JOURNAL OF STRATEGIC INNOVATION AND BUSINESS MANAGEMENT

***RESEARCH ARTICLE***

Check for updates   OPEN ACCESS

# Digital Transformation and Sustainability Governance in Industrial Ecosystems: A Conceptual Framework for Industrial Estates

**Didik Prasetiyono[1,2]*, Ahmad Yusri Authoni[1], Rafika Nur Kusumawati[1,3]**

[1]*Postgraduate School, Universitas Airlangga, Surabaya, Indonesia*
[2]*Indonesian Industrial Estates Association (HKI), Jakarta, Indonesia*
[3]*Universitas Sebelas Maret, Surakarta, Indonesia*
**Corresponding author: didik.prasetiyono-2024@pasca.unair.ac.id*

**ARTICLE INFO**

*Article history:*

Submitted 04 June 2026
Revised 15 June 2026
Accepted 24 June 2026

**DOI: https://doi.org/10.54250/tb33zq82**

***KEYWORDS:***

***Digital sustainability governance; Digital transformation; Industrial ecosystems; Industrial estates; Emerging economies; Sustainability governance***

*HIGHLIGHTS*

- Proposes a Smart Digital Sustainability Governance Model.
- Integrates governance, digital transformation, and industrial ecosystems.
- Identifies four pillars supporting sustainability governance.
- Positions digital systems as enablers of ecosystem governance



**ABSTRACT**

Sustainability governance in industrial estates increasingly relies on coordinated infrastructure management, environmental accountability, and collaboration across multiple stakeholders. While sustainability governance and digital transformation have each received considerable scholarly attention, their integration remains limited, particularly in explaining how digital systems support governance across complex industrial ecosystems. This paper develops a conceptual framework for Digital Sustainability Governance through a structured literature synthesis. The proposed Smart Digital Sustainability Governance Model comprises four interrelated pillars: governance leadership, digital sustainability infrastructure, industrial ecosystem collaboration, and institutional policy alignment. The framework emphasizes that sustainability governance extends beyond firm-level ESG practices to include estate-level leadership, digital monitoring, collaborative coordination, and institutional support. Drawing on the Indonesian context, with reference to Surabaya Industrial Estate Rungkut (SIER) as an illustrative context, the paper shows how digital transformation can strengthen sustainability governance in industrial ecosystems and offers an integrated framework applicable to emerging economies.

## INTRODUCTION

Global economic development is increasingly shaped by the intersection of industrial transformation (Ba & Galik, 2023; Li & Zhao, 2023), technological innovation (Ahmad et al., 2023; Weng et al., 2024), and sustainability imperatives (Voßbeck & Fastenrath, 2024), which together are redefining pathways toward more competitive, adaptive, and environmentally responsible growth (He, 2026; Shahzad & Muhammad, 2025). The global commitment to the Sustainable Development Goals has intensified expectations that firms embed environmental and social responsibility into long-term strategy (Almnadheh et al., 2025; Sarkar et al., 2023; Sasaki et al., 2024). In this setting, governance is no longer viewed merely as a mechanism of control, compliance, or shareholder protection (Dandapani & Shahrokhi, 2022), but increasingly as a strategic arrangement through which organizations align economic performance with social legitimacy and environmental accountability (Aguilera & Ruiz Castillo, 2025; O'Higgins, 2023). This shift has strengthened the incorporation of stakeholder interests, ESG commitments, and sustainability oversight into contemporary governance logics (Ludwig & Sassen, 2022; Sousa & de Bem Machado, 2024; S. Wang & Wang, 2022).

At the same time, digital transformation has reconfigured how industrial organizations operate, coordinate, and make decisions through increasingly data-intensive systems (Brarda et al., 2026; Fantozzi et al., 2025; Yaqub & Alsabban, 2023). The expansion of the Internet of Things, digital monitoring systems, analytics platforms, and integrated enterprise infrastructures has enabled firms to capture and process operational information at greater speed and scale (Basingab, 2025; Duan & Xu, 2024; Karic et al., 2025). Most studies connect digitalization to productivity, efficiency, and technological upgrading (Chauhan et al., 2021; Li et al., 2020). Yet its implications extend beyond operational improvement. As information becomes more visible, traceable, and shareable across organizational boundaries, digital systems increasingly shape how responsibility is allocated, how sustainability performance is monitored, and how collective decisions are coordinated in complex industrial environments (Coskun-Setirek et al., 2024; Tariq et al., 2026).

Despite their relevance, sustainability governance and digital transformation remain insufficiently integrated in the literature (Beier et al., 2020; Guandalini, 2022; Nadeem et al., 2026). Research on corporate governance and ESG has advanced understanding of oversight, disclosure, accountability, and stakeholder engagement (Escamez et al., 2026; Ludwig & Sassen, 2022; Yang et al., 2024). By contrast, digital transformation research has concentrated more on technology adoption, process optimization, innovation capability, and organizational agility (Chatterjee et al., 2021; Duan & Xu, 2024; Fantozzi et al., 2025). These streams rarely converge in ways that explain how digital infrastructures actively support sustainability governance, particularly where environmental and governance challenges are distributed across multiple actors rather than contained within a single firm (Irajifar et al., 2023; Mihai et al., 2025; Mulligan et al., 2024).

This conceptual gap becomes especially visible in industrial ecosystems, where economic activities, shared infrastructures, environmental pressures, and institutional responsibilities are deeply interconnected (Burström et al., 2024; Le Tellier et al., 2022; Sgambaro et al., 2026). Industrial estates provide a particularly relevant setting because they bring together tenant firms, estate managers, regulators, infrastructure providers, service organizations, and surrounding communities within a shared governance environment that requires continuous coordination across organizational boundaries (Taddeo, 2016; Hudalah et al., 2019; Burström et al., 2024). In such settings, sustainability outcomes are not determined solely by the internal practices of individual firms. They depend on cross-actor coordination, the management of shared infrastructure and environmental risks, and governance mechanisms that connect information, accountability, and collective action across organizational boundaries (Pärli et al., 2021; Sundqvist-Andberg & Åkerman, 2022; Wang et al., 2023; Zhao et al., 2023). Industrial ecosystems therefore require governance arrangements that move beyond firm-level compliance and support collaborative sustainability management at the ecosystem level (Burström et al., 2024; Han & Xie, 2025).

The issue is particularly salient in emerging economies, where industrial estates are expected simultaneously to drive industrialization, support regional development, and respond to mounting environmental and institutional pressures (Adegbite, 2021; Schack et al., 2024; Nainggolan et al., 2020). These overlapping demands often expose a tension between policy ambition and governance capacity (Bourguignon & Libois, 2023; Samaratunge & Alam, 2021). Indonesia offers a relevant setting because industrial-estate development is increasingly positioned at the intersection of industrial expansion, green transformation, and digital industrial policy (Alriansyach et al., 2024; Mursadi et al., 2024; Sjaifuddin, 2020). Within this trajectory, SIER is analytically useful as an illustrative case of how sustainability governance in a multi-actor industrial environment depends not only on firm-level commitment, but also on coordination capacity, infrastructure management, stakeholder engagement, and institutional support (Hudalah et al., 2019; Nainggolan et al., 2020; Noegroho, 2025).

Against this background, this study develops a conceptual framework for understanding how digital transformation can strengthen sustainability governance in industrial ecosystems, with relevance to industrial estates in emerging economies. The article argues that digital transformation should be examined not merely as a technological or operational shift, but as part of the governance architecture through which sustainability-related information becomes visible, coordinated, and actionable (Tariq et al., 2026). The theoretical novelty of this study lies in integrating governance and digital transformation at the ecosystem level. Unlike conventional corporate governance models, which primarily explain sustainability through internal firm structures and board-level oversight, the present framework conceptualizes sustainability governance as an ecosystem-level capacity shaped by interdependence, shared infrastructure, and multi-actor coordination (Ludwig & Sassen, 2022; Burström et al., 2024; Han & Xie, 2025). Likewise, unlike generic digital transformation models that emphasize productivity, automation, or organizational agility, this framework treats digitalization as a governance-enabling mechanism that supports visibility, accountability, and coordinated sustainability action across industrial estates (Guandalini, 2022; Tariq et al., 2026). Drawing on a structured synthesis of literature on corporate governance, sustainability management, digital transformation, and industrial ecosystem governance, the paper proposes a Smart Digital Sustainability Governance Model composed of four interrelated pillars: governance leadership, digital sustainability infrastructure, industrial ecosystem collaboration, and institutional policy alignment.

This study makes three contributions. First, it brings digital transformation into the sustainability governance conversation as an enabling governance mechanism rather than a background condition of modernization (Guandalini, 2022; Shabbir, 2025). Second, it extends the analytical focus from the individual firm to the industrial ecosystem, where sustainability is shaped by interdependence, shared infrastructures, and cross-actor coordination (Le Tellier et al., 2022; Dunn et al., 2023; Sgambaro et al., 2026). Third, it offers an integrated conceptual basis for explaining how industrial estates may strengthen sustainability governance through the combined roles of leadership, digital systems, collaboration, and institutional alignment (Burström et al., 2024; Han & Xie, 2025; Stötzel, 2024).

## Corporate Governance and Sustainability Governance

Corporate governance has traditionally been understood as the system through which firms are directed, monitored, and controlled, with primary emphasis on accountability, transparency, fiduciary responsibility, and the protection of shareholder interests (Dandapani & Shahrokhi, 2022; O'Higgins, 2023). Over time, however, this understanding has expanded in response to intensifying environmental pressures, social expectations, and demands for more responsible forms of long-term value creation. As a result, governance is increasingly viewed not only as an internal control mechanism, but also as a strategic arrangement through which firms align economic performance with stakeholder expectations and broader societal legitimacy (Wang & Wang, 2022; Aguilera & Ruiz Castillo, 2025).

This shift has contributed to the rise of sustainability governance, a perspective that links governance structures to the integration of environmental, social, and governance (ESG) considerations into corporate strategy, oversight, and accountability. Recent studies show that board structures, governance mechanisms, stakeholder engagement, and sustainability-oriented oversight increasingly influence how firms respond to ESG demands, sustainability disclosure, and broader developmental agendas such as the Sustainable Development Goals (Ludwig & Sassen, 2022; Sousa & de Bem Machado, 2024; Escamez et al., 2026). In this context, governance is no longer limited to preventing managerial opportunism or ensuring compliance. It also shapes how organizations define sustainability priorities, allocate responsibility, and internalize long-term environmental and social commitments (Kateb et al., 2025; Saha et al., 2026).

