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Governance of digital transformation for sustainable development: aligning digital innovation with the sustainable development goals

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The accelerating pace of digital innovation presents new governance challenges, necessitating the establishment of robust policy, legislative, and institutional frameworks to mitigate risks and maximize sustainability benefits. This study examines the intersection between digital transformation (DT), governance, and sustainability within the context of the United Nations Sustainable Development Goals (SDGs). The purpose of this study is to synthesize and critically evaluate the evidence on how DT governance influences progress toward the SDGs. Using a systematic mapping and structured qualitative evidence synthesis, aligned with PRISMA 2020 guidelines, the study reviews peer-reviewed literature published between 2015 and 2024 on the governance of DT in relation to the SDGs. Sixty-five studies were analyzed across governance scales, digital technologies, and sustainability dimensions. The findings reveal strong optimism regarding DT contributions to the SDGs, alongside persistent governance gaps, contextual inequalities, and underexamined trade-offs. To address these gaps, the study proposes an evidence-informed framework for sustainable DT governance that integrates inclusivity, adaptability, transparency, and multi-stakeholder collaboration. The framework is positioned relative to existing digital and sustainability governance models and highlights implementation challenges, particularly in low- and middle-income country contexts. The results advance policy-relevant insights for aligning digital innovation with long-term sustainability objectives.

KEYWORDS

digital transformation, governance, qualitative evidence synthesis, sustainability, sustainable development goals, systematic mapping

1 Introduction

The digital era is reshaping every aspect of life with the integration of advanced digital technologies such as Artificial Intelligence (AI), Big Data, Cloud Computing, Video Analytics, Virtual and Augmented Realities, and the Internet of Things (IoT) into sustainable development practices presenting both unparalleled opportunities and considerable challenges ([World Economic Forum, 2019](#)). In this context, Digital Transformation (DT) offers a promising potential for accelerating the achievement of the UN Sustainable Development Goals (SDGs) by streamlining processes and enhancing efficiency across economic, environmental, and social pillars ([Bai et al., 2025](#); [World Economic Forum, 2020b](#)). Nonetheless, the emergence and rapid expansion of digital technologies also raises significant concerns regarding the capacity to

address pressing global challenges, particularly sustainability (United Nations Conference on Trade and Development, 2018), defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987; United Nations, 2020; World Bank, 2019).

The UN views sustainability through a framework of the SDGs built upon three interconnected pillars: economic, environmental, and social, and designed to promote environmental protection, social equity, and economic development (Allen et al., 2016; Allen et al., 2018; Berawi, 2017; Glavič and Lukman, 2007; Ruggerio, 2021; Sachs et al., 2019; United Nations, 2015a; United Nations, 2015b; United Nations Conference on Trade and Development, 2018). Embracing sustainability is beyond just a moral imperative but rather an economic and social necessity, becoming also essential in the business and governance fields (Goralski and Tan, 2020; Jones et al., 2017). In parallel, Digital transformation, or DT, described as the integration of digital technologies into business areas (El hilali and El manouar, 2019), is altering how organizations operate and deliver value to customers (Ghobakhloo et al., 2021a; Khakurel et al., 2018; Stock et al., 2018). It involves the digitization of information and the evolution of systems, processes, and organizational culture to boost efficiency, performance, and value creation (Etzion and Aragon-Correa, 2016; Santarius et al., 2023a) and to adapt to a dynamically changing digital economy (Norström et al., 2023; Zhang et al., 2024), marking a shift towards more efficient, innovative, and customer-focused operations (Gong and Ribiere, 2021).

Both DT and sustainability have steadily emerged as central concepts of focus in the contemporary global context, intersecting and providing opportunities to leverage digital technologies towards achieving sustainable development (SD). Combining technological advancements with robust sustainability practices leads to enhanced quality of life through democratized services and drives towards an economically stable, socially equitable, and environmentally healthy global society (Bai et al., 2025; Brenner and Hartl, 2021; Guandalini, 2022; Ji and Huang, 2024). Concurrently, DT is also associated with risks and challenges (Truby, 2020; Young et al., 2020) of significant concerns to be addressed to ensure that the DT does not undermine sustainability (Bekaroo et al., 2016). In this context, DT governance refers to policies and guidelines that regulate the development, implementation, and use of digital technologies. It can be leveraged to support the UN SDGs by guiding the effective, ethical, and equitable use of technologies towards addressing global challenges like poverty, education, inequality, and climate change.

Emerging efforts underscore the need for a holistic approach that integrates digital and sustainability transformations, while recognizing the interconnected nature of these fields and the critical role of robust national policies and global actions to ensure their effective implementation and beneficial outcomes (United Nations Department of Economic and Social Affairs, 2018). The purpose of this study is to synthesize and critically assess the evidence on how digital transformation governance shapes environmental, social, and economic progress toward the United Nations Sustainable Development Goals. Given the policy-oriented and multi-scalar nature of digital transformation governance, this study applies an adapted governance-oriented analytical structure that defines (i) contexts (governance level and socio-economic setting); (ii) governance interventions (policies, regulatory instruments and institutional arrangements); and (iii) sustainability-related outcomes in relation to the UN SDGs. As such, this study presents a systematic mapping and qualitative evidence synthesis of the

role of DT governance in the pursuit of the UN SDGs, by addressing the following questions:

- 1) How do DT initiatives influence progress toward the environmental, social, and economic dimensions of the UN SDGs across different governance levels and socio-economic contexts?
- 2) Which DT governance mechanisms—such as policies, regulatory frameworks, institutional arrangements, and coordination instruments—shape the direction and magnitude of DT impacts on SDG progress? and
- 3) What governance approaches and policy practices have been reported as effective in aligning digital transformation with the UN SDGs, and under what institutional and geographic conditions are these practices transferable or constrained?

Past efforts emphasized the use of DT to support the governance of sustainability, rather than the governance of DT itself in a sustainable manner, leaving a critical gap in understanding how governance structures can manage DT towards sustainability. While highlighting the importance of DT governance, previous studies stopped short of synthesizing knowledge gaps to address governance challenges. Unlike earlier studies that narrowly focus on specific SDGs or emphasize technological benefits without fully exploring trade-offs, this study adopts a holistic approach, examining interconnections across all SDGs while providing a balanced analysis of benefits and challenges. The success of DT in promoting sustainability depends heavily on regional, economic, and social contexts, which are underexplored in past efforts. Therefore, we consider regional variability and contextual sensitivity to ensure that the findings are globally applicable and locally relevant. Additionally, we highlight policy pathways and strategic actions for effective DT governance aiming to support sustainable development. Finally, this study develops an inductively derived, evidence-based governance framework that synthesizes recurring patterns in governance mechanisms, institutional capacity, and contextual implementation challenges shaping the sustainability outcomes of digital transformation, offering an analytical lens for understanding DT governance in relation to the UN SDGs and identifying key knowledge gaps and future research directions.

2 Methodology

2.1 Systematic mapping and structured qualitative synthesis protocol and search strategy

A systematic mapping and structured qualitative evidence synthesis was conducted to identify knowledge gaps and opportunities, along with a critical assessment of relevant studies addressing the effects of DT governance on the progress of SDGs. First, a screening was conducted in accordance with the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework 2020 (Page et al., 2021), ensuring a scientifically rigorous and transparent approach to systematic analysis through a standard methodology and guideline checklist. A protocol was established to define the search strategy, inclusion and exclusion criteria, data extraction, and analysis procedures. The search targeted three prominent electronic

bibliographic databases: Scopus, Web of Science, and Science Direct, chosen for their recognized impact indices and coverage of credible peer-reviewed literature in sustainability and digital transformation. The search was limited to relatively recent articles published since 2015 onwards, coinciding with the adoption of SDGs. Only English-language publications were included for feasibility. Relevant bibliographies were screened manually to identify additional eligible studies. The review was also restricted to peer-reviewed open-access articles to enhance transparency, reproducibility, and accessibility of the evidence base for policy-oriented audiences, particularly in resource-constrained contexts. While this criterion supports equitable access, it may introduce selection bias by underrepresenting paywalled governance and theoretical studies; the implications of this limitation are explicitly addressed in the Discussion and inform the identification of future research directions. Search terms were expanded to capture as many relevant studies as possible, including “Sustainable Development Goals” or “SDGs,” “Digital Transformation” or “Digital Technologies” or “ICT” and “Governance” or “Policy” or “Strategy.” The complete database-specific Boolean search strings used for each bibliographic source are provided in [Appendix A](#) to enhance transparency and replicability. Inclusion and exclusion criteria ([Table 1](#)) were then defined and used to filter studies that analyzed the role and impacts of DT governance and policies on the SDGs.

The collection of articles was conducted in three rounds. The first round involved an initial search in SCOPUS ($n = 152$) articles, Web of Science ($n = 89$) articles, and Science Direct databases ($n = 236$) articles, resulting in a total of ($n = 477$) studies. After excluding duplicates, ($n = 461$) studies remained. In the first screening round, 126 articles were excluded for being irrelevant to the research question or not focused on the governance of DT (EC-3). In the second round, ($n = 39$) publications were excluded for addressing the governance of DT at the corporate or business levels rather than the national or

global level (EC-4). In the third round, the remaining studies were further screened, and the full texts of eligible publications were reviewed for relevance, with 237 studies excluded for being sector or industry-specific not generalizable to all sectors (EC-5), with ($n = 54$) remaining studies. Manual screening of reference lists of relevant studies yielded 11 additional papers. The overall process is presented in the PRISMA flow diagram in [Figure 1](#) with 65 relevant studies.

2.2 Quality appraisal and assessment criteria of included studies

A structured quality appraisal was conducted using an adapted Mixed Methods Appraisal Tool (MMAT) framework appropriate for interdisciplinary, mixed-methods, and governance-oriented research ([Hong et al., 2018](#)). The appraisal assessed studies against core criteria relevant to governance and policy analysis, including methodological transparency, coherence between research questions, design and conclusions, and the clarity and plausibility of governance and policy implications. Detailed appraisal criteria, scoring logic, and summary outcomes are reported in [Appendix B](#). Given the conceptual, normative, and policy-analytical orientation of a substantial portion of the reviewed literature, the quality appraisal was applied in a context-sensitive and non-exclusionary manner. Rather than serving as a basis for study exclusion, appraisal results were used to contextualize the synthesis, inform interpretation of findings, and distinguish robust evidence from more tentative findings. The appraisal indicates that the evidence base linking digital transformation governance to SDGs outcomes is substantial but uneven. Empirically grounded findings are more prevalent in the high- and moderate-quality literature, while strongly optimistic or solutionist narratives are disproportionately represented among lower-quality and conceptual studies. This pattern reinforces the review’s identification of a positivity bias and underpins the decision to treat reported sustainability benefits of DT as conditional on governance quality, institutional capacity, and context, rather than as universally transferable outcomes. These quality considerations are explicitly reflected in the Discussion and governance framework interpretation.

3 Results and discussion

3.1 Digital transformation, sustainability and governance

3.1.1 Key findings

Reported studies were extracted from peer reviewed scientific journals focusing on sustainability, digital transformation, and governance or policy-related subjects. Prior to the Paris agreement and the promulgation of the UN SDGs in 2016, limited efforts connecting DT with sustainability appeared from 2011 to 2015, during which, a disconnect is evident between sustainability goals and DT initiatives, hindering their effective implementation ([Norström et al., 2023](#)). A noticeable increase in publications is observed from 2016 to 2024 ([Figure 2](#)), conceding the relationship between DT and sustainability. This surge underscores the growing recognition of the role that DT can play in promoting economic prosperity, social equity, and environmental conservation ([Lange and Santarius, 2020](#); [Stock et al.,](#)

TABLE 1 Inclusion and Exclusion criteria for the selection of studies.

Inclusion Criteria (ICs)	Exclusion Criteria (ECs)
IC-1. Studies addressing the governance of DT and its impacts on the UN SDGs	EC-1. Proceedings of congresses, conference papers, books, book chapters, dissertations, and thesis studies
	EC-2. Written in languages other than English
IC-2. Written in the English language	EC-3. Studies that are off-topic (irrelevant to the research questions) or not focused on the governance of DT
IC-3. Available in full text (Open Access)	EC-4. Studies addressing the governance of DT at the corporate or business levels
IC-4. Published between 2015 and 2024	EC-5. Studies addressing a specific industry or sector, not generalized to all sectors
	EC-6. Studies not available in full text

DT: Digital Transformation; IC: Inclusion Criteria; EC: Exclusion Criteria.

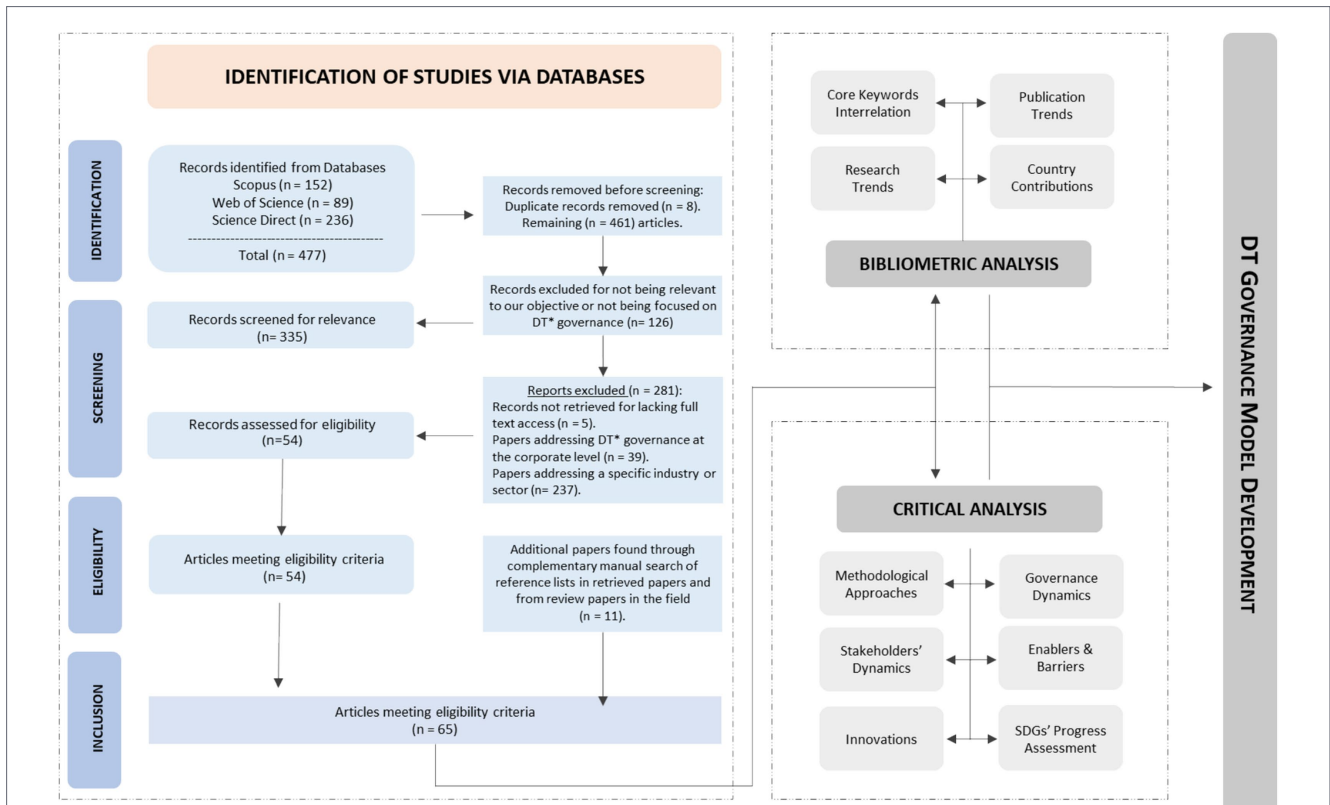


FIGURE 1 Flow diagram for the systematic analysis using PRISMA 2020 guidelines. DT: Digital transformation; n: number of articles.

