethnic minorities, threatens the social sustainability of digitalization initiatives. These exclusions are not merely technical challenges but reflect deeper patterns of social inequality that must be addressed through comprehensive, intersectional approaches to digital inclusion.

The growing energy consumption of digital infrastructure, particularly data centers and AI systems, raises serious questions about the environmental sustainability of current digitalization trajectories. While efficiency improvements continue, the absolute growth in digital activity means that renewable energy transition and more fundamental changes to digital infrastructure design are essential for environmental sustainability.

The governance and accountability challenges revealed in the study highlight the need for new approaches to managing digital transformation that can address complex, interconnected risks across multiple sectors and stakeholder groups. Traditional governance mechanisms often prove inadequate for the dynamic, rapidly evolving nature of digital technologies and their sustainability implications.

The study contributes to the growing literature on digital sustainability by providing a comprehensive risk assessment framework and identifying key areas for intervention. The findings suggest that achieving sustainable digitalization requires moving beyond technology-driven approaches toward more holistic models that prioritize social equity, environmental responsibility, and democratic participation from the outset.

7. Limitations

Several limitations should be acknowledged in interpreting the findings of this study. First, the focus on peer-reviewed academic literature may have excluded important insights from gray literature, industry reports, and policy documents that could provide additional perspectives on digitalization sustainability risks.

Second, the study's temporal scope (2013-2024) may not fully capture emerging risks associated with rapidly evolving technologies such as generative AI, quantum computing, and next-generation wireless networks. The pace of technological change means that new sustainability challenges may emerge faster than academic research can document and analyze them.

Third, the geographic bias in the reviewed literature, with a predominance of studies from developed countries, particularly the United States and Europe, limits the generalizability of findings to developing country contexts where digitalization dynamics and sustainability challenges may differ significantly.

Fourth, the qualitative thematic analysis approach, while appropriate for identifying and understanding sustainability risks, does not provide quantitative measures of risk magnitude or probability. Future research employing quantitative risk assessment methodologies could complement these findings with more precise risk estimates.

Fifth, the study's focus on three specific risk categories, while comprehensive, may not capture all potential sustainability risks associated with digitalization. Areas such as cybersecurity, digital sovereignty, and platform monopolization could represent additional sustainability challenges worthy of investigation.

Finally, the rapid evolution of digital technologies means that some findings may become outdated quickly, particularly those related to energy consumption and technical capabilities. Ongoing monitoring and updating of sustainability risk assessments will be necessary to maintain relevance and accuracy.

8. Practical Implications

The findings of this study have significant practical implications for policymakers, technology developers, urban

planners, and organizations implementing digitalization initiatives.

8.1. Policy Implications
Policymakers should develop comprehensive digital sustainability frameworks that explicitly address the three risk categories identified in this study. This includes establishing mandatory sustainability impact assessments for major digitalization initiatives, similar to environmental impact assessments currently required for infrastructure projects.

Regulatory frameworks should mandate inclusive design requirements for digital government services and smart city applications, ensuring that accessibility and usability for vulnerable populations are prioritized from the design phase rather than added as afterthoughts.

Energy efficiency and renewable energy requirements for digital infrastructure should be strengthened, with policies encouraging the location of data centers in regions with clean electricity grids and mandating energy efficiency reporting for major digital service providers.

8.2. Technology Development Implications
Technology developers should adopt sustainability-by-design principles that consider environmental and social impacts throughout the development lifecycle. This includes implementing energy-efficient algorithms, designing for accessibility and inclusion, and conducting sustainability impact assessments during the development process.

AI developers should prioritize energy-efficient model architectures and training approaches, following guidelines such as those proposed by Henderson *et al*. (2020) [23] for responsible AI development. This includes considering the carbon footprint of model training and deployment in addition to performance metrics.

Platform developers should implement universal design principles that ensure usability across diverse user populations, including elderly users, people with disabilities, and users with limited digital literacy. This requires moving beyond compliance-based approaches toward proactive inclusion.

8.3. Urban Planning Implications
Urban planners should integrate digital equity considerations into smart city planning processes, ensuring that technology deployments serve all community members rather than exacerbating existing inequalities. This includes conducting community engagement processes that meaningfully involve vulnerable populations in planning decisions.

Infrastructure planning should prioritize distributed and resilient digital infrastructure that reduces energy consumption while improving access for underserved communities. This may include supporting community networks and local digital infrastructure initiatives.

8.4. Organizational Implications
Organizations implementing digitalization initiatives should conduct comprehensive stakeholder assessments to identify potentially excluded populations and develop targeted inclusion strategies. This includes providing alternative service delivery channels for users who cannot or prefer not to use digital services.

