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Managing the Green Economy through Digital Technologies: Opportunities, Mechanisms, and Prospects

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Abstract

This article analyzes the theoretical and methodological foundations, practical mechanisms, and prospects of managing the green economy through digital technologies. The interrelationship between the green economy and digital transformation is examined from the perspective of the "twin transition." The study substantiates the role of artificial intelligence, Big Data, the Internet of Things (IoT), and blockchain technologies in improving energy efficiency, tracking carbon footprints, managing waste, and shaping green finance flows, and proposes institutional mechanisms for their governance. Drawing on a comparative analysis of international experience (the European Union, China, the United Arab Emirates, the United Kingdom, and Singapore) and Uzbekistan's practice, supported by official statistical data, the authors develop an original conceptual model, the "digital-green governance cycle," together with practical recommendations for managing the digital-green transition in Uzbekistan. The research methodology combines systems analysis, a comparative-historical approach, and the generalization of statistical data.

Keywords: green economy; digital transformation; artificial intelligence; twin transition; sustainable development; carbon footprint; green finance.

1. INTRODUCTION

Two defining processes are increasingly reinforcing each other in the development of the global economy. The first is the need to transition to a green (sustainable) economy, driven by climate change, resource scarcity, and environmental crises; the second is the shift of the economy to a digital basis as a result of scientific and technological progress. In official documents of the European Union, these two processes are captured by the concept of the "twin transition," that is, the combined digital and green transition. In this sense, effective management of the green economy now requires not traditional administrative instruments but modern governance systems built on digital technologies.

The relevance of the topic is determined by several factors. First, the United Nations Sustainable Development Goals (SDGs), particularly Goals 7, 9, 12, and 13, define energy efficiency, innovative infrastructure, responsible production, and climate action in close connection with digital tools. Second, growing green demand in global markets, including carbon markets, green bonds, and the introduction of ESG reporting, is making digital monitoring and reporting systems mandatory for both companies and states. Third, the adoption of Uzbekistan's Strategy for the Transition to a Green Economy for 2019-2030 [1] and the designation of digital transformation and green growth as priority areas in the "Uzbekistan 2030" Strategy [2] call for an in-depth scientific analysis of this issue in national governance practice.

The concept of the green economy entered academic discourse in the 1980s, when the concept of sustainable development was beginning to take shape [3]. The term has its roots in ecological economics, whose founders, H. Daly and R. Costanza [4,5], viewed the economic system as part of the biosphere and substantiated the existence of ecological limits to economic growth. Accordingly, in contrast to the

traditional "development equals growth" paradigm, the green economy is defined as a form of economic activity that improves human well-being and ensures social equity while significantly reducing environmental risks.

The most widely accepted definition of the green economy was given by the United Nations Environment Programme (UNEP) in 2011, according to which a green economy is one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities [6]. The methodological significance of this definition lies in the fact that it presents the green economy as the intersection of three interrelated components: economic efficiency, social inclusion, and environmental sustainability.

The following approaches to interpreting the essence of the green economy can be distinguished in the academic literature:

- The resource-oriented approach (H. Daly, R. Costanza) [4, 5] studies the economy as a subsystem of the biosphere;
- The institutional approach (D. North, E. Ostrom) [7, 8] emphasizes the decisive role of informal norms, property rights, and the institutional environment in the green transition;
- The innovation and technology approach (F. Geels, J. Schot) [9-11] explains the transition to a green economy through technological transformation and changes in socio-technical regimes;
- The financial approach (the green finance school) examines mechanisms for redirecting capital flows toward green purposes.

The issue is also receiving growing attention in Uzbek academic scholarship. National studies have examined the green economy in the context of, on the one hand, renewing the sectoral structure of the economy and, on the other, improving energy efficiency and developing renewable energy sources (RES). In recent years, national researchers have also addressed the formation of a national model of green growth within the framework of the "Uzbekistan 2030" Strategy. However, most of these works focus on the structural aspects of the green economy, while the digital mechanisms for managing it remain insufficiently explored, which defines the scientific novelty of this study.

Green economy governance is a set of activities carried out by state, market, and civil society institutions to plan, organize, coordinate, and control the green transformation of the economy. This process should rest on the following core principles:

- The principle of systemic integrity: comprehensive consideration of the interdependence of environmental, economic, and social factors;
- The prevention principle: prioritizing the prevention of environmental damage over its remediation;
- The "polluter pays" principle: internalizing environmental externalities;
- The principle of information availability and transparency: ensuring a reliable flow of information for decisions at all levels;
- The principle of inclusiveness: expanding the participation of diverse stakeholders (the state, business, and civil society);
- The principle of adaptability: making flexible management decisions under conditions of uncertainty.