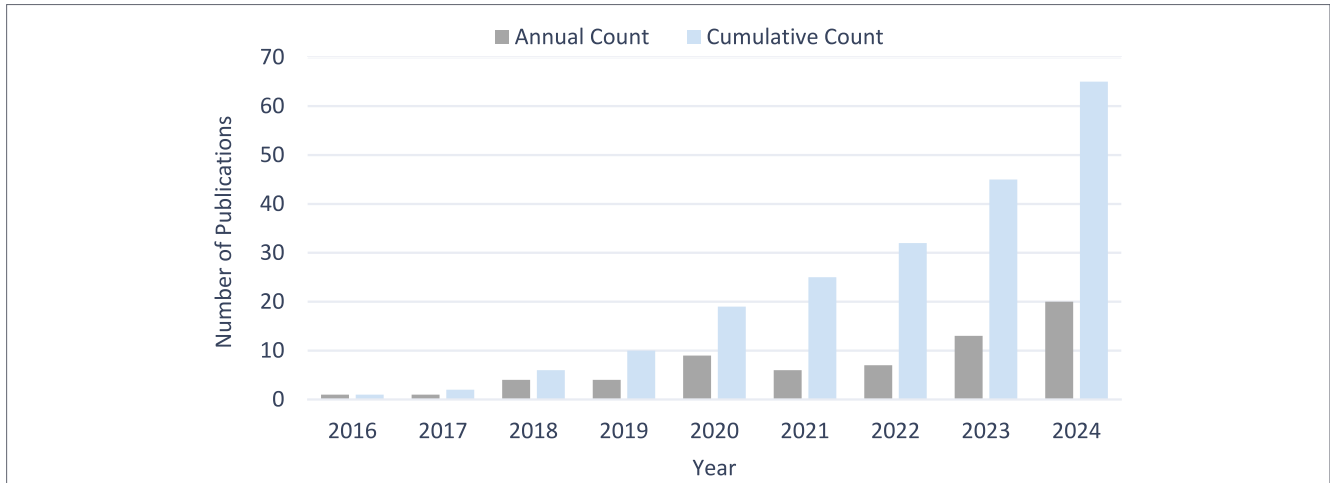


FIGURE 2 Publications trend: 2016–2024.

2018). For instance, the relationship between digital technologies and sustainability was first explored in 2017 (Gebhardt, 2017) then in 2019 (Gazzola et al., 2019), suggesting that aligning smart technologies with green principles can stimulate transformative change and opportunities for the industry to embrace sustainability and digital progress simultaneously.

Figure 3 exhibits a bibliographic network analysis visualizing keywords displayed with varying sizes, where the size of each word reflects its frequency or prominence within the reported studies. It also provides a visual depiction of keyword clusters and their interconnections, categorizing main keywords into three distinct sub-themes

(clusters): [a] “Digital Transformation,” [b] “Sustainability,” and [c] “Governance.”

Frequently cited journals include “Sustainability,” “Technological Forecasting and Social Change,” “Cities,” and “Government Information Quarterly.” Only one paper was extracted from each of the remaining publishers (Table 2) with the geographical spread of all, according to countries of authorship represented in Figure 4.

The impacts of DT on the achievement of the SDGs indicate that DT can have varying effects (positive, negative, or dual) contingent upon the context of its adoption, such as the extent of DT implementation, the effectiveness of adopted DT governance and policies, and

TABLE 2 Distribution of number of publications per publisher.

Journal name (Publisher)	#	Journal name (Publisher)	#
Problems of Sustainable Development	1	Sustainable development	1
Equilibrium. Quarterly Journal of Economics and Economic Policy	1	The International Journal of Management Education	1
Data and Policy Published online by Cambridge University Press	1	IEEE Technology and Society Magazine	1
Structural Change and Economic Dynamics	1	Current Opinion in Environmental Sustainability	1
Energy, Sustainability and Society	1	Nature Communications	1
Systems	1	Telematics and Informatics	1
Statistics, Politics and Policy	1	Technology in Society	1
SAGE Open	1	Environmental Science and Policy	1
Journal of Urban Management	1	The Computer Law and Security Report	1
Remote Sensing	1	Sustainable Cities and Society	1
Information Polity	1	Southeast Asian Studies	1
Sustainability Science	1	International Journal of Digital Earth	1
Futures	1	World Development	1
Frontiers in Blockchain	1	Machine Learning with Applications	1
Ecological Economics	1	Telecommunications Policy	2
Journal of Management and Organization	1	Information Systems Frontiers	2
Digital Policy, Regulation and Governance	1	Sustainable Futures	2
Ecological Indicators	1	Administrative Sciences	2
Heliyon	1	Government Information Quarterly	3
Annals of Telecommunications	1	Cities	4
Journal of Cleaner Production	1	Technological Forecasting and Social Change	6
Baltic Journal of Economic Studies	1	Sustainability	7
International Review of Administrative Sciences (SAGE Pub)	1		

Number of publications.

Delgosha et al., 2021; ElMassah and Mohieldin, 2020; Imasiku et al., 2019; Khan et al., 2024; Kolupaieva and Tiesheva, 2023; Kolupaieva et al., 2024; Kostoska and Kocarev, 2019; Nahar, 2024; Nosratabadi et al., 2023; Schulz et al., 2020; Sparviero and Ragnedda, 2021; Spulbar et al., 2022; Stahl et al., 2022; Stahl et al., 2023; Zeng and Duan, 2024), with 14 targeting the global level (Clark et al., 2022; Goralski and Tan, 2020; Gouvea et al., 2018; Gritsenko, 2024; Higón et al., 2017; Janowski, 2016; Janowski et al., 2018; Kolesnichenko et al., 2021; Pascale and Romagno, 2024; Pollex and Lenschow, 2018; Truby, 2020; Vinuesa et al., 2020; Young et al., 2020; Zambrano, 2020), and 15 the national/country level (Alojail and Khan, 2023; de Galdino Magalhães Santos, 2024; Hong and Xiao, 2024; Irtyshcheva et al., 2020; Ji and Huang, 2024; Kassen, 2019; Liu, 2024; Madon and Masiero, 2024; Mir et al., 2020; Palos-Sánchez et al., 2023; Quattrone and Chen, 2023; Santarius et al., 2023b; Siekmann et al., 2023; Ufua et al., 2021; van der Hoogen et al., 2024). Only four studies focused on the regional effects (Fernández-Aller et al., 2021; Mienye et al., 2024; Värzaru et al., 2023; Zhang et al., 2024), while another group of seven explored the sub-national or local scale of such effects at city (urban) or municipality level (Allan et al., 2024; David et al., 2024; Furtado et al., 2023; Ibrahim, 2022; Jacob, 2018; Sha et al., 2024; Shahmohammad et al., 2024).

These studies addressed all SDGs or a specific subset of them (Table 3) while covering various geographical scopes from global to specific country groupings. Most (Brundtland, 1987) targeted all sustainability dimensions concurrently (Bibri, 2019) or sustainability in a broad sense without specifying which SDG in particular (Alojail and Khan, 2023), recognizing the need to consider and achieve them as an integrated whole. On the other hand, several studies focused on individual SDGs or groups of them. The focused approach could be a result of many factors, including the complexity of simultaneously studying the effects of DT governance on all SDGs, the differential impacts DT can have on SDGs, the lack of data about certain SDGs, or the contextual necessity to focus on specific SDG areas relevant to the country under study.

Diverse methods were used in assessing the impacts of DT governance on SDGs including qualitative, quantitative, or mixed methods as highlighted in Table 4 alongside the type of data relied upon. Many (Coroama and Höjer, 2016) employed qualitative analysis (Allan et al., 2024; Clark et al., 2022; David et al., 2024; Fernández-Aller et al., 2021; Furtado et al., 2023; de Galdino Magalhães Santos, 2024; Goralski and Tan, 2020; Gritsenko, 2024; Janowski et al., 2018; Kassen, 2019; Kolesnichenko et al., 2021; Kostoska and Kocarev, 2019; Madon and Masiero, 2024; Meijer, 2024; Mienye et al., 2024; Palos-Sánchez et al., 2023; Quattrone and Chen, 2023; Santarius et al., 2023a; Santarius et al., 2023b; Sha et al., 2024; Sparviero and Ragnedda, 2021; Stahl et al., 2022; Stahl et al., 2023; Truby, 2020; Ufua et al., 2021; Vinuesa et al., 2020; Zeng and Duan, 2024) while (Bostrom and Nayyar, 2023) were based on quantitative analysis (Bergantino et al., 2024; Bostrom and Nayyar, 2023; Bühler et al., 2021; Delgosha et al., 2021; ElMassah and Mohieldin, 2020; Hong and Xiao, 2024; Jacob, 2018; Ji and Huang, 2024; Khan et al., 2024; Kolupaieva and Tiesheva, 2023; Liu, 2024; Nahar, 2024; Nosratabadi et al., 2023; Pascale and Romagno, 2024; Schulz et al., 2020; Siekmann et al., 2023; Spulbar et al., 2022; Värzaru et al., 2023; Zhang et al., 2024) and (Bibri, 2019) used a mixed-approach (Akande et al., 2019; Alojail and Khan, 2023; Gouvea et al., 2018; Higón et al., 2017; Ibrahim, 2022; Imasiku et al., 2019; Irtyshcheva et al., 2020; Janowski, 2016; Kolupaieva et al., 2024; Mir et al., 2020; Pollex and Lenschow,

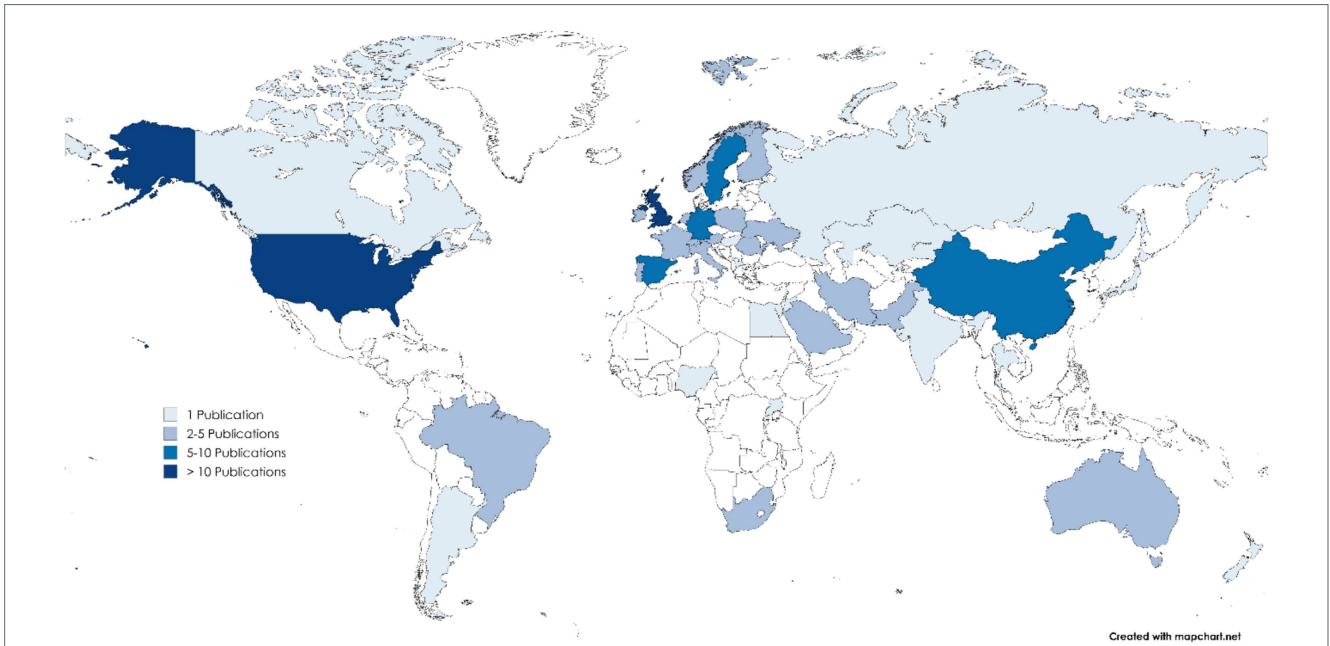


FIGURE 4
Geographic spread of publications.

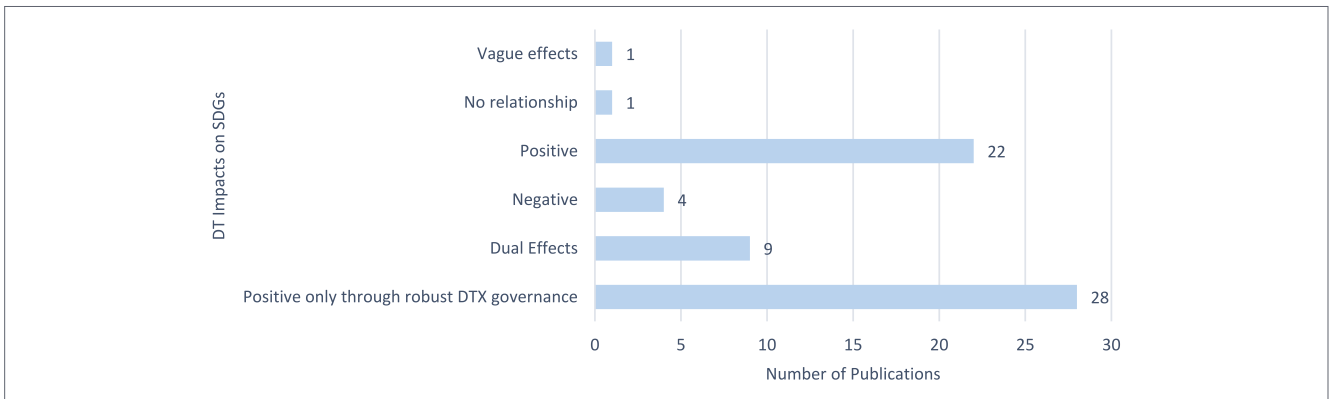


FIGURE 5
Distribution of publications according to the impacts of DT on the SDGs. DT: Digital transformation; SDGs: Sustainable Development Goals.

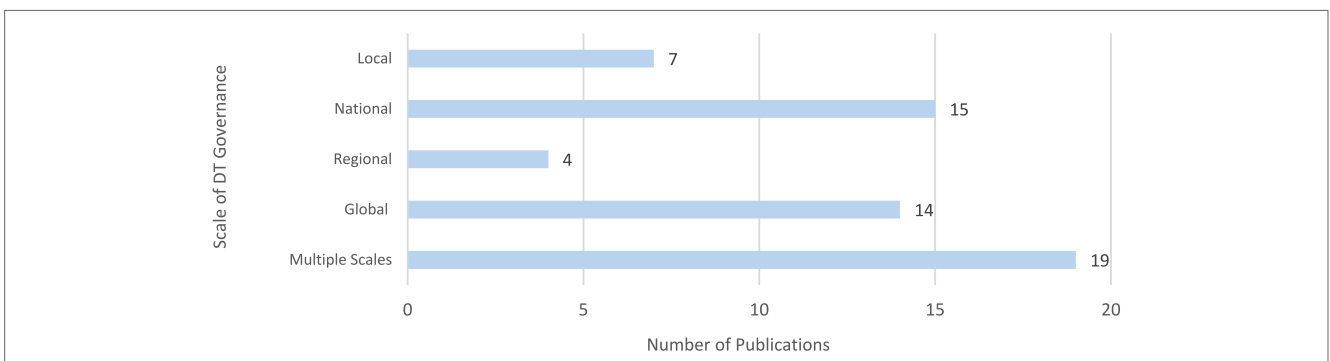


FIGURE 6
Distribution of publications according to the examined scale of DT governance.

