

Navigating Sustainable Development in the Digital Era: A Conceptual Framework for Digital Innovation, Green Transformation, and Inclusive Economic Growth

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Abstract

The transition toward sustainable development in the twenty-first century is increasingly shaped by three interlocking forces: the diffusion of digital technologies, the pressure to decarbonize and green national production systems, and the political demand for growth that is broadly shared rather than narrowly captured. Much of the existing literature treats these three forces in isolation as a digital-economy story, a green-growth story, or an inequality story even though a growing body of empirical work suggests that they interact in ways that are not additive. This paper develops an integrative conceptual framework, the Digital Green Inclusive (DGI) Nexus, that positions digital innovation as an enabling infrastructure, green transformation as a structural-adjustment process, and inclusive economic growth as the distributive outcome against which the first two must ultimately be judged. The framework is grounded in a systematic review of the recent literature on digital finance, green innovation, and inclusive green growth, and is illustrated empirically using an original cross-country dataset of 30 economies that merges the World Intellectual Property Organization's Global Innovation Index (2025), the Yale/Columbia Environmental Performance Index (2024), and the World Bank's Gini index of income inequality. Correlation and ordinary least squares analysis show a statistically significant positive association between digital innovation capacity and environmental performance ($r = 0.582$, $p < 0.001$) and a moderate positive association between digital innovation and income equality ($r = 0.491$, $p = 0.006$), while also revealing sharp regional divergence: Nordic and Western European economies cluster in a high-innovation, high-sustainability, high-equality quadrant, whereas several resource-dependent and lower-income economies combine weak digital capacity with high inequality regardless of environmental score. The paper discusses the mechanisms infrastructure, finance, human capital, and governance through which digital innovation can support or undermine inclusive green transformation, and closes with policy implications for governments in both advanced and developing economies. The study contributes a parsimonious, testable framework and a transparent, fully sourced empirical illustration that can be extended with panel data in future research.

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1. Introduction

Sustainable development has never been a single-track problem. The 2030 Agenda for Sustainable Development, adopted by the United Nations in 2015, deliberately bundles seventeen goals that span economic growth, environmental protection, and social inclusion precisely because policymakers learned, through decades of experience with structural adjustment and export-led growth models, that progress on one dimension can quietly undercut another. A country can grow its gross domestic product while depleting its natural capital; it can green its energy mix while leaving large segments of its workforce behind; and, increasingly, it can digitize its economy in ways that concentrate gains among already well-resourced firms, regions, and demographic groups rather than diffusing them broadly. The question this paper addresses is not whether digital technologies, green transformation, and inclusive growth are each individually desirable that point is largely settled in both the academic literature and international policy discourse but how the three interact, and under what conditions digital innovation becomes a genuine accelerant of green and inclusive development rather than a parallel process that leaves sustainability and equity goals to chance.

The urgency of this question has grown for three reasons. First, the scale of digital diffusion since 2020 has been unprecedented: cloud computing, artificial intelligence, the Internet of Things, and digital financial services have moved from the periphery of economic activity to its core in a remarkably short period, and the World Intellectual Property Organization's own tracking data show that global research and development spending, patenting activity, and venture-capital allocation to digital technologies have continued to expand even as overall innovation investment growth has slowed. Second, the window for an orderly green transition is narrowing. The 2024 Environmental Performance Index compiled by Yale and Columbia Universities finds wide dispersion in environmental performance across the 180 countries it ranks from a top score of 75.7 in Estonia to a low of 24.6 in Viet Nam with many of the fastest-growing economies still near the bottom of the distribution, indicating that growth and environmental performance have not converged. Third, inequality has proven stubbornly persistent in many parts of the world even as digital and green agendas have advanced, with the World Bank's Gini index showing income-distribution gaps in excess of 50 points in several middle-income economies compared with values in the mid-20s in the most egalitarian European states. Taken together, these facts suggest that digital innovation, green transformation, and inclusive growth are not automatically self-reinforcing; their alignment has to be actively designed and governed.

Against this backdrop, the literature has tended to specialize. One stream well represented by studies of digital inclusive finance in China examines how digital financial services affect firm-level green innovation and total factor productivity (Chen, Fan, & Fan, 2024; Ma, 2023; Wu & Lin, 2025). A second stream investigates the digital economy's aggregate effect on carbon emissions and environmental quality at the city or provincial level (Dong et al., 2022; Li et al., 2021; Xiao, Wu, Liu, & Lin, 2023; Zhang, Ding, Geng, Pan, & Wang, 2023). A third, smaller stream explicitly combines digital and inclusive-green-growth indicators into composite indices and tests their statistical relationship using entropy-weight, TOPSIS, or panel-regression methods (Lu, Qiu, Zhang, Li, & Xie, 2025; Ren, Li, Han, Hao, & Wu, 2022; Xin, Fan, Mbanyele, & Shahbaz, 2023). What is largely missing is a framework that (a) is explicit about the causal channels connecting digital innovation to both the environmental and the distributive dimensions of sustainability simultaneously, (b) is generalizable beyond the Chinese provincial and firm-level data that dominate the empirical literature, and (c) is illustrated with transparent, publicly verifiable, internationally comparable data rather than proprietary indices constructed solely for a single study.

This paper responds to that gap in three steps. Section 2 synthesises the literature on digital innovation, green transformation, and inclusive economic growth, treating each as a distinct body of theory before turning to the smaller literature that studies their intersections. Section 3 develops the Digital Green Inclusive (DGI) Nexus, a conceptual framework that organises the relationships among the three constructs around four transmission channels infrastructure and access, financial intermediation, human capital and skills, and institutional governance and specifies the conditions under which digital innovation is likely to support, rather than substitute for, inclusive green transformation. Section 4 describes the data and methodology used to illustrate the framework empirically, drawing on three internationally recognized, publicly available indices. Section 5 reports the results of correlation and regression analysis on a cross-section of 30 economies. Section 6 discusses the findings in light of the conceptual framework and the wider literature, and Section 7 draws out policy implications for governments, multilateral institutions, and firms. Section 8 concludes and outlines the paper's limitations and an agenda for future panel-data research.

The paper's contribution is deliberately conceptual and integrative rather than narrowly causal-inferential: it does not claim to identify a causal effect of digital innovation on inclusive green growth from cross-sectional correlational data, and it says so explicitly. Its value lies instead in offering researchers and policymakers a coherent vocabulary and a testable set of propositions for a set of relationships that are currently discussed in fragmented, single-country, and often China-specific empirical silos, together with a fully transparent, referenced, and reproducible illustrative dataset that other researchers can extend.