Most of these principles, particularly transparency and adaptability, cannot be fully ensured by traditional administrative instruments: their implementation requires a continuous flow of information and real-time monitoring, which is possible only through digital technologies. This logical link forms the theoretical foundation of the "twin transition" concept analyzed in the following section.

Over the past decade, the synergy between green and digital transformations has become a distinct research area in the international academic literature. The term "twin transition," formally used in the European Commission's strategic documents [12,13], implies that the green and digital transitions should be managed as a paired process in which each can either accelerate or slow down the other. International studies have established the following key positions (Table 1):

Table 1. Key positions of international studies on the "twin transition" concept

Author / Organization	Main view
OECD (2019) [14]	Digital technologies can reduce aggregate resource consumption by improving energy efficiency; however, the "rebound effect" (the re-consumption of saved resources) must be taken into account.
European Commission (2022) [15]	The green and digital transitions must be "twinned": digital technologies are essential for achieving climate neutrality, while their own energy and resource footprint must be reduced.
Geels F.W., Schot J. (2007) [9]	Sustainability transitions unfold through interactions between niches, socio-technical regimes, and the broader landscape, following distinct transition pathways in which technological innovations can accelerate green transformation.
Antonioli D., Cecere G., Mazzanti M. (2018) [16]	The joint adoption of information and communication technologies and environmental innovations is associated with higher firm productivity, indicating complementarity between digital and green technologies.
ADB (2021) [17]	Digital technologies can strengthen climate action, disaster resilience, and environmental sustainability in developing Asia, but their deployment requires enabling policies and institutional capacity.
Akberdina V., et al. (2024) [18]	Digital transformation reduces resource consumption on the one hand, but on the other, digital infrastructure itself may generate additional energy consumption and electronic waste.
Montresor S., Vezzani A. (2023) [19]	Census data on more than 150,000 firms show that investments in digital technologies, particularly artificial intelligence, are positively associated with eco-innovation.
Du J., et al. (2023) [20]	The green development behavior of local governments depends on institutional coordination and multi-sectoral cooperation.

Conceptual frameworks for governing the twin transition already exist at the policy and transition-studies level: the European Commission has formally articulated the need to "twin" the green and digital transitions [12,13,15], the classical transition-management literature provides a general governance cycle for steering sustainability transitions through goal-setting, experimentation, and reflexive monitoring [21], and recent conceptual work has begun to operationalize the twin transition specifically for organizational and industrial settings [22]. These contributions, however, remain either high-level policy framings or are developed for firm- and industry-level contexts in advanced economies; they do not provide an operational governance sequence calibrated to the institutional and resource conditions of a transition economy such as Uzbekistan, nor do they classify the specific digital technologies that perform each governance function. Accordingly, this article does not claim to fill a conceptual gap where none exists; rather, its contribution is to operationalize the twin transition as a context-specific, technology-explicit governance roadmap for Uzbekistan and, by extension, for Central Asia. Two further gaps remain that this article addresses: (1) practice in developing countries, particularly in Central Asia and Uzbekistan, remains understudied in the twin-transition literature; and (2) there is no functional classification of individual digital technologies according to their specific role within the governance cycle. What is original in this study is not the general idea of a twin transition — which is drawn from

established European Commission policy framing [12,13,15] and transition-management theory [21,22] — but the specific four-function closed-loop synthesis (sensing, analytics and forecasting, accountability and transparency via blockchain, and digital green finance) applied to Uzbekistan's institutional context, together with the phased implementation roadmap developed in Section 3.

The aim of the study is to substantiate scientifically the role, mechanisms, and effectiveness of digital technologies in green economy governance and to develop a conceptual model for governing the digital-green transition in Uzbekistan. To achieve this aim, the following objectives were set:

- to reveal the essence, principles, and institutional foundations of green economy governance;
- to classify the functional capabilities of digital technologies (AI, Big Data, IoT, blockchain, and cloud computing) in green governance;
- to identify effective mechanisms through a comparative analysis of international and national practice;
- to propose an original model of green economy governance based on digital technologies in Uzbekistan and to develop practical recommendations.

2. METHODOLOGY

This is a qualitative theoretical and conceptual study based on systems analysis, a comparative-historical approach, and the generalization of statistical data. The logical sequence of the research comprises four stages (Table 2). First, the literature on the green economy and digital transformation was reviewed in a structured manner and the research gap was identified. Second, the functional capabilities of digital technologies in governance were classified. Third, international and national practices were analyzed using the comparative-historical method. Finally, the results of the analysis were generalized through inductive reasoning to develop the authors' original conceptual model.