2018; van der Hoogen et al., 2024; Young et al., 2020; Zambrano, 2020) combining expert insights or policy documents with other methods such as statistical analysis. The mixed approach helps in minimizing potential biases encountered in qualitative methods and enhances the robustness of the analysis by correlating experts’

insights with empirical data from credible sources. It enhances the validity and reliability of findings by enabling cross-verification of results.

Noteworthy, a few studies (Allen et al., 2018) conducted literature surveys (Kolade and Owoseni, 2022; Rosário and Dias, 2022; Sha et

TABLE 3 Dimension(s) of sustainability reported in the literature.

Dimension(s) of sustainability	Number of studies
• Economic (Alojail and Khan, 2023; Delgosha et al., 2021; Imasiku et al., 2019; Kharrazi et al., 2016)	4
• Environmental (Bühler et al., 2021; IIASA, 2019; Mazzi and Floridi, 2023; Pierli et al., 2023; Santarius et al., 2020)	5
• Social (ElMassah and Mohieldin, 2020; de Galdino Magalhães Santos, 2024; Janowski, 2016; Jones et al., 2017; Mienye et al., 2024; Spulbar et al., 2022; Townsend and Coroama, 2018; Wu et al., 2018)	8
• Economic and Environmental (Gouvea et al., 2018; Higón et al., 2017; Hong et al., 2018; Palos-Sánchez et al., 2023; Santarius et al., 2023a; Zeng and Duan, 2024)	6
• Economic and Social (Bergantino et al., 2024; Bostrom and Nayyar, 2023; David et al., 2024; Gritsenko, 2024; Janowski et al., 2018; Kolesnichenko et al., 2021; Lennerfors et al., 2015; Maarooof, 2015; Mondejar et al., 2021; Norström et al., 2023; Sparviero and Ragnedda, 2021; Stahl et al., 2022; Turcu, 2013; Young et al., 2020; Zambrano, 2020)	15
• Environmental and Social (Allan et al., 2024; Irtysheva et al., 2020; Page et al., 2021; Sha et al., 2024; Truby, 2020; United Nations Sustainable Development Solutions Network, 2019)	6
• Economic, Environmental and Social (Akande et al., 2019; Fernández-Aller et al., 2021; Furtado et al., 2023; Goralski and Tan, 2020; Khakurel et al., 2018; Kolade and Owoseni, 2022; Kolupaieva and Tiesheva, 2023; Meijer, 2024; Pollex and Lenschow, 2018; Quattrone and Chen, 2023; Santarius et al., 2023b; Shahmohammad et al., 2024; Sharifi et al., 2024; Värzaru et al., 2023)	14
• Sustainability in general (Clark et al., 2022; Huang et al., 2023; Jain et al., 2023; Kolupaieva et al., 2024; Seele and Lock, 2017; Siekmann et al., 2023; van der Hoogen et al., 2024)	7

TABLE 4 Types of data used in published efforts: Quantitative vs. Qualitative.

Quantitative Data	Qualitative Data
<ul style="list-style-type: none"> Country-level panel and statistical data from databases of national agencies and international institutions (World Bank, Eurostat, UN SDG Indicators database, SDG Global Database, World Development Indicators database, International Telecommunication Union, Our World in Data, OECD, European Statistical Service, European Commission, International Energy Agency...) Country-level self-reported data and progress reports, municipal data from official sources, biometric data, urban databases... Numerical data from Google, big data, the internet or data from social media (social networks, blogs or news portals...) Remote sensing data (geospatial, climate, and environmental data) from Copernicus Climate Data Store and sensor data from sensors owned by governmental agencies or by citizens. 	<ul style="list-style-type: none"> Field studies, surveys, interviews, questionnaires and workshops with experts, researchers, practitioners, decision-makers or local municipal and governmental officials, stakeholder board meeting, focus group, experts' opinions... Policy documents and publicly available reports by agencies such as the UN, Cities Climate Leadership Group reports... Qualitative data from Google, big data, the internet or data from social media (social networks, blogs or news portals...) Existing models and literature (Socio-technical systems, consensus-based expert elicitation process...)

UN: United Nations; SDGs: Sustainable Development Goals.

al., 2024; Shahmohammad et al., 2024; Sharifi et al., 2024; Tura and Ojanen, 2022) using various approaches targeting DT governance in alignment with sustainability albeit with a narrow focus, often emphasizing specific SDGs, technologies, or challenges while overlooking broader intersections and trade-offs across sustainability objectives.

These surveys exhibited a bias towards positive impacts of technologies or solutions while understating adverse effects. Geographic and contextual variations, critical for tailoring solutions to diverse regions and socio-economic conditions, were not explored adequately. Moreover, while challenges and suggestions were identified, actionable frameworks or implementation strategies for policymakers are lacking, limiting the practical applicability of findings. Table 5 summarizes the reported effects of DT on the achievement of the UN SDGs, according to the literature. The Supplementary material provides information about each paper, including focus and objectives, analysis type and methodologies, technologies and levels of DT governance, data sources, study period, and geographical context. It also highlights the targeted SDGs and their dimensions, key findings about the impacts of DT on SDGs (positive, negative, or dual), among other notable observations. The analysis identified correlations and patterns with a summary of metrics (word cloud, publications by journal, geographical spread, and keyword cluster), as well as key insights, gaps, and future directions.

3.1.2 Impacts of DT on SDGs

DT can play a key role in catalyzing sustainability efforts across various sectors with well-documented examples of positive outcomes (Table 6) by providing innovative solutions to address environmental, social, and economic challenges (Berawi, 2017; Brenner and Hartl, 2021; WBGU, German Advisory Council on Global Change, 2019).

The reviewed literature documents a wide range of environmental, economic, and social impacts of DT on progress toward the SDGs, reporting positive, negative, and mixed effects across sectors and contexts. Environmentally, many studies indicate that DT supports sustainable development by enabling real-time climate monitoring, optimization of resource and energy use, waste reduction, and emissions mitigation (Akande et al., 2019; Bibri, 2019; Bibri and Krogstie, 2017; Bifulco et al., 2016; Guo et al., 2018; Higón et al., 2017; Hong and Xiao, 2024; Imasiku et al., 2019; Kramers et al., 2013; Santarius et al., 2020; Seele, 2016; Seele and Lock, 2017; Tura and Ojanen, 2022;

TABLE 5 Reported impacts of digital transformation (DT) on the SDGs by governance scale by governance scale.

Governance scale	Positive	Negative	Dual (positive and negative)	Conditional on governance	Total
Global	6	2	3	8	19
National	7	2	2	9	20
Regional	3	0	1	2	6
Local/Sub-national	3	1	2	3	9
Multi-level	4	0	1	6	11
Total	23	5	9	28	65

DT: Digital Transformation; SDGs: Sustainable Development Goals. Positive impacts refer to studies reporting predominantly enabling effects of DT on SDG achievement; Negative impacts refer to studies identifying primarily adverse or undermining effects; Dual impacts indicate coexisting benefits and risks.; Conditional impacts refer to outcomes explicitly dependent on governance capacity, regulatory design, or institutional context. Study-level mapping of DT impacts on SDGs is provided in [Supplementary Tables S1, S2](#).

TABLE 6 How digital technologies can be used to support the achievement of the UN SDGs.

Digital technologies	Main sustainability contribution pathways
Artificial intelligence and advanced analytics	Resource optimization, decision support, climate modeling (Goralski and Tan, 2020; Imasiku et al., 2019; Jacob, 2018; Mondejar et al., 2021; Sharifi et al., 2024; Ghobakhloo and Fathi, 2021; Mienye et al., 2024; Nahar, 2024; Nosratabadi et al., 2023; Pierli et al., 2023; Santarius et al., 2023a; Ufua et al., 2021; van der Hoogen et al., 2024; Zhang et al., 2024)
Internet of things (IoT)	Real-time monitoring, energy and water efficiency (Akande et al., 2019; Gazzola et al., 2019; Gelenbe and Caseau, 2015; Gijzen, 2013; Goh, 2021; Higón et al., 2017; Maarroof, 2015; Kostoska and Kocarev, 2019; Salam, 2020; Tjoa and Tjoa, 2016; van der Hoogen et al., 2024)
Big data and data platforms	Evidence-based policymaking, SDG monitoring (Bühler et al., 2021; ElMassah and Mohieldin, 2020; Goralski and Tan, 2020; Hernandez, 2017; Imasiku et al., 2019; Maarroof, 2015)
Blockchain and distributed ledger technologies	Transparency, traceability, accountability (European Economic and Social Committee, 2020; Rosário and Dias, 2022; Santarius et al., 2023a; Townsend and Coroama, 2018; Coroama and Höjer, 2016; Guo et al., 2018; Jones et al., 2017; Truby, 2020; World Economic Forum, 2019; Shahmohammad et al., 2024)
Digital twins and remote sensing	Urban planning, climate adaptation (Alojail and Khan, 2023; Bai et al., 2025; Guandalini, 2022; Mondejar et al., 2021; Seele, 2016; World Economic Forum, 2019; Bühler et al., 2021; Jacob, 2018; Kostoska and Kocarev, 2019; Allan et al., 2024; Guo et al., 2018; Guo, 2020; Hernandez, 2017)
Smart city systems	Integrated service delivery, urban sustainability (Bühler et al., 2021; Kolesnichenko et al., 2021; Quattrone and Chen, 2023; Higón et al., 2017; Jacob, 2018; Santarius et al., 2023b; van der Hoogen et al., 2024; Zhang et al., 2024; Aldieri et al., 2019; Alojail and Khan, 2023; Barbier and Burgess, 2019; Kassen, 2019; Sharifi et al., 2024; Tura and Ojanen, 2022)
Digital government tools	Administrative efficiency, participation, transparency (Alakeson and Wilsdon, 2002; Clark et al., 2022; Etzion and Aragon-Correa, 2016; Stahl et al., 2022; Stahl et al., 2023; Truby, 2020; Young et al., 2020; Gritsenko, 2024)

IoT: Internet of Things; SDGs: Sustainable Development Goals; IoT: Internet of Things. Contribution pathways are synthesized from recurring patterns across the reviewed studies. Detailed study-level mappings are provided in [Supplementary Table S3](#).

van der Hoogen et al., 2024; Zhang et al., 2024), as well as enhanced decision support for sustainability planning and management (Akande et al., 2019; Santarius et al., 2023a; Sharifi et al., 2024; Vinuesa et al., 2020). Digital technologies are also reported to contribute to circular economy practices (Hong et al., 2018; Rosário and Dias, 2022; Santarius et al., 2023a; Ufua et al., 2021) and more sustainable supply chains through improved transparency, traceability, and sourcing (Coroama and Höjer, 2016; Ghobakhloo and Fathi, 2021; Hong et al., 2018; Pierli et al., 2023; Sha et al., 2024; Shahmohammad et al., 2024; Vinuesa et al., 2020). At the same time, several studies document environmental risks and rebound effects associated with DT, including increased energy demand and the growing material footprint and electronic waste generated by data centers and digital infrastructures (Higón et al., 2017; Liu, 2024; Nosratabadi et al., 2023; Santarius et al., 2023a), which may undermine climate mitigation efforts if left unaddressed (van der Hoogen et al., 2024; Zhang et al., 2024). Economically,

the literature associates DT with economic growth, improved access to resources, productivity gains, innovation, and enhanced public-sector performance, including more data-informed planning and service delivery (Gritsenko, 2024; Janowski et al., 2018; Meijer, 2024). During the COVID-19 pandemic, digital services played an important role in sustaining economic activity and employment (Bai et al., 2025; Kolesnichenko et al., 2021). Conversely, distributional tensions—such as labor-market disruption, job displacement, skills polarization, and unequal capture of digital value—are widely acknowledged but often insufficiently integrated into sustainability assessments unless explicitly addressed through complementary policies on reskilling, fair competition, and public value creation (Bostrom and Nayyar, 2023; ElMassah and Mohieldin, 2020; Kolade and Owoseni, 2022; Nosratabadi et al., 2023; Ufua et al., 2021). Socially, many studies highlight the potential of digital platforms and e-governance to expand access to services, strengthen public engagement and participation,

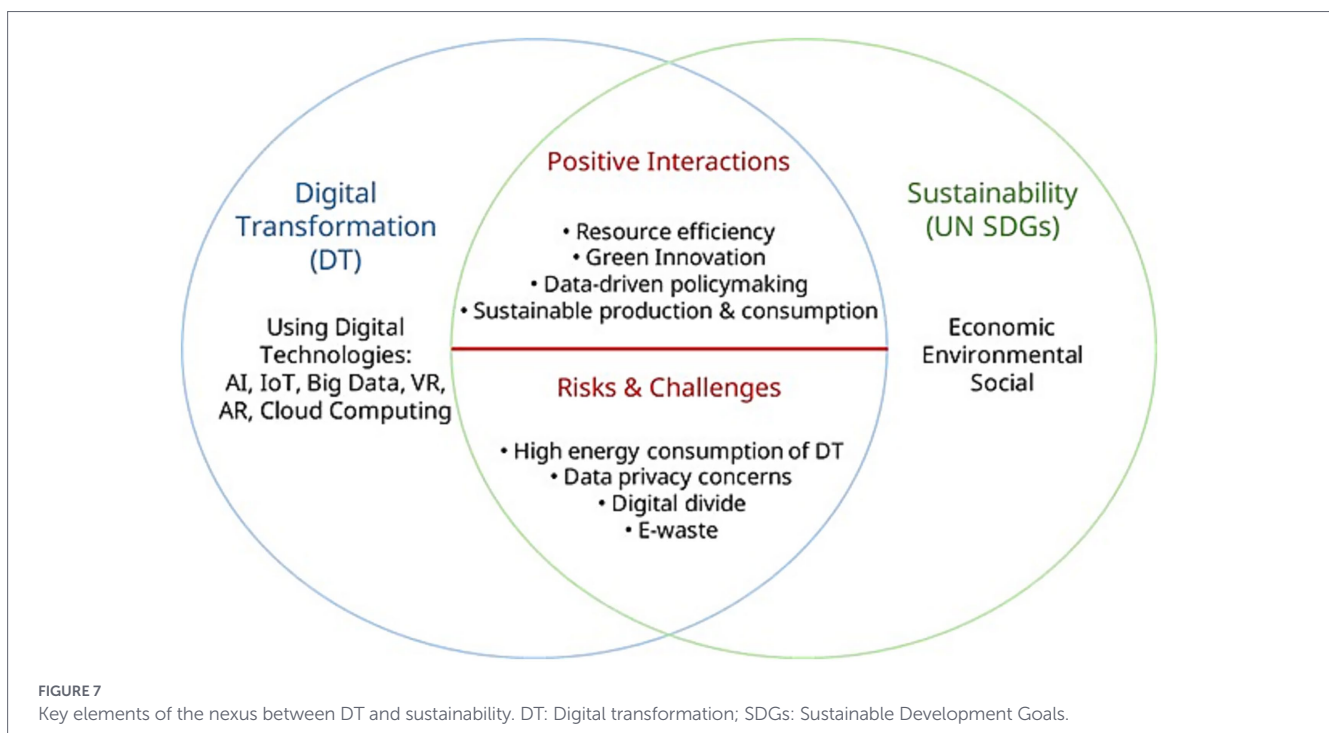
and improve transparency (Janowski, 2016; Kassen, 2019). Contributions are reported in areas such as education, healthcare, poverty reduction, and social well-being through improved service delivery and inclusion mechanisms (Aldieri et al., 2019; Allan et al., 2024; Barbier and Burgess, 2019; Bergantino et al., 2024; David et al., 2024; Fernández-Aller et al., 2021; Gritsenko, 2024; Kassen, 2019; Kolesnichenko et al., 2021; Mienye et al., 2024; Mondejar et al., 2021; Nahar, 2024; Seele and Lock, 2017; Sha et al., 2024; Zeng and Duan, 2024). However, the literature also identifies significant social risks associated with DT, including widening digital divides, unequal access to technologies and skills, and the exclusion of marginalized populations (Bergantino et al., 2024; Kolupaieva and Tiesheva, 2023; Liu, 2024; Zambrano, 2020). Governance deficits related to cybersecurity, data protection, accountability, and rights-preserving design further threaten social sustainability outcomes and public trust (Clark et al., 2022; Gritsenko, 2024; Hong et al., 2018; IIASA, 2019; Palos-Sánchez et al., 2023; Shahmohammad et al., 2024; Sharifi et al., 2024; Stahl et al., 2022; Stahl et al., 2023; World Economic Forum, 2019; Truby, 2020).