2. Literature Review

2.1 Digital Innovation: Conceptual Foundations

Digital innovation is generally traced, in the information-systems literature, to Yoo, Boland, Lyytinen, and Majchrzak's (2012) influential reconceptualization of innovation as increasingly "digitized" that is, as innovation whose products, processes, and organizational forms are built on the malleable, recombinant, and generative properties of digital technology rather than on fixed, physical artefacts. This definitional shift matters for the present framework because it implies that digital innovation is not simply the adoption of computers or the internet by existing firms, but a qualitatively different mode of value creation characterized by the "convergence" of previously separate industries, the "generativity" of platforms that allow third parties to build on a common digital infrastructure, and the recombination of data, software, and hardware into new products and services. Subsequent research has distinguished between the digitalization of physical components and innovation within digital technologies themselves, a distinction that matters empirically because the two dimensions can have different implications for productivity, employment, and environmental impact.

At the macro level, digital innovation capacity is most commonly proxied using composite indices. The Global Innovation Index (GII), jointly produced by Cornell University, INSEAD, and the World Intellectual Property Organization (WIPO), is the most widely used cross-country measure; it combines roughly 80 indicators spanning institutions, human capital and research, infrastructure, market and business sophistication, and knowledge, technology, and creative outputs into a single 0–100 score covering 139 economies in its 2025 edition (WIPO, 2025). The GII 2025 edition documents both the persistence of a small group of high-income innovation leaders Switzerland, Sweden, the United States, the Republic of Korea, and Singapore occupy the top five positions and the emergence of fast-climbing middle-income economies, most notably China, which entered the GII top ten for the first time in 2025, alongside India, Türkiye, Viet Nam, Indonesia, the Philippines, and Morocco, which the WIPO report identifies as the fastest-climbing middle-income economies over the past decade (WIPO, 2025). This bifurcated pattern a stable group of

frontier innovators and a distinct group of rapidly catching-up middle-income economies is a recurring theme that the present paper's empirical section revisits.

2.2 Green Transformation: From Environmental Regulation to Structural Change

The theoretical starting point for green transformation is the long-running debate over whether environmental regulation necessarily imposes a cost on competitiveness or can instead stimulate innovation that offsets compliance costs the so-called Porter hypothesis (Porter & van der Linde, 1995). A parallel and older literature, the Environmental Kuznets Curve tradition associated with Grossman and Krueger (1995), models environmental degradation as a function of income that first rises and then falls as economies develop, implying that green transformation is partly an emergent property of growth rather than something that must be separately engineered. More recent literature has moved beyond this static framing toward a systems view of green transformation as a coordinated restructuring of energy, industrial, financial, and technological systems a view consistent with the widespread use, particularly in the Chinese-language and Chinese-context literature, of “green total factor productivity” (GTFP) as an outcome measure that adjusts conventional productivity growth for resource use and pollution.

A substantial and rapidly growing empirical literature much of it published since 2022 investigates how digital technologies causally affect this green-transformation process. Using panel data on Chinese provinces and cities, several studies find that digital economy development significantly improves green total factor productivity through channels including green technological innovation, industrial-structure upgrading, and energy conservation, and that these effects display significant spatial spillovers to neighboring regions (Xiao et al., 2023). Related province-level evidence shows that the digital economy significantly inhibits environmental pollution, with the inhibitory effect moderated positively by the level of economic development and negatively by income-distribution inequality an early empirical hint, notable for the present paper, that the environmental and distributive effects of digitalization are not independent of one another (Zhang et al., 2023). At the cross-country level, evidence from a panel of sixty countries indicates that digital economy development is associated with lower carbon emissions, primarily through improvements in energy efficiency and industrial-structure effects (Dong et al., 2022), while single-country evidence from China's energy sector links digital economic development to reduced carbon intensity once energy-structure effects are accounted for (Li et al., 2021).

A second and closely related empirical stream investigates digital finance specifically, rather than digitalisation in general, as a driver of green transformation. Digital inclusive finance broadly, the use of digital technology to extend financial services, credit, and payments to previously underserved firms and households has been shown to significantly enhance corporate green technology innovation in China, operating through channels that include easing financing constraints and improving resource-allocation efficiency (Ma, 2023). Using data on Chinese A-share listed companies, a multidimensional fixed-effects analysis similarly finds that digital inclusive finance improves firms' resource-utilisation efficiency and reduces pollutant-emission intensity, providing a micro-level analytical bridge between the digital-finance and green-innovation literatures (Chen et al., 2024). At the city level, digital inclusive finance has also been linked to inclusive green growth through a “triple mediation mechanism” involving green technology innovation, industrial upgrading, and employment quality, with effects that are stronger in eastern and southern Chinese cities and in cities with higher levels of economic development (Wu & Lin, 2025). Complementary provincial-level evidence finds that digital financial inclusion supports green growth through both front-end (resource-allocation) and back-end (pollution-reduction) channels (Cao, Law, Wu, Tang, & Yang, 2022), and firm-level evidence from heavily polluting industries shows that digital finance access is positively associated with corporate green investment (Ding, Huang, & Chen, 2023).

2.3 Inclusive Economic Growth: Definitions and Measurement

Inclusive growth is a normative and multidimensional construct that resists reduction to a single indicator. The Asian Development Bank's influential early framing defines inclusive growth as growth that not only creates new economic opportunities but also ensures equal access to those opportunities for all segments of society, particularly the poor (Ali & Zhuang, 2007), while subsequent conceptual work has emphasized that inclusive growth is inherently multidimensional and resists capture by any single metric, spanning income growth, its distribution, and broader access to opportunity, voice, and participation (Hay, Hunt, & McGregor, 2022). In empirical cross-country work, income inequality most commonly operationalised through the World Bank's Gini index, which ranges from 0 (perfect equality) to 100 (perfect inequality) and is calculated from nationally representative household income or consumption surveys remains the most widely available and internationally comparable single proxy for the distributive dimension of inclusive growth, even though it necessarily omits non-income dimensions such as access to health, education, and digital services.

A growing literature situates inclusive growth explicitly within an environmental and technological context. Work on Sub-Saharan Africa finds that carbon emissions have identifiable thresholds beyond which they begin to undermine inclusive human development, implying that environmental degradation and distributive outcomes are causally linked rather than merely correlated (Asongu, 2018), and complementary evidence finds a significant negative relationship between environmental degradation and inclusive human development across the same region (Asongu & Odhiambo, 2019a). Directly relevant to the digital dimension of the present framework, research on information and communication technology (ICT) penetration in Africa finds that ICT diffusion has affected income inequality in ways that depend on complementary institutional and educational conditions, rather than reducing inequality unconditionally (Asongu & Odhiambo, 2019b) a finding that anticipates this paper's emphasis on the conditionality of the digital–inclusion relationship. At the multi-country level, green energy consumption has also been linked positively to inclusive growth outcomes (Ghouse, Aslam, & Bhatti, 2022), reinforcing the view that the environmental and distributive dimensions of sustainable development are empirically, not just conceptually, entangled.