At the same time, the literature suggests that firm-level governance remains only part of the picture. Much of the existing work still centers on internal organizational arrangements such as board composition, audit structures, disclosure quality, ownership patterns, and stakeholder responsiveness within individual firms (Yang et al., 2024; Ding et al., 2024; Doni et al., 2022). These dimensions are clearly important, yet their explanatory reach becomes more limited when sustainability outcomes depend on shared infrastructures, inter-organizational coordination, and external institutional conditions rather than internal decision structures alone. This limitation is especially relevant in industrial environments where multiple firms, service providers, and regulators contribute jointly to sustainability-related outcomes.

For this reason, the governance literature provides an important foundation for the present study, but not a complete explanation. It clarifies why authority, accountability, and strategic direction matter for sustainability, yet it leaves underdeveloped how governance operates when sustainability challenges are distributed across interconnected actors and organizational boundaries. This limitation points toward the need to extend sustainability governance from the level of the individual firm to the level of the industrial ecosystem, where governance must coordinate not only internal commitments but also shared operational and institutional responsibilities.

**Digital Transformation in Industrial Organizations**

Digital transformation in industry is widely understood as a systemic reconfiguration of processes, structures, business models, and organizational capabilities through digital technologies rather than a narrow program of technical upgrading alone (Yaqub & Alsabban, 2023; Ghosh et al., 2022). Within industrial settings, this transformation is commonly associated with Industry 4.0 technologies such as the Internet of Things (IoT), cyber-physical systems, artificial intelligence, cloud computing, big data analytics, and digital twins (Karic et al., 2025; Vuksanović-Herceg et al., 2020). These technologies enable firms to generate richer operational data, automate information flows, and coordinate production and managerial decisions with greater speed and precision (Duan & Xu, 2024; Karic et al., 2025).

Unsurprisingly, the literature often links digital transformation to productivity gains, process efficiency, quality improvement, and organizational resilience (Paucar et al., 2025; Wang & Shao, 2024).

Its significance, however, extends beyond operational performance. Digital systems affect not only what firms can do, but also how they observe, evaluate, and govern organizational activities (Coskun-Setirek et al., 2024; Tariq et al., 2026). Data infrastructures make processes more visible, traceability systems render flows and transactions more auditable, and integrated platforms expand the feasibility of coordination across units and across organizational boundaries (Kloppenburg et al., 2022). Consequently, digital transformation increasingly influences how accountability is structured, how compliance is monitored, and how strategic decisions are informed by real-time or near-real-time information (Chen et al., 2025; Hu & Yang, 2024). Recent work therefore begins to frame digital transformation not only as an efficiency tool, but also as part of a broader governance architecture (Tariq et al., 2026).

The governance implications of digital transformation become clearer when attention shifts from isolated technologies to digital infrastructures and ecosystems. Data governance influences whether information is interoperable, reliable, and actionable across organizational boundaries (Engvall & Flak, 2022). Digital platforms shape how participation, coordination, and oversight are organized among multiple actors (Salamzadeh et al., 2024). Artificial intelligence and analytics add predictive and adaptive capacity by helping organizations monitor performance, detect anomalies, and optimize responses to emerging sustainability problems (Munonye et al., 2025; Spilotro et al., 2025). Blockchain and related traceability systems strengthen verification, auditability, and trust, especially where multiple actors rely on shared information that must remain transparent and resistant to manipulation (Kumar & Shah, 2025; Suta & Tóth, 2023; Schulz et al., 2020). Taken together, these developments suggest that digital transformation becomes governance-enabling when it is embedded in arrangements that connect data, decision rights, and accountability.

Even so, digital transformation does not automatically produce governance benefits. Its effects depend on organizational capabilities, strategic alignment, workforce skills, data quality, and institutional support (Kans & Campos, 2024; Hansen et al., 2025; Ghosh et al., 2022). Weak strategy, organizational inertia, limited digital capabilities, cultural resistance, and cybersecurity challenges can all constrain the outcomes of digital transformation (Hansen et al., 2025; Kans & Campos, 2024; Shahzad et al., 2025). Digital technologies therefore do not govern by themselves. Their governance value depends on whether organizations and ecosystems can align technology adoption with broader structures of coordination, oversight, and collective action (Ghosh et al., 2022; Coskun-Setirek et al., 2024; Tariq et al., 2026). This insight is central to the present study because it opens the possibility of understanding digital transformation not merely as modernization, but as an enabling condition for sustainability governance in complex industrial environments.

**Industrial Ecosystems and Industrial Estates**

Industrial ecosystems are increasingly conceptualized as socio-technical systems in which co-located or interconnected firms exchange resources, share infrastructures, and develop interdependent economic and environmental relationships (Burström et al., 2024; Babkin et al., 2021). This perspective draws heavily from industrial symbiosis, where by-products, waste, water, energy, and services circulate across firms to improve resource efficiency and environmental performance (Wang et al., 2022; Palagonia et al., 2025). More recent work extends this view by emphasizing governance, coordination, digital integration, and institutional embedding as central features of industrial ecosystems (Babkin et al., 2021; Burström et al., 2024; Palagonia et al., 2025).

Industrial estates concentrate tenant firms, estate managers, infrastructure operators, regulators, logistics actors, service providers, and surrounding communities within a shared spatial setting (Taddeo, 2016; Hudalah et al., 2019). Because they depend on shared infrastructures and generate overlapping environmental externalities, sustainability outcomes are shaped not only by the practices of individual firms but also by the quality of collective coordination and the governance of shared systems (Burström et al., 2024; Perrucci et al., 2022).

The literature on industrial ecosystems and eco-industrial parks underscores this point. Research shows that collaborative exchange, shared utilities, coordinated waste treatment, joint monitoring, and institutional support are critical to whether industrial ecosystems generate meaningful environmental and economic benefits (Le Tellier et al., 2022; Wang et al., 2023; Jarusen & Cheunkamon, 2025). At the same time, studies also indicate that ecosystem performance is often constrained by weak coordination, fragmented responsibilities, trust deficits, unequal capabilities, and limited policy coherence (Sundqvist-Andberg & Åkerman, 2022; Goldschmeding et al., 2024; Bourguignon & Libois, 2023). These findings suggest that interdependence alone does not produce sustainability outcomes. What matters is whether actors can translate spatial proximity and shared infrastructure into workable arrangements of information exchange, collective action, and governance.

This issue becomes especially salient in emerging economies, where industrial estates are expected to support industrialization, regional development, environmental upgrading, and policy implementation simultaneously. Under such conditions, governance is often shaped by uneven digital maturity, limited administrative capacity, and fragmented institutional support. Industrial estates therefore provide an important setting for examining how sustainability governance can be organized under conditions of shared infrastructure, distributed accountability, and institutional complexity, and, by extension, for developing a framework that links governance leadership, digital transformation, and ecosystem-level sustainability.

**Digital Sustainability Governance**

Taken together, the preceding literatures reveal a clear conceptual gap. Sustainability governance research remains largely focused on firm-level accountability and oversight. Digital transformation research explains how organizations build visibility and adaptive capacity through digital technologies. And industrial ecosystem research emphasizes interdependence and coordination in shared industrial environments. What remains insufficiently theorized is how digital systems can support sustainability governance when responsibility is distributed across multiple actors, shared infrastructures, and institutional levels, precisely the conditions that characterize industrial estates in emerging economies.

This gap is particularly significant because sustainability problems in industrial estates are rarely confined to internal organizational decisions. Waste treatment, water use, emissions monitoring, logistics flows, and infrastructure efficiency are shaped by shared systems and collective operational interdependence rather than by isolated firm behavior alone (Pärli et al., 2021; Wang et al., 2023; Jarusen & Cheunkamon, 2025). Under such conditions, sustainability governance cannot rely exclusively on formal compliance structures, reporting routines, or board-level commitments. It also depends on the capacity to generate reliable information, coordinate responses across organizations, and align local operational practices with broader institutional expectations (Zhao et al., 2023; Burström et al., 2024; Han & Xie, 2025). In this context, digital systems become strategically important because they provide the informational and operational architecture through which distributed governance can be made visible, coordinated, and actionable (Coskun-Setirek et al., 2024; Tariq et al., 2026).

On this basis, this study defines digital sustainability governance as a socio-technical governance arrangement in which digital infrastructures, organizational coordination mechanisms, and institutional structures jointly support sustainability-oriented monitoring, accountability, collaboration, and decision-making across industrial ecosystems. This concept rests on four interrelated assumptions. First, sustainability governance increasingly depends on timely and shared visibility rather than static disclosure alone (Escamez et al., 2026; Tariq et al., 2026). Second, digital transformation can provide such visibility through sensing, analytics, traceability, and platform-based coordination (Karic et al., 2025; Duan & Xu, 2024). Third, the governance value of digitalization becomes more salient where actors are operationally interdependent and sustainability challenges emerge from collective resource use (Le Tellier et al., 2022; Sundqvist-Andberg & Åkerman, 2022). Fourth, these digital capacities generate sustained governance effects only when they are embedded in leadership structures, collaborative routines, and institutional alignment rather than implemented as isolated technological upgrades (Burström et al., 2024; Han & Xie, 2025; Mulligan et al., 2024).

Accordingly, digital sustainability governance should not be understood as the simple coexistence of sustainability initiatives and digital modernization. Rather, it refers to a governance logic through which leadership, digital systems, inter-organizational collaboration, and policy alignment are combined to organize sustainability in complex industrial environments. This perspective shifts the analytical focus from technology adoption as an end in itself toward digitally enabled governance as a mechanism for improving coordination, accountability, and adaptive capacity in industrial ecosystems. It also extends sustainability governance beyond firm-centric assumptions by recognizing that many environmental and social outcomes are produced through shared infrastructures, overlapping responsibilities, and multi-actor interactions.

This conceptualization provides the theoretical basis for the model proposed in the next section. Specifically, it suggests that effective sustainability governance in industrial estates depends not only on managerial commitment or technological investment, but on the alignment of governance leadership, digital sustainability infrastructure, industrial ecosystem collaboration, and institutional policy support within an integrated architecture.