Table 2. Stage-by-stage methodological design of the study

Stage	Content	Outcome
Stage I	Structured review of international and national literature on the green economy and digital transformation	Classification of theoretical approaches and identification of the research gap
Stage II	Functional classification of digital technologies according to green governance functions	A model of five functional groups: sensing, analytics and forecasting, accountability and transparency, coordination, and incentives
Stage III	Comparative-historical analysis of practices in the European Union, China, the United Arab Emirates, the United Kingdom, Singapore, and Uzbekistan	Classification of three governance models: top-down (regulatory), market (financial), and technology (platform)
Stage IV	Development of the authors' original conceptual model based on the results of the analysis	The "digital-green governance cycle" model and an implementation roadmap

The information base of the study comprises documents of the United Nations, the United Nations Development Programme (UNDP), the European Commission, the World Bank, the United Nations Economic Commission for Europe (UNECE), the International Renewable Energy Agency (IRENA), and the Government of the Republic of Uzbekistan, official data of the National Statistics Committee of the Republic of Uzbekistan, and relevant peer-reviewed publications indexed in Scopus, including works published by Springer, Frontiers, MDPI, and in the journal Heliyon.

A methodological limitation should be specifically noted: this study is theoretical and conceptual in nature and does not involve the collection or testing of data through a primary empirical survey or an econometric model. The proposed "digital-green governance cycle" model was developed through inductive reasoning based on existing international experience, a review of the literature, and official statistical evidence; quantitative validation of each of its relationships is a task for future empirical research (see Section 4).

3. RESULTS

In the process of green economy governance, digital technologies can be conventionally divided into five functional groups (Table 3).

Table 3. Functional classification of digital technologies in green governance

Functional group	Technologies	Governance function
Sensing (monitoring)	IoT, sensors, satellite data	Real-time measurement of environmental indicators
Analytics and forecasting	AI/ML, Big Data	Forecasting resource consumption and emissions, and assessing risks
Accountability and transparency	Blockchain, digital platforms	Carbon footprint tracking, green certification, and ESG reporting
Coordination	Cloud platforms, e-government systems	Coordinating interaction among the state, business, and citizens
Incentives (influence)	Digital green finance, smart grids, smart contracts	Targeted direction of incentives and economic stimuli

This classification is methodologically important because it makes it possible to view digital technologies not as isolated innovations but as a system of instruments that support the stages of the governance cycle (sensing, analytics and forecasting, decision-making, incentives, and monitoring and verification). This systemic view forms the basis of the authors' original model presented below (Figure 1).

Artificial intelligence and Big Data technologies are the most versatile instruments in green economy governance. Examples include, in the energy sector, forecasting the performance of renewable energy facilities (which is particularly important given the variability of solar and wind power), as well as balancing the power grid and distributing loads; in water management, optimizing irrigation systems, which is of decisive importance for countries facing acute water scarcity, such as Uzbekistan; in agriculture, precision agriculture, which enables highly accurate management of soil moisture and of fertilizer and pesticide use; and in urban management, optimizing waste sorting and logistics and forecasting air pollution levels. From a governance perspective, the significance of AI and Big Data lies in their ability to shift environmental policy from a reactive stage (responding after a process has occurred) to a proactive one (forecasting and intervening in advance).

IoT technologies perform the sensing function in green economy governance, that is, they provide a continuous, real-time flow of information on the state of the object being governed. Whereas conventional environmental monitoring relies on periodic measurements, IoT makes monitoring continuous and shifts governance to a real-time mode. The most relevant areas of application are smart grids, which automatically balance energy generation, transmission, and consumption; smart water meters, which detect water consumption and losses and represent, for Uzbekistan, one of the fastest sources of water savings; smart city systems, which reduce vehicle emissions by optimizing traffic flows; and industrial ecosystems, where the waste and emission flows of enterprises are recorded automatically. An important conclusion from the standpoint of governance science is that IoT data form the information

base for governance decisions: the reliability and completeness of sensor data become a direct precondition for the effectiveness of environmental policy.

If IoT is an instrument of sensing, blockchain is an instrument of trust: it ensures the immutability of data coming from different sources. In green economy governance, this addresses the following problems: (1) carbon footprint tracking chains, that is, the reliable recording of emissions throughout the entire life cycle of a product, which is vital for export-oriented enterprises, particularly in light of new requirements such as the European Union's Carbon Border Adjustment Mechanism (CBAM) [23]; (2) combating the counterfeiting of green certificates, since recording renewable energy certificates on a blockchain prevents their duplication and resale; (3) transparency in green finance, including tracking the targeted use of green bond proceeds and reducing the risk of greenwashing; and (4) smart contracts enabling the automatic, intermediary-free sale of renewable electricity among members of energy communities. At the same time, the literature also criticizes blockchain itself as an energy-intensive technology; energy-efficient consensus protocols such as proof-of-stake and permissioned blockchain platforms are proposed in response. This leads to another important governance conclusion: digital instruments themselves must also become objects of green governance.