Several studies explicitly report dual or mixed impacts of DT on sustainability. For example, artificial intelligence has been shown to support 134 SDG targets while potentially hindering 59 others (Vinuesa et al., 2020). Similarly, the United Nations highlights both the benefits of frontier technologies for economic, environmental, and health outcomes and the associated social, ethical, and environmental risks, emphasizing the coexistence of positive and negative effects (United Nations Department of Economic and Social Affairs, 2018). Overall, the literature indicates that DT-related impacts on the SDGs are heterogeneous and frequently involve simultaneous benefits and risks (Bergantino et al., 2024; Liu, 2024; Sharifi et al., 2024; Spulbar et al., 2022; Stahl et al., 2022; Stahl et al., 2023; Truby, 2020; Young et al., 2020; Zheng et al., 2025). Figure 7 depicts the intersection among key elements of DT and sustainability, as synthesized from the analysis.

The intersections between DT and the SDGs can support data-driven policy and governance through real-time data and advanced analytics to monitor environmental changes, assess the effectiveness of sustainability initiatives, and make informed decisions to achieve the SDGs (Bühler et al., 2021; ElMassah and Mohieldin, 2020; de Galdino Magalhães Santos, 2024; van der Hoogen et al., 2024). Evidently, the dynamic and rapidly evolving nature of DT calls for adaptive governance structures and policies to alleviate DT negative impacts and maximize the contribution to sustainable development (Pollex and Lenschow, 2018; Siekmann et al., 2023).

3.2 Governance of DT in alignment with the SDGs

Efforts to assess the role of DT in advancing the SDGs consistently emphasize the importance of robust DT governance and integrated policy frameworks that align digital and sustainability objectives, ensuring ethical, inclusive, and accountable implementation (Bissio, 2018; Clark et al., 2022; David et al., 2024; Gazzola et al., 2019; Gebhardt, 2017; Ibrahim, 2022; Kharrazi et al., 2016; Kolupaieva and Tiesheva, 2023; Norström et al., 2023). Across the literature, governance is framed as a key enabler for reorienting science, technology, and innovation toward sustainability through coordinated policy, regulatory, and financing interventions (El hilali and El manouar, 2019; Kharrazi et al., 2016; Sachs et al., 2016). New governance mechanisms are therefore considered necessary to oversee the expanding role of digital technologies and manage associated risks (Young et al., 2020). Multiple studies highlight governance levers through which DT may support SDG progress, including responsible and ethical technology adoption (David et al., 2024; Furtado et al., 2023; Goh, 2021; Hernandez, 2017; Khakurel et al., 2018; Kolupaieva et al., 2024; Kürpick et al., 2023; Mazzi and Floridi, 2023; Osburg, 2017; Sha et al., 2024; United Nations Development Group, 2017; Vinuesa et al., 2020; Wu et



al., 2018; Young et al., 2020), data privacy protection (Maarroof, 2015), and transparency and accountability in digital systems (Truby, 2020; Ufua et al., 2021). Policy interventions are also frequently linked to social objectives, such as promoting digital inclusion, accessibility, and skills development through education and training programs (Berawi, 2017; Bergantino et al., 2024; Clark et al., 2022; Ghobakhloo et al., 2021b; Gouvea et al., 2018; Kolade and Owoseni, 2022; Kolesnichenko et al., 2021; Liu, 2024; Mir et al., 2020; Pascale and Romagno, 2024; Sha et al., 2024; Spulbar et al., 2022; Ufua et al., 2021), as well as supporting job creation and economic participation in the digital economy (Jain et al., 2023; Ji and Huang, 2024; Nosratabadi et al., 2023; Sha et al., 2024; Townsend and Coroama, 2018; World Economic Forum, 2019; World Economic Forum, 2020a; World Economic Forum, 2020b). Environmental considerations similarly feature in governance discussions, with policies aimed at minimizing the digital carbon footprint and ensuring that technological innovation does not undermine environmental sustainability (Alakeson and Wilsdon, 2002; Bai et al., 2025; Coroama and Höjer, 2016; Gelenbe and Caseau, 2015; Hong et al., 2018; Jacob, 2018; Kostoska and Kocarev, 2019; Kramers et al., 2013; Lennerfors et al., 2015; Santarius et al., 2020; Stock et al., 2018). In addition, several studies stress the role of public-private partnerships and international cooperation in accelerating the diffusion of sustainable digital solutions and aligning national DT strategies with global sustainability agendas (Akande et al., 2019; Aldieri et al., 2019; Bissio, 2018; Del Río Castro et al., 2021; Gijzen, 2013; Janowski, 2016; Janowski et al., 2018; Kassen, 2019; Sachs et al., 2019; Sparviero and Ragnedda, 2021; Stahl et al., 2023). Overall, this body of literature outlines a broad set of governance instruments, policy domains, and normative objectives through which DT is expected to support the SDGs, but it largely frames these mechanisms as normative goals or high-level policy intentions rather than empirically grounded practices. Figure 8 accentuates how effective governance of digital processes can harness DT to support sustainability objectives. DT, underpinned by robust governance, can be leveraged to enhance social equity, economic prosperity, and environmental conservation (Akande et al., 2019; Gebhardt, 2017; Hong and Xiao, 2024; Ji and Huang, 2024; Palos-Sánchez et al., 2023).

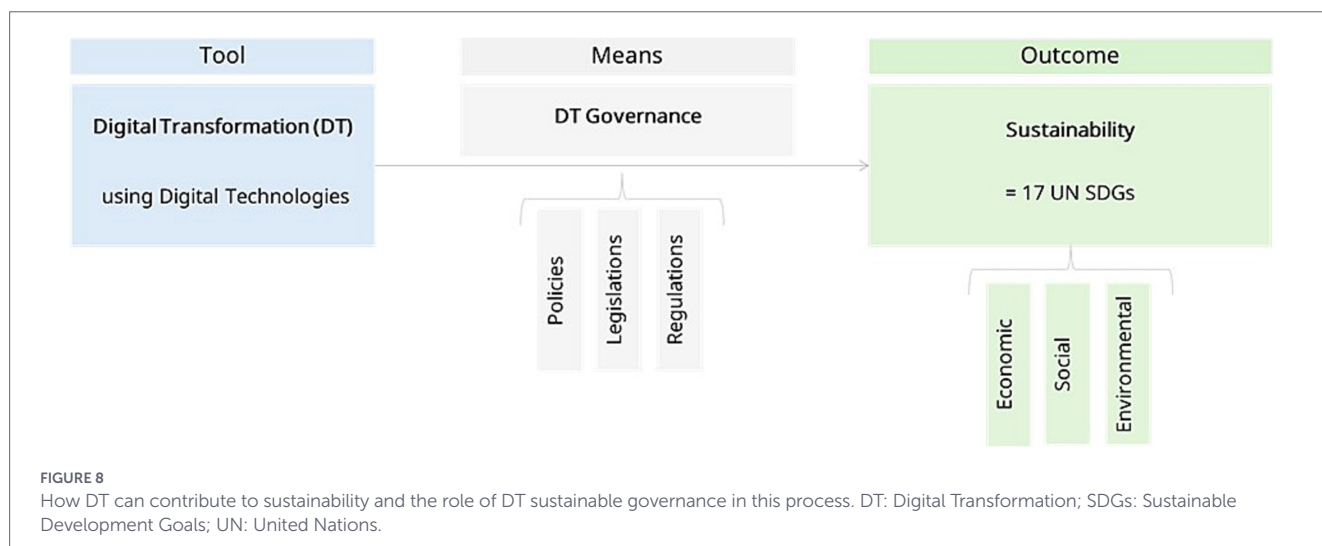
Building on this descriptive mapping of governance approaches, the following analysis moves beyond listing policy instruments to

critically examine how and why different governance arrangements produce divergent sustainability outcomes across contexts.

3.2.1 From DT potential to sustainable outcomes: a governance-centered synthesis

Building on the descriptive mapping of reported environmental, economic, and social impacts of DT on the SDGs, the analysis adopts a comparative, governance-centered lens to examine how governance arrangements and contextual conditions shape variation in sustainability outcomes. Across the reviewed literature, a consistent conclusion emerges: DT can support progress toward the SDGs, but its net contribution is highly contingent on governance quality, institutional capacity, and contextual conditions (ElMassah and Mohieldin, 2020; Higón et al., 2017), with outcomes varying markedly across governance scales, development contexts, and policy designs (Janowski, 2016; Kassen, 2019).

A first comparative pattern concerns governance scale and coordination. Studies focusing on global and national levels tend to emphasize strategic alignment, standard-setting, and policy coherence, often reporting more optimistic assessments of DT-related sustainability outcomes (Janowski et al., 2018; Santarius et al., 2023b). In contrast, local and subnational studies more frequently highlight implementation barriers, capacity constraints, and context-specific trade-offs that are less visible at higher levels of analysis (Akande et al., 2019; Clark et al., 2022). This divergence suggests that reported effectiveness is partly a function of analytical distance from implementation realities, underscoring the importance of multi-level governance integration and coordination in shaping observed outcomes (Meijer, 2024). A second dimension of variation relates to governance orientation. Top-down, technology-driven approaches often prioritize efficiency, scalability, and rapid deployment, sometimes at the expense of inclusivity and adaptability (Pollex and Lenschow, 2018; Truby, 2020). Conversely, participatory and adaptive governance models tend to emphasize stakeholder engagement, flexibility, and responsiveness to contextual change. Although these approaches are often slower and more resource-intensive, they are more likely to sustain equitable and resilient sustainability outcomes over time (Kostoska and Kocarev, 2019; Schulz et al., 2020). The literature thus reveals a persistent



tension between the speed of digital innovation and the robustness of governance arrangements.

A critical cross-cutting insight emerging from this synthesis is the prevalence of positivity bias in how DT is framed in relation to sustainability, a tendency that appears to be reinforced by restricting the analysis to peer-reviewed open-access and policy-oriented literature. Such publication channels disproportionately privilege applied, solution-focused, and impact-affirming studies, while underrepresenting critical, legal, and theoretically grounded analyses that interrogate governance failures, power asymmetries, trade-offs, and long-term unintended consequences. This interaction shapes the composition of the evidence base and the dominant policy narratives through which DT is understood, encouraging solutionist framings that emphasize technological opportunity over governance risk while downplaying uncertainty, conditionality, rebound effects, long-term externalities, distributional impacts, and institutional capacity constraints. As a result, governance limitations and sustainability trade-offs—though present in the literature—are often treated as secondary considerations rather than as central determinants of outcomes, fostering overconfident expectations at the policy design stage and obscuring negative or conditional effects that tend to emerge only during or after implementation. Recognizing this dynamic is essential for interpreting reported sustainability benefits as conditional, context-dependent, and governance-dependent rather than inherently sustainability-enhancing or universally transferable, and it underscores the need for more precautionary, reflexive, and institutionally grounded approaches to DT governance and sustainability assessment.

3.2.2 DT governance: the key components

DT governance aligned with sustainability consists of structured policies, regulations, and guidelines that oversee the ethical, secure, equitable and effective use of digital technologies, ensuring systemic integration of technologic policies in alignment with societal, economic, and environmental goals. The proposed governance framework is inductively derived from recurring patterns in the literature, synthesizing governance elements that consistently shape the sustainability outcomes of DT across empirical, conceptual, and policy-oriented studies. The evidence indicates that progress toward the SDGs depends less on technological adoption than on governance capacity, institutional coordination, and contextual fit, with stronger administrative and data governance systems better able to translate digitalization into sustainability gains (Janowski, 2016), while weaker institutional settings experience uneven or adverse outcomes (ElMassah and Mohieldin, 2020; Higón et al., 2017). Across contexts, five recurring clusters inform the framework's core components: strategic alignment between digital and sustainability objectives (Alojail and Khan, 2023; Janowski, 2016); robust data governance, transparency, and accountability (de Galdino Magalhães Santos, 2024; Truby, 2020); inclusive access, skills development, and institutional capacity building (Clark et al., 2022; Nosratabadi et al., 2023); adaptive and reflexive governance capable of responding to rapid technological change (Kostoska and Kocarev, 2019; Schulz et al., 2020); and sensitivity to contextual and implementation constraints, particularly in low- and middle-income countries (LMICs) (ElMassah and Mohieldin, 2020; Zambrano, 2020). Positioned relative to existing approaches, the framework integrates insights that are often fragmented across digital governance, e-government, smart city, and sustainability transition literatures. Whereas prior frameworks tend to emphasize

administrative efficiency (Janowski et al., 2018; Meijer, 2024), technological integration with mixed sustainability outcomes (Akande et al., 2019; Sharifi et al., 2024), or treat digitalization as a background enabler (Pollex and Lenschow, 2018; Santarius et al., 2023b), this framework explicitly conceptualizes DT as a governance challenge with sustainability consequences across environmental, social, and economic dimensions. Governance-oriented studies consistently show that sustainability outcomes are shaped not by technology choice alone, but by institutional design, regulatory capacity, and contextual conditions, positioning governance as the key “conversion mechanism” through which digital capabilities are translated into SDG-relevant outcomes (Janowski, 2016; Meijer, 2024; Pollex and Lenschow, 2018; Santarius et al., 2023b).

Positive outcomes are consistently associated with several governance components including coherent strategic vision (El hilali and El manouar, 2019), clearly defined leadership and accountability (Goralski and Tan, 2020; Osburg, 2017), effective data governance and interoperability (Gensch et al., 2017; Guo et al., 2018; Kolade and Owoseni, 2022; Kolesnichenko et al., 2021; Truby, 2020; Turcu, 2013; Sachs et al., 2019; United Nations Development Group, 2017), safeguards for data privacy (Etzion and Aragon-Correa, 2016) and cybersecurity (Sharifi et al., 2024; Vinuesa et al., 2020), participatory mechanisms (Ghobakhloo, 2020; Seele and Lock, 2017; World Economic Forum, 2019; Young et al., 2020), and monitoring systems capable of tracking SDG-related impacts over time (de Galdino Magalhães Santos, 2024; Meijer, 2024; Sharifi et al., 2024; Truby, 2020; Zambrano, 2020). Sustainability-oriented DT requires policy instruments that internalize environmental costs, incentivize low-impact design, and embed digital deployment within broader climate and circular-economy strategies. Policies must ensure inclusivity—covering connectivity, digital literacy, skills development, ethical digital practices and accessibility standards—as core enabling conditions to avoid social fragmentation (Bergantino et al., 2024; David et al., 2024; Ghobakhloo et al., 2021b; Mazzi and Floridi, 2023; Sha et al., 2024). Policies ought also to standardize performance metrics to measure the progress and success of DT initiatives (Barbier and Burgess, 2019; Bidarbakhtnia, 2020; Campagnolo et al., 2018; Guo, 2020; Nhamo et al., 2020; Pollex and Lenschow, 2018; Siekmann et al., 2023; Tjoa and Tjoa, 2016). Moreover, effective governance requires adaptive regulatory structures, enhanced policy capacity, and legal compliance (ElMassah and Mohieldin, 2020; Young et al., 2020; Zheng et al., 2025). Rapid technological change renders static regulatory frameworks and fragmented policy approaches increasingly obsolete, creating governance gaps that are particularly consequential in lower-capacity contexts (ElMassah and Mohieldin, 2020; Kostoska and Kocarev, 2019; Santarius et al., 2023b; Schulz et al., 2020). From this perspective, sustainable DT governance is best understood not as a fixed model, but as an ongoing institutional process that requires learning, reflexivity, and continuous adjustment to evolving technological, social, and environmental conditions.