## MATERIALS AND METHODS

### Methods

This study adopts a conceptual research design to develop a framework for understanding digital sustainability governance in industrial ecosystems, with relevance to industrial estates in emerging economies. A structured literature-synthesis approach was selected because the focal problem is not the absence of prior research, but the lack of an integrative framework linking sustainability governance, digital transformation, and industrial ecosystem governance within a single explanatory model (Beier et al., 2020; Guandalini, 2022; Burström et al., 2024). This approach is appropriate for concept development in fragmented and cross-disciplinary fields because it enables the systematic identification, comparison, and theoretical integration of dispersed constructs (Jiang et al., 2020; Ullah, 2021; De Matteis et al., 2025).

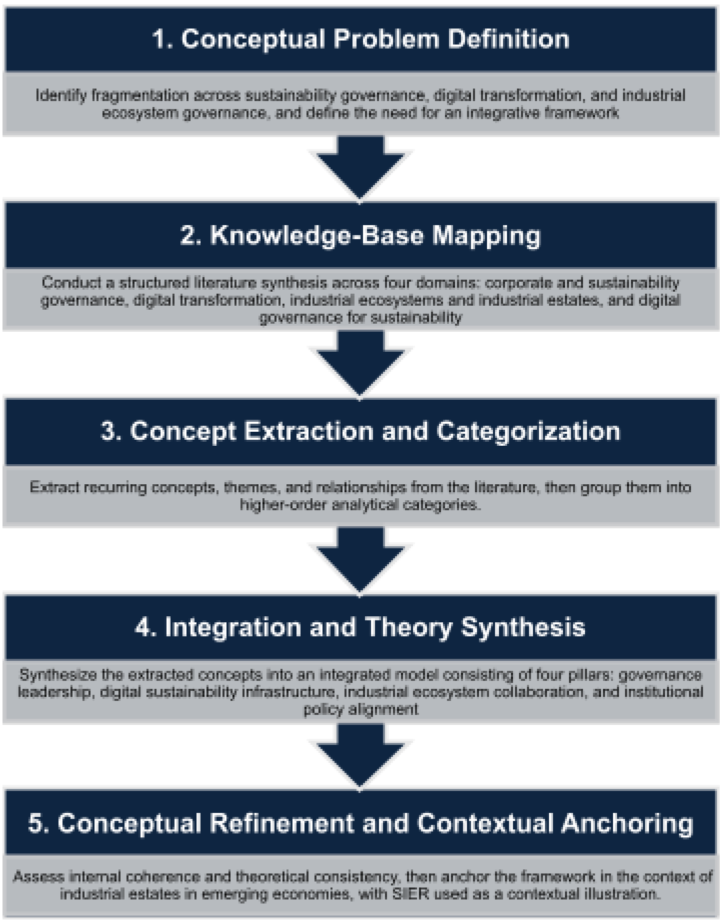


**Figure. 1.** Methodological stages for developing the Smart Digital Sustainability Governance Model. Source: Authors' elaboration based on Jiang et al. (2020), Ullah (2021), De Matteis et al. (2025), and Sewenet et al. (2026).

The data for this study were obtained primarily from the Scopus database, which was selected because of its broad multidisciplinary coverage and rigorous indexing of high-quality international journals in business, management, and sustainability research (Baas et al., 2020). In line with the methodological stages presented in Figure 1, the literature mapping process was conducted as a structured and iterative synthesis rather than as a single-query extraction. The search process focused on four literature domains underpinning this study: (1) corporate governance and sustainability governance, (2) digital transformation in industrial organizations, (3) industrial ecosystems and industrial estates, and (4) digital governance for sustainability.

Within this second stage of knowledge-base mapping, Scopus searches were conducted using combinations of keywords such as "corporate governance," "sustainability governance," "ESG," "digital transformation," "digitalization," "Industry 4.0," "digital governance," "industrial ecosystems," "industrial estates," "eco-industrial parks," and "industrial symbiosis." Additional contextual terms such as "shared infrastructure," "collaboration," "coordination," and "emerging economies" were used to broaden coverage of ecosystem-level and institutional dimensions. Searches were applied primarily to titles, abstracts, and keywords and were limited mainly to publications from 2020 to 2026 to capture current developments, while selected foundational studies were retained to preserve conceptual continuity and theoretical grounding.

The literature selection process also followed basic inclusion and exclusion criteria. Included studies were those that addressed at least one of the following dimensions in a conceptually relevant way: sustainability governance, digital transformation with governance implications, industrial ecosystems or industrial estates, and institutional or collaborative arrangements related to sustainability. Preference was given to peer-reviewed journal articles, recent conceptual and empirical studies, and high-relevance scholarly publications. Articles were excluded when they focused solely on firm-level operational digitization without governance implications, on sustainability disclosure without ecosystem relevance, or on industrial clusters without meaningful engagement with governance or digital dimensions. In addition to the primary Scopus search, relevant sources were further refined through iterative screening and selective citation-based tracing to ensure conceptual completeness across the four literature domains. This procedure was consistent with the purpose of knowledge-base mapping, namely, to build a sufficiently rich and analytically relevant corpus for subsequent conceptual extraction and synthesis.

Following the mapped knowledge base, the third stage involved concept extraction and categorization. Through iterative comparison of the reviewed studies, the analysis identified recurring concepts, themes, and relationships related to strategic direction, digital information capacity, inter-organizational coordination, and institutional embedding. These recurring elements were then grouped into higher-order analytical categories.

The fourth stage involved integration and theory synthesis. At this stage, the extracted concepts were synthesized into an integrated model consisting of four interrelated pillars: governance leadership, digital sustainability infrastructure, industrial ecosystem collaboration, and institutional policy alignment. Their selection was guided by their recurrence in the literature and their integrative value in connecting governance, digital transformation, and industrial ecosystem management within a unified conceptual framework (Ullah, 2021; De Matteis et al., 2025).

The fifth stage involved conceptual refinement and contextual anchoring. The framework was refined by assessing its internal coherence and theoretical consistency, particularly in relation to the dynamics of shared industrial environments. It was then anchored in the context of industrial estates in emerging economies, with Surabaya Industrial Estate Rungkut (SIER) used as a contextual illustration. This step was not intended as full empirical validation, but as a contextual exercise to assess the practical relevance of the framework in settings characterized by infrastructural interdependence, multi-actor coordination, and institutional complexity (Hudalah et al., 2019; Nainggolan et al., 2020; Noegroho, 2025).

Accordingly, this study does not claim the procedural exhaustiveness of a formal systematic literature review in the strictest sense. Rather, it employs a structured and theory-oriented synthesis designed to support conceptual integration and framework development. This approach is intended to balance transparency, conceptual breadth, and analytical focus, ensuring that the proposed model emerges from a coherent synthesis of governance, digital transformation, and industrial ecosystem literatures (Ullah, 2021; De Matteis et al., 2025; Sewenet et al., 2026).

## RESULTS

### Proposed Conceptual Framework: Smart Digital Sustainability Governance Model

Building on the preceding synthesis, this study proposes a Smart Digital Sustainability Governance Model for industrial ecosystems, with relevance to industrial estates in emerging economies. The model conceptualizes sustainability governance as an ecosystem-level capacity shaped by the alignment of four interrelated pillars: governance leadership, digital sustainability infrastructure, industrial ecosystem collaboration, and institutional policy alignment. Rather than treating sustainability governance as a firm-bound function or digital transformation as a purely technical process, the framework explains how governance capacity in shared industrial environments emerges through the interaction of authority structures, information systems, collaborative arrangements, and institutional conditions (Burström et al., 2024; Han & Xie, 2025; Tariq et al., 2026).

### Governance Leadership

The first pillar, governance leadership, refers to the strategic and institutional capacity to define sustainability priorities, allocate responsibility, and mobilize coordinated action across the industrial ecosystem. Leadership remains central because sustainability governance does not arise automatically from data availability or technological connectivity. It requires actors with the authority and legitimacy to frame collective objectives, mediate competing interests, and embed sustainability into decision-making structures (O'Higgins, 2023; Aguilera & Ruiz Castillo, 2025). In corporate governance research, sustainability-oriented oversight increasingly shapes long-term organizational direction through ESG structures, stakeholder-responsive governance, and board-level accountability (Almnadheh et al., 2025; Ludwig & Sassen, 2022; Kateb et al., 2025). In industrial ecosystems, however, leadership extends beyond the governance boundary of a single firm and becomes an ecosystem-level function involving estate managers, anchor firms, regulators, infrastructure providers, and other actors capable of influencing collective priorities (Hudalah et al., 2019; Burström et al., 2024; Han & Xie, 2025).

This pillar is essential because shared industrial environments are characterized by interdependence, yet interdependence alone does not ensure coordination. Collective sustainability efforts often weaken when no actor or coalition of actors can translate broad sustainability ambitions into governance routines, resource commitments, and operational priorities (Sundqvist-Andberg & Åkerman, 2022; Pärli et al., 2021). In industrial estates, firms may face common environmental risks while operating under different incentives, capabilities, and time horizons (Taddeo, 2016; Hudalah et al., 2019; Burström et al., 2024; Schack et al., 2024). Within the proposed model, governance leadership therefore performs an integrative function by linking sustainability goals to institutional authority, ensuring that digital systems serve governance purposes, and creating conditions under which collaboration and policy alignment can be pursued coherently.

### Digital Sustainability Infrastructure

The second pillar, digital sustainability infrastructure, refers to the digital systems, data architectures, and information-processing capacities that enable sustainability-related visibility, monitoring, traceability, and decision support across the industrial ecosystem. This includes IoT-based sensing systems, digital monitoring platforms, analytics infrastructures, integrated ecosystem platforms, and traceability technologies such as blockchain-based verification systems (Karic et al., 2025; Basingab, 2025; Duan & Xu, 2024; Schulz et al., 2020). While industrial digitalization research often treats these systems primarily as instruments of efficiency, productivity, or automation (Li et al., 2020; Karic et al., 2025), the present framework positions them as governance-enabling infrastructures that shape how sustainability-relevant information is generated, circulated, and acted upon (Coskun-Setirek et al., 2024; Tariq et al., 2026).

This pillar matters because sustainability governance in industrial ecosystems depends heavily on informational capacity. Shared environmental risks, collective resource dependencies, and multi-actor accountability arrangements require more than static reporting routines. They require continuous or near-continuous access to reliable information on emissions, waste flows, resource use, infrastructure performance, and operational anomalies (Spilotro et al., 2025; Kloppenburg et al., 2022; Engvall & Flak, 2022). Digital sustainability infrastructure provides this informational backbone by making processes more visible, comparable, and traceable across actors and organizational boundaries (Kloppenburg et al., 2022; Engvall & Flak, 2022). It can also reduce information asymmetries that weaken governance when actors possess uneven access to operational or sustainability-relevant knowledge (Madanchian & Taherdoost, 2025; Mulligan et al., 2024).