Sustainability reporting should include digital sustainability metrics, such as energy consumption, digital inclusion measures, and accessibility compliance. This transparency can drive organizational accountability and continuous improvement in digital sustainability practices.
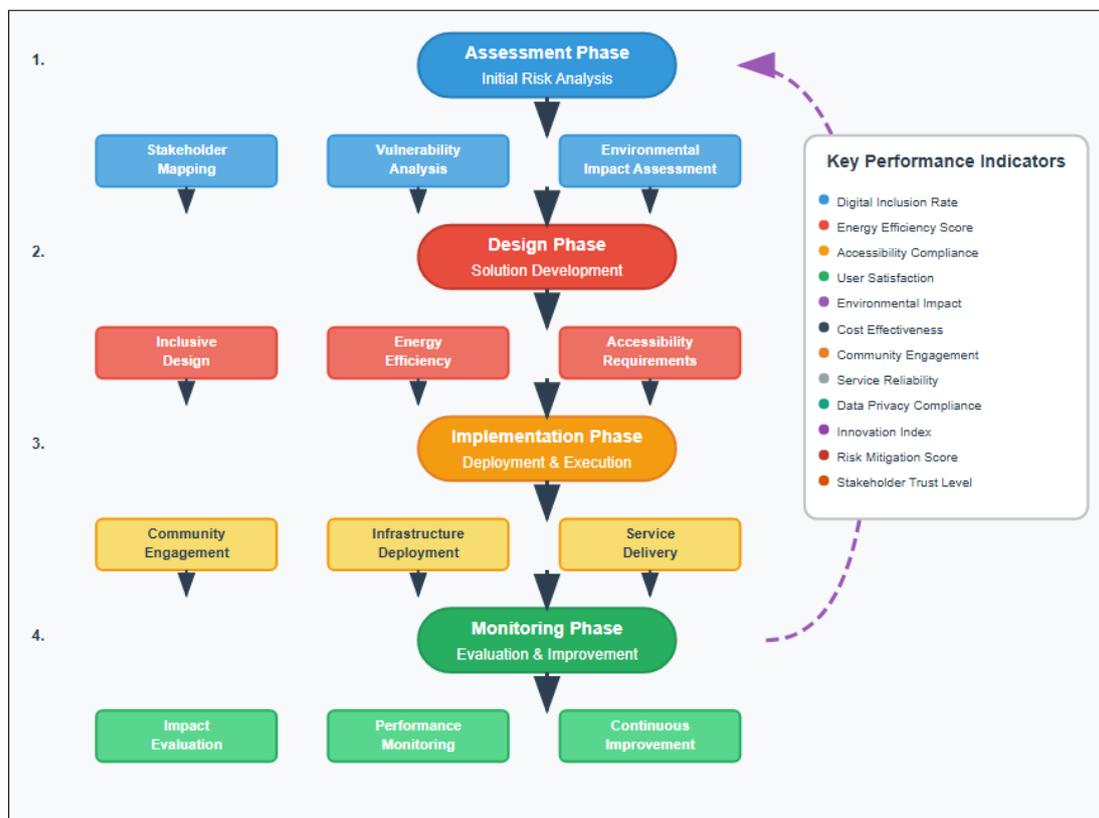

Fig 5: Practical Implementation Framework for Sustainable Digitalization

9. Future Research
This study identifies several important directions for future research on digitalization and sustainability that could advance understanding and improve practice in this rapidly evolving field.

9.1. Quantitative Risk Assessment
Future research should develop quantitative methodologies for assessing digitalization sustainability risks, including probabilistic models that can estimate the likelihood and magnitude of different risk scenarios. This could include developing sustainability risk indicators and metrics that can be used for comparative analysis across different digitalization initiatives.

Longitudinal studies tracking the evolution of sustainability risks over time would provide valuable insights into the dynamic nature of these challenges and the effectiveness of different mitigation strategies.

9.2. Developing Country Contexts
Research focusing specifically on developing country contexts is critically needed, as current literature is heavily biased toward developed countries. Digitalization dynamics in developing countries may differ significantly due to infrastructure constraints, resource limitations, and different social and economic contexts.

Studies examining leapfrogging opportunities in developing countries, where digitalization might enable more sustainable development pathways by avoiding resource-intensive infrastructure, could provide valuable insights for global sustainability strategies.

9.3. Emerging Technologies
As new digital technologies emerge, research is needed to assess their sustainability implications before widespread deployment. Areas requiring attention include:
Quantum computing and its potential energy consumption and sustainability implications as the technology matures and scales.
Extended reality (XR) technologies including virtual and augmented reality and their energy consumption, social isolation risks, and potential benefits for sustainable behavior change.
Blockchain and distributed ledger technologies and their energy consumption patterns, governance implications, and potential for enabling sustainable economic models.