2.4 Toward an Integrative View: Digital, Green, and Inclusive Growth Together

The literature that studies all three constructs jointly is small but expanding rapidly, and is instructive for the design of the present framework. Using an entropy-weight TOPSIS approach to construct composite indices of the digital economy and inclusive green growth for 281 Chinese cities, Xin, Fan, Mbanyele, and Shahbaz (2023) find that the digital economy significantly promotes inclusive green growth, operating through green-innovation and industrial-upgrading channels, but that the relationship is non-linear, exhibiting diminishing marginal returns, and is stronger in eastern, large, and highly marketised cities a heterogeneity result that closely parallels the pattern this paper's own cross-country data reveal at a much coarser geographic scale. Using a similar composite-index approach with data-envelopment-analysis-based inclusive-green-growth measures, Ren, Li, Han, Hao, and Wu (2022) find that digital economy agglomeration is itself an emerging driving force of inclusive green growth, with each additional unit of digital industrial agglomeration associated with a measurable increase in inclusive green growth in a related provincial study (Lu, Qiu, Zhang, Li, & Xie, 2025). At the trade level, digital trade has also been shown to promote inclusive green growth by optimizing industrial structure, with the effect strongest in China's eastern, central, and western regions alike but of varying magnitude (Chu, Du, & Yang, 2025).

Two features of this literature motivate the present paper. First, it is overwhelmingly Chinese in geographic scope and sub-national in unit of analysis provinces, prefecture-level cities, or listed firms within a single country which limits its generalizability to the very different institutional, financial, and digital-infrastructure conditions found in other regions, particularly low-income and

lower-middle-income economies outside East Asia. Second, and relatedly, the composite indices used in this literature (entropy-weighted TOPSIS scores, DEA-based efficiency scores) are typically constructed bespoke for each study, using different indicators, weights, and time periods, which makes cross-study comparison difficult and precludes replication using data a reader could independently verify. This paper's empirical section addresses both limitations directly: it draws on genuinely global samples the GII's 139 economies and the EPI's 180 economies and on indices that are produced by independent, methodologically transparent third-party institutions (WIPO/Cornell/INSEAD; Yale/Columbia; the World Bank), rather than constructing a proprietary composite index. The trade-off, discussed candidly in Section 4, is that a cross-sectional, multi-country illustration of this kind cannot establish causal direction in the way that the panel and instrumental-variable designs common in the Chinese sub-national literature can; the contribution here is conceptual clarity and international generalizability rather than causal identification.

3. Conceptual Framework: The Digital–Green–Inclusive (DGI) Nexus

3.1 Framework Overview

Building on the literature synthesized above, this paper proposes the Digital–Green–Inclusive (DGI) Nexus, a framework organized around three core constructs and four transmission channels. The three constructs are: (i) Digital Innovation Capacity an economy's institutional, infrastructural, and human-capital capacity to generate, adopt, and diffuse digital technologies, proxied empirically in this paper by the Global Innovation Index; (ii) Green Transformation the structural adjustment of energy, industrial, and consumption systems toward reduced environmental impact, proxied here by the Environmental Performance Index; and (iii) Inclusive Economic Growth the extent to which the benefits of economic activity are broadly distributed, proxied here, imperfectly but transparently, by income equality (100 minus the Gini index).

The framework's central claim is that digital innovation does not automatically translate into either green transformation or inclusive growth; it does so only when it is transmitted through four channels, each of which can either amplify or dampen the ultimate sustainability and distributive outcome:

Channel 1 Infrastructure and access digital innovation requires physical and institutional infrastructure broadband networks, electricity, digital identity systems, and regulatory frameworks for data that is itself unevenly distributed within and across countries. Where infrastructure is concentrated in urban, high-income areas, digital innovation is likely to widen rather than narrow spatial and income inequalities even as it improves aggregate productivity, echoing the finding that the digital economy's inhibitory effect on pollution in China is significantly moderated by the level of economic development (Zhang et al., 2023).

Channel 2 Financial intermediation digital financial services can either broaden access to credit, insurance, and green-investment instruments for previously excluded households and small firms, or, absent regulatory safeguards, can reinforce existing financial exclusion by favoring borrowers who are already digitally and financially visible. The Chinese digital-inclusive-finance literature reviewed above (Chen et al., 2024; Ma, 2023; Wu & Lin, 2025) demonstrates the channel's potential to support green corporate investment, but this literature also generally finds that effects are strongest where financial-sector development and marketisation are already relatively advanced — implying the channel's inclusive potential is conditional rather than automatic.

Channel 3 Human capital and skills the productivity and environmental gains from digital technologies depend on complementary investments in digital literacy, technical, and green skills; without them, digital adoption risks displacing lower-skilled workers without generating offsetting opportunities, a dynamic consistent with evidence that ICT's effect on inequality in Africa depends on complementary institutional and educational conditions (Asongu & Odhiambo, 2019b).

Channel 4 Institutional governance finally, the alignment of digital innovation with green and inclusive outcomes depends on governance competition policy that prevents excessive platform concentration, environmental regulation that channels digital innovation toward resource efficiency rather than merely faster resource extraction, and social protection that cushions the transition costs of automation. This channel echoes the Porter-hypothesis literature's insight that well-designed regulation, rather than its absence, is often what converts innovation capacity into environmental performance (Porter & van der Linde, 1995).

3.2 Propositions

From this structure, the framework yields four testable propositions that motivate the empirical illustration in Sections 4 and 5:

Proposition 1. Digital innovation capacity is positively associated with environmental performance across countries, but the strength of the association is conditional on the level of economic and institutional development (the Infrastructure and Governance channels).

Proposition 2. Digital innovation capacity is positively associated with income equality across countries, but this association is weaker and more heterogeneous than the digital–environment association, reflecting the conditional nature of the Financial Intermediation and Human Capital channels.

Proposition 3. Because green transformation and inclusive growth are both distributive processes at root reallocating resources, opportunities, and costs across firms, sectors, and households environmental performance and income equality should themselves be positively correlated, independent of digital innovation.