Within the model, digital sustainability infrastructure does not function as a neutral technical layer. Its governance significance depends on whether it supports accountability, learning, coordination, and institutional responsiveness. Data alone does not produce governance, but when digitally enabled information is connected to leadership structures, collaborative processes, and regulatory expectations, it can improve auditability, strengthen monitoring, and align sustainability objectives with operational realities (Hu & Yang, 2024; Chen et al., 2025). For this reason, the model treats digital infrastructure as a constitutive element of governance rather than a background condition of modernization.

**Industrial Ecosystem Collaboration**

The third pillar, industrial ecosystem collaboration, refers to the forms of coordination, information sharing, joint problem-solving, and collective action through which multiple actors respond to shared sustainability challenges. This pillar is grounded in the recognition that sustainability outcomes in industrial estates are rarely produced by isolated firms acting independently. Instead, they emerge through the interactions of tenants, estate managers, infrastructure operators, regulators, communities, and service providers linked by spatial proximity, shared infrastructures, and interdependent environmental externalities (Burström et al., 2024; Sgambaro et al., 2026). Research on industrial symbiosis has shown that exchanges of materials, water, energy, and services depend not only on technical opportunity, but also on relational and institutional coordination among actors (Wang et al., 2022; Palagonia et al., 2025). The same logic applies to sustainability governance more broadly.

Collaboration is essential because many sustainability problems in industrial ecosystems are collective-action problems. Waste management, pollution control, resource efficiency, and environmental monitoring frequently cannot be resolved by one actor alone, particularly when infrastructure is shared and impacts spill across organizational boundaries (Le Tellier et al., 2022; Wang et al., 2023). Studies on collaborative governance indicate that coordination quality, trust, knowledge exchange, and the distribution of power shape whether collective arrangements become effective or remain largely symbolic (Dunn et al., 2023; Sundqvist-Andberg & Åkerman, 2022; Zuhdi et al., 2025). In this context, collaboration is not a supplementary feature of sustainability governance, but one of its core conditions.

Within the proposed framework, industrial ecosystem collaboration performs two main functions. First, it translates information into action by creating channels through which shared sustainability data can be interpreted, discussed, and used collectively. Second, it reduces fragmentation by linking actors that might otherwise treat sustainability as an individual compliance burden rather than an ecosystem-level governance issue (Pärli et al., 2021; Hall & Meng, 2023). This pillar is particularly important in emerging-economy settings, where institutional gaps and uneven capabilities often make formal governance arrangements insufficient unless supported by collaborative bridging mechanisms across organizations and sectors (Bourguignon & Libois, 2023; Goldschmeding et al., 2024).

**Institutional Policy Alignment**

The fourth pillar, institutional policy alignment, refers to the extent to which sustainability governance in industrial ecosystems is supported by coherent regulations, policy frameworks, governance standards, and institutional incentives. This pillar recognizes that ecosystem-level sustainability governance cannot be sustained by leadership, infrastructure, or collaboration alone if external institutional conditions remain fragmented, contradictory, or weakly enforced (Narayan et al., 2025; Bourguignon & Libois, 2023).

Its relevance is particularly pronounced in emerging economies, where governance capacity often varies across sectors, territorial levels, and public agencies (Samaratunge & Alam, 2021; Bourguignon & Libois, 2023). Regulatory ambitions may be present, yet implementation often remains fragmented because of institutional voids, weak enforcement, coordination failures, or limited technical capability (Narayan et al., 2025). Similar challenges appear in industrial-estate governance when sustainability transitions are not matched by legal certainty, consistent policy support, or adequate management capacity (Nainggolan et al., 2020; Noegroho, 2025). In this framework, institutional policy alignment therefore refers not only to the existence of formal regulation, but also to the coherence between sustainability goals, digital policy, and industrial governance arrangements.

Within the model, this pillar performs enabling and stabilizing functions. It creates incentives for actors to adopt shared governance practices, reduces ambiguity in accountability, and embeds ecosystem-level sustainability efforts within wider developmental and regulatory agendas (Anas & Cahyawati, 2023; Mursadi et al., 2024). It also helps prevent digital sustainability initiatives from remaining isolated pilots by linking them to mandates, reporting expectations, and institutional support mechanisms (Mulligan et al., 2024; Tariq et al., 2026). In this sense, policy alignment converts fragmented experimentation into more durable governance capacity.

Beyond its regulatory role, institutional policy alignment provides the enabling environment within which the other three pillars can operate as an integrated governance system. Governance leadership is more effective when supported by clear policy direction and regulatory legitimacy, digital sustainability infrastructure requires coherent standards for data governance and interoperability, and industrial ecosystem collaboration becomes more durable when reinforced by consistent institutional incentives and accountability mechanisms. Accordingly, this pillar functions not merely as an external contextual condition, but as the institutional foundation that enhances the coherence, continuity, and scalability of digital sustainability governance across industrial ecosystems, particularly in emerging economies.

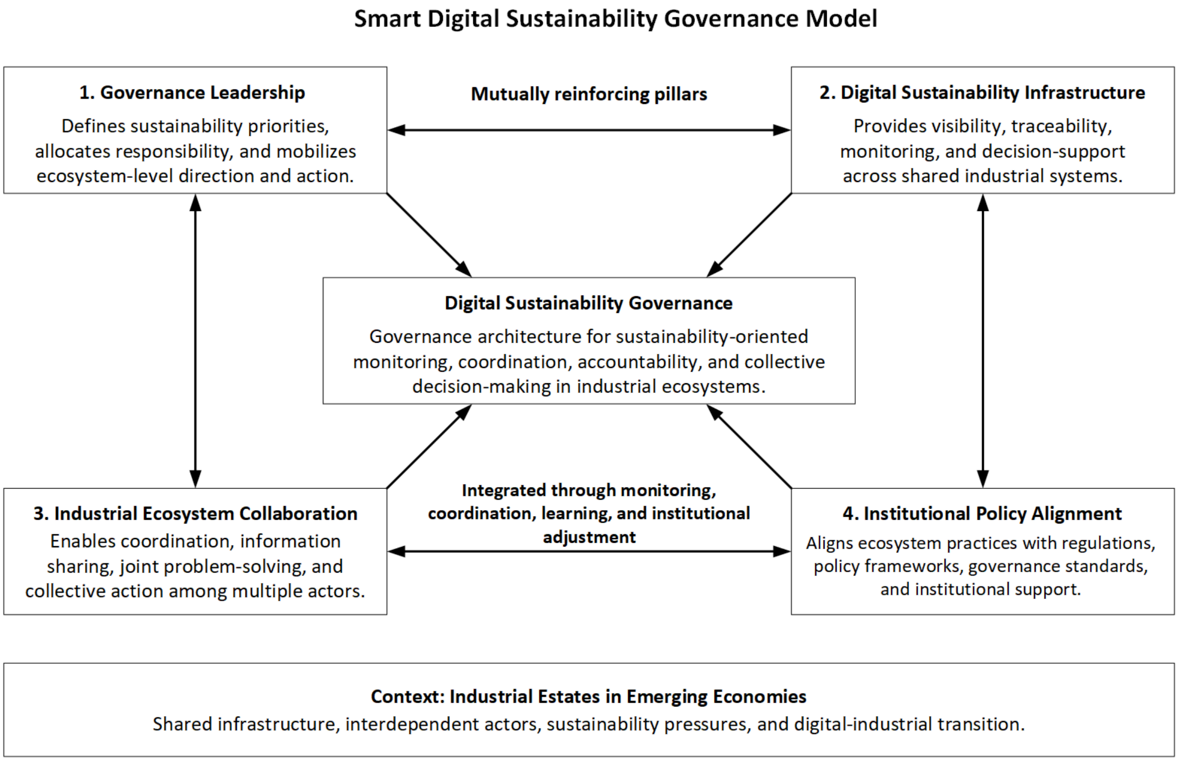


**Figure 2.** Smart Digital Sustainability Governance Model. Source: Authors' elaboration based on the reviewed literature

### Interrelationship Among the Four Pillars

Although each pillar captures a distinct dimension of digital sustainability governance, the framework assumes that the four pillars are mutually reinforcing rather than independent. Governance leadership provides strategic direction by defining priorities, allocating responsibility, and mobilizing action. Digital sustainability infrastructure provides informational visibility by enabling monitoring, traceability, and data-driven coordination. Industrial ecosystem collaboration provides relational capacity by translating shared information into collective response. Institutional policy alignment provides external coherence by embedding local governance practices within broader regulatory and developmental structures. Effective digital sustainability governance therefore emerges from the interaction of all four pillars rather than from any single one in isolation.

Their relationship is both sequential and recursive. Leadership without digital infrastructure risks producing sustainability commitments that are normatively strong but informationally weak. Digital infrastructure without collaboration may generate visibility without collective response. Collaboration without policy alignment may remain fragile, informal, or difficult to scale. Policy alignment without leadership may create formal requirements that are weakly internalized by ecosystem actors. Sustainability governance becomes more robust when these pillars co-evolve through repeated cycles of monitoring, coordination, learning, and institutional adjustment (Han & Xie, 2025; Stötzel, 2024; Tariq et al., 2026).

From this perspective, the proposed framework is not a checklist of desirable elements, but an explanatory model of governance capacity in complex industrial environments. It suggests that industrial estates are more likely to move toward coherent sustainability governance when leadership mobilizes digital infrastructures for shared objectives, when digital systems support collaboration rather than siloed control, when collaboration is reinforced by institutional arrangements, and when policy frameworks enable rather than fragment ecosystem-level action.

**Framework Application: Industrial Estates and SIER**

Industrial estates provide a relevant context for applying the proposed framework because they concentrate multiple firms, shared infrastructures, environmental externalities, and overlapping governance responsibilities within a bounded spatial setting (Taddeo, 2016; Hudalah et al., 2019; Burström et al., 2024). In such environments, sustainability outcomes are shaped not only by the internal commitments of individual firms, but also by the quality of coordination among estate managers, tenants, regulators, service providers, and surrounding communities (Pärli et al., 2021; Burström et al., 2024; Han & Xie, 2025). This makes industrial estates analytically important for examining how sustainability governance operates under conditions of interdependence, collective resource use, and distributed accountability (Le Tellier et al., 2022; Wang et al., 2023).