3.2.3 DT governance challenges, limitations and contextual constraints

Although a growing body of literature has proposed governance approaches to align DT with sustainability objectives (Allan et al., 2024; David et al., 2024; Fernández-Aller et al., 2021; Ibrahim, 2022; Janowski et al., 2018; Kolupaieva and Tiesheva, 2023; Kostoska and Kocarev, 2019; Mienye et al., 2024; Santarius et al., 2023a; Schulz et al.,

2020; Stahl et al., 2022; Stahl et al., 2023; Ufua et al., 2021; United Nations Sustainable Development Solutions Network, 2019; Zambrano, 2020), these efforts remain fragmented and limited in scope. Existing models variously emphasize smart and sustainable governance drivers (Furtado et al., 2023), centralized or networked governance structures (Schulz et al., 2020), digital democracy and data-driven governance (Kostoska and Kocarev, 2019), or evolutionary governance and citizen–administration relationships (Janowski et al., 2018). However, many of these frameworks remain largely conceptual, lack empirical validation, and provide limited guidance on implementation, risk management, and contextual adaptation. In particular, they often overlook hybrid governance arrangements, stakeholder inclusivity, efficient resource allocation, and the need for governance adaptability in rapidly evolving digital environments (Bai et al., 2025). Structural and regulatory challenges further constrain DT governance. The literature highlights the absence of universally agreed data protection and privacy principles (El hilali and El manouar, 2019; Gebhardt, 2017; Goralski and Tan, 2020; Sachs et al., 2019; Zambrano, 2020), fragmentation and poor compliance in regulatory frameworks (Shahmohammad et al., 2024; van der Hoogen et al., 2024; Young et al., 2020), and growing governance gaps as technological innovation outpaces regulatory capacity (Irtysheva et al., 2020; Zheng et al., 2025). These challenges have prompted calls for coordinated cross-sectoral responses, including proposals for a “Digital Green Deal” to better align digitalization with sustainability and SDG objectives (Santarius et al., 2023b). At the same time, the complexity of evaluating and monitoring DT impacts on SDG progress remains a persistent challenge, underscoring the need for standardized assessment methods and clearer mechanisms for legal compliance and accountability (Pollex and Lenschow, 2018; Siekmann et al., 2023). Ethical concerns related to transparency, accountability, equity, and inclusion further complicate governance design, requiring continuous legal adaptation and institutional learning (Alojail and Khan, 2023; Clark et al., 2022; David et al., 2024; Ibrahim, 2022; Sha et al., 2024; Ufua et al., 2021).

Empirical evidence consistently shows that these governance challenges are intensified by contextual and institutional constraints, particularly in low- and middle-income countries (LMICs). Studies document limited regulatory enforcement, fragmented institutional mandates, insufficient technical capacity, and dependence on external digital platforms as key barriers to effective oversight (Kassen, 2019; Ufua et al., 2021; Zambrano, 2020). In many contexts, DT initiatives advance faster than governance frameworks, increasing exposure to risks such as data misuse, exclusion, and governance lock-ins (Schulz et al., 2020; Truby, 2020). Infrastructure deficits—including uneven connectivity, unreliable energy supply, and limited digital literacy—frequently reinforce existing digital divides rather than reducing them (Clark et al., 2022; Kolupaieva and Tiesheva, 2023; Nosratabadi et al., 2023). Similar dynamics are observed in smart city contexts, where efficiency gains may coexist with weak environmental and social sustainability outcomes in the absence of inclusive governance arrangements (Akande et al., 2019; Sharifi et al., 2024). These constraints are further shaped by broader political-economy factors, such as limited fiscal space, donor dependence, and asymmetries in technological ownership and control, which may prioritize short-term efficiency or growth over long-term sustainability objectives (Bostrom and Nayyar, 2023; Santarius et al., 2023b). Collectively, the literature suggests that sustainable DT governance requires adaptive, context-sensitive, and phased approaches that prioritize institutional capacity building,

cross-sectoral coordination, and regulatory learning over the transplantation of uniform best practices (Bühler et al., 2021; David et al., 2024; European Economic and Social Committee, 2020; ElMassah and Mohieldin, 2020; Furtado et al., 2023; Gritsenko, 2024; Imasiku et al., 2019; Madon and Masiero, 2024; Sha et al., 2024; Sharifi et al., 2024; Siekmann et al., 2023; Sparviero and Ragnedda, 2021; Stahl et al., 2023; United Nations Conference on Trade and Development, 2018; United Nations Development Group, 2017; World Economic Forum, 2019; Wu et al., 2018). Recognizing these constraints is essential for designing governance frameworks that are both practically implementable and responsive to real-world institutional limitations.

3.2.4 DT governance guidelines inspired from best practices

Based on the literature analysis, best practices for integrating DT with sustainability objectives are outlined in Table 7. Such practices inspired from leading countries can provide an exemplary model for integrating DT with the UN SDGs (Allan et al., 2024; Alojail and Khan, 2023; Bergantino et al., 2024; Bühler et al., 2021; Clark et al., 2022; David et al., 2024; ElMassah and Mohieldin, 2020; Fernández-Aller et al., 2021; Furtado et al., 2023; Gouvea et al., 2018; Ibrahim, 2022; Hong and Xiao, 2024; Ibrahim, 2022; Imasiku et al., 2019; Irtysheva et al., 2020; Jacob, 2018; Janowski, 2016; Janowski et al., 2018; Kassen, 2019; Khan et al., 2024; Kolade and Owoseni, 2022; Kolesnichenko et al., 2021; Kolupaieva and Tiesheva, 2023; Kostoska and Kocarev, 2019; Liu, 2024; Madon and Masiero, 2024; Meijer, 2024; Mienye et al., 2024; Mir et al., 2020; Nosratabadi et al., 2023; Pascale and Romagno, 2024; Pollex and Lenschow, 2018; Rosário and Dias, 2022; Santarius et al., 2023a; Santarius et al., 2023b; Schulz et al., 2020; Sha et al., 2024; Sharifi et al., 2024; Siekmann et al., 2023; Sparviero and Ragnedda, 2021; Spulbar et al., 2022; Stahl et al., 2022; Stahl et al., 2023; Truby, 2020; Tura and Ojanen, 2022; Ufua et al., 2021; United Nations Department of Economic and Social Affairs, 2018; United Nations Sustainable Development Solutions Network, 2019; Zeng and Duan, 2024; Zhang et al., 2024). Globally, Europe defined benchmarks in DT governance and sustainability, leading to practices supporting innovation and sustainability (Stahl et al., 2022).

3.2.5 Sustainable DT governance

The synthesis demonstrates that DT does not constitute a uniform pathway toward sustainable development. Instead, sustainability outcomes emerge from dynamic interactions between technology, governance arrangements, and socio-economic context (Higón et al., 2017; Santarius et al., 2023a). Sustainable DT governance is an innovative approach that integrates long-term economic, social, and environmental sustainability goals into policymaking processes, offering significant advantages over conventional approaches to DT governance. Its “sustainable” component stands for the adaptability and ethical focus of governance when integrating DT with sustainability objectives. Unlike conventional governance approaches, it is dynamic and flexible, able to respond to rapid technological developments and emerging sustainability challenges through proactive risk management and built-in feedback systems. Framing SDG-aligned DT governance around interdependent requirements—such as [1] Inclusivity and equity, [2] Adaptability and resilience, [3] Transparency and accountability, and [4] Partnership and collaboration—clarifies how policy success depends less on technology choice alone and more on

TABLE 7 Core best practices for integrating digital transformation (DT) with sustainability objectives.

Governance domain	Core best practices
Strategic governance and policy alignment	<ul style="list-style-type: none"> Align national and local DT strategies with SDG priorities (Kassen, 2019; Pollex and Lenschow, 2018) Integrate sustainability objectives into digital policy design and budgeting (Alojail and Khan, 2023; Ibrahim, 2022; Bühler et al., 2021; ElMassah and Mohieldin, 2020; Sharifi et al., 2024) Adopt anticipatory and systemic regulatory approaches allowing governance oversight (Alojail and Khan, 2023; Janowski, 2016; Truby, 2020) Establish sector-specific policies (Grinfeld and Houghton, 2013)
Data governance, transparency and interoperability	<ul style="list-style-type: none"> Establish data governance frameworks supporting data sharing and interoperability (Bühler et al., 2021; Imasiku et al., 2019; Siekmann et al., 2023; World Economic Forum, 2020a) Enforce data privacy, cybersecurity, and ethical AI regulations (Sharifi et al., 2024; Stahl et al., 2022; Stahl et al., 2023; United Nations Sustainable Development Solutions Network, 2019) Use data for evidence-based policymaking and SDG monitoring (Bühler et al., 2021; de Galdino Magalhães Santos, 2024; Imasiku et al., 2019; Kolesnichenko et al., 2021; Kolupaieva and Tiesheva, 2023; Kolupaieva et al., 2024; Pascale and Romagno, 2024; Pollex and Lenschow, 2018; Rosário and Dias, 2022)
Digital inclusion and human capital development	<ul style="list-style-type: none"> Invest in digital skills, literacy and capacity building (Bergantino et al., 2024; Gouvea et al., 2018; Hong and Xiao, 2024; Irtyshcheva et al., 2020; Khan et al., 2024; Kolade and Owoseni, 2022; Sha et al., 2024; Spulbar et al., 2022; Tura and Ojanen, 2022; Ufua et al., 2021; Zeng and Duan, 2024; Zhang et al., 2024) Ensure equitable access to digital infrastructure and services (Clark et al., 2022; David et al., 2024; Liu, 2024; Sha et al., 2024; United Nations Department of Economic and Social Affairs, 2018) Deploy digital identity systems to improve access to public services (Madon and Masiero, 2024; Mir et al., 2020)
Sustainability-oriented innovation and practices	<ul style="list-style-type: none"> Promote co-innovation of low-carbon and resource-efficient digital solutions (Jacob, 2018; Meijer, 2024) Integrate sustainability metrics into DT strategies (Santarius et al., 2023a; Santarius et al., 2023b) Mandate sustainable supply chains and circular economy practices (Rosário and Dias, 2022; Ufua et al., 2021)
Financial and market incentives	<ul style="list-style-type: none"> Provide grants, subsidies and tax incentives for sustainable DT (Mienye et al., 2024) Regulate data center energy use and pricing (Jones et al., 2017; Stahl et al., 2023) Incentivize reuse, recycling and green procurement practices (ElMassah and Mohieldin, 2020)
Digital and physical infrastructure development	<ul style="list-style-type: none"> Invest in resilient, low-impact digital infrastructure (Alojail and Khan, 2023; Nosratabadi et al., 2023; Pascale and Romagno, 2024; World Economic Forum, 2020a) Support R&D in green digital technologies (Allan et al., 2024; Alojail and Khan, 2023) Integrate data governance into urban planning and infrastructure policy (Allan et al., 2024; IIASA, 2019; Kolesnichenko et al., 2021)
Multi-stakeholder coordination and cooperation	<ul style="list-style-type: none"> Enable cross-sector and public-private collaboration (Gritsenko, 2024; Janowski et al., 2018; Kassen, 2019; Stahl et al., 2022; Stahl et al., 2023) Strengthen international and regional cooperation for sustainable DT (Gritsenko, 2024; Janowski et al., 2018; Kassen, 2019; Stahl et al., 2022; Stahl et al., 2023) Support collaborative crisis-response and resilience planning (Sparviero and Ragnedda, 2021; United Nations Sustainable Development Solutions Network, 2019)

AI: Artificial Intelligence; DT: Digital Transformation; SDGs: Sustainable Development Goals; R&D: Research and Development. Detailed country cases and best-practice examples are reported in [Supplementary Table S4](#).

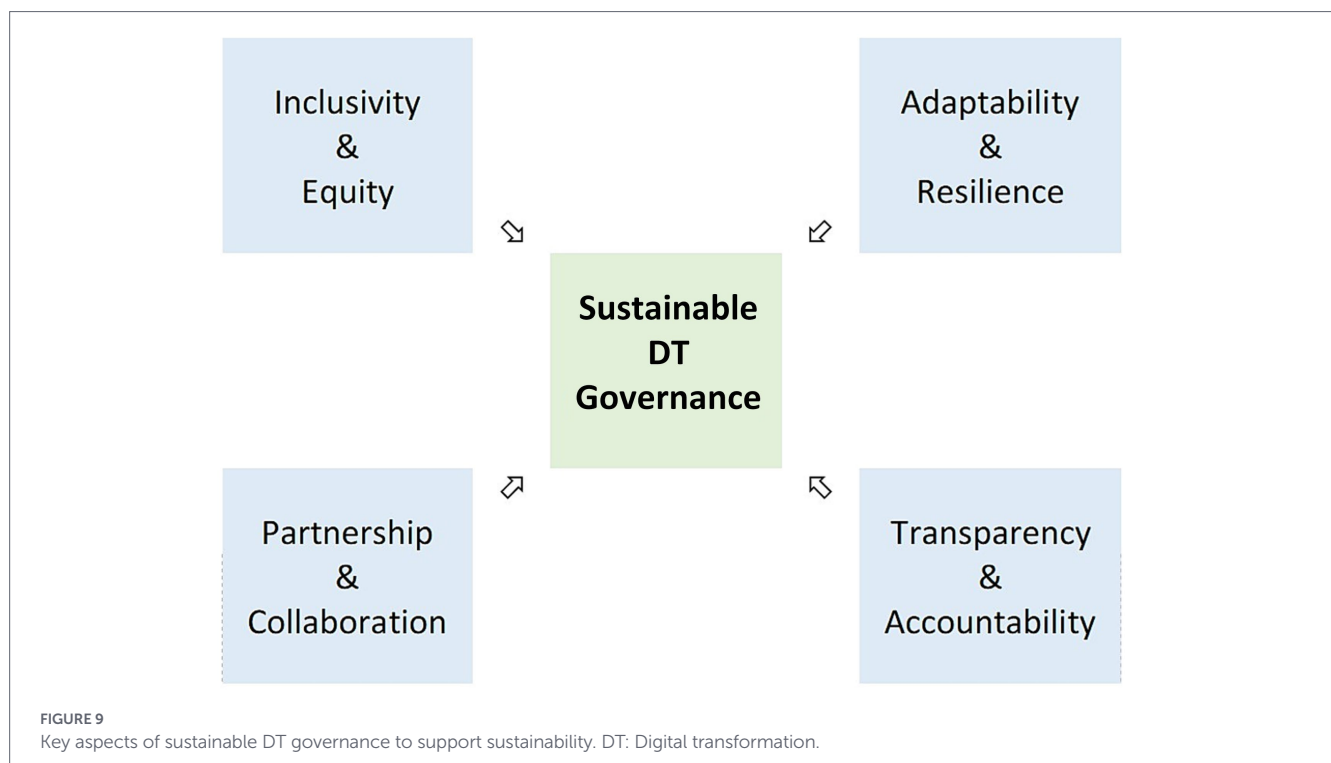
the coherence and capacity of governance systems shaping implementation trajectories over time (Figure 9).