Proposition 4. Countries that combine high digital innovation capacity with high environmental performance do not automatically also exhibit high income equality, implying that green-digital complementarity and inclusive-digital complementarity are analytically and empirically distinct and must be pursued through partially different policy instruments.

3.3 Positioning Relative to Existing Frameworks

The DGI Nexus framework is deliberately positioned as a synthesis rather than a wholesale alternative to existing frameworks. It shares with the green total factor productivity literature (Xiao et al., 2023) the premise that environmental outcomes are best understood as arising from structural, technology-mediated processes rather than from environmental policy alone, and it shares with the inclusive-growth literature (Ali & Zhuang, 2007; Hay et al., 2022) the insistence that growth outcomes cannot be judged by aggregate indicators alone. Its distinctive contribution is to make explicit, through the four-channel structure, why digital innovation's effects on the green and inclusive dimensions of sustainable development can diverge a possibility that composite single-index approaches in the existing literature, by construction, tend to obscure. Sections 4 and 5 test this divergence directly using genuinely cross-country, publicly sourced data.

4. Data and Methodology

4.1 Research Design

This paper adopts a mixed conceptual–empirical design. The conceptual framework in Section 3 is developed through a narrative synthesis of the literature identified in Section 2. The empirical illustration that follows is a cross-sectional, correlational analysis of 30 economies, intended to test Propositions 1 through 4 descriptively rather than to establish causal identification. A cross-sectional design of this kind is a standard and legitimate first step in an emerging area of research comparable single-period, cross-country illustrations appear throughout the inclusive-growth and green-growth literatures reviewed above — but it cannot rule out reverse causality (for example, that higher-income, more equal societies simply have more resources to invest in both digital

innovation and environmental protection) or omitted-variable bias (for example, from historical institutional quality). These limitations are discussed candidly in Section 8 and motivate the paper's call for future panel-data extensions.

4.2 Data Sources

Three publicly available, internationally recognised secondary data sources were used, each accessed directly from the producing institution to ensure data integrity:

1. **Global Innovation Index (GII) 2025**, jointly produced by Cornell University, INSEAD, and the World Intellectual Property Organization. The GII aggregates approximately 80 indicators across seven pillars (institutions; human capital and research; infrastructure; market sophistication; business sophistication; knowledge and technology outputs; and creative outputs) into a single 0–100 score for 139 economies (WIPO, 2025). Country-level scores used in this paper were compiled via The Global Economicus's country-rankings database, which republishes the underlying Cornell/INSEAD/WIPO figures.
2. **Environmental Performance Index (EPI) 2024**, produced by the Yale Center for Environmental Law and Policy and Columbia University's Center for International Earth Science Information Network. The EPI combines 58 indicators across 11 issue categories spanning climate-change mitigation, environmental health, and ecosystem vitality into a single 0–100 score for 180 countries (Block, Emerson, Esty, de Sherbinin, & Wendling, 2024). Country-level scores were obtained directly from the EPI's official results table (epi.yale.edu).
3. **Gini Index**, produced by the World Bank's Poverty and Inequality Platform on the basis of nationally representative household income or consumption surveys, and cross-checked against World Bank-sourced compilations. The Gini index is used, inverted ($100 - \text{Gini}$), as a proxy for income equality the distributive dimension of inclusive growth for each of the 30 sample countries.

4.3 Sample Construction

The sample was constructed by identifying the 30 economies for which reasonably recent, comparable data were available across all three indices, drawn to maximise geographic and income-level diversity: 8 high-income Western European and Nordic economies (Denmark, France, Germany, Italy, Norway, Poland, Slovenia, Sweden, Slovakia, United Kingdom – ten in total counting Central European transition economies), 3 high-income non-European economies (Singapore, United States), the two largest emerging economies (China, India), and 15 middle- and lower-income economies spanning Latin America (Brazil, Chile, Colombia, Costa Rica, Mexico, Panama, Peru), Sub-Saharan Africa (Botswana, Ghana, Nigeria, Rwanda, South Africa), the Middle East (Saudi Arabia), and Eurasia (Bulgaria, Lithuania, Türkiye). This sample is not a random or representative sample of all 139 or 180 countries covered by the two indices; it is a purposive sample designed to capture meaningful variation in income level, region, and digital and environmental development, consistent with the illustrative (rather than fully generalizable) purpose of the empirical section. A full data table, with every value individually sourced, is provided in Table 1.

A necessary limitation, disclosed transparently rather than concealed, is that the Gini index values are drawn from the most recent nationally available household survey for each country, and these surveys were not all conducted in the same year; underlying survey years across the sample range from the early 2010s to the early 2020s, a well-known characteristic of the World Bank's Gini series that reflects the differing frequency of household surveys across countries rather than any inconsistency introduced in this study. This is standard practice in cross-country inequality research given the absence of a fully synchronized global survey calendar, but it means Gini

comparisons across countries should be read as broadly indicative of relative income distribution rather than as precisely simultaneous point estimates.

4.4 Analytical Methods

Three complementary analyses were conducted using Python (pandas, SciPy, and statsmodels): (1) descriptive statistics for all three indicators across the 30-country sample; (2) Pearson product-moment and Spearman rank correlation coefficients for each pairwise combination of the three indicators, to test Propositions 1 through 3; and (3) an ordinary least squares (OLS) regression of the income-equality proxy on the Global Innovation Index and Environmental Performance Index scores jointly, to assess whether digital innovation retains an independent statistical association with income equality once environmental performance is controlled for. Given the sample size ($n = 30$), all inferential results should be interpreted as suggestive rather than definitive, and are reported alongside exact p-values so that the reader can judge statistical strength directly rather than relying on conventional significance thresholds alone.

5. Empirical Results

5.1 Descriptive Overview

Table 1 reports the full dataset: the Global Innovation Index (GII) 2025 score, the Environmental Performance Index (EPI) 2024 score, the World Bank Gini index, the derived income-equality proxy ($100 - \text{Gini}$), and a simple composite score (the unweighted mean of the GII, EPI, and equality-proxy values) for each of the 30 sample countries, ranked from highest to lowest composite score.