This relevance is particularly pronounced in emerging economies, where industrial estates are often expected simultaneously to drive industrialization, support regional development, and respond to mounting environmental and institutional pressures (Adegbite, 2021; Schack et al., 2024; Nainggolan et al., 2020). Yet these ambitions frequently unfold under conditions of uneven governance capacity, variable digital maturity, and fragmented institutional support (Samaratunge & Alam, 2021; Bourguignon & Libois, 2023). As a result, sustainability efforts in industrial estates often depend not only on formal policy intent, but also on the ability of local actors to connect infrastructure management, data visibility, stakeholder coordination, and regulatory expectations within a workable governance arrangement (Nainggolan et al., 2020; Goldschmeding et al., 2024).

Within this broader context, SIER provides a useful application setting for the proposed framework. The discussion in this section draws on publicly available company materials, particularly PT SIER's Annual Report 2024 and corporate presentation materials. Accordingly, the SIER case is used here as a contextual application of the framework rather than as a substitute for full empirical field validation. This distinction is important because the available materials provide credible evidence of SIER's strategic positioning, estate portfolio, infrastructure base, and development trajectory, while not constituting a comprehensive independent audit of its sustainability governance practices.

The company materials indicate that SIER positions itself as a green, modern, and integrated industrial-estate operator in East Java. PT SIER manages and develops industrial-estate operations across Surabaya, Sidoarjo, and Pasuruan, while also pursuing expansion through the Ngawi industrial-estate project. The same materials emphasize utility fulfilment, digitalization, environmental sustainability, and synergy building as central strategic directions. What makes SIER analytically useful in this context is not simply that it operates shared infrastructure, but that it is already combining utility provision, digitalization, environmental management, and multi-stakeholder coordination within a broader modernization agenda.

To make the framework application more concrete, Table 1 distinguishes between conditions that are currently evidenced in SIER's documented operations and strategic strengthening directions that would deepen digital sustainability governance. This distinction is analytically important because SIER already demonstrates several governance- and infrastructure-related features relevant to ecosystem-level sustainability governance, while more advanced forms of digital sustainability integration remain more appropriately framed as developmental directions than as fully verified present conditions.

**Table 1.** Framework Application of SIER Against the Smart Digital Sustainability Governance Model

| Pillar | Currently Evidenced Conditions in SIER | Strategic Strengthening Direction |
|---|---|---|
| **Governance Leadership** | SIER is presented as a long-established industrial-estate operator in East Java and explicitly positions itself as a green, modern, and integrated | Formalize cross-tenant sustainability governance routines, assign clearer |

| Pillar | Currently Evidenced Conditions in SIER | Strategic Strengthening Direction |
|---|---|---|
| | estate manager. The company manages industrial-estate operations across Surabaya, Sidoarjo, and Pasuruan, indicating an ecosystem-level governance role that extends beyond a single site and requires strategic coordination across multiple industrial locations. Company materials also reflect a governance orientation that emphasizes GCG, sustainability, and long-term industrial development. | ecosystem-level sustainability responsibilities, and institutionalize estate-wide sustainability oversight mechanisms. |
| **Digital Sustainability Infrastructure** | SIER already demonstrates concrete evidence of estate-scale digital and utility infrastructure. Company disclosures indicate the use of IoT for utility monitoring, including clean water, wastewater, and public street lighting; implementation of fiber-optic infrastructure; and development of an integrated estate management system with real-time monitoring through the Industrial Operation Hub. SIER also reports complete and modern estate infrastructure, including roads, drainage systems, clean water treatment, electricity, wastewater treatment, and supporting facilities. In addition, the company highlights the use of solar panels, EV charging infrastructure, and zero-waste-oriented waste management as part of its green industrial-estate development. | Deepen the existing infrastructure into a more explicit digital sustainability governance platform by expanding integrated sustainability dashboards, environmental reporting systems, estate-wide data interoperability, predictive utility analytics, and broader real-time monitoring of emissions and resource efficiency. |
| **Industrial Ecosystem Collaboration** | SIER's disclosures indicate active coordination with tenants and support for tenant business strategies, alongside collaboration with government, educational institutions, SMEs, NGOs, and local communities. These practices suggest that SIER's role extends beyond land provision and includes ecosystem-level interaction among estate management, tenants, service functions, and external stakeholders. | Develop more formal collective sustainability forums, shared reporting and feedback mechanisms, joint waste and resource-management initiatives, and structured cross-actor problem-solving platforms. |
| **Institutional Policy Alignment** | SIER's strategy is broadly aligned with Indonesia's wider agenda of industrial modernization, sustainability, digitalization, and green industrial development. The company explicitly links its operations to renewable energy, Smart Eco Industrial Park development, SDG implementation, environmental management, and industrial-estate expansion. Its certifications and compliance-related systems also indicate alignment with broader governance, quality, safety, and information-security standards. | Strengthen alignment with green industrial-estate standards, digital reporting requirements, environmental compliance systems, and broader sustainability policy incentives at national and region level. |

*Source: Compiled by the authors from PT SIER Annual Report 2024 and PT SIER corporate presentation materials.

The mapping suggests that SIER already exhibits several foundational conditions relevant to the proposed framework, particularly in governance leadership, estate-scale infrastructure management, digital utility monitoring, and institutional positioning. The available evidence is stronger at the level of infrastructure, service management, and operational digitalization than at the level of fully integrated sustainability analytics. SIER therefore appears to possess a credible operational and infrastructural base upon which a more explicit and advanced form of digital sustainability governance could be built, making it possible to interpret the estate as an evolving governance platform in which sustainability outcomes are increasingly linked to data visibility, infrastructural integration, and institutional alignment.

This distinction strengthens the analytical use of the case precisely because it avoids overstating SIER's current digital maturity while still showing why the estate is relevant to the proposed model. The analytical value of the case lies in showing both what is already present and what remains to be strengthened: SIER illustrates an estate operator that has developed substantial governance and infrastructure capacity, while not yet fully operationalizing advanced digital sustainability functions such as estate-wide sustainability dashboards, predictive environmental analytics, or integrated cross-actor data governance. If SIER is to move from integrated industrial-estate management toward more fully developed digital sustainability governance, these remain the critical directions for development.

Taken together, the SIER application reinforces the central claim of this study: industrial estates should be understood not merely as clusters of co-located firms, but as governance spaces in which sustainability transitions depend on the interaction of leadership, shared infrastructure, digital systems, collaboration, and institutional support. The case also illustrates why ecosystem-level sustainability governance is a critical and unfinished challenge for industrial development in emerging economies, one that requires not only infrastructure investment, but the deliberate alignment of digital systems, governance capacity, and institutional conditions.

## DISCUSSION

This framework contributes to the literature by clarifying how digital transformation acquires governance significance in sustainability-oriented industrial ecosystems, rather than functioning solely as an instrument of operational modernization. It responds to a persistent fragmentation in prior research, where sustainability governance has largely been examined through firm-level oversight and accountability, while digital transformation has been treated primarily as a driver of efficiency, innovation, or process modernization (Guandalini, 2022; Ludwig & Sassen, 2022; Fantozzi et al., 2025). By integrating these streams, the article shows that digital systems are strategically important not only because they improve information processing, but because they can reshape how sustainability responsibilities are organized across interdependent actors and shared infrastructures (Coskun-Setirek et al., 2024; Tariq et al., 2026).

In this respect, the proposed framework differs from existing governance and digital transformation models in three ways. First, it shifts the analytical level from the individual firm to the industrial ecosystem. Second, it interprets digital transformation as part of the governance architecture through which sustainability is monitored, coordinated, and enacted, rather than primarily as a technical modernization variable (Tariq et al., 2026). Third, it integrates leadership, digital systems, collaboration, and institutional alignment into a single explanatory model of ecosystem-level sustainability governance (Burström et al., 2024; Han & Xie, 2025). This combination offers a clearer explanation of how sustainability governance may operate in shared industrial environments than models that examine governance, digitalization, or ecosystem coordination separately (Beier et al., 2020; Burström et al., 2024; Guandalini, 2022).

Each of these differences carries a corresponding theoretical implication. A first implication is that the framework extends sustainability governance beyond firm-centric assumptions. Much of the existing governance literature still implicitly treats sustainability outcomes as the result of internal organizational choices, board oversight, disclosure quality, or stakeholder management within individual firms (Wang & Wang, 2022; Yang et al., 2024; Escamez et al., 2026). While these dimensions remain important, they are insufficient in industrial ecosystems where environmental performance, resource efficiency, and social legitimacy are shaped by cross-organizational interdependence. In industrial estates, sustainability outcomes often depend on how actors collectively manage wastewater systems, logistics networks, energy flows, environmental monitoring, and shared compliance responsibilities (Le Tellier et al., 2022; Wang et al., 2023; Burström et al., 2024; Han & Xie, 2025). The framework therefore shifts the unit of analysis from the isolated firm toward the ecosystem as a governance space in which sustainability is produced relationally rather than independently.

A second implication concerns the governance value of digital infrastructures. Existing research often highlights the performance benefits of digital technologies in terms of efficiency, automation, visibility, and innovation capability (Chatterjee et al., 2021; Duan & Xu, 2024; Karic et al., 2025). The present framework suggests that their deeper significance lies in enabling governance functions that are difficult to achieve through conventional administrative arrangements alone — improving traceability, strengthening shared visibility, supporting real-time monitoring, and facilitating coordination across organizational boundaries (Karic et al., 2025; Kloppenburg et al., 2022). Understood in this way, digital infrastructures form part of the socio-technical architecture through which sustainability governance becomes more coherent and actionable (Chen et al., 2025; Hu & Yang, 2024; Tariq et al., 2026).

A third contribution concerns the need for integrated governance architecture. The proposed model suggests that sustainability governance in industrial estates cannot be explained by any single element in isolation, whether leadership commitment, technological capability, collaborative intent, or policy support. Instead, effective governance emerges from the alignment of these elements within a broader socio-technical arrangement. This argument is particularly relevant to industrial estates in emerging economies, where governance often unfolds under conditions of institutional complexity, uneven digital maturity, and competing developmental priorities (Samaratunge & Alam, 2021; Schack et al., 2024). Under such conditions, fragmented investment in digital tools may fail to strengthen sustainability governance if actors lack coordination mechanisms, if policy frameworks remain weakly aligned, or if leadership does not translate strategic intent into operational routines (Goldschmeding et al., 2024; Mulligan et al., 2024; Narayan et al., 2025).