Green transformation requires substantial capital, and the direction of financial flows is one of the most important governance instruments. Digital technologies open up a number of opportunities in this regard. Digital green bond platforms integrate issuance, registration, and tracking into a single system; the digital infrastructure of carbon markets automates the allocation, trading, and retirement of allowances; fintech-based green lending enables the assessment and rapid financing of small businesses' green projects on the basis of Big Data; and ESG rating data platforms create a unified digital space in which investors can compare companies' sustainability performance. In summary, digital technologies form a new three-link "data, decision, incentive" chain in green economy governance, in which all governance functions can be integrated into a single continuous digital ecosystem.

The six cases examined below — the European Union, China, the United Arab Emirates, the United Kingdom, Singapore, and Uzbekistan — were not selected at random. They were chosen deliberately to maximize institutional diversity along three dimensions relevant to testing whether the proposed governance-cycle framework generalizes beyond a single type of economy: development stage (high-income economies such as the EU, the UK, the UAE, and Singapore, alongside upper-middle-income China and lower-middle-income Uzbekistan); governance model (supranational regulatory governance in the EU, centralized state-led governance in China and the UAE, and market-oriented common-law governance in the UK and Singapore); and digital/green policy maturity (from mature, codified twin-transition strategies in the EU to an early, strategy-adoption stage in Uzbekistan). This deliberate variation allows the comparison that follows (Table 4 and Table 4a) to probe whether the same governance functions recur across structurally different institutional settings, rather than being an artifact of any single development model, and to identify which institutional preconditions explain why a given mechanism transfers more or less readily to Uzbekistan's context.

An analysis of international practice makes it possible to distinguish three governance models: a top-down (regulatory) model, a market (financial) model, and a technology (platform) model (Table 4).

Table 4. Three international models of green-digital governance

Model	Example country / union	Key mechanism	Outcome
Top-down (regulatory) model	European Union	Mandatory standards linked to the European Green Deal, CBAM, and digital strategies	The most comprehensive example of integrating the "twin transition" at the level of official policy
Market (financial)	United Kingdom,	Green finance institutions,	High effectiveness

Model	Example country / union	Key mechanism	Outcome
model	Singapore	carbon markets, and disclosure requirements	in attracting private capital to green projects
Technology (platform) model	China, United Arab Emirates	State-level integration of smart cities, artificial intelligence, and renewable energy; the concept of ecological civilization supported by digital technologies	Large-scale deployment of smart grids and monitoring systems

China's experience is of particular interest: the country is accelerating the digitalization of its national eco-environment monitoring network, which combines ground-based monitoring of air and water quality with satellite remote sensing and artificial intelligence and is expected to develop into an integrated aerial, terrestrial, and maritime monitoring network by 2030 [24]. The United Arab Emirates, in turn, is implementing its National Strategy for Artificial Intelligence 2031 alongside the UAE Net Zero 2050 Strategic Initiative [25, 26], while sustainable urban projects such as Masdar City in Abu Dhabi serve as testbeds for combined digital and green solutions. The most important aspect of the European Union's experience is the vertical integration of governance: the goals of the Green Deal (climate neutrality by 2050) [12] are pursued in close connection with the targets of the Digital Decade [13], and the European Commission explicitly calls for "twinning" the green and digital transitions [15]. Within the market model, the United Kingdom relies on its green finance strategy and mandatory climate-related disclosures to mobilize private capital for green projects [27], while Singapore combines its green finance agenda with digital infrastructure for sustainability data, such as the Gprnt platform launched by the Monetary Authority of Singapore to simplify ESG data collection and reporting [28]. Among middle-income countries, examples include Kazakhstan, which operates a national emissions trading system and has established the Green Finance Centre of the Astana International Financial Centre [29, 30], and Türkiye, which adopted its first Climate Law in 2025, providing the legal basis for a national emissions trading system [31].