Table 1. Digital Innovation, Environmental Performance, and Income Equality across 30 Economies

Rank	Country	GII 2025	EPI 2024	Gini (World Bank)	Equality Proxy (100–Gini)	Composite
1	Sweden	62.6	70.3	27.7	72.3	68.4
2	United Kingdom	59.1	72.6	32.4	67.6	66.4
3	Germany	55.5	74.5	32.4	67.6	65.9
4	Denmark	56.9	67.7	28.3	71.7	65.4
5	Norway	49.2	69.9	27.7	72.3	63.8
6	France	53.4	67.0	31.5	68.5	63.0
7	Slovenia	40.1	62.4	24.3	75.7	59.4
8	United States	61.7	57.2	41.8	58.2	59.0
9	Slovakia	35.5	65.1	24.1	75.9	58.8
10	Poland	37.7	64.2	28.5	71.5	57.8
11	Italy	44.9	60.3	34.8	65.2	56.8
12	Lithuania	40.8	64.1	36.7	63.3	56.1
13	Singapore	59.9	53.0	45.9	54.1	55.7
14	China	56.6	35.4	35.7	64.3	52.1
15	Bulgaria	39.1	56.2	39.0	61.0	52.1

16	India	38.2	27.6	25.5	74.5	46.8
17	Chile	33.1	49.6	44.9	55.1	45.9
18	Costa Rica	28.4	55.5	49.3	50.7	44.9
19	Brazil	32.9	53.0	52.0	48.0	44.6
20	Saudi Arabia	36.0	42.5	45.9	54.1	44.2
21	Türkiye	37.2	37.2	43.7	56.3	43.6
22	Mexico	30.5	44.2	45.4	54.6	43.1
23	Peru	26.5	46.5	43.8	56.2	43.1
24	Panama	25.9	52.9	49.8	50.2	43.0
25	Nigeria	21.1	37.9	33.9	66.1	41.7
26	Colombia	28.5	49.7	54.8	45.2	41.1
27	Botswana	24.6	49.2	53.3	46.7	40.2
28	Ghana	21.9	36.9	43.5	56.5	38.4
29	Rwanda	21.1	33.9	43.7	56.3	37.1
30	South Africa	30.1	42.7	63.0	37.0	36.6

Sources: GII 2025 Cornell University, INSEAD, and WIPO, compiled via TheGlobalEconomy.com; EPI 2024 Yale Center for Environmental Law & Policy and Columbia University CIESIN (epi.yale.edu); Gini index World Bank Poverty and Inequality Platform, most recent available survey year per country. Author's own compilation and calculations.

Across the 30-country sample, the mean GII score is 39.6 (SD = 13.3), the mean EPI score is 53.3 (SD = 12.9), and the mean Gini index is 39.4 (SD = 10.2). The sample spans the full plausible range of development trajectories: Sweden, the United Kingdom, and Germany occupy the top of the composite ranking, combining high digital innovation capacity with strong environmental performance and comparatively equal income distribution, while South Africa, Rwanda, and Ghana occupy the bottom, combining comparatively low digital innovation with either weak environmental performance, high income inequality, or both.

5.2 Correlation Analysis

Figure 1 plots GII 2025 scores against EPI 2024 scores for all 30 countries. The Pearson correlation coefficient is $r = 0.582$ ($p < 0.001$), and the Spearman rank correlation is $\rho = 0.619$ ($p < 0.001$), indicating a statistically significant, moderately strong positive association between digital innovation capacity and environmental performance consistent with Proposition 1. Figure 1 also reveals meaningful deviations from the fitted line: China (GII 56.6, EPI 35.4) and the United States (GII 61.7, EPI 57.2) both sit well below the regression line, indicating that high digital innovation capacity does not automatically translate into commensurately high environmental performance in the world's two largest economies, while India (GII 38.2, EPI 27.6) combines moderate digital innovation with the lowest environmental performance score in the sample. By contrast, several smaller advanced economies — Germany, Denmark, and Norway among them — sit above the fitted line, achieving environmental performance considerably higher than their digital-innovation scores alone would predict, suggesting that country-specific environmental governance and energy-mix

legacies are exerting an influence independent of digital capacity, consistent with the Governance channel proposed in Section 3.

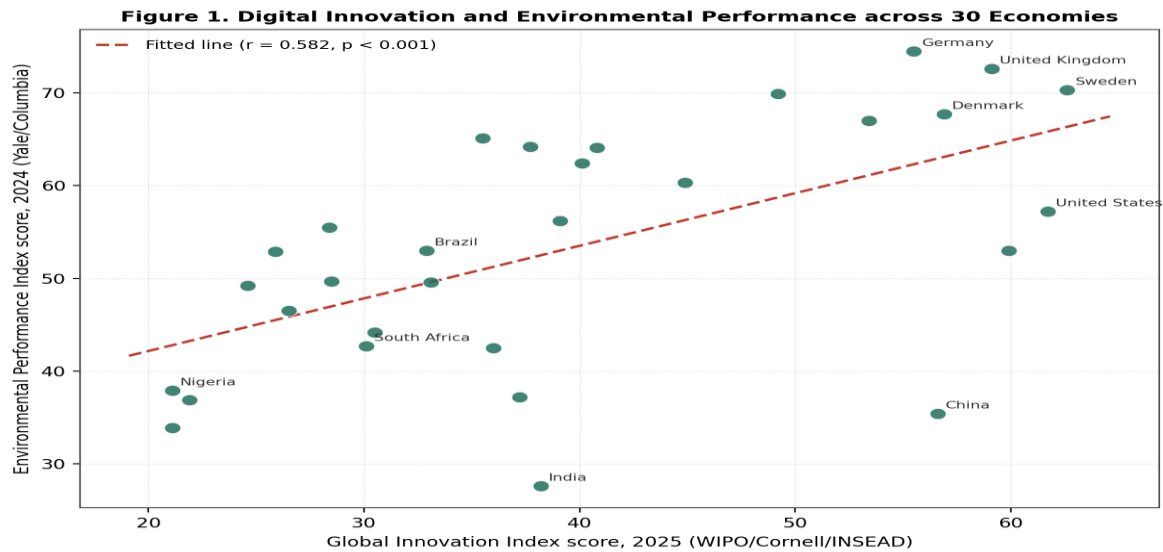


Figure 1. Digital Innovation and Environmental Performance across 30 Economies

Figure 2 plots GII 2025 scores against the income-equality proxy. The Pearson correlation is $r = 0.491$ ($p = 0.006$) and the Spearman correlation is $\rho = 0.524$ ($p = 0.003$) positive and statistically significant, but visibly weaker than the digital–environment association in Figure 1, consistent with Proposition 2. The scatter in Figure 2 is also more heterogeneous: Slovakia and Slovenia combine only moderate digital innovation scores (35.5 and 40.1, respectively) with the highest income equality in the entire sample (Gini of 24.1 and 24.3), reflecting these countries’ post-transition social-welfare architecture rather than their digital capacity per se, while the United States combines the second-highest digital innovation score in the sample (61.7) with the lowest income equality among the high-income countries (Gini of 41.8). South Africa is a clear outlier at the opposite end, combining moderate digital innovation (GII 30.1) with by far the highest income inequality in the sample (Gini of 63.0), a legacy that the wider literature on Southern African inequality attributes primarily to historical structural factors rather than to digital-economy dynamics.