Inclusivity and equity ensure that all stakeholders, especially marginalized communities, are involved in decision-making, fostering diverse perspectives and equitable solutions. They can be achieved by addressing inequalities and ensuring fair distribution of resources and opportunities across regions and demographics. Adaptability and resilience respond effectively to evolving challenges, such as climate change, rapid technologic expansions, and shifting social dynamics. Risk mitigation strategies would address issues such as resource-intensive technologies, e-waste, and algorithmic biases, while promoting responsible innovation like green IT solutions and renewable energy-powered technologies. Transparency and accountability, supported by robust monitoring and evaluation systems (through feedback mechanisms), can build trust through liability mechanisms and open communication. Partnership and collaboration across sectors—governments, private entities, academia, and civil society—can

leverage diverse expertise and resources to co-create innovative solutions for sustainability challenges. This forward-looking approach redefines governance as a critical tool for fostering a resilient, inclusive, and sustainable future.

3.3 Knowledge gaps and future needs

Sustainability and DT governance are increasingly influential in contemporary global policy and research agendas. Both fields are dynamic and rapidly evolving, generating substantial scholarly and policy attention regarding their potential to reshape societies, environmental systems, and business practices. Despite this growing interest, the intersection between sustainability and DT governance remains relatively underexplored. Notably, the UN SDGs do not explicitly address DT, highlighting a gap in their scope and objectives, because they were promulgated at a time when DT were in their early developmental phase. This temporal disconnect has created conceptual and



analytical gaps in understanding how DT governance interacts with and shapes progress toward the SDGs.

To identify these gaps, this review systematically analyzed the existing literature to assess current knowledge and uncover under-examined areas. The findings point to several priorities for future research. These include the need for interdisciplinary studies that examine the environmental, social, and economic implications of DT governance in an integrated manner; the development of standardized evaluation metrics and monitoring approaches to assess the effectiveness of regulatory and governance interventions; and use of mixed-method designs and longitudinal analyses to capture long-term and cumulative impacts. Additional gaps concern the limited availability of cross-country comparative research to benchmark governance approaches against global standards, as well as the underrepresentation of perspectives from the Global South.

These identified knowledge gaps and future research directions are synthesized into a novel framework that integrates analytical methods and policy-relevant insights to guide the development of sustainable DT governance aligned with the SDGs. A central direction for future work is the empirical validation of this framework using real-world data and national statistics, which is essential for strengthening its practical relevance and informing evidence-based policy design. [Table 8](#) provides a summary of key knowledge gaps and proposed future research topics.

[Figure 10](#) presents a framework outlining a roadmap for further studies towards addressing the future directions. It consists of five related phases with actionable activities to address knowledge gaps in DT governance with Phase 1: Impact Assessment of DT governance, starting with (a) Environmental Impact Assessment (EIA) through quantitative methods such as KPI analysis of carbon footprint and energy modeling, Panel Data Regression (PDR), Risk Assessment (RA) and cross-country comparative analysis, resulting in the development of DT policies that support environmental SDGs; (b) Economic Impact Analysis (quantitative analysis) can be conducted through cost-benefit

analysis (CBA), and Input–Output (I–O) analysis, and cross-country comparative analysis, resulting in the formulation of DT policies that support economic SDGs; and (c) Social Impact Analysis can be carried out through KPI Analysis for digital accessibility indexing (broadband penetration and internet access mapping, digital affordability index), geospatial and demographic analysis of digital accessibility, and public perception and adoption analysis (surveys and focus groups), resulting in the establishment of DT policies that support social SDGs.

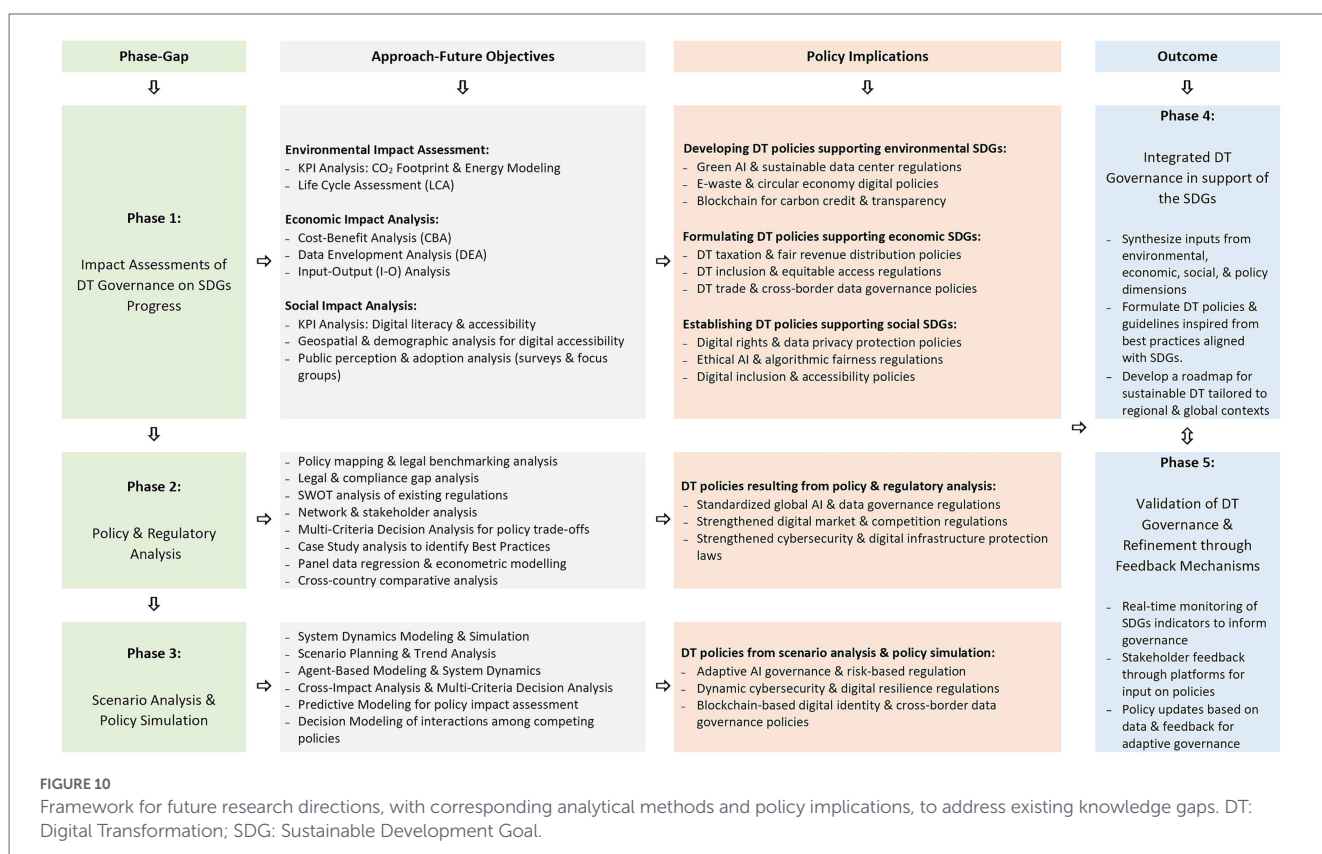
Subsequently, Phase 2: Policy and regulatory analysis can be carried out through policy mapping and legal benchmarking, legal compliance gap analysis, network and stakeholder analysis, Data Envelopment Analysis (DEA), Panel Data Regression (PDR) for policy efficiency assessment, case study analysis for best practice identification, and cross-country comparative analysis, resulting in the formulation of key DT policies, including standardized global AI and data governance regulations, digital market and competition regulations, as well as cybersecurity and digital infrastructure protection laws. Following phase 2, Phase 3: Scenario analysis and policy simulation involves scenario planning and trend analysis for future governance models, predictive modelling for policy impact assessment, system dynamics modelling, game theory and decision modelling of interactions between competing policies, resulting in the development of adaptive and dynamic DT governance policies.

Building upon the findings from all previous phases, we synthesize the environmental, economic, social and regulatory dimensions to converge into Phase 4: The development of an integrated sustainable DT governance model in support of sustainability, where effective DT policies are formulated in alignment with the UN SDGs. Finally, Phase 5: Validation of framework and refinement through feedback mechanisms ensures an adaptive and impactful model by relying on real-time monitoring, stakeholder feedback, and iterative policy updates, to promote a dynamic governance approach that evolves in response to emerging challenges and opportunities. This phase consolidates phase 4 (the DT governance model), creating an

TABLE 8 Knowledge gaps and future directions.

Knowledge Gaps	Suggested Future Directions
Gap I: Lack of standardized evaluation metrics and monitoring methods	<ul style="list-style-type: none"> • Develop standardized, SDG-linked indicators to assess the sustainability impacts of digital transformation policies. • Establish harmonized monitoring frameworks to enable cross-context evaluation of DT governance effectiveness.
Gap II: Limited integrated impact assessment of DT governance	<ul style="list-style-type: none"> • Apply integrated environmental and socio-economic impact assessments combining KPIs, life-cycle analysis (LCA), and cost–benefit analysis (CBA). • Use spatial and distributional methods to assess digital divides, accessibility barriers, and regional inequalities.
Gap III: Insufficient comparative analysis of DT governance models	<ul style="list-style-type: none"> • Conduct systematic policy mapping and legal benchmarking of DT governance models across countries. • Undertake comparative cross-country studies to identify transferable governance practices aligned with SDGs.
Gap IV: Absence of an integrated sustainable DT governance model	<ul style="list-style-type: none"> • Develop integrated governance models aligning digital transformation with environmental, social, and economic SDGs. • Empirically validate governance models using longitudinal data and comparative case studies.

DT: Digital Transformation; SDG: Sustainable Development Goal; KPI: Key Performance Indicator; LCA: Life-Cycle Analysis; CBA: Cost–Benefit Analysis; DEA: Data Envelopment Analysis; SWOT: Strengths, Weaknesses, Opportunities, Threats.



interconnected cycle that underpins sustainable development through DT governance.

4 Conclusion

This systematic mapping and structured qualitative evidence synthesis explored past efforts examining how DT governance shapes progress

across the environmental, social, and economic dimensions of the UN SDGs. While DT exhibits substantial potential to support sustainability, the findings consistently demonstrate that positive outcomes are contingent on governance quality, institutional capacity, and contextual fit rather than on technological adoption alone. Robust, ethical, and inclusive governance—supported by coherent policies at organizational, national, and international levels—emerges as a critical condition for aligning digitalization with long-term sustainability objectives. By synthesizing a fragmented and multidisciplinary literature, this study

advances an evidence-informed, inductively derived governance framework that links DT governance mechanisms to SDG outcomes across governance scales, explicitly accounting for contextual variability, institutional constraints, and implementation trade-offs. Rather than proposing a prescriptive model, the framework provides an analytical lens for understanding how governance arrangements condition sustainability impacts, particularly in low- and middle-income countries where capacity limitations are most pronounced. The quality appraisal indicates that the strength of policy-relevant insights varies across the evidence base. Empirically grounded and mixed-methods studies provide more robust support for governance conditions associated with positive SDG outcomes, whereas more optimistic or solution-oriented claims are disproportionately drawn from exploratory, conceptually oriented, or lower-quality studies. Accordingly, the policy implications advanced in this review are framed as conditional and adaptive, and interpreted as indicative rather than conclusive, emphasizing governance functions, monitoring, and institutional fit over the direct transfer of best-practice models, and underscoring the need for context-sensitive policymaking and further empirical validation before applying governance approaches across diverse institutional and socio-economic settings. Building on these insights, the analysis identifies several priority knowledge gaps, including the need for standardized sustainability metrics, stronger integration of ethical and equity considerations into DT governance, deeper empirical examination of long-term SDG impacts, and broader inclusion of critical governance perspectives that challenge technology-forward narratives. Addressing these gaps will require interdisciplinary, mixed-methods, and longitudinal research designs, alongside greater inclusion of diverse regional and socio-economic contexts and empirical validation through comparative case studies and real-world data. Finally, while restricting the analysis to peer-reviewed open-access literature enhances transparency and accessibility, it may also reinforce dominant policy narratives and contribute to the observed positivity bias, underscoring that reported sustainability benefits depend on governance capacity and socio-economic context, rather than representing universally generalizable outcomes. Future efforts could strengthen the evidence base by incorporating subscription-based scholarship, legal analyses, and policy reports to enable a more comprehensive and critical assessment of DT governance for sustainable development. The proposed framework thus provides a foundation for future research aimed at advancing ethical, inclusive, and resilient DT governance aligned with the SDGs, while recognizing that the rapid evolution of digital technologies, combined with regional, cultural, and disciplinary diversity, continues to challenge the development of cohesive and generalizable governance models.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author/s.

Author contributions

SG: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft,

Writing – review & editing. ME-F: Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frsc.2026.1743552/full#supplementary-material>