These theoretical contributions must, however, be interpreted alongside real-world governance frictions. Sustainability governance in industrial estates may be constrained by power asymmetries between large anchor firms and smaller tenants, uneven digital capabilities, and trust deficits in the sharing of operational or sustainability-related data. Smaller firms may lack the technical capacity to participate in digitally enabled monitoring systems, while others may resist data disclosure due to concerns over confidentiality, competitive exposure, or managerial surveillance. Under such conditions, digital sustainability infrastructure may generate visibility without genuine cooperation, or even encourage symbolic compliance rather than substantive governance change. These barriers are consistent with wider research showing that multi-actor sustainability arrangements are often weakened by unequal capabilities, resistance to change, coordination failures, and institutional inertia (Bourguignon & Libois, 2023; Goldschmeding et al., 2024; Sundqvist-Andberg & Åkerman, 2022). Effective digital sustainability governance therefore depends not only on technological availability, but also on trust, inclusion, and the institutional design of collaborative arrangements (Hall & Meng, 2023; Han & Xie, 2025).

These frictions are not merely theoretical possibilities. Their relevance is visible in industrial estates such as SIER, where sustainability outcomes depend on estate-level coordination, infrastructure management, stakeholder engagement, and institutional support in addition to firm-level commitment (Hudalah et al., 2019; Nainggolan et al., 2020; Noegroho, 2025). The value of the framework in this context is not that it empirically validates causal relationships, but that it provides a structured lens for interpreting how sustainability governance may be strengthened when digital systems are embedded within a broader governance arrangement — making the model analytically useful for understanding industrial estates as organizational fields in which sustainability transitions are mediated by both technological capability and collective governance capacity (Burström et al., 2024; Han & Xie, 2025).

The framework also generates several practical implications. For industrial-estate managers, digital investment should be linked explicitly to governance objectives: technologies such as environmental monitoring platforms, integrated reporting systems, and shared data infrastructures are more likely to contribute to sustainability when they support accountability, coordination, and adaptive response across tenant networks (Chen et al., 2025; Coskun-Setirek et al., 2024). For policymakers, the framework indicates that sustainability governance requires not only environmental regulation, but also institutional support for digital coordination, data interoperability, and collaborative governance mechanisms (Anas & Cahyawati, 2023; Mursadi et al., 2024). For tenant firms and service providers, effective participation in shared governance arrangements becomes especially important where sustainability performance depends on collective compliance and infrastructure interdependence (Pärli et al., 2021; Wang et al., 2023).

When these elements are effectively aligned, the four pillars of the model are expected to support improved environmental compliance, stronger accountability and auditability, more efficient resource use, better coordination among ecosystem actors, and greater resilience in responding to regulatory, environmental, and operational pressures (Chen et al., 2025; Han & Xie, 2025; Tariq et al., 2026). In this sense, the proposed framework offers a systemic basis for understanding how industrial estates may pursue sustainability transitions that are adaptive, coordinated, and institutionally grounded, rather than dependent on isolated technological investment or firm-level compliance alone (Guandalini, 2022; Schack et al., 2024).

The theoretical and practical contributions outlined above also point toward an empirical research agenda. To support future development of the proposed framework, this study offers three explicit propositions. First, industrial estates characterized by stronger governance leadership and more developed digital sustainability infrastructure are expected to exhibit more coherent forms of ecosystem-level sustainability governance. This proposition highlights that strategic direction and digitally enabled coordination are more likely to produce coherent sustainability governance when they are mutually reinforcing rather than developed in isolation.

Second, the governance benefits of digital sustainability infrastructure are expected to be contingent rather than uniform across industrial-estate contexts. More specifically, the positive contribution of digital sustainability infrastructure to sustainability governance is likely to weaken when collaborative trust among ecosystem actors is low. Under such conditions, digital systems may improve visibility and monitoring capacity while still failing to generate meaningful collective action, if actors remain reluctant to share data, coordinate responses, or engage in joint problem-solving.

Third, institutional policy alignment is expected to reinforce the contribution of industrial ecosystem collaboration to sustainability governance outcomes. Where policy incentives, regulatory expectations, and governance standards are more coherent, collaborative arrangements are more likely to generate durable and meaningful sustainability effects. Conversely, when institutional support remains fragmented, the effectiveness of collaboration may be constrained even when local actors are willing to cooperate.

These propositions give rise to three corresponding research questions for future empirical investigation: How does governance leadership shape the effectiveness of digital sustainability infrastructure in industrial estates? Under what conditions does collaboration enhance or constrain the governance value of digital systems? And how does institutional policy alignment influence the sustainability outcomes of ecosystem-level governance arrangements? Translating these questions into empirical research, across different industrial-estate contexts and governance settings, represents the critical next step in developing and testing the framework proposed here.

## CONCLUSION

This study develops a conceptual framework explaining how digital transformation can strengthen sustainability governance in industrial ecosystems, with particular relevance to industrial estates in emerging economies. The analysis suggests that sustainability governance cannot be understood solely through firm-level commitments, as sustainability outcomes increasingly depend on shared infrastructure, inter-organizational coordination, and institutional alignment across the industrial ecosystem. Accordingly, digital transformation should be viewed not merely as a technological or operational change but as a governance-enabling mechanism that enhances visibility, coordination, accountability, and sustainability-oriented decision-making.

The study makes three principal contributions. First, it repositions digital transformation as an integral component of sustainability governance rather than a separate process of technological modernization. Second, it extends the analytical focus from the individual firm to the industrial ecosystem, where sustainability outcomes emerge through interactions among multiple actors and shared infrastructures. Third, it proposes the Smart Digital Sustainability Governance Model, which integrates governance leadership, digital sustainability infrastructure, industrial ecosystem collaboration, and institutional policy alignment into a unified conceptual framework.

The framework also offers practical implications for industrial-estate managers, policymakers, and tenant firms. It suggests that digital investments are more likely to strengthen sustainability transitions when they are aligned with governance objectives, collaborative coordination, and supportive institutional arrangements rather than implemented as isolated technological initiatives. By integrating these four pillars, industrial estates may enhance environmental performance, accountability, resource efficiency, ecosystem coordination, and long-term resilience.

As a conceptual study, this research has inherent limitations. The proposed framework has not yet been empirically validated and therefore should be regarded as a theoretical foundation for future investigation. Subsequent studies are encouraged to examine the relationships among the four pillars across different industrial-estate contexts, compare governance arrangements in developed and emerging economies, and assess the framework using quantitative, qualitative, or mixed-method research designs.

## REFERENCES

Adegbite, O. (2021). A Hard Look at Industrial Estate Development in Nigeria. In Perspectives on Industrial Development in Nigeria: Issues, Challenges and Hard Choices (pp. 153–173). Springer Nature Switzerland. https://doi.org/10.1007/978-3-030-84375-5_6

Aguilera, R. V., & Ruiz Castillo, M. (2025). Toward an updated corporate governance framework: Fundamentals, disruptions, and future research. BRQ Business Research Quarterly, 28(2), 336–348. https://doi.org/10.1177/23409444251320399

Ahmad, N., Li, Y., Žiković, S., & Belyaeva, Z. (2023). The effects of technological innovation on sustainable development and environmental degradation: Evidence from China. Technology in Society, 72, 102184. https://doi.org/10.1016/j.techsoc.2022.102184

Almnadheh, Y., Samara, H., & AlQudah, M. Z. (2025). Enhancing ESG integration in corporate strategy: A bibliometric study and content analysis. International Journal of Law and Management, 68(4), 676–700. https://doi.org/10.1108/IJLMA-10-2024-0385

Alriansyach, I. D., Utomo, C., Rahmawati, Y., & Aqsha, A. (2024). Performance of Green Industrial Estate: A Review. Engineering Proceedings, 74(1), Article 5. https://doi.org/10.3390/engproc2024074005

Anas, T., & Cahyawati, E. (2023). Strategic investment policies for digital transformation: The case of Indonesia. Journal of Southeast Asian Economies, 40(1), 96–126. https://doi.org/10.1355/ae40-1e

Babkin, A., Glukhov, V., Shkarupeta, E., Kharitonova, N., & Barabaner, H. (2021). Methodology for assessing industrial ecosystem maturity in the framework of digital technology implementation. International Journal of Technology, 12(7), 1397–1415. https://doi.org/10.14716/ijtech.v12i7.5390

Ba, Y., & Galik, C. S. (2023). Historical industrial transitions influence local sustainability planning, capability, and performance. Environmental Innovation and Societal Transitions, 46, 100690. https://doi.org/10.1016/j.eist.2022.100690

Baas, J., Schotten, M., Plume, A., Côté, G., & Karimi, R. (2020). Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. Quantitative Science Studies, 1(1), 377–386. https://doi.org/10.1162/qss_a_00019

Basingab, M. S. (2025). AI-based data-driven framework optimizing smart manufacturing in industrial systems. Journal of Industrial Information Integration, 48, 100996. https://doi.org/10.1016/j.jii.2025.100996

Beier, G., Ullrich, A., Niehoff, S., Reißig, M., & Habich, M. (2020). Industry 4.0: How it is defined from a sociotechnical perspective and how much sustainability it includes—A literature review. Journal of Cleaner Production, 259, 120856. https://doi.org/10.1016/j.jclepro.2020.120856

Bourguignon, F., & Libois, F. (2023). Gathering Evidence on the Quality of Institutions. In State and Business in Tanzania’s Development (pp. 58–92). Cambridge University Press. https://doi.org/10.1017/9781009285803.005

Brarda, P. G., Ayala, N. F., & Mendes, G. H. S. (2026). Roadmap to Digital Factories in Industry 4.0: Insights from multiple case studies. International Journal of Production Economics, 292, 109829. https://doi.org/10.1016/j.ijpe.2025.109829

Burström, T., Lahti, T., Parida, V., & Wincent, J. (2024). Industrial ecosystems: A systematic review, framework, and research agenda. Technological Forecasting and Social Change, 203, 123656. https://doi.org/10.1016/j.techfore.2024.123656

Chatterjee, S., Rana, N. P., Dwivedi, Y. K., & Baabdullah, A. M. (2021). Understanding AI adoption in manufacturing and production firms using an integrated TAM-TOE model. *Technological Forecasting and Social Change*, 170, 120880. https://doi.org/10.1016/j.techfore.2021.120880