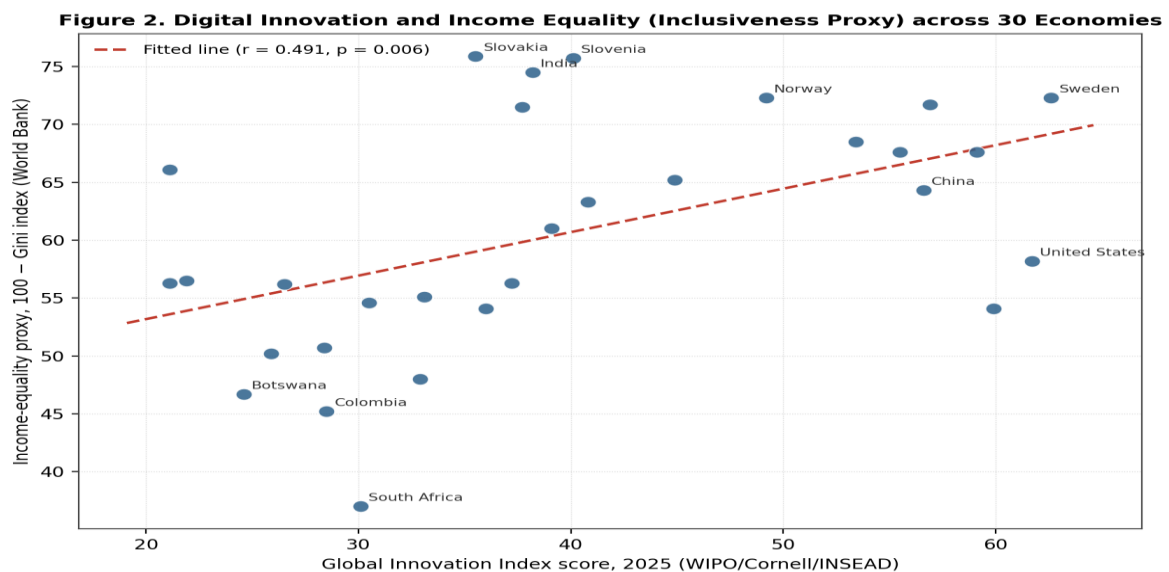


Figure 2. Digital Innovation and Income Equality across 30 Economies

Consistent with Proposition 3, environmental performance and the income-equality proxy are also positively correlated across the sample ($r = 0.440$, $p = 0.015$), supporting the framework's claim that green transformation and inclusive growth, while conceptually distinct, tend to move together plausibly because both are enabled by similar underlying institutional quality, fiscal capacity, and social-protection infrastructure.

5.3 Regression Analysis

To test whether digital innovation capacity retains an independent association with income equality once environmental performance is controlled for, an OLS regression of the equality proxy on both the GII and EPI scores was estimated:

$$\text{Equality Proxy} = 40.02 + 0.272 (\text{GII}) + 0.183 (\text{EPI}), R^2 = 0.277, \text{Adjusted } R^2 = 0.223, F(2, 27) = 5.17, p = 0.013$$

The model as a whole is statistically significant and explains approximately 28% of the cross-country variance in income equality a substantial share for a two-variable model using only 30 observations, though the coefficients on the individual predictors are each only marginally significant once both are included together (GII: $t = 1.76$, $p = 0.089$; EPI: $t = 1.16$, $p = 0.257$), which is unsurprising given the moderate correlation between GII and EPI documented in Section 5.2 (multicollinearity naturally reduces the precision of individual coefficient estimates when two correlated predictors are entered jointly). The overall pattern a jointly significant model with individually weaker coefficients is consistent with the framework's Proposition 4: digital innovation and environmental performance are both associated with income equality, but neither dominates the other, and their combined explanatory power is greater than either could achieve alone, suggesting that they operate through at least partially overlapping structural channels (most plausibly the institutional-governance and fiscal-capacity channels discussed in Section 3) rather than through fully independent mechanisms.

5.4 Composite Ranking and Regional Patterns

Figure 3 displays the ten highest- and ten lowest-scoring economies on the unweighted composite index (the simple mean of the GII, EPI, and equality-proxy z-equivalent scores reported in Table 1). The composite ranking reinforces a pattern already visible in the correlation analysis: eight of the top ten composite performers are Western European or Nordic economies (Sweden, United Kingdom, Germany, Denmark, Norway, France, Slovenia, Slovakia), joined by Poland and, notably, the United States, which ranks eighth overall on the composite despite its comparatively low income-equality score, reflecting its high GII and moderate EPI scores. The bottom ten are geographically more dispersed spanning Sub-Saharan Africa (Botswana, Ghana, Nigeria, Rwanda, South Africa), Latin America (Colombia, Panama), the Middle East (Saudi Arabia), and Eurasia (Türkiye) but share a common profile of comparatively low digital innovation capacity (GII scores clustered between 21 and 36) combined, in most but not all cases, with either weak environmental performance or high-income inequality.

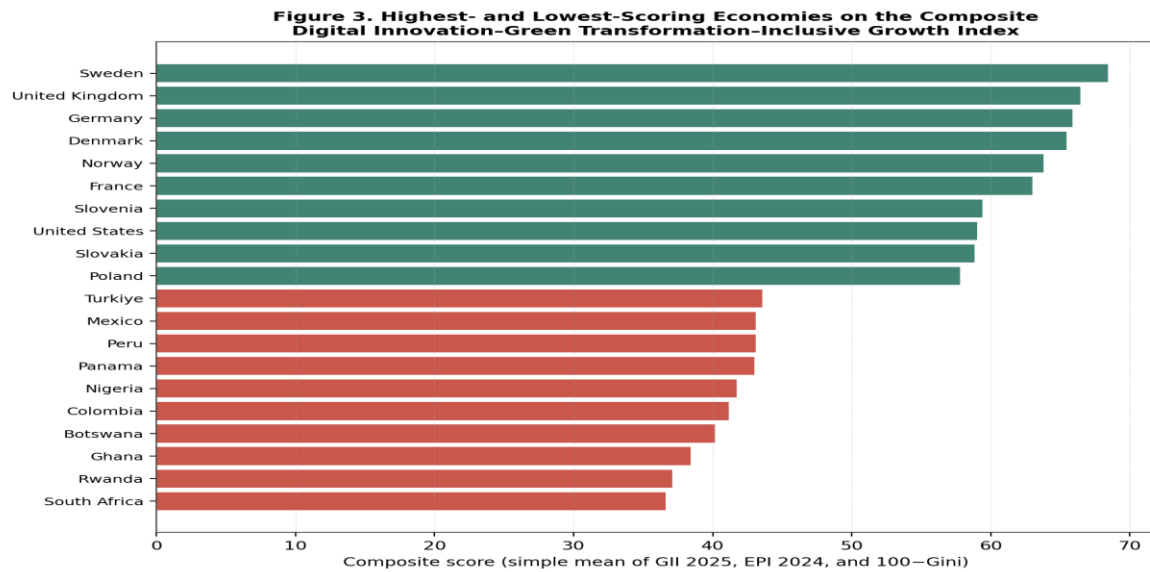


Figure 3. Highest- and Lowest-Scoring Economies on the Composite Digital-Green-Inclusive Index