In Uzbekistan, green and digital transformation has been established at the level of state policy. In 2019, Resolution of the President of the Republic of Uzbekistan No. PP-4477 on the Strategy for the Transition to a Green Economy for 2019-2030 was adopted [1], with priority areas including increasing the share of renewable energy, improving energy efficiency, and deploying digital technologies. The "Uzbekistan 2030" Strategy [2] sets out a green economy and modern cities, as well as a competitive economy and innovative development, as distinct goals. Within the framework of the "Digital Uzbekistan 2030" Strategy [32], the digitalization of public services is expanding, including electronic interactive services in the environmental sphere.

Official statistics clearly demonstrate the scale of this shift. According to the National Statistics Committee of the Republic of Uzbekistan, the share of value added generated in the ICT sector in GDP increased from 1.78% in 2015 to 2.43% in 2024 [33]. Within the framework of the "Digital Uzbekistan 2030" Strategy, the share of internet users rose from 43.6% to 85% between 2015 and 2024, the number of electronic public services reached 595, and the length of fiber-optic networks reached 100,000 kilometers [34]. In parallel, according to IRENA data, the country's renewable energy capacity grew from 2,429 MW in 2022 to 10,027 MW in 2025, an increase of almost 4.1 times; the share of green energy in total installed capacity rose from 13.3% in 2016 to 36.1% in 2025 [35]. According to the Ministry of Energy, electricity generated by solar and wind power plants increased from 0.434 billion kWh in 2022 to more than 10.5 billion kWh in 2025, raising the share of green energy in the total electricity balance to 30% [36]. These figures provide statistical evidence of the significant growth in renewable energy projects, particularly wind and solar power plants, observed in 2021-2024.

3.1. Comparative Institutional Preconditions, Implementation Costs, and Outcomes

Table 4 classifies the six cases by governance model; Table 4a makes explicit the institutional preconditions, the qualitative implementation cost or burden, the outcome achieved, and — most importantly for addressing why some models succeed and others face obstacles — the success or failure factor behind each outcome. Because this study does not collect primary cost or performance data, the cost and outcome assessments below are qualitative syntheses of the case material already reviewed, not independent empirical measurements.

Table 4a. Comparative institutional preconditions, implementation costs, and outcomes across the six cases

Case	Institutional preconditions	Implementation cost / burden (qualitative)	Outcome	Success / failure factor
European Union	Supranational legal mandate (Green Deal, Digital Decade), mature statistical and regulatory infrastructure, deep capital markets	High — harmonizing standards across 27 member states and operationalizing CBAM/ESG compliance imposes substantial administrative and compliance costs on member states and firms	Most comprehensive codified integration of the twin transition at the level of official policy; CBAM operational	Supranational legal authority and pre-existing regulatory capacity drive success; the burden is partly offset by common EU funding instruments
China	Strong centralized state capacity, large-scale industrial policy apparatus, extensive existing sensor and surveillance infrastructure	Moderate-high — large upfront capital for sensor networks and AI systems, offset by state-directed financing and economies of scale	Rapid, large-scale deployment of smart-grid and monitoring systems; eco-environment monitoring network expanding toward integrated aerial-terrestrial-maritime coverage by 2030	Centralized decision-making and state investment capacity enable speed, but the model is difficult to transfer to decentralized or resource-constrained settings
United Arab Emirates	High fiscal capacity (oil revenue), compact governance structure, a flagship-project	Moderate — capital-intensive showcase projects (e.g., Masdar City) but concentrated within a small, wealthy	AI 2031 and Net Zero 2050 strategies operational; globally visible pilot and testbed	Success reflects fiscal capacity and small governance scale rather than a broadly replicable institutional design, which limits generalization to larger

Case	Institutional preconditions	Implementation cost / burden (qualitative)	Outcome	Success / failure factor
	policy culture	jurisdiction	projects	or poorer states
United Kingdom	Mature financial regulatory system, established disclosure and audit institutions, deep capital markets	Moderate — relies mainly on disclosure mandates and market mechanisms rather than large public capital outlays, which keeps direct fiscal cost comparatively low	Mobilization of private capital for green projects through mandatory climate-related disclosures	Success depends on institutional trust in disclosure regimes and functioning capital markets; less transferable where financial-market depth or audit capacity is limited
Singapore	High administrative capacity, compact city-state governance, advanced digital-government infrastructure, strong public-private coordination	Moderate — platform development (Gprnt) required coordinated investment but builds on already mature digital-government infrastructure	Functioning digital ESG-data platform that simplifies reporting and reduces greenwashing risk	Success reflects strong baseline e-government infrastructure and small-jurisdiction coordination; replicating it requires comparable administrative and digital maturity
Uzbekistan	An emerging legal basis (PP-4477, UP-6079, UP-158) but fragmented inter-agency data systems, developing digital infrastructure, and growing but still-limited specialist capacity	Low-to-moderate for the pilot phases proposed (IoT pilots, data standards), rising substantially at later phases (blockchain-based carbon accounting, the Green Data Platform)	Strategic framework established; renewable energy capacity and the ICT sector's share of GDP are rising, but data fragmentation and periodic monitoring persist	Partial progress reflects top-down strategy adoption that has not yet been matched by China's centralized execution capacity, the EU's regulatory depth, or the Gulf/Singapore model's fiscal and administrative scale; the phased sequencing in Table 5 is designed to build these preconditions incrementally