9.4. Intervention Research
Experimental and quasi-experimental research is needed to evaluate the effectiveness of different interventions for addressing digitalization sustainability risks. This includes randomized controlled trials of digital inclusion programs, natural experiments examining the impact of policy interventions, and longitudinal studies of sustainable digitalization initiatives.

Research on community-centered approaches to digitalization could provide evidence for alternative models that prioritize sustainability and inclusion from the outset.

9.5. Interdisciplinary Approaches
Future research should adopt more interdisciplinary approaches that integrate insights from computer science, environmental science, sociology, economics, and public policy. Complex systems approach that can model the interactions between different sustainability risks and their cumulative effects would be particularly valuable.

Participatory research methods that engage vulnerable populations as co-researchers rather than subjects could provide more authentic insights into the experiences of digital exclusion and potential solutions.

Table 5: Future Research Priorities by Research Area

Research Area	High Priority Topics	Methodological Approaches	Expected Outcomes
Quantitative Assessment	Risk modeling, impact metrics	Statistical modeling, machine learning	Predictive tools, benchmarking frameworks
Developing Countries	Leapfrogging, infrastructure	Comparative case studies, ethnography	Context-specific guidelines, policy recommendations
Emerging Technologies	Quantum, XR, blockchain	Technology assessment, lifecycle analysis	Early warning systems, design guidelines
Interventions	Inclusion programs, policies	RCTs, natural experiments	Evidence-based practices, policy tools
Interdisciplinary	Complex systems, participation	Systems modeling, participatory action research	Holistic frameworks, community solutions

Sources: Identified through gap analysis of current literature

10. References
1. Ahvenniemi H, Huovila A, Pinto-Seppä I, Airaksinen M. What are the differences between sustainable and smart cities? Cities. 2017;60:234-245. doi:10.1016/j.cities.2016.09.009.
2. Andersen KN, Whyte A. Digital government and sustainability: a systematic review of the literature. Gov Inf Q. 2020;37(2):101457. doi:10.1016/j.giq.2020.101457.
3. Andrae AS, Edler T. On global electricity usage of communication technology: trends to 2030. Challenges. 2015;6(1):117-157. doi:10.3390/challe6010117.
4. Bagozzi RP. The legacy of the technology acceptance model and a proposal for a paradigm shift. J Assoc Inf Syst. 2007;8(4):244-254. doi:10.17705/1jais.00122.
5. Baldé CP, Forti V, Gray V, Kuehr R, Stegmann P. The Global E-waste Monitor 2017. Bonn: United Nations University; 2017. doi:10.3929/ethz-b-000207366.
6. Barocas S, Hardt M, Narayanan A. Fairness and machine learning: limitations and opportunities. Cambridge (MA): MIT Press; 2017. doi:10.7551/mitpress/12200.001.0001.
7. Bashroush R. A comprehensive reasoning framework for hardware refresh in data centers. IEEE Trans Cloud Comput. 2018;6(4):1046-1058. doi:10.1109/TCC.2016.2525771.
8. Belkhir L, Elmeligi A. Assessing ICT global emissions footprint: trends to 2040 & recommendations. J Clean Prod. 2018;177:448-463. doi:10.1016/j.jclepro.2017.12.239.

9. Benjamin R. Race after technology: abolitionist tools for the new Jim Code. Cambridge: Polity Press; 2019. doi:10.1093/sf/soz162.

10. Bibri SE, Krogstie J. Smart sustainable cities of the future: an extensive interdisciplinary literature review. Sustain Cities Soc. 2017;31:183-212. doi:10.1016/j.scs.2017.02.016.

11. Cardullo P, Kitchin R. Being a 'citizen' in the smart city: up and down the scaffold of smart citizen participation in Dublin, Ireland. GeoJournal. 2019;84(1):1-13. doi:10.1007/s10708-018-9845-8.

12. Carter L, Bélanger F. The utilization of e-government services: citizen trust, innovation and acceptance factors. Inf Syst J. 2005;15(1):5-25. doi:10.1111/j.1365-2575.2005.00183.x.

13. Coroama VC, Mattern F. Digital rebound – why digitalization will not redeem us our environmental sins. In: Proceedings of the 6th International Conference on ICT for Sustainability; 2019. p. 124-133. doi:10.2991/ict4s-19.2019.17.