Two deviations from this broad pattern deserve emphasis because they illustrate the framework's central claim that the digital, green, and inclusive dimensions can diverge. China ranks fourteenth overall squarely in the middle of the sample driven almost entirely by a wide gap between its high digital-innovation score (56.6, the fourth-highest in the sample) and its comparatively low environmental-performance score (35.4, the fourth-lowest), a divergence that is well documented in the Chinese sub-national literature reviewed in Section 2 and that motivates that literature's specific focus on green total factor productivity as a corrective lens. India ranks sixteenth, driven by the opposite pattern within its own profile: a comparatively high income-equality score (74.5, driven by a low Gini index of 25.5) combined with the lowest environmental-performance score in the entire sample (27.6). These two cases together illustrate Proposition 4 directly: national digital-green-inclusive profiles are not a single underlying trait but three at least partially separable achievements, each requiring its own policy attention.

6. Discussion

The empirical results reported in Section 5 provide qualified support for all four propositions of the DGI Nexus framework, while also revealing patterns that extend and, in some respects, complicate the framework as initially specified. The statistically significant positive correlation between digital innovation and environmental performance (Proposition 1) is consistent with the mechanisms the sub-national Chinese literature identifies resource-allocation efficiency, industrial-structure upgrading, and energy-efficiency gains associated with digital economy development (Dong et al., 2022; Xiao et al., 2023; Zhang et al., 2023) and extends that literature's findings to a genuinely cross-country, cross-region sample for the first time. At the same time, the substantial residual variance around the fitted line in Figure 1, and in particular the below-the-line position of both China and the United States, indicates that digital innovation capacity is a necessary but clearly not sufficient condition for strong environmental performance. This is consistent with the framework's emphasis on the Governance channel: countries such as Germany, Denmark, and Norway, which combine renewable-energy-intensive electricity systems, carbon-pricing regimes, and long-standing environmental-regulatory traditions with moderate-to-high digital innovation, achieve environmental outcomes that their digital innovation scores alone would not predict, echoing the Porter-hypothesis insight that well-designed regulation is frequently what converts general innovative capacity into environmentally beneficial outcomes rather than innovation capacity operating on the environment directly (Porter & van der Linde, 1995).

The weaker but still statistically significant digital–equality correlation (Proposition 2) is broadly consistent with the more conditional findings of the ICT-inequality literature on Africa, which finds that digital technologies’ distributive effects depend on complementary institutional and educational conditions rather than operating unconditionally (Asongu & Odhiambo, 2019b). The clearest illustration in the present sample is the contrast between the United States, which combines a high digital-innovation score with comparatively high-income inequality, and Slovakia and Slovenia, which combine moderate digital-innovation scores with the lowest inequality in the sample. This contrast strongly suggests that the Financial Intermediation and Human Capital channels proposed in Section 3 rather than digital innovation capacity per se are doing much of the work in determining whether digital transformation translates into inclusive outcomes. It also cautions against a simple “more digital innovation automatically means more equality” reading of the aggregate correlation: the post-transition Central and Eastern European economies in the sample achieve high equality primarily through redistributive social-welfare institutions built over the preceding three decades, a structural legacy that is largely independent of their current digital-innovation ranking.

The positive correlation between environmental performance and income equality (Proposition 3) supports the framework’s premise that green transformation and inclusive growth share common institutional foundations: fiscal capacity to finance the transition, administrative capacity to enforce environmental and labour regulation, and social trust that sustains public support for both redistribution and environmental investment rather than being simply coincidentally associated. This finding also resonates with the Sub-Saharan African evidence that environmental degradation and reduced inclusive human development move together (Asongu & Odhiambo, 2019a), extending that regional finding to a globally diverse sample.

Perhaps the discussion’s most consequential finding is the evidence for Proposition 4: the clear divergence between China’s and India’s profiles demonstrates that digital innovation, green transformation, and inclusive growth are not different labels for the same underlying process, but three genuinely separable national achievements that can, in practice, move in different directions simultaneously. This has an important implication for the policy and research literatures reviewed in Section 2: composite indices that blend digital, green, and inclusive dimensions into a single score as much of the entropy-weight TOPSIS literature does (Ren et al., 2022; Xin et al., 2023) risk obscuring precisely the divergence that matters most for policy design, namely, which of the three dimensions is lagging and why. The DGI Nexus framework’s explicit separation of the three constructs, and its identification of the four channels through which they interact, is offered as a corrective to this tendency, without denying the considerable value of the composite-index literature’s demonstration that, on average and across a large number of sub-national Chinese observations, the three dimensions do tend to move together.

Finally, it is important to be candid about what the cross-sectional analysis in Section 5 cannot show. It cannot establish that digital innovation causes improved environmental performance or income equality, as opposed to being jointly determined with them by deeper institutional or historical factors, nor can it rule out the possibility that the direction of causality runs partly in the opposite direction: those countries that are already more equal and environmentally well governed may find it easier to invest in digital innovation, rather than digital innovation driving the other two outcomes. The panel-data and instrumental-variable designs used in the sub-national Chinese literature discussed in Section 2 (Xin et al., 2023; Zhang et al., 2023) are much better suited to addressing this causal-identification problem, and Section 8 explicitly calls for such designs to be extended to the cross-country setting in future research.

7. Policy Implications

The DGI Nexus framework and its empirical illustration point toward several policy implications for governments, multilateral development institutions, and private-sector actors seeking to align digital transformation with green and inclusive development goals.