Table 4a makes explicit what Table 4's typology of regulatory, market, and technology-platform models leaves implicit. Three patterns emerge. First, the cases that progressed furthest share either strong centralized execution capacity (China, the UAE) or strong pre-existing regulatory and market institutions (the EU, the UK, Singapore); neither precondition is yet fully in place in Uzbekistan, which explains why its progress to date is concentrated in strategy adoption rather than operational execution. Second, implementation cost depends less on technological sophistication than on how far a mechanism must build new institutional capacity from scratch: Singapore's and the UK's market-based mechanisms are comparatively low-cost to administer because they leverage existing disclosure and digital-government infrastructure, whereas Uzbekistan's proposed blockchain-based carbon accounting system (Table 5,

Phase III) is relatively more costly because the underlying data standards and verification infrastructure do not yet exist. Third, the cases that combine high fiscal or administrative capacity with centralized decision-making (China, the UAE, the EU through its supranational authority) can move fastest, but their models are the least directly transferable to a resource-constrained setting; conversely, Singapore's and the UK's market-oriented mechanisms are more readily adaptable to Uzbekistan's institutional scale but presuppose a baseline of market and disclosure infrastructure that Uzbekistan is still developing. This comparative reading, rather than a single country's model adopted wholesale, is what underlies the phased sequencing proposed in Table 5: the roadmap builds institutional preconditions (data standards, platform integration, personnel capacity) in the order the comparative evidence suggests is necessary before each subsequent mechanism can function.

At the same time, systemic problems persist in national practice: (1) data fragmentation, as environmental, energy, and economic data are stored in the closed systems of different agencies and have not yet been integrated into a single national platform; (2) the periodic nature of monitoring, as many indicators are calculated on the basis of annual reports, which limits the capacity for real-time governance; (3) human resources and institutional capacity, reflected in a shortage of specialists at the intersection of green and digital competencies; (4) underdeveloped incentive mechanisms, as a system of digitally based financial incentives for green investment (carbon accounting and green certification) is still at the formation stage; and (5) international requirements such as CBAM, which create new risks for national exporters and call for a national digital system for measuring and verifying carbon footprints.

As the main scientific result of the study, the following conceptual model of green economy governance is proposed. The essence of the model is to integrate all stages of the governance cycle into a continuous digital chain and to embed it within an institutional framework (Figure 1).

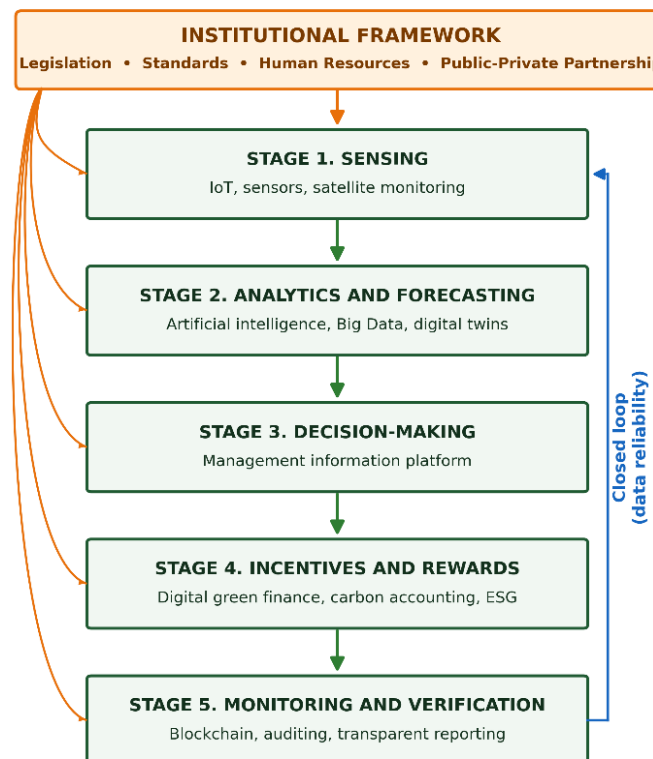


Figure 1. The “digital-green governance cycle” model

The key ideas of the model are as follows:

1. Continuity of the chain (closed loop). In traditional governance, the cycle from reporting to decision-making could take years; in the proposed model, IoT and AI make it possible to shorten this cycle to months and even days. Governance thus shifts from a reactive to a proactive and adaptive form.