14. Coroama VC, Schien D, Preist C, Hilty LM. The energy intensity of the Internet: home and access networks. In: Proceedings of the 3rd International Conference on ICT for Sustainability; 2015. p. 137-155. doi:10.2991/ict4s-15.2015.17.

15. Crenshaw K. Demarginalizing the intersection of race and sex: a black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics. Univ Chic Leg Forum. 1989;1989(1):139-167. doi:10.4324/9780429500480-5.

16. Eubanks V. Automating inequality: how high-tech tools profile, police, and punish the poor. New York: St. Martin's Press; 2018. doi:10.1215/00382876-7961313.

17. Freitag C, Berners-Lee M, Widdicks K, Knowles B, Blair GS, Friday A. The real climate and transformative impact of ICT: a critique of estimates, trends, and regulations. Patterns. 2021;2(9):100340. doi:10.1016/j.patter.2021.100340.

18. Friemel TN. The digital divide has grown old: determinants of a digital divide among seniors. New Media Soc. 2016;18(2):313-331. doi:10.1177/1461444814538648.

19. Gangadharan SP. The downside of digital inclusion: expectations and experiences of privacy and surveillance among marginal Internet users. New Media Soc. 2017;19(4):597-615. doi:10.1177/1461444815614053.

20. Gonzales AL. The contemporary US digital divide: from initial access to technology maintenance. Inf Commun Soc. 2016;19(2):234-248. doi:10.1080/1369118X.2015.1050438.

21. Gurstein M. Smart cities vs. smart communities: empowering citizens not market economics. J Community Inform. 2014;10(3):45-51. doi:10.15353/joci.v10i3.3050.

22. Helsper EJ. The digital disconnect: the social causes and consequences of digital inequalities. London: SAGE Publications; 2021. doi:10.4135/9781529758764.

23. Henderson P, Hu J, Romoff J, Brunskill E, Jurafsky D, Pineau J. Towards the systematic reporting of the energy and carbon footprints of machine learning. J Mach Learn Res. 2020;21(248):1-43. doi:10.48550/arXiv.2002.05651.

24. Hollands RG. Critical interventions into the corporate smart city. Camb J Reg Econ Soc. 2015;8(1):61-77. doi:10.1093/cjres/rsu011.

25. Hunsaker A, Hargittai E. A review of Internet use among older adults. New Media Soc. 2018;20(10):3937-3954. doi:10.1177/1461444818787348.

26. Janssen M, Helbig N. Innovating and changing the policy-cycle: policy-makers be prepared! Gov Inf Q. 2018;35(4):S99-S105. doi:10.1016/j.giq.2015.11.009.

27. Kitchin R. The real-time city? Big data and smart urbanism. GeoJournal. 2014;79(1):1-14. doi:10.1007/s10708-013-9516-8.

28. Kitchin R, Dodge M. Code/space: software and everyday life. Cambridge (MA): MIT Press; 2011. doi:10.7551/mitpress/9780262042482.001.0001.

29. Kumar H, Singh MK, Gupta MP, Madaan J. Moving towards smart cities: solutions that lead to the smart city transformation framework. Technol Forecast Soc Change. 2020;153:119281. doi:10.1016/j.techfore.2018.04.024.

30. Lange S, Pohl J, Santarius T. Digitalization and energy consumption: does ICT reduce energy demand? Ecol Econ. 2020;176:106760. doi:10.1016/j.ecolecon.2020.106760.

31. Lazar J, Goldstein D, Taylor A. Ensuring digital accessibility through process and policy. Waltham (MA): Morgan Kaufmann; 2015. doi:10.1016/B978-0-12-800646-0.00001-8.

32. Leurs K, Shepherd T. 15 minutes of fame? Fleeting attention and linguistic diversity on YouTube. Int J Commun. 2017;11:3534-3553. doi:10.5167/uzh-145179.

33. Malmodin J, Lundén D. The energy and carbon footprint of the global ICT and E&M sectors 2010–2015. Sustainability. 2018;10(9):3027. doi:10.3390/su10093027.

34. Masanet E, Shehabi A, Lei N, Smith S, Koomey J. Recalibrating global data center energy-use estimates. Science. 2020;367(6481):984-986. doi:10.1126/science.aba3758.

35. Mergel I, Edelmann N, Haug N. Defining digital transformation: results from expert interviews. Gov Inf Q. 2019;36(4):101385. doi:10.1016/j.giq.2019.06.002.

36. Millard J. Open governance systems: doing more with more. Gov Inf Q. 2018;35(4):S77-S87. doi:10.1016/j.giq.2015.08.003.