Chauhan, C., Singh, A., & Luthra, S. (2021). Barriers to Industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy. Journal of Cleaner Production, 285, 124809. https://doi.org/10.1016/j.jclepro.2020.124809

Chen, S., Dong, S., & Huang, Y. (2025). Government digital governance and urban green economic efficiency in China. *Journal of Environmental Management*, 392, 126686. https://doi.org/10.1016/j.jenvman.2025.126686

Coskun-Setirek, A., Annosi, M. C., Hurst, W., Dolfsma, W., & Tekinerdogan, B. (2024). Architecture and governance of digital business ecosystems: A systematic literature review. Information Systems Management, 41(1), 58–90. https://doi.org/10.1080/10580530.2023.2194063

Dandapani, K., & Shahrokhi, M. (2022). Guest editorial: Historical perspectives on corporate governance debate and introduction to the special issue on corporate governance and sustainability. Managerial Finance, 48(9/10), 1205–1208. https://doi.org/10.1108/MF-05-2022-0237

De Matteis, F., Angelelli, M., Striani, F., & Corallo, A. (2025). Managerial implications of blockchains in the public sector: Elements for the development of a conceptual framework for innovation. Journal of Management and Governance. Advance online publication. https://doi.org/10.1007/s10997-024-09724-w

Ding, X., Chourou, L., & Ben-Amar, W. (2024). Carbon emissions and audit fees: Evidence from emerging markets. *Emerging Markets Review, 61, 101139.* https://doi.org/10.1016/j.ememar.2024.101139

Doni, F., Corvino, A., & Bianchi Martini, S. (2022). Corporate governance model, stakeholder engagement and social issues: Evidence from European oil and gas industry. *Social Responsibility Journal.* https://doi.org/10.1108/SRJ-08-2020-0336

Duan, L., & Xu, L. da. (2024). Data analytics in Industry 4.0: A survey. *Information Systems Frontiers*. https://doi.org/10.1007/s10796-021-10190-0

Dunn, M. E., Huan, Y., & Howe, C. (2023). Centralized and dense network of United Nations biodiversity partnerships influences support of the Kunming-Montreal Global Biodiversity Framework. *One Earth*. https://doi.org/10.1016/j.oneear.2023.06.001

Engvall, T. S., & Flak, L. S. (2022). The state of information infrastructure for global climate governance. *Transforming Government: People, Process and Policy*. https://doi.org/10.1108/TG-05-2022-0064

Escamez, P. P., Santos-Jaén, J. M., Gallardo-Vázquez, D., & Martínez-Conesa, I. (2026). Corporate governance and ESG integration: pathways to sustainability in European companies. *Economics of Governance*, 27(1), 10. https://doi.org/10.1007/s10101-026-00352-8

Fantozzi, I. C., Olhager, J., Johnsson, C., & Schiraldi, M. M. (2025). Guiding organizations in the digital era: Tools and metrics for success. *International Journal of Engineering Business Management*, 17. https://doi.org/10.1177/18479790241312804

Ghosh, S., Hughes, M., Hodgkinson, I., & Hughes, P. (2022). Digital transformation of industrial businesses: A dynamic capability approach. *Technovation*, 113, 102414. https://doi.org/10.1016/j.technovation.2021.102414

Goldschmeding, F., Vasseur, V., & Kemp, R. (2024). Inertia and resistance to change in multi-actor innovation processes: Evidence from two cases in the Netherlands. *Environmental Innovation and Societal Transitions, 52*, 100880. https://doi.org/10.1016/j.eist.2024.100880

Guandalini, I. (2022). Sustainability through digital transformation: A systematic literature review for research guidance. *Journal of Business Research*, 148, 456–471. https://doi.org/10.1016/j.jbusres.2022.05.003

Hall, D., & Meng, T. (2023). Intermediating sustainable finance: A case study of The Aotearoa Circle's Sustainable Finance Forum. Policy Studies, 44(5), 666–686. https://doi.org/10.1080/01442872.2022.2162032

Han, Y., & Xie, L. (2025). Sustainable governance of digital platform ecosystem: A life cycle perspective through multiple governance parties. *Sustainability*, 17(8), 3628. https://doi.org/10.3390/su17083628

Hansen, A. K., Christiansen, L., & Lassen, A. H. (2025). Technology isn't enough for Industry 4.0: On SMEs and hindrances to digital transformation. International Journal of Production Research, 63(18), 6585–6605. https://doi.org/10.1080/00207543.2024.2305800

He, Y. (2026). Reconfiguring Korea's dual transition: Empirical insights on the role of Industry 4.0 technologies. Technology in Society, 84, 103084. https://doi.org/10.1016/j.techsoc.2025.103084

Hudalah, D., Nurrahma, V., Sofhani, T. F., & Salim, W. A. (2019). Connecting fragmented enclaves through network? Managing industrial parks in the Jakarta-Bandung urban corridor. *Cities*, 87, 1–10. https://doi.org/10.1016/j.cities.2019.01.005

Hu, C., & Yang, X. (2024). A study on the impact of digital governance on disclosure quality of listed companies. *Finance Research Letters*, 69, 106062. https://doi.org/10.1016/j.frl.2024.106062

Irajifar, L., Chen, H., Lak, A., Sharifi, A., & Cheshmehzangi, A. (2023). The nexus between digitalization and sustainability: A scientometrics analysis. *Heliyon*, 9(5), e15172. https://doi.org/10.1016/j.heliyon.2023.e15172

Jarusen, J., & Cheunkamon, E. (2025). The sustainable development of eco-industrial parks affecting the satisfaction of the Map Ta Phut industrial estate community. Sustainable Futures, 10, 101076. https://doi.org/10.1016/j.sftr.2025.101076

Jiang, Y., Jia, F., Blome, C., & Chen, L. (2020). Achieving sustainability in global sourcing: Toward a conceptual framework. Supply Chain Management: An International Journal, 25(1), 35–60. https://doi.org/10.1108/SCM-12-2018-0448

Karic, H., Arockiadoss, A. S., & Schilberg, D. (2025). Smart factory and Industry 4.0: A survey on advancements, technologies, methods and perspectives of digital transformation in manufacturing. Applied Human Factors and Ergonomics International. https://doi.org/10.54941/ahfe1006444

Kateb, I., Alahdal, W. M., Sahu, M., & Baatwah, S. R. (2025). Sustainable transitions in OECD nations: Does governance performance drive the SDGs integration with carbon emissions? Innovation and Green Development, 4, 100282. https://doi.org/10.1016/j.igd.2025.100282

Kans, M., & Campos, J. (2024). Digital capabilities driving Industry 4.0 and 5.0 transformation: Insights from an interview study in the maintenance domain. Journal of Open Innovation: Technology, Market, and Complexity, 10(4), 100384. https://doi.org/10.1016/j.joitmc.2024.100384

Kloppenburg, S., Gupta, A., Kruk, S. R. L., Makris, S., Bergsvik, R., Korenhof, P., Solman, H., & Toonen, H. M. (2022). Scrutinizing environmental governance in a digital age: New ways of seeing, participating, and intervening. *One Earth*, 5(3), 232–241. https://doi.org/10.1016/j.oneear.2022.02.004

Kumar, S., & Shah, P. (2025). Digital ESG as a catalyst for achieving the Sustainable Development Goals: A systematic review and bibliometric analysis of digital transformation for a resilient future. Sustainable Futures, 10, 101458. https://doi.org/10.1016/j.sftr.2025.101458

Le Tellier, M., Berrah, L., Audy, J.-F., Stutz, B., & Barnabé, S. (2022). A sustainability assessment model for industrial parks: A Choquet integral aggregation approach. *Journal of Environmental Management*, 316, 115165. https://doi.org/10.1016/j.jenvman.2022.115165

Li, Q., & Zhao, S. (2023). The impact of digital economy development on industrial restructuring: Evidence from China. *Sustainability,* 15(14), 10847. https://doi.org/10.3390/su151410847

Li, Y., Dai, J., & Cui, L. (2020). The impact of digital technologies on economic and environmental performance in the context of Industry 4.0: A moderated mediation model. *International Journal of Production Economics*, 229, 107777. https://doi.org/10.1016/j.ijpe.2020.107777

Ludwig, P., & Sassen, R. (2022). Which internal corporate governance mechanisms drive corporate sustainability?. *Journal of Environmental Management*, 301, 113780. https://doi.org/10.1016/j.jenvman.2021.113780

Madanchian, M., & Taherdoost, H. (2025). A narrative review and gap analysis of blockchain for transparency, traceability, and trust in data-driven supply chains. *Applied Sciences*. https://doi.org/10.3390/app15179571

Mihai, L.-S., Sitnikov, V. V., Sichigea, M., Vasilescu, L., Băndoi, A., Sitnikov, C., & Mănescu, L.-G. (2025). A Bibliometric Analysis of the Role of Digitalization in Achieving Sustainability-Oriented Innovation. *Sustainability*, 17(13), 5822. https://doi.org/10.3390/su17135822

Mulligan, C., Morsfield, S., & Cheikosman, E. (2024). Blockchain for sustainability: A systematic literature review for policy impact. *Telecommunications Policy*, 48(2), 102676. https://doi.org/10.1016/j.telpol.2023.102676

Munonye, W. C., Ajonye, G. O., Ahonsi, S. O., Munonye, D. I., Akinloye, O. A., & Chigozie, I. O. (2025). Governing circular intelligence: How AI-driven policy tools can accelerate the circular economy transition. *Cleaner and Responsible Consumption*, 19, 100324. https://doi.org/10.1016/j.clrc.2025.100324

Mursadi, R. A., Sin, T. C., Ramli, M. F., Hilmi, A. H. B., Ahmad, R., & Azmi, H. (2024). A review of Industry 4.0 development progress in Indonesia. AIP Conference Proceedings, 3088(1), 050006. https://doi.org/10.1063/5.0180600

Nainggolan, H., Surya Wardhani, N. W. S., Leksono, A. S., & Santoso, I. (2020). Driving factors for the success of the green industrial estate: A case study of Pasuruan Industrial Estate Rembang. IOP Conference Series: Earth and Environmental Science, 475(1), 012071. https://doi.org/10.1088/1755-1315/475/1/012071

Nadeem, K., Za, S., & Smacchia, M. (2026). Exploring the relationship of digital transformation and sustainability: a bibliometric analysis and future research agenda. Sustainability Accounting, Management and Policy Journal, 17(1), 49–87. https://doi.org/10.1108/SAMPJ-03-2024-0280