2. The decisive role of the institutional framework. The technological chain operates effectively only when it is embedded in an institutional environment (standards, data standards, mandates, and qualified personnel). Otherwise, technologies do not produce green outcomes on their own, which is associated with the risks of the rebound effect and the digital divide identified in the literature.
3. Data sovereignty and trust. Data authenticity is required at every link of the chain; therefore, in the model, Stage 5 (blockchain-based verification) logically returns to Stage 1, forming a closed loop of reliable data.
4. An integration point at the national level. A unified national Green Data Platform is proposed as the technical core for implementing the model, bringing together energy, water, emissions, waste, and economic indicators within a single digital ecosystem.

A phased approach is proposed for adapting the model to the conditions of Uzbekistan (Table 5).

Table 5. Phased roadmap for implementing the model

Phase	Content	Indicative timeframe
Phase I	Introducing IoT monitoring in pilot sectors (energy and irrigation) and developing data standards	1-2 years
Phase II	Establishing a unified national Green Data Platform and ensuring inter-agency integration	2-3 years
Phase III	Linking AI forecasting models and the carbon accounting system to governance decisions	3-4 years
Phase IV	Integrating green finance mechanisms (digital certification and ESG reporting) into the platform	4-5 years

4. DISCUSSION

The results obtained address the two gaps identified in the Introduction, while remaining explicit about what is original and what is drawn from established theory. The "digital-green governance cycle" model does not claim to introduce the concept of a twin transition, which is already established in European Commission policy documents [12,13,15] and in the broader transition-management tradition [21, 22]; instead, it operationalizes that concept by integrating the five functional groups (Table 3) and an institutional framework into a single, technology-explicit, continuous governance chain calibrated to Uzbekistan's conditions. First, the model and the comparative analysis of international experience (Table 4, and the extended comparative discussion in Section 3.1) adapt the twin-transition idea to the conditions of a developing country, directly addressing the limited study of Central Asian practice. Second, the functional classification presented in Table 3 systematizes the role of digital technologies in governance in a way that general twin-transition frameworks do not. In this sense, the contribution is best described as a context-specific operationalization and implementation roadmap rather than as a new conceptual model of the twin transition itself.

The results are also consistent with international econometric evidence. The large-scale firm-level study by Montresor and Vezzani (2023) [19] found that investments in digital technologies, particularly artificial intelligence, are positively associated with eco-innovation, which indirectly confirms the practical effectiveness of the "data, decision, incentive" chain described in this article. At the same time, the tension between the environmental benefits and costs of digitalization highlighted by Akberdina et al. (2024) [18] is explicitly addressed in the second key idea of the proposed model (the decisive role of the institutional framework): the model treats digital instruments themselves as objects of oversight, which helps mitigate this tension at the institutional level. The need for multi-sectoral cooperation among local governments, demonstrated by Du et al. (2023) [20] in the case of China, is directly aligned with

the "Coordination" functional group of the model (Table 3) and with the proposal for a unified Green Data Platform.

The proposed model and roadmap are of practical significance for Uzbekistan, as they offer specific stages aimed directly at addressing existing systemic problems (data fragmentation, the periodic nature of monitoring, the shortage of qualified personnel, insufficient incentive mechanisms, and the lack of preparedness for CBAM). In particular, the idea of a unified national Green Data Platform directly targets the problem of data fragmentation, while IoT pilot projects directly target the problem of periodic monitoring.

In the interest of scientific integrity, the limitations of the model should also be noted. The first is the rebound effect: resources saved through digital instruments may be consumed again (for example, consumption increases as energy becomes cheaper), and preventing this requires strict standards alongside economic incentives. The second is data security: national environmental data are of strategic importance, and the principle of data sovereignty should take priority in their storage. The third is the digital divide: affordable digital solutions accessible to small businesses are needed to ensure that differences in technological capacity between regions and enterprises do not create new imbalances. The fourth is the explainability of AI models: algorithmic forecasts used in governance decisions must be transparent and auditable.

Since this study is theoretical and conceptual in nature, testing each relationship in the proposed "digital-green governance cycle" model (for example, the quantitative relationship between the intensity of IoT monitoring and resource efficiency) through an empirical survey or an econometric model is an important task for future research. In particular, the practical effectiveness of the model could be quantitatively assessed by applying panel data analysis to indicators of digital infrastructure and green economic development across the regions of Uzbekistan, or by conducting a PLS-SEM-based survey among agricultural and industrial enterprises.