References

- Akande, A., Cabral, P., and Casteleyn, S. (2019). Assessing the gap between technology & the environmental sustainability of European cities. *Inf. Syst. Front.* 21, 581–604. doi: 10.1007/s10796-019-09903-3
- Alakeson, V., and Wilsdon, J. (2002). Digital sustainability in Europe. *J. Ind. Ecol.* 6, 10–12. doi: 10.1162/108819802763471744
- Aldieri, L., Carlucci, F., Vinci, C. P., and Yigitcanlar, T. (2019). Environmental innovation, knowledge spillovers and policy implications: a systematic review of the economic effects literature. *J. Clean. Prod.* 239:118051. doi: 10.1016/j.jclepro.2019.118051
- Allan, M., Rajabifard, A., and Foliente, G. (2024). Climate resilient urban regeneration and SDG 11-stakeholders' view on pathways and digital infrastructures. *Int. J. Digit. Earth* 17:e2385076. doi: 10.1080/17538947.2024.2385076
- Allen, C., Metternicht, G., and Wiedmann, T. (2016). National pathways to the sustainable development goals (SDGs): a comparative review of scenario modelling tools. *Environ. Sci. Pol.* 66, 199–207. doi: 10.1016/j.envsci.2016.09.008
- Allen, C., Metternicht, G., and Wiedmann, T. (2018). Initial progress in implementing the sustainable development goals (SDGs): a review of evidence from countries. *Sustain. Sci.* 13, 1453–1467. doi: 10.1007/s11625-018-0572-3
- Alojail, M., and Khan, S. B. (2023). Impact of digital transformation toward sustainable development. *Sustainability* 15:14697. doi: 10.3390/su152014697
- Bai, C., Du, X., and Chua, S. Y. (2025). The green potential of the digital economy in balancing economic growth and carbon emissions. *Sci. Rep.* 15:19365. doi: 10.1038/s41598-025-04616-x
- Balogun, A.-L., Marks, D., Sharma, R., Shekhar, H., Balmes, C., Maheng, D., et al. (2020). Assessing the potentials of digitalization as a tool for climate change adaptation and sustainable development in urban centres. *Sustain. Cities Soc.* 53:101888. doi: 10.1016/j.scs.2019.101888
- Barbier, E. B., and Burgess, J. C. (2019). Sustainable development goal indicators: analyzing trade-offs and complementarities. *World Dev.* 122, 295–305. doi: 10.1016/j.worlddev.2019.05.026
- Bekaroo, G., Bokhoree, C., and Pattinson, C. (2016). Impacts of ICT on the natural ecosystem: a grassroot analysis for promoting socio-environmental sustainability. *Renew. Sust. Energ. Rev.* 57, 1580–1595. doi: 10.1016/j.rser.2015.12.147
- Berawi, M. A. (2017). The role of technology in achieving sustainable development goals. *Int. J. Technol.* 8, 362–365. doi: 10.14716/ijtech.v8i3.9296
- Bergantino, A. S., Intini, M., and Nademi, Y. (2024). Rethinking poverty: an econometric analysis of the role of ICT poverty in a global context. *Telecommun. Policy.* 49:102876. doi: 10.1016/j.telpol.2024.102876
- Bibri, S. E. (2019). On the sustainability of smart and smarter cities in the era of big data: an interdisciplinary and transdisciplinary literature review. *J. Big Data* 6, 1–64. doi: 10.1186/s40537-019-0182-7
- Bibri, S. E., and Krogstie, J. (2017). Smart sustainable cities of the future: an extensive interdisciplinary literature review. *Sustain. Cities Soc.* 31, 183–212. doi: 10.1016/j.scs.2017.02.016
- Bidarbakhtnia, A. (2020). Measuring sustainable development goals (SDGs): an inclusive approach. *Glob. Policy* 11, 56–67. doi: 10.1111/1758-5899.12774
- Bifulco, F., Tregua, M., Amitrano, C. C., and D'Auria, A. (2016). ICT and sustainability in smart cities management. *Int. J. Public Sect. Manag.* 29, 132–147. doi: 10.1108/IJPSM-07-2015-0132
- Bissio, R. (2018). Vector of hope, source of fear, spotlight on sustainable development 2018: Exploring new policy pathways. Available online at: https://www.2030spotlight.org/sites/default/files/spot2018/chaps/Spotlight_Innenteil_2018_chapter3_bissio.pdf (Accessed February 10, 2025)
- Bostrom, A., and Nayyar, S. (2023). Fit for purpose? The patents regime, the fourth industrial revolution, and sustainable development. *Data Policy* 5:e18. doi: 10.1017/dap.2023.17
- Brenner, B., and Hartl, B. (2021). The perceived relationship between digitalization and ecological, economic, and social sustainability. *J. Clean. Prod.* 315:128128. doi: 10.1016/j.jclepro.2021.128128
- Brundtland, G. H. C. (1987). *Our Common Future* Oxford, United Kingdom: Oxford University Press.
- Bühler, M. M., Sebald, C., Rechid, D., Baier, E., Michalski, A., Rothstein, B., et al. (2021). Application of Copernicus data for climate-relevant urban planning using the example of water, heat, and vegetation. *Remote Sens* 13:3634. doi: 10.3390/rs13183634
- Campagnolo, L., Eboli, F., Farnia, L., and Carraro, C. (2018). Supporting the UN SDGs transition: methodology for sustainability assessment and current worldwide ranking. *Economics* 12, 1–19. doi: 10.5018/economics-ejournal.ja.2018-10
- Clark, S., MacLachlan, M., Marshall, K., Morahan, N., Carroll, C., Hand, K., et al. (2022). Including digital connection in the United Nations sustainable development goals: a systems thinking approach for achieving the SDGs. *Sustainability* 14:1883. doi: 10.3390/su14031883
- Coroama, V., and Höjer, M. (2016). "Assessing GHG benefits induced by ICT services in practice: a case study and resulting challenges" in Proceedings of ICT for sustainability 2016, 29–35.
- David, A., Yigitcanlar, T., Desouza, K., Li, R. Y. M., Cheong, P. H., Mehmood, R., et al. (2024). Understanding local government responsible AI strategy: an international municipal policy document analysis. *Cities* 155:105502. doi: 10.1016/j.cities.2024.105502
- de Galdino Magalhães Santos, L. (2024). Open government data in the Brazilian digital government: enabling an SDG acceleration agenda. *Comput. Law Secur. Rev.* 54:106029. doi: 10.1016/j.clsr.2024.106029
- Del Río Castro, G., González Fernández, M. C., and Uruburu Colsa, Á. (2021). Unleashing the convergence amid digitalization and sustainability towards pursuing the sustainable development goals (SDGs): a holistic review. *J. Clean. Prod.* 280:122204. doi: 10.1016/j.jclepro.2020.122204
- Delgosha, M. S., Saheb, T., and Hajiheydari, N. (2021). Modelling the asymmetrical relationships between digitalisation and sustainable competitiveness: a cross-country configurational analysis. *Inf. Syst. Front.* 23, 1317–1337. doi: 10.1007/s10796-020-10029-0
- El hilali, W., and El manouar, A. (2019). Unlocking digitalization's possibilities: Reaching sustainability by adopting the right digital strategy, 1–6. Piscataway, New Jersey, United States: Institute of Electrical and Electronics Engineers (IEEE).
- ElMassah, S., and Mohieldin, M. (2020). Digital transformation and localizing the sustainable development goals (SDGs). *Ecol. Econ.* 169:106490. doi: 10.1016/j.ecolecon.2019.106490
- Etzion, D., and Aragon-Correa, J. A. (2016). Big data, management, and sustainability: strategic opportunities ahead. *Organ. Environ.* 29, 147–155. doi: 10.1177/1086026616650437
- European Economic and Social Committee. 2020. Digitalisation and sustainability - status quo and need for action from a civil society perspective. Opinion NAT/794. Available online at: <https://webapi2016.eesc.europa.eu/v1/documents/EESC-2020-01918-00-00-AS-TRA-EN.docx/pdf> (Accessed January 7, 2025)
- Fernández-Aller, C., de Velasco, A. F., Manjarrés, Á., Pastor-Escuredo, D., Pickin, S., Criado, J. S., et al. (2021). An inclusive and sustainable artificial intelligence strategy for Europe based on human rights. *IEEE Technol. Soc. Mag.* 40, 46–54. doi: 10.1109/MTS.2021.3056283
- Furtado, L. S., Silva, T. L. C. da, Ferreira, M. G. F., Macedo, J. A. F. de, and Moreira, J. K. de M. L. C. (2023). A framework for digital transformation towards smart governance: using big data tools to target SDGs in Ceará, Brazil. *J. Urban Manag.* 12, 74–87. doi: 10.1016/j.jum.2023.01.003
- Gazzola, P., Del Campo, A. G., and Onyango, V. (2019). Going green vs going smart for sustainable development: quo vadis? *J. Clean. Prod.* 214, 881–892. doi: 10.1016/j.jclepro.2018.12.234
- Gebhardt, C. (2017). *Humans in the loop: the clash of concepts in digital sustainability in smart cities* Cham: Springer International Publishing, 85–93.
- Gelenbe, E., and Caseau, Y. (2015). The impact of information technology on energy consumption and carbon emissions. *Ubiquity* 2015, 1–15. doi: 10.1145/2755977
- Gensch, C.-O., Prakash, S., and Hilbert, I. (2017). *Is digitalisation a driver for sustainability?* Cham: Springer International Publishing, 117–129.
- Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *J. Clean. Prod.* 252:119869. doi: 10.1016/j.jclepro.2019.119869
- Ghobakhloo, M., and Fathi, M. (2021). Industry 4.0 and opportunities for energy sustainability. *J. Clean. Prod.* 295:126427. doi: 10.1016/j.jclepro.2021.126427
- Ghobakhloo, M., Fathi, M., Iranmanesh, M., Maroufkhani, P., and Morales, M. E. (2021a). Industry 4.0 ten years on: a bibliometric and systematic review of concepts, sustainability value drivers, and success determinants. *J. Clean. Prod.* 302:127052. doi: 10.1016/j.jclepro.2021.127052
- Ghobakhloo, M., Iranmanesh, M., Grybauskas, A., Vilkas, M., and Petraitė, M. (2021b). Industry 4.0, innovation, and sustainable development: a systematic review and a roadmap to sustainable innovation. *Bus. Strat. Environ.* 30, 4237–4257. doi: 10.1002/bse.2867
- Gijzen, H. (2013). Development: big data for a sustainable future. *Nature* 502:38. doi: 10.1038/502038d
- Glavič, P., and Lukman, R. (2007). Review of sustainability terms and their definitions. *J. Clean. Prod.* 15, 1875–1885. doi: 10.1016/j.jclepro.2006.12.006
- Goh, H.-H. (2021). *Artificial intelligence in achieving sustainable development goals* Ithaca, NY, United States: Cornell University Library.
- Gong, C., and Ribiere, V. (2021). Developing a unified definition of digital transformation. *Technovation* 102:102217. doi: 10.1016/j.technovation.2020.102217
- Goralski, M. A., and Tan, T. K. (2020). Artificial intelligence and sustainable development. *Int. J. Manag. Educ.* 18:100330. doi: 10.1016/j.ijme.2019.100330
- Gouvea, R., Kapelians, D., and Kassicieh, S. (2018). Assessing the nexus of sustainability and information & communications technology. *Technol. Forecast. Soc. Change* 130, 39–44. doi: 10.1016/j.techfore.2017.07.023
- Gritsenko, D. (2024). Advancing UN digital cooperation: lessons from environmental policy and governance. *World Dev.* 173:106392. doi: 10.1016/j.worlddev.2023.106392

- Grunfeld, H., and Houghton, J. (2013). Using ICT for climate change adaptation and mitigation through agro-ecology in the developing world. Melbourne, Australia: Centre for Strategic Economic Studies (CSES), Victoria University.
- Guandalini, I. (2022). Sustainability through digital transformation: a systematic literature review for research guidance. *J. Bus. Res.* 148, 456–471. doi: 10.1016/j.jbusres.2022.105668
- Guo, H. (2020). Big earth data facilitates sustainable development goals. *Big Earth Data* 4, 1–2. doi: 10.1080/20964471.2020.1730568
- Guo, H., Liu, J., Qiu, Y., Menenti, M., Chen, F., Uhlir, P. F., et al. (2018). The digital belt and road program in support of regional sustainability. *Int. J. Digit. Earth* 11, 657–669. doi: 10.1080/17538947.2018.1471790
- Hernandez, M. (2017). A digital earth platform for sustainability. *Int. J. Digit. Earth* 10, 342–355. doi: 10.1080/17538947.2016.1272646
- Higón, D. A., Gholami, R., and Shirazi, F. (2017). ICT and environmental sustainability: a global perspective. *Telemat. Inform.* 34, 85–95. doi: 10.1016/j.tele.2017.01.001
- Hong, Q. N., Pluye, P., Fàbregues, S., Bartlett, G., Boardman, F. K., Cargo, M., et al. (2018). Mixed methods appraisal tool (MMAT), version 2018, for information professionals and researchers. *Educ. Inf.* 34, 285–291. doi: 10.3233/EFI-180221
- Hong, Z., and Xiao, K. (2024). Digital economy structuring for sustainable development: the role of blockchain and artificial intelligence in improving supply chain and reducing negative environmental impacts. *Sci. Rep.* 14:3912. doi: 10.1038/s41598-024-53760-3
- Huang, L., Zhang, H., Si, H., and Wang, H. (2023). Can the digital economy promote urban green economic efficiency? Evidence from 273 cities in China. *Ecol. Indic.* 155:110977. doi: 10.1016/j.ecolind.2023.110977
- Ibrahim, A. M. (2022). A mapping towards a unified municipal platform: an investigative case study from a Norwegian municipality. *Sustain. Futures* 4:100063. doi: 10.1016/j.sfr.2022.100063
- IIASA (2019). “TWI2050 - the world in 2050. The digital revolution and sustainable development: opportunities and challenges” in *Report prepared by the world in 2050 initiative* (Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA)).
- Imasiku, K., Thomas, V., and Ntagwirumugara, E. (2019). Unraveling green information technology systems as a global greenhouse gas emission game-changer. *Adm. Sci.* 9, 1–29. doi: 10.3390/admsci9020043
- Irtysheva, I., Trushliakova, A., and Sirenko, I. (2020). Strategic human capital management in the context of digitalization. *Balt. J. Econ. Stud.* 6, 178–183. doi: 10.30525/2256-0742/2020-6-5-178-183
- Jacob, P. (2018). Information and communication technology in shaping urban low carbon development pathways. *Curr. Opin. Environ. Sustain.* 30, 133–137. doi: 10.1016/j.cosust.2018.05.015
- Jain, A., Gue, I. H., and Jain, P. (2023). Research trends, themes, and insights on artificial neural networks for smart cities towards SDG-11. *J. Clean. Prod.* 412:137300. doi: 10.1016/j.jclepro.2023.137300
- Janowski, T. (2016). Implementing sustainable development goals with digital government – aspiration-capacity gap. *Gov. Inf. Q.* 33, 603–613. doi: 10.1016/j.giq.2016.12.001
- Janowski, T., Estevez, E., and Baguma, R. (2018). Platform governance for sustainable development: reshaping citizen-administration relationships in the digital age. *Gov. Inf. Q.* 35, S1–S16. doi: 10.1016/j.giq.2018.09.002
- Ji, Z., and Huang, Y. (2024). Does digital transformation promote economic resilience? Urban-level evidence from China. *Helvion* 10:e26461. doi: 10.1016/j.helivon.2024.e26461
- Jones, P., Wynn, M., Hillier, D., and Comfort, D. (2017). The sustainable development goals and information and communication technologies. *Indones. J. Sustain. Account. Manag.* 1:1. doi: 10.28992/ijSAM.v1i1.22
- Kassen, M. (2019). Promoting public cooperation in government: key drivers, regulation, and barriers of the e-collaboration movement in Kazakhstan. *Int. Rev. Adm. Sci.* 85, 743–762. doi: 10.1177/0020852317735595
- Khakurel, J., Penzenstadler, B., Porras, J., Knutas, A., and Zhang, W. (2018). The rise of artificial intelligence under the lens of sustainability. *Technologies (Basel)* 6:100. doi: 10.3390/technologies6040100
- Khan, S., Ullah, S., and Nobanee, H. (2024). ICT diffusion, E-governance, and sustainability in the digital era. *Sustain. Futures* 8:100272. doi: 10.1016/j.sfr.2024.100272
- Kharrazi, A., Qin, H., and Zhang, Y. (2016). Urban big data and sustainable development goals: challenges and opportunities. *Sustainability* 8, 1293–1293. doi: 10.3390/su8121293
- Kolade, O., and Owoseni, A. (2022). Employment 5.0: the work of the future and the future of work. *Technol. Soc.* 71:102086. doi: 10.1016/j.techsoc.2022.102086
- Kolesnichenko, O., Mazelis, L., Sotnik, A., Yakovleva, D., Amelkin, S., Grigorevsky, I., et al. (2021). Sociological modeling of smart city with the implementation of UN sustainable development goals. *Sustain. Sci.* 16, 581–599. doi: 10.1007/s11625-020-00889-5
- Kolupaeva, I., Sheiko, I., and Polozova, T. (2024). Digital transformation in the context of sustainable development of European countries. *Probl. Ekorozw.* 19, 89–102. doi: 10.35784/preko.5413
- Kolupaeva, I., and Tiesheva, L. (2023). Asymmetry and convergence in the development of digital technologies in the EU countries. *Equilibrium. Q. J. Econ. Econ. Policy* 18, 687–716. doi: 10.24136/eq.2023.022
- Kostoska, O., and Kocarev, L. (2019). A novel ICT framework for sustainable development goals. *Sustainability* 11:1961. doi: 10.3390/su11071961
- Kramers, A., Höjer, M., Lövehagen, N., and Wangel, J. (2013). “ICT for sustainable cities: how ICT can support an environmentally sustainable development in cities. ICT4S 2013” in *Proceedings of the first international conference on information and communication Technologies for Sustainability* (Zurich, Switzerland: ETH Zurich), 183–189.
- Kürpick, C., Rasor, A., Scholtysik, M., Kühn, A., Koldewey, C., and Dumitrescu, R. (2023). An integrative view of the transformations towards sustainability and digitalization: the case for a dual transformation. *Procedia CIRP* 119, 614–619. doi: 10.1016/j.procir.2023.02.155
- Lange, S., and Santarius, T. (2020). *Smart green world? Making digitalization work for sustainability* London, United Kingdom: Taylor and Francis.
- Lennerfors, T. T., Fors, P., and van Rooijen, J. (2015). Ict and environmental sustainability in a changing society. *Inf. Technol. People* 28, 758–774. doi: 10.1108/itp-09-2014-0219
- Liu, S. (2024). Infrastructure and gender disparity in information communication technology literacy: a cross-country comparative study. *Stat. Polit. Policy* 15, 47–64. doi: 10.1515/spp-2023-0017
- Maarof, A. (2015). Big data and the 2030 agenda for sustainable development, report for UN ESCAP. Available online at: http://www.unescap.org/sites/default/files/Final%20Draft_%20stock-taking%20report_For%20Comment_301115.pdf (Accessed November 25, 2024)
- Madon, S., and Masiero, S. (2024). Digital connectivity and the SDGs: conceptualising the link through an institutional resilience lens. *Telecommun. Policy* 49:102879. doi: 10.1016/j.telpol.2024.102879
- Mazzi, F., and Floridi, L. (2023). *The ethics of artificial intelligence for the sustainable development goals*: Vol. 152. (1st 2023); Cham: Springer International Publishing.
- Meijer, A. (2024). Perspectives on the twin transition: instrumental and institutional linkages between the digital and sustainability transitions. *Inf. Polity* 29, 35–51. doi: 10.3233/IP-230015
- Miénye, I. D., Sun, Y., and Ileberi, E. (2024). Artificial intelligence and sustainable development in Africa: a comprehensive review. *Mach. Learn. Appl.* 18:100591. doi: 10.1016/j.mlwa.2024.100591
- Mir, U. B., Kar, A. K., Dwivedi, Y. K., Gupta, M. P., and Sharma, R. S. (2020). Realizing digital identity in government: prioritizing design and implementation objectives for Aadhaar in India. *Gov. Inf. Q.* 37:101442. doi: 10.1016/j.giq.2019.101442
- Mondejar, M. E., Avtar, R., Diaz, H. L. B., Dubey, R. K., Esteban, J., Gómez-Morales, A., et al. (2021). Digitalization to achieve sustainable development goals: steps towards a smart green planet. *Sci. Total Environ.* 794:148539. doi: 10.1016/j.scitotenv.2021.148539
- Nahar, S. (2024). Modeling the effects of artificial intelligence (AI)-based innovation on sustainable development goals (SDGs): applying a system dynamics perspective in a cross-country setting. *Technol. Forecast. Soc. Change* 201:123203. doi: 10.1016/j.techfore.2023.123203
- Nhamo, G., Nhemachena, C., and Nhamo, S. (2020). Using ICT indicators to measure readiness of countries to implement industry 4.0 and the SDGs. *Environ. Econ. Policy Stud.* 22, 315–337. doi: 10.1007/s10018-019-00259-1
- Norström, L., Magnusson, J., and Mankevich, V. (2023). The great divide: empirical evidence of a decoupling of digital transformation and sustainability, Cham: Springer Nature Switzerland AG. 73–88.
- Nosratabadi, S., Atobishi, T., and Hegeđús, S. (2023). Social sustainability of digital transformation: empirical evidence from EU-27 countries. *Adm. Sci.* 13:126. doi: 10.3390/admsci13050126
- Osburg, T. (2017). “Sustainability in a digital world needs trust” in *Sustainability in a digital world: New opportunities through new technologies*. eds. T. Osburg and C. Lohrmann (Cham: Springer International Publishing), 3–19.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 372:n71. doi: 10.1136/bmj.n71
- Palos-Sánchez, P. R., Baena-Luna, P., García-Ordaz, M., and Martínez-López, F. J. (2023). Digital transformation and local government response to the COVID-19 pandemic: an assessment of its impact on the sustainable development goals. *SAGE Open* 13:21582440231167343. doi: 10.1177/21582440231167343
- Pascale, G. D., and Romagno, A. (2024). Globalization and ICT capital endowment: how do they impact on an inclusive green growth index? *Struct. Change Econ. Dyn.* 69, 463–474. doi: 10.1016/j.strueco.2024.03.003
- Pierli, G., Murmura, F., and Bravi, L. (2023). *Digital transformation and sustainability. A systematic literature review* Cham: Springer Nature Switzerland.
- Pollex, J., and Lenschow, A. (2018). Surrendering to growth? The European Union's goals for research and technology in the horizon 2020 framework. *J. Clean. Prod.* 197, 1863–1871. doi: 10.1016/j.jclepro.2016.10.195
- Quattrone, G., and Chen, L. (2023). Shenzhen—how to further implement the sustainability and resilience towards 2030? *Cities* 136:104263. doi: 10.1016/j.cities.2023.104263
- Rosário, A. T., and Dias, J. C. (2022). Sustainability and the digital transition: a literature review. *Sustainability* 14:4072. doi: 10.3390/su14074072