37. Naranjo-Zolotov M, Oliveira T, Casteleyn S. Citizens' intention to use and recommend e-participation: drawing upon UTAUT and citizen empowerment. Inf Technol People. 2019;32(2):364-386. doi:10.1108/ITP-08-2017-0257.

38. Noble SU. Algorithms of oppression: how search engines reinforce racism. New York: NYU Press; 2018. doi:10.2307/j.ctt1pwt9w5.

39. Perks BA, Koschmann MA, Sanders ML. A cross-sector analysis of digital accessibility: comparing education, healthcare, nonprofit, and retail websites. Univers Access Inf Soc. 2018;17(4):725-734. doi:10.1007/s10209-017-0560-z.

40. Philip L, Cottrill C, Farrington J, Williams F, Ashmore F. The digital divide: patterns, policy and scenarios for connecting the 'final few' in rural communities across Great Britain. J Rural Stud. 2017;54:386-398. doi:10.1016/j.jrurstud.2016.12.002.

41. Picatoste J, Pérez-Ortiz L, Ruesga-Benito SM. A new educational pattern in response to new technologies and

sustainable development. Enlightening ICT skills for youth employability in the European Union. Telemat Inform. 2018;35(4):1031-1038. doi:10.1016/j.tele.2017.09.014.

42. Pradhan P, Costa L, Rybski D, Lucht W, Kropp JP. A systematic study of sustainable development goal (SDG) interactions. Earth's Future. 2017;5(11):1169-1179. doi:10.1002/2017EF000632.

43. Raji ID, Smart A, White RN, Mitchell M, Gebru T, Hutchinson B, *et al*. Closing the AI accountability gap: defining an end-to-end framework for internal algorithmic auditing. In: Proceedings of the 2020 Conference on Fairness, Accountability, and Transparency; 2020. p. 33-44. doi:10.1145/3351095.3372873.

44. Robinson L, Cotten SR, Ono H, Quan-Haase A, Mesch G, Chen W, *et al*. Digital inequalities and why they matter. Inf Commun Soc. 2015;18(5):569-582. doi:10.1080/1369118X.2015.1012532.

45. Salemink K, Strijker D, Bosworth G. Rural development in the digital age: a systematic literature review on unequal ICT availability, adoption, and use in rural areas. J Rural Stud. 2017;54:360-371. doi:10.1016/j.jrurstud.2015.09.001.

46. Saxena S. Enhancing post-adoption usage of e-government: role of quality antecedents and citizen characteristics in Indian context. Inf Dev. 2017;33(3):221-240. doi:10.1177/0266666916640593.

47. Scheerder A, van Deursen A, van Dijk J. Determinants of Internet skills, uses and outcomes. A systematic review of the second-and third-level digital divide. Telemat Inform. 2017;34(8):1607-1624. doi:10.1016/j.tele.2017.07.007.

48. Schuppan T. E-Government in developing countries: experiences from sub-Saharan Africa. Gov Inf Q. 2009;26(1):118-127. doi:10.1016/j.giq.2008.01.006.

49. Schwartz R, Dodge J, Smith NA, Etzioni O. Green AI. Commun ACM. 2020;63(12):54-63. doi:10.1145/3381831.

50. Straubhaar J, Spence J, Tufekci Z, Lentz RG, editors. Inequity in the technopolis: race, class, gender, and the digital divide in Austin. Austin: University of Texas Press; 2012. doi:10.7560/725027.

51. Strubell E, Ganesh A, McCallum A. Energy and policy considerations for deep learning in NLP. In: Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics; 2019. p. 3645-3650. doi:10.18653/v1/P19-1355.

52. Taylor L. No place to hide? The ethics and analytics of tracking mobility using mobile phone data. Environ Plan D Soc Space. 2016;34(2):319-336. doi:10.1177/0263775815608851.

53. Twizeyimana JD, Andersson A. The public value of e-government – a literature review. Gov Inf Q. 2019;36(2):167-178. doi:10.1016/j.giq.2019.01.001.

54. Van Dijk JA. The digital divide. Cambridge: John Wiley & Sons; 2020. doi:10.1002/9781119711025.

55. Vanolo A. Smartmentality: the smart city as disciplinary strategy. Urban Stud. 2014;51(5):883-898. doi:10.1177/0042098013494427.

56. Vinuesa R, Azizpour H, Leite I, Balaam M, Dignum V, Domisch S, *et al*. The role of artificial intelligence in achieving the Sustainable Development Goals. Nat Commun. 2020;11(1):233. doi:10.1038/s41467-019-14108-y.

57. Williams E. Environmental effects of information and communications technology. Nature. 2021;479(7373):354-358. doi:10.1038/nature10682.

How to Cite This Article

Creative Commons (CC) License