To make this validation pathway concrete rather than a general disclaimer, Table 6 proposes an indicative set of measurable indicators that a future monitoring framework and pilot study could track for each functional group of the model, together with the empirical design best suited to testing each relationship. A monitoring framework built around these indicators, piloted in the energy and irrigation sectors identified in Phase I of the roadmap (Table 5), is the concrete next step through which the practical credibility of the model's recommendations can be empirically established.

Table 6. Indicative KPIs and validation designs for a future monitoring and pilot framework

Functional group	Candidate KPI(s) for a future monitoring framework	Suggested validation design
Sensing (IoT)	Share of pilot sites with continuous real-time monitoring coverage (%); sensor-data completeness rate (%)	Pilot IoT deployment with before/after measurement in 2-3 pilot districts
Analytics and forecasting (AI/Big Data)	Forecast error (e.g., MAPE) for resource-consumption and emissions predictions; lead time gained in anomaly detection	Time-series or panel comparison of forecast-informed versus baseline governance decisions
Accountability and transparency (blockchain)	Share of tracked product or certificate volume verified on-chain; reduction in duplicate or fraudulent certificate incidents	Before/after comparative case study in a pilot export sector (e.g., textiles, under CBAM)
Coordination (digital platforms)	Number of integrated inter-agency data feeds; average inter-agency reporting lag (days)	Process-tracing or qualitative case study of Green Data Platform rollout (Table 5, Phase II)

Functional group	Candidate KPI(s) for a future monitoring framework	Suggested validation design
Incentives (digital green finance)	Volume of digitally tracked green-finance flows; SME uptake rate of digital green lending	PLS-SEM survey of enterprise-level adoption and perceived barriers, as proposed above
Overall model (closed loop)	Composite "digital-green governance maturity index" and its change over time	Panel data analysis of digital infrastructure and green-economy indicators across the regions of Uzbekistan, as proposed above

5. CONCLUSION AND RECOMMENDATIONS

This study has substantiated the need to govern the green economy and digital transformation not separately, but as a mutually reinforcing pair within the twin transition. Today, digital technologies are among the most effective instruments for achieving green goals, as they make it possible to shift the governance process from a reactive to a proactive form. The role of these technologies in green governance was classified into five functional groups: sensing (IoT), analytics (artificial intelligence and Big Data), accountability and transparency (blockchain), coordination (digital platforms), and incentives (digital green finance), and it was shown that each of them corresponds to a specific stage of the governance cycle.

The comparative analysis of international experience made it possible to distinguish three governance models: the regulatory, market, and technology platform models. Individual elements of each of these models can serve as useful sources for Uzbekistan; however, adopting them wholesale would not be appropriate, and a synthetic approach that takes the national institutional environment into account is required. The analysis showed that the legal and regulatory foundations of green and digital policy have already been established in Uzbekistan. Clear evidence of this is the increase in the share of the ICT sector in GDP from 1.78% to 2.43% between 2015 and 2024, and the growth of renewable energy capacity from 2,429 MW to 10,027 MW between 2022 and 2025. Nevertheless, a number of systemic barriers persist in practice: data fragmentation, the periodic nature of monitoring, insufficiently developed incentive mechanisms, and the absence of a national system for responding to international requirements such as CBAM.

To address the identified problems, the study proposes an original model, the "digital-green governance cycle." The model combines a continuous five-stage technological chain with an institutional framework and is intended to be implemented around a unified national Green Data Platform.

Based on the findings of the study, the following practical recommendations have been developed. First and foremost, it is necessary to develop a concept for establishing a unified Green Data Platform in Uzbekistan and to link it closely with the "Uzbekistan 2030" Strategy. In addition, it is recommended to launch IoT monitoring pilot projects in the energy, water management, and waste management sectors and to adopt unified data standards that meet interoperability requirements. Introducing a national carbon accounting and CBAM adaptation system based on blockchain technology is of particular importance for export-oriented enterprises. Developing digital green bond and ESG reporting platforms in the green finance market, as well as introducing digital audit tools to counter the risk of greenwashing, are also among the pressing tasks. In the personnel training system, universities and professional development programs should introduce specializations that address the shortage of specialists at the intersection of green and digital competencies. Finally, it is necessary to reduce the digital divide by subsidizing affordable digital green solutions for small and medium-sized enterprises (based on a cloud services model).

The implementation of these recommendations will, on the one hand, improve the effectiveness of governing the transition to a green economy in Uzbekistan and, on the other, significantly accelerate the country's integration into international green standards and markets.

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