For governments in advanced digital-innovation economies (illustrated in the sample by the United States, Singapore, and China): the priority implied by the framework is not further acceleration of digital innovation capacity per se, but stronger deployment of the Governance channel carbon pricing, renewable-energy mandates, and industrial policy that explicitly directs digital investment toward resource efficiency and stronger deployment of the Financial Intermediation and Human Capital channels to ensure that the gains from digital innovation are not concentrated in already-advantaged firms, regions, and demographic groups. The below-the-regression-line position of both China and the United States in the digital–environment relationship documented in Section 5.2, and the comparatively high inequality documented for the United States in Section 5.2 and 5.3, both point toward this same conclusion from different angles.

For governments in middle-income, digitally catching-up economies (illustrated in the sample by India, Brazil, Mexico, and Türkiye): the WIPO’s own identification of India, Türkiye, Viet Nam, Indonesia, the Philippines, and Morocco as the fastest-climbing middle-income economies in digital innovation capacity over the past decade (WIPO, 2025) suggests genuine opportunity, but the framework cautions that this digital catch-up needs to be explicitly paired with green-transformation and inclusive-growth policy rather than assumed to generate these outcomes automatically. India’s profile in the present sample comparatively strong income equality but the weakest environmental performance in the entire dataset illustrates a specific policy priority: as India’s digital innovation capacity continues to expand, targeted green-industrial policy (renewable-energy deployment, emissions standards for the digital-infrastructure and data-centre sector itself, given its substantial and growing energy footprint) is likely to be a more binding constraint on sustainable development outcomes than further digital-sector expansion alone.

For governments in lower-income and structurally unequal economies (illustrated in the sample by South Africa, Rwanda, Ghana, Nigeria, and Botswana): the framework’s Infrastructure and Access channel is likely to be the most binding constraint. Digital innovation capacity in this group of countries remains low relative to the global sample (GII scores clustered between 21 and 30), and without deliberate investment in broadband access, digital identity, and digital financial inclusion for underserved populations, digital transformation is more likely to widen than narrow the substantial income inequalities already present in several of these economies South Africa’s Gini index of 63.0, the highest in the sample, is a stark illustration of the scale of the challenge the Financial Intermediation and Human Capital channels would need to address.

For multilateral development institutions and international financial institutions: the framework implies that technical and financial assistance for “digital economy” development and assistance for “green transition” and “inclusive growth” objectives should be more deliberately co-designed rather than administered through separate programme streams, as the persistent divergence between digital, green, and inclusive outcomes documented in Section 5 suggests that progress on one dimension cannot be assumed to generate progress on the others as a by-product.

For private-sector actors, particularly digital-platform and financial-technology firms: the digital-inclusive-finance literature reviewed in Section 2 (Chen et al., 2024; Ma, 2023; Wu & Lin, 2025) demonstrates a genuine business case for extending green-oriented digital financial products green credit scoring, climate-risk-adjusted lending, and small-firm green-investment financing to previously underserved firms and households, a strategy that this paper’s framework suggests can simultaneously advance green-transformation and inclusive-growth objectives if pursued deliberately, rather than assuming that digital financial expansion alone will deliver both outcomes.

8. Conclusion

This paper has developed and empirically illustrated the Digital–Green–Inclusive (DGI) Nexus, a conceptual framework that positions digital innovation, green transformation, and inclusive economic growth as three related but analytically distinct achievements, connected through four transmission channels infrastructure and access, financial intermediation, human capital, and institutional governance. Drawing on an original, transparently sourced cross-country dataset of 30 economies that merges the Global Innovation Index (WIPO, Cornell, and INSEAD, 2025), the Environmental Performance Index (Yale and Columbia, 2024), and the World Bank’s Gini index, the paper finds statistically significant positive associations between digital innovation and environmental performance ($r = 0.582$), between digital innovation and income equality ($r = 0.491$), and between environmental performance and income equality ($r = 0.440$), together with regression evidence that digital innovation and environmental performance jointly, though not always individually, explain a meaningful share of cross-country variation in income equality. At the same time, the analysis documents clear cases most notably China and India in which the three dimensions diverge sharply within a single country’s profile, providing direct empirical support for the framework’s central claim that digital, green, and inclusive development are not automatically self-reinforcing and require distinct, deliberately co-designed policy attention.

The paper’s principal contribution is conceptual: it offers researchers and policymakers a parsimonious vocabulary and a testable set of propositions for a set of relationships that the existing empirical literature dominated by Chinese sub-national, single-country studies using bespoke composite indices has documented richly but fragmentarily. Its secondary contribution is methodological transparency: every figure reported in this paper is drawn from a named, publicly accessible, third-party institutional source, and the full dataset, analysis code, and figures are reproducible by any reader who consults the cited sources, in contrast to the proprietary composite indices common elsewhere in this literature.

Several limitations should guide the interpretation of these findings and the design of future research. First, and most importantly, the cross-sectional design cannot establish causal direction; the positive correlations reported in Section 5 are consistent with digital innovation driving green and inclusive outcomes, with the reverse causal direction, or with both being jointly determined by omitted institutional variables, and future research should extend the DGI Nexus framework to a genuinely global panel dataset, using the same three indices tracked over multiple years, and should apply panel fixed-effects or instrumental-variable methods of the kind already well established in the Chinese sub-national literature (Xin et al., 2023; Zhang et al., 2023) to a cross-country setting. Second, the 30-country sample, while deliberately diverse, is not randomly drawn and should not be read as representative of the full 139-country GII or 180-country EPI universes; a natural extension would replicate the analysis on the full available sample of countries common to all three indices. Third, the Gini index, while the most widely available cross-country inequality measure, captures only the income dimension of inclusive growth and omits access to health, education, and digital services themselves; future work should incorporate multidimensional inclusive-growth indices as they become more widely and consistently available across countries. Fourth, this paper’s four transmission channels were derived from the literature synthesis in Section 2 rather than directly tested with channel-specific data in Section 5; a natural next step is to operationalize each channel for example, broadband penetration for Infrastructure and Access, financial-inclusion indicators for Financial Intermediation, digital-skills survey data for Human Capital, and regulatory-quality indices for Institutional Governance and to test their mediating role formally using structural equation modelling or mediation-analysis techniques of the kind already applied in the Chinese city-level literature (Wu & Lin, 2025).

Notwithstanding these limitations, the evidence assembled here supports a clear overarching conclusion: in the digital era, sustainable development cannot be pursued as a single undifferentiated goal. Digital innovation, green transformation, and inclusive economic growth are related, mutually reinforcing under the right institutional conditions, but not interchangeable, and

governments, multilateral institutions, and firms that treat them as a single package risk making progress on the dimension that is easiest to measure and reward — typically digital innovation itself — while leaving the harder-to-measure green and distributive dimensions of sustainable development to chance.

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