- Ruggerio, C. A. (2021). Sustainability and sustainable development: a review of principles and definitions. *Sci. Total Environ.* 786, 147481–147481. doi: 10.1016/j.scitotenv.2021.147481
- Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., and Rockström, J. (2019). Six transformations to achieve the sustainable development goals. *Nat. Sustain.* 2, 805–814. doi: 10.1038/s41893-019-0352-9
- Sachs, J.D., Modi, V., Figueroa, H., Machado Fantacchiotti, M., Sanyal, K., Khatun, F., et al. (2016). ICTs & SDGs: How information and communications technology can accelerate action on the sustainable development goals. Available online at: <https://www.ericsson.com/49e8f7/assets/local/news/2016/05/ict-sdg.pdf> (Accessed December 9, 2024)
- Salam, A. (2020). Internet of things for sustainable community development: introduction and overview (pp. 1–31). Cham: Springer International Publishing AG.
- Santarius, T., Bieser, J. C. T., Frick, V., Hoejer, M., Gossen, M., Hilty, L. M., et al. (2023a). Digital sufficiency: conceptual considerations for ICTs on a finite planet. *Ann. Telecommun.* 78, 277–295. doi: 10.1007/s12243-022-00914-x
- Santarius, T., Dencik, L., Diez, T., Ferreboeuf, H., Jankowski, P., Hankey, S., et al. (2023b). Digitalization and sustainability: a call for a digital green Deal. *Environ. Sci. Pol.* 147, 11–14. doi: 10.1016/j.envsci.2023.04.020
- Santarius, T., Pohl, J., and Lange, S. (2020). Digitalization and the decoupling debate: can ICT help to reduce environmental impacts while the economy keeps growing? *Sustainability* 12:7496. doi: 10.3390/su12187496
- Schulz, K. A., Gstrein, O. J., and Zwitter, A. J. (2020). Exploring the governance and implementation of sustainable development initiatives through blockchain technology. *Futures* 122:102611. doi: 10.1016/j.futures.2020.102611
- Seele, P. (2016). Envisioning the digital sustainability panopticon: a thought experiment of how big data may help advancing sustainability in the digital age. *Sustain. Sci.* 11, 845–854. doi: 10.1007/s11625-016-0381-5
- Seele, P., and Lock, I. (2017). The game-changing potential of digitalization for sustainability: possibilities, perils, and pathways. *Sustain. Sci.* 12, 183–185. doi: 10.1007/s11625-017-0426-4
- Sha, K., Taeihagh, A., and Jong, M. D. (2024). Governing disruptive technologies for inclusive development in cities: a systematic literature review. *Technol. Forecast. Soc. Change* 203:123382. doi: 10.1016/j.techfore.2024.123382
- Shahmohammad, M., Salamattalab, M. M., Sohn, W., Kouhizadeh, M., and Aghamohammadi, N. (2024). Opportunities and obstacles of blockchain use in pursuit of sustainable development goal 11: a systematic scoping review. *Sustain. Cities Soc.* 112:105620. doi: 10.1016/j.scs.2024.105620
- Sharifi, A., Allam, Z., Bibri, S. E., and Khavarian-Garmis, A. R. (2024). Smart cities and sustainable development goals (SDGs): a systematic literature review of co-benefits and trade-offs. *Cities* 146:104659. doi: 10.1016/j.cities.2023.104659
- Siekmann, F., Schlör, H., and Venghaus, S. (2023). Linking sustainability and the fourth industrial revolution: a monitoring framework accounting for technological development. *Energy Sustain. Soc.* 13:26. doi: 10.1186/s13705-023-00405-4
- Sparvierio, S., and Ragnedda, M. (2021). Towards digital sustainability: the long journey to the sustainable development goals 2030. *Digit. Policy Regul. Gov.* 23, 216–228. doi: 10.1108/DPRG-01-2021-0015
- Spulbar, C., Anghel, L. C., Birau, R., Ermiş, S. I., Trepăt, L.-M., and Mitroi, A. T. (2022). Digitalization as a factor in reducing poverty and its implications in the context of the COVID-19 pandemic. *Sustainability* 14:10667. doi: 10.3390/su141710667
- Stahl, B. C., Brooks, L., Hatzakis, T., Santiago, N., and Wright, D. (2023). Exploring ethics and human rights in artificial intelligence – a Delphi study. *Technol. Forecast. Soc. Change* 191:122502. doi: 10.1016/j.techfore.2023.122502
- Stahl, B. C., Rodrigues, R., Santiago, N., and Macnish, K. (2022). A European agency for artificial intelligence: protecting fundamental rights and ethical values. *Comput. Law Secur. Rev.* 45:105661. doi: 10.1016/j.clsr.2022.105661
- Stock, T., Obenaus, M., Kunz, S., and Kohl, H. (2018). Industry 4.0 as enabler for a sustainable development: a qualitative assessment of its ecological and social potential. *Process. Saf. Environ. Prot.* 118, 254–267. doi: 10.1016/j.psep.2018.06.026
- Tjoa, A. M., and Tjoa, S. (2016). The role of ICT to achieve the UN sustainable development goals (SDG) (pp. 3–13). Cham: Springer International Publishing.
- Townsend, J. H., and Coroama, V. C. (2018). Digital acceleration of sustainability transition: the paradox of push impacts. *Sustainability* 10:2816. doi: 10.3390/su10082816
- Truby, J. (2020). Governing artificial intelligence to benefit the UN sustainable development goals. *Sustain. Dev.* 28, 946–959. doi: 10.1002/sd.2048
- Tura, N., and Ojanen, V. (2022). Sustainability-oriented innovations in smart cities: a systematic review and emerging themes. *Cities* 126:103716. doi: 10.1016/j.cities.2022.103716
- Turcu, C. (2013). Re-thinking sustainability indicators: local perspectives of urban sustainability. *J. Environ. Plan. Manag.* 56, 695–719. doi: 10.1080/09640568.2012.698984
- Ufua, D. E., Emielu, E. T., Olujobi, O. J., Lakhani, F., Borishade, T. T., Ibidunni, A. S., et al. (2021). Digital transformation: a conceptual framing for attaining sustainable development goals 4 and 9 in Nigeria. *J. Manage. Organ.* 27, 836–849. doi: 10.1017/jmo.2021.45
- United Nations (2015a), *General assembly resolution 70/1, transforming our world: the 2030 agenda for sustainable development, a/res/70/1*. Available online at: <https://sustainabledevelopment.un.org/post2015/transformingourworld/publication/> (Accessed September 27, 2024)
- United Nations 2015b United Nations sustainable development goals. Available online at: www.un.org/sustainabledevelopment/sustainable-development-goals/ (Accessed September 27, 2024)
- United Nations 2020 Sustainable development goals report 2020. Sustainable development goals report 2020 | United Nations. Available online at: <https://www.un.org/en/desa/sustainable-development-goals-report-2020> (Accessed September 27, 2024)
- United Nations Conference on Trade and Development (2018). Technology and innovation report 2018, harnessing frontier technologies for sustainable development. Geneva, Switzerland: United Nations Conference on Trade and Development (UNCTAD).
- United Nations Department of Economic and Social Affairs (2018), *World economic and social survey 2018 frontier technologies for sustainable development*. Available online at: https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/WESS2018_full_web.pdf (Accessed December 15, 2024)
- United Nations Development Group (2017). *Guidance note on big data for SDGs: data privacy, data protection and data ethics*. Available online at: <https://undg.org/document/undg-guidance-note-on-big-data-for-achievement-of-the-2030-agenda-data-privacy-ethics-and-protection/> (Accessed December 22, 2024)
- United Nations Sustainable Development Solutions Network (2019). *Counting on the world to act. A roadmap for governments to achieve modern data systems for sustainable development*. Available online at: <https://countingonthe.world.sdsntrends.org/2019/> (Accessed December 12, 2024)
- van der Hoogen, A., Fashoro, I., Calitz, A. P., and Luke, L. (2024). A digital transformation framework for smart municipalities. *Sustainability* 16:1320. doi: 10.3390/su16031320
- Vărzaru, A. A., Bocean, C. G., Simion, D., Berceanu, D., and Mangra, M. G. (2023). Digital revolution, sustainability, and government revenues: a transversal analysis of how digital transformation and sustainable practices impact sustainable government revenues. *Systems* 11:546. doi: 10.3390/systems11110546
- Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch, S., et al. (2020). The role of artificial intelligence in achieving the sustainable development goals. *Nat. Commun.* 11, 233–210. doi: 10.1038/s41467-019-14108-y
- WBGU, German Advisory Council on Global Change (2019). “Digital momentum for the UN sustainability agenda in the 21st century” in *Policy Paper 10* (Berlin: WBGU).
- World Bank 2019 World Development Indicators World Bank Washington DC
- World Economic Forum (2019). *The global risks report 2019*. Geneva: World Economic Forum.
- World Economic Forum 2020a Unlocking technology for the global goals 2020. Geneva, Switzerland: World Economic Forum. Available online at: <https://www.weforum.org/reports/unlocking-technology-for-the-global-goals> (Accessed February 2, 2025)
- World Economic Forum (2020b), *Vision 2030. World economic forum 2020*. Available online at: <https://www.weforum.org/projects/frontier-2030> (Accessed February 2, 2025)
- Wu, J., Guo, S., Huang, H., Liu, W., and Xiang, Y. (2018). Information and communications technologies for sustainable development goals: state-of-the-art, needs and perspectives. *IEEE Commun Surv Tutor* 20:2389–2406. doi: 10.1109/comst.2018.2812301
- Young, O. R., Yang, J., and Guttman, D. (2020). Meeting cyber age needs for governance in a changing global order. *Sustainability* 12:5557. doi: 10.3390/su12145557
- Zambrano, R. (2020). Taming the beast: harnessing blockchains in developing country governments. *Front. Blockchain* 2:27. doi: 10.3389/fbloc.2019.00027
- Zeng, D., and Duan, H. (2024). Inter-construction goals: navigating Thailand’s digital economy from a sustainable development perspective. *Southeast Asian Stud.* 13, 229–253.
- Zhang, X., Lau, C. K. M., Li, R., Wang, Y., Wanjiru, R., and Setetaram, N. (2024). Determinants of carbon emissions cycles in the G7 countries. *Technol. Forecast. Soc. Change* 201:123261. doi: 10.1016/j.techfore.2024.123261
- Zheng, S., Zhang, Y., Luo, T., and Gong, Y. (2025). Synergistic effects of digital technology and environmental regulation on the green transformation of China’s manufacturing industry. *Sci. Rep.* 15:36092. doi: 10.1038/s41598-025-20077-8