Narayan, M., Kumar, N., Parida, V. K., & Kumari, P. (2025). Sustainable finance in emerging markets: Adaptive governance and environmental, social, and governance innovation for equitable climate resilience. Development and Sustainability in Economics and Finance, 2, 100101. https://doi.org/10.1016/j.dsef.2025.100101

Noegroho, N. (2025). Challenges in Developing Green Industrial Estate with ESG Principles, Case Study: Industrial Estate in Semarang Indonesia. *IOP Conference Series: Earth and Environmental Science*, 1462(1), 012047. https://doi.org/10.1088/1755-1315/1462/1/012047

O'Higgins, E. (2023). Building Back Better - A New Paradigm For Corporate Governance. In Research Handbook on Corporate Governance and Ethics (pp. 68–85). *Edward Elgar Publishing*. https://doi.org/10.4337/9781800880603.00012

Palagonia, C., Michelini, L., & Mattelin-Pierrard, C. (2025). Spanning the industrial symbiosis within the circular economy: Critical issues and future research agenda. Journal of Industrial Ecology, 29(4), 1177–1195. https://doi.org/10.1111/jiec.70005

Pärli, R., Fischer, M., & Lieberherr, E. (2021). Information exchange networks among actors for the implementation of SDGs. *Current Research in Environmental Sustainability*, 3, 100049. https://doi.org/10.1016/j.crsust.2021.100049

Paucar, L. M. M., Larico, J. C. P., Hancco, C. A., & Apaza, J. F. (2025). Impact of Digital Transformation on Administrative Management: Perspectives from Cloud Computing and Big Data in Industry 4.0. *Journal of Ecohumanism*, 4(2). https://doi.org/10.62754/joe.v4i2.5932

Perrucci, D. V., Aktaş, C. B., Sorentino, J., Akanbi, H., & Curabba, J. (2022). A review of international eco-industrial parks for implementation success in the United States. *In City and Environment Interactions* (Vol. 16). Elsevier B.V. https://doi.org/10.1016/j.cacint.2022.100086

Saha, A. K., Khan, I., Karim, M. R., & Alam, M. K. (2026). Strategic climate change disclosures across temporal, directional, and thematic dimensions: Board dynamics and role of institutional ownership. Journal of Environmental Management, 392, 128437. https://doi.org/10.1016/j.jenvman.2025.128437

Salamzadeh, A., Hadizadeh, M., Feyzabadi, J. G., Yasin, N., & Paramba, J. N. (2024). The role of digital platforms in transforming corporate governance. In Transforming Corporate Governance with Digital Platforms and Artificial Intelligence (pp. 111–136). IGI Global. https://doi.org/10.4018/979-8-3693-6750-6.ch006

Samaratunge, R., & Alam, Q. (2021). Accountability and transparency in emerging countries: Governance, democratic currents and change. *Public Administration and Development,* 41(4), 147–156. https://doi.org/10.1002/pad.1963

Sarkar, S., Moolearambil Sukumaran Nair, M., & Datta, A. (2023). Role of environmental, social, and governance in achieving the UN Sustainable Development Goals: A special focus on India. Environmental Progress & Sustainable Energy, 42(5), e14204. https://doi.org/10.1002/ep.14204

Sasaki, K., Stubbs, W., & Farrelly, M. (2024). The influence of the Sustainable Development Goals on large companies' adoption and implementation of a broader corporate purpose. Corporate Governance: The International Journal of Business in Society, 24(5), 1018–1038. https://doi.org/10.1108/CG-04-2023-0167

Schack, C., Neise, T., & Franz, M. (2024). Erfolgsfaktoren für eine nachhaltige Entwicklung von Gewerbegebieten. *Standort*, 48(2), 132–139. https://doi.org/10.1007/s00548-023-00848-z

Schulz, K. A., Gstrein, O. J., & Zwitter, A. J. (2020). Exploring the governance and implementation of sustainable development initiatives through blockchain technology. *Futures,* 122, 102611. https://doi.org/10.1016/j.futures.2020.102611

Sewenet, A. D., Boulaksil, Y., & Pisano, P. (2026). Circular economy, circularity, and sustainability: A systematic review and conceptual framework. Cleaner Environmental Systems, 15, 100405. https://doi.org/10.1016/j.cesys.2026.100405

Shabbir, M. (2025). Corporate sustainability reimagined: A bibliometric–systematic literature review of governance, technology, and stakeholder-driven strategies for SDG impact. Business Strategy and the Environment, 34(6), 70070. https://doi.org/10.1002/bse.70070

Shahzad, K., Imran, F., & Butt, A. (2025). Digital transformation and changes in organizational structure: Empirical evidence from industrial organizations. Research-Technology Management, 68(5), 43–55. https://doi.org/10.1080/08956308.2025.2465706

Shahzad, U., & Muhammad, S. (2025). Digital pathways to sustainability: The role of Europe-Central Asia region's digitalization, trade, and geography maximizing sustainable development in China. Journal of Environmental Management, 389, 127341. https://doi.org/10.1016/j.jenvman.2025.127341

Sgambaro, L., Chiaroni, D., & Urbinati, A. (2026). Unpacking the enabling role of digital technologies in industrial symbiosis: A novel framework on digital functions and industrial symbiosis life-cycle. *Journal of Innovation & Knowledge*, 15, 100995. https://doi.org/10.1016/j.jik.2026.100995

Sjaifuddin, S. (2020). Environmental management of industrial estate based on eco-industrial parks: A system dynamics modeling. *Industrial Engineering and Management Systems*, 19(1), 211–224. https://doi.org/10.7232/iems.2020.19.1.211

Sousa, M. J., & de Bem Machado, A. (2024). Integrating the SDGs in corporate governance. In The Routledge Handbook of Accounting for the Sustainable Development Goals (pp. 169–187). *Routledge*. https://doi.org/10.4324/9781003404118-13

Spilotro, C., Secundo, G., Magaletti, N., Zini, E., Tognon, C., & Zerega, A. (2025). Data-Driven ESG KPIs Optimization: A Framework for Smart Buildings and Smart Factories. *Sustainability*, 17(23), 10837. https://doi.org/10.3390/su172310837

Stötzel, C. (2024). The Digital Ecosystem of Kenya. *Springer Fachmedien Wiesbaden*. https://doi.org/10.1007/978-3-658-45553-8

Sundqvist-Andberg, H., & Åkerman, M. (2022). Collaborative governance as a means of navigating the uncertainties of sustainability transformations: The case of Finnish food packaging. *Ecological Economics*, 197, 107455. https://doi.org/10.1016/j.ecolecon.2022.107455

Suta, A., & Tóth, Á. (2023). Systematic review on blockchain research for sustainability accounting applying methodology coding and text mining. *Cleaner Engineering and Technology,* 13, 100648. https://doi.org/10.1016/j.clet.2023.100648

Taddeo, R. (2016). Local industrial systems towards the eco-industrial parks: The model of the ecologically equipped industrial areas. *Journal of Cleaner Production*, 131, 189–197. https://doi.org/10.1016/j.jclepro.2016.05.051

Tariq, W., Chen, Y., Tariq, A., & Sumbal, M. S. (2026). Digital governance for sustainable development: A holistic review, framework, and roadmap. Technology in Society, 84, 103135. https://doi.org/10.1016/j.techsoc.2025.103135

Ullah, F. (2021). A beginner's guide to developing review-based conceptual frameworks in the built environment. *Architecture*, 1(1), 5. https://doi.org/10.3390/architecture1010003

Vuksanović-Herceg, I. V., Kuč, V., Mijušković, V. M., & Herceg, T. (2020). Challenges and driving forces for Industry 4.0 implementation. *Sustainability*, 12(10), 4208. https://doi.org/10.3390/su12104208

Voßbeck, N., & Fastenrath, S. (2024). How resilient are regional industrial decarbonization pathways? Insights from the building materials industry in Lower Austria. *Progress in Economic Geography*, 2(2), 100019. https://doi.org/10.1016/j.peg.2024.100019

Wang, D., & Shao, X. (2024). Research on the impact of digital transformation on the production efficiency of manufacturing enterprises: Institution-based analysis of the threshold effect. *International Review of Economics & Finance,* 91, 883–897. https://doi.org/10.1016/j.iref.2024.01.046

Wang, S., & Wang, D. (2022). Exploring the relationship between ESG performance and green bond issuance*. Frontiers in Public Health*, 10, 897577. https://doi.org/10.3389/fpubh.2022.897577

Wang, S., Zhang, Z., Wang, Z., & Liu, G. (2022). Exploring the multidimensional factors and emergence mechanisms of industrial symbiotic relationships based on machine learning. *Journal of Cleaner Production*, 382, 135169. https://doi.org/10.1016/j.jclepro.2022.135169

Wang, H., Qi, T., Qiao, X., Li, X., Ding, S., & Liu, Y. (2023). Method for ensuring the safety and effectiveness of wastewater treatment under centralized treatment mode by using a petrochemical park as case study. *Journal of Water Process Engineering*, 56, 104421. https://doi.org/10.1016/j.jwpe.2023.104421

Weng, S., Tao, W., & Lu, Y. (2024). Unlocking the carbon emission efficiency improvement path of technological innovation: A perspective on industrial restructuring and R&D element flows. Environmental Science and Pollution Research, 31(14), 21172–21188. https://doi.org/10.1007/s11356-024-32510-y

Yaqub, M. Z., & Alsabban, A. (2023). Industry-4.0-enabled digital transformation: Prospects, instruments, challenges, and implications for business strategies. *Sustainability*, 15(11), 8553. https://doi.org/10.3390/su15118553

Yang, Z., Na, J., & Dong, X. (2024). Corporate governance for sustainable development: A study on mechanism configuration. *Journal of Cleaner Production*, 457, 142509. https://doi.org/10.1016/j.jclepro.2024.142509

Zhao, H., Wang, H., Jin, S., & He, Z. (2023). Evolutionary game and simulation analysis of collaborative innovation mechanisms of industrial internet platform-based ecosystem. *Sustainability*, 15(6), 4884. https://doi.org/10.3390/su15064884

Zuhdi, S., Saputra, T., Hernimawati, & Dailiati, S. (2025). Dynamics of collaborative governance in sustainable waste bank management: power and interests of actors. *E3S Web of Conferences*, 678, 04001. https://doi.org/10.1051/e3sconf/202567804001