The Impact and Mechanisms of the Digital Economy and Innovative Services on Urban Green Development

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ABSTRACT

When the dual carbon goals achieve in-depth integration with the ongoing digital development wave, the digital economy and innovative services will be able to greatly reshape the overall development path of urban green transformation. Different from traditional research that evaluates the digital economy merely from a macro aggregate perspective, this paper divides digital innovative services into two core dimensions, which are technical supply capacity and supply quality, so as to explore and analyze the specific influence mechanisms that they exert on urban green development. The research findings have proven that urban green transformation can be significantly driven forward by both the technical supply capacity and supply quality of digital innovative services, and the technical supply capacity has acted as the basic prerequisite that supports the improvement of supply quality. This research has sorted out the complete evolutionary path of digital empowerment, which realizes a gradual shift from scale expansion to quality upgrading. For this reason, the best development way is to generate a sound synergistic effect between supply capacity and supply quality. In practical urban construction work, more attention needs to be paid to improving the adaptation accuracy of digital technology in typical scenarios including smart energy. This paper can effectively improve the existing theoretical analytical framework for relevant research fields, and it also provides solid practical empirical evidence for local governments. With the support of the research conclusions, local governments can avoid the development dilemma of valuing hardware construction while ignoring application scenarios, and they can better promote the high-quality progress of urban green development in a scientific manner.

Keywords: Digital economy; Innovative services; Urban green development; Technical supply capacity; Technical supply quality; Coordination mechanisms

1. Introduction

Ongoing efforts to advance green economic and social transformation have greatly changed the developmental direction of cities, which lets local governments incorporate digitization and greening into their overall strategic layout. At the current new development stage of China, the dual carbon goals are gradually integrating with the booming digital economy, which will bring both developmental opportunities and practical challenges. Modern innovative digital economy services have broken away from basic information matching functions and have been fully applied in urban production activities: the Internet of Things and intelligent algorithms can be used to greatly raise the allocation efficiency of energy resources; public demands for low-carbon progress are also pushing cities to complete the transformation driven by efficiency improvement and technological innovation. These digitally supported measures are core developmental investments that cities have made to strike a balance between economic growth and energy consumption reduction (Zhu & Lin, 2022).

Nevertheless, achieving effective digital-green synergy remains hindered by diverse restrictive factors and practical operational challenges in industrial practice (Izunobi & Burinskiene, 2025). Mere expansion of project scale cannot ensure effective on-site implementation. In practice, digital infrastructure development often falls into a prevalent developmental pitfall, overemphasizing hardware installation while ignoring scenario-based practical utilization (Wang & Kassim, 2025). On top of that, digital systems themselves will consume large amounts of energy, and blind-scale expansion without sound green regulatory constraints can further aggravate local resource scarcity issues. The above conditions make the research raise a key question: how can the digital economy deliver effective empowerment for urban green transition in real terms? Though existing academic studies have discussed this research topic widely, there are still two obvious research deficiencies left. One point is that most prior studies regard the digital economy as a unified whole and seldom differentiate technical supply capacity that stands for scale characteristics and technical supply quality that reflects adaptive performance within a unified analytical framework. The other point is that current comparative analyses are inadequate in exploring the heterogeneous and nonlinear effects that different dimensions impose on green development performance, which makes most existing policy suggestions stay at a shallow level and merely focus on continuous infrastructure construction (Pan et al., 2022).

Against such a research backdrop, this paper mainly targets the influence that the digital economy and innovative services can exert on urban green development, and it tries to resolve three core research questions. One is how urban green development will be affected respectively by technical supply capacity and supply quality as two independent dimensions. The second is whether these two factors can present nonlinear features or obvious threshold effects when they drive the progress of urban green development. The third is how the functional performance of each dimension will differ under diverse resource endowment conditions and different environmental regulation intensities. By carrying out systematic empirical investigation, this paper intends to turn the existing research perspective from single total-volume analysis to the dual dimension of capacity and quality, so as to make up for the academic ignorance of supply quality indicators. This study provides implementable optimization guidance for municipal and county-level government governance. Something is compelling digital-economy and innovative-service industries to reorder their priorities. Not a gentle shift, but a break from blind infrastructure build-up to targeted resource allocation, and green outcomes that are empirically verifiable (Jiang et al., 2022). We find this reorientation intriguing—and overdue.

2. Literature review

2.1 Research Framework

Our attempt to explain how the digital economy and innovative services drive urban green growth forced an uneasy marriage, GPT theory with supply-output analysis. The resulting framework foregrounds not just synergy between operational capacity and developmental quality, as Rathi et al. (2022)stress via scale and deep integration, but their temporal ordering, which, we argue, dictates green outcomes.

Busch et al. (2014) treat technical supply capacity as a material base, a stable resource stock. We see it differently, a precondition that may steer green transition pace—or fail to—without complementary shifts. Hypothesis 2 banks on scale economies for this steering. But our intuition? Robust facilities underpin quality improvements (Hypothesis 1), enabling tailored services. Then, elevated quality lifts green output (Hypothesis 3)—optimized resource allocation and precise governance act, we argue, as hidden mediators.

Our framework aligns with China's urban low-carbon transition—so far, so unsurprising. What grates, however, is how directly it refutes a stubborn misconception: that infrastructure building, on its own, can carry both economic and ecological progress. We find this mistaken belief oddly durable. Digital innovation's value does not hinge on scale. It seeps, instead, through every stage of green development—advancing, as we read it, along a trajectory from capacity expansion to quality upgrading. This logic, provisional and in need of stress-testing, anchors the empirical work that follows (Chen et al., 2026).

2.2 Historical Literature on the Selected Research Factors

Cities exhibit a dynamic capacity to translate digital resources into innovative services. Yu et al. (2025) frame technical supply capacity as the core driver of urban green development—a frame we largely accept, though we suspect it underplays the multilayered nature of this capacity (Kubica, 2020). Modern technical supply extends far beyond hardware investment; it encompasses computing power, R&D capabilities, and professional talent reserves. This systemic framework, in our judgment, bridges digital technologies and real economic operations. Past studies have already verified its supportive role, Kazancoglu et al. (2025) pointed out that it can lift operational transparency and strengthen supply chain resilience. Such findings can help us understand how digital scale gets transformed into green driving forces. For this reason, the paper defines technical supply capacity as the overall supply scale of a city in infrastructure coverage, ICT R&D and digital talent reserves. It explores how digital infrastructure capacity and R&D inputs can boost green technologies, and aims to clarify the mechanisms through which large-scale digital supply fuels urban green development (Wang et al., 2026)

Technical supply quality can effectively reflect the implementation accuracy and value creation capabilities possessed by digital innovative services, and it will act as a key core factor that drives the urban green development process (Dong et al., 2023). It not only embodies the practical implementation effect of digital technologies, but also can build a valid connection between technical supply, market demand and final green output. The evaluation standards for this indicator have gradually moved past single technical parameters, and have developed into a multi-dimensional assessment system that covers industrial adaptability and green value-added performance.

Existing academic studies have backed up such an action path. Related research has pointed out that intelligent matching mechanisms are able to greatly improve overall governance efficiency. Relevant papers have also confirmed that digitization can do far more to lift innovation quality than expand innovation quantity, and highly adapted technical solutions can effectively cut down regional energy consumption. Additional empirical results have proven that supply quality acts as the core driving force for sustainable development performance (Wang, 2026). These existing conclusions can provide solid theoretical support for the targeted application of digital technology to empower low-carbon transformation. On this basis, this paper defines technical supply quality as the matching and transformation level between digital innovative services and actual green governance demands. This study focuses on analyzing the scenario adaptability of digital systems and the practical carbon reduction improvements brought by data interoperability, so as to explain how highly matched and high-value-added technical supply can ultimately promote the progress of urban green development (Sun & Gong, 2026)

Urban green development can capture the dynamic balance between economic benefits and ecological benefits, and it has long served as a core benchmark for judging a region's sustainable transformation level(Yang et al., 2026).Following the ongoing digital revolution, urban green development has gone beyond simple ecological infrastructure construction and turned into a full-scale upgrade of low-carbon governance modes, which can well connect macro policy arrangements with micro resource allocation behaviors. Due to its complex internal driving mechanisms, this topic has gained wide academic attention: existing studies have proven that green infrastructure can greatly strengthen the ecological resilience of cities. On this basis, this paper regards urban green development as a comprehensive evaluation dimension that realizes coordinated economic growth and carbon emission reduction under digital empowerment. It explores how digital economy innovative services (namely technical supply capacity and technical supply quality) can promote urban green development progress, and further discusses how macro factors including resource endowments and environmental regulation will produce moderating impacts throughout this process.

2.3 Hypotheses development

Serving as crucial driving forces for urban transformation, the digital economy and innovative services represent emerging technological supplies and business models that can lower ecological pressures and realize modern governance dividends (Chen et al., 2025). Different from conventional factor inputs, digital innovation services have unique features of high permeability, network externalization and dynamic iteration characteristics Zhang and Hu (2025) By breaking traditional industrial segmentation barriers and facilitating cross-regional resource flow, such characteristics enhance inter regional resource mobility while creating both structural optimization opportunities and systematic governance challenges for urban green development. Based on existing theoretical research, this study categorizes digital innovative services into two core dimensions: technical supply capacity and technical supply quality. These two dimensions do differ greatly in their empowerment paths, value transformation logic, and ecological benefit generation effects.

Technical supply capacity measures urban digital economy's infrastructure coverage scope, computing power scale and digital resource stock (Tian & Guo, 2023). Fundamentally, it lays physical groundwork for urban green transformation. Studies show expanded digital infrastructure can eliminate extemporization frictions, drive green technological innovation and improve green total factor productivity. In environmental governance, sound technical supply capacity breaks long-standing information silos via data node connections (Subrato, 2025). It largely cuts marginal costs for pollution monitoring and carbon tracing, while supplying sufficient computing power for complex low-carbon demands.

Though this capability mostly appears as basic hardware infrastructure, its core is to deliver key support for complex environmental governance systems. Against China's dual transition context, large-scale tech supply can directly push the environmental industry forward. It also releases a clear macro policy signal of the government's resolve to pursue green progress, and builds a firm base for digital-enabled ecological governance. From the above analysis, this paper puts forward.

H1：Technical supply capacity has a significant positive impact on urban green development.

Technical supply quality shows the accuracy, compatibility and value creation level when digital innovation services match urban green governance demands (Yin & Zhao, 2024). Supply capacity builds the base for transformation, yet supply quality decides its final results. Related studies note that high-standard digital supply can effectively fuel urban green tech innovation through better resource allocation.

Within environmental governance scenarios, technical supply quality lifts overall governance performance via measurable emission reduction features (Radulescu et al., 2024). For instance, accurate smart energy scheduling systems and green financial tools can deliver practical means to boost environmental performance. They also fix improper resource distribution and information imbalance with well-adapted digital services, which cuts down uncertainties during governance work. Besides, high-grade digital services reflect urban efforts to upgrade basic infrastructure and reach deep emission cuts. This clear green commitment turns digital technology potential into tangible low-carbon results. Following the above reasoning, this paper proposes.

H2：The quality of technical supply has a positive impact on urban green development.

Powerful data processing and basic infrastructure can back technical supply capacity, which can bring notable upgrades to technical supply quality (Wu et al., 2025). For instance, AI matches supply and demand accurately, block chain enables transparent tracking, and big data optimizes resources; all rely on basic computing power to deliver high-quality innovation. As other studies note, cities that fully utilize digital infrastructure during industrial transformation can allocate production factors better and judge how applicable technologies are. This digital empowerment eases information gaps on both sides, and it cuts down risks from faulty tech application and mismatching.

Meanwhile, the continuous upgrade of supply capacity shows that service providers are ready to take on higher sunk R&D costs and face pressures to remodel service workflows via network adjustment. Relevant studies also prove digitization can push innovation to shift from quantity expansion toward quality improvement. This in-depth structural optimization delivers a clear long-term commitment, and it greatly raises the stability and credibility of technical supply in practical use. Based on the above points, this paper proposes.

H3：Technical supply capacity has a positive impact on technical supply quality.

3. Methodology

3.1 Participants

This research targets business managers and technical professionals working in China's major digital economy cities who have practical experience in green transformation. All participants need to be aged 18 or above and have taken part in digital projects including smart energy, smart manufacturing and smart environmental protection over the prior six months. Respondents possess firsthand professional experience in technology-driven carbon abatement, matching the paper's research context perfectly.

From January 2025 to May 2026, we ran field investigations in three pilot cities—Beijing, Hangzhou, Shenzhen—branded respectively as 'Northern Innovation Hub,' 'Eastern Digital Hub,' and 'Southern Low-Carbon Pioneer.' I find these labels oversimplify reality. The target industrial population: roughly 1.5 million (600,000 in Beijing, 400,000 in Hangzhou, 500,000 in Shenzhen). Our design was cross-sectional, quota-sampled by regional scale, combining online questionnaires with face-to-face interviews， a mixed-mode choice that worried me, but we saw no better alternative.

We ended up with 615 raw samples, 246 from Beijing, 164 from Hangzhou, 205 from Shenzhen. The spread does, on the surface, echo the regional population profile. That should, in principle, capture enough geographic and economic heterogeneity to ground claims of representatives. Should—but I remain uneasy. Six hundred and fifteen cases. It clears the lowest bar for multivariate analysis; nothing more comforting than that. Yet these data, for all their modesty, give us a foothold to examine how technical supply capacity and quality impinge on urban green development. And, with a measure of caution, the patterns we extract might just travel beyond these three cities.

3.2 Instruments

We relied on closed-ended questionnaires, all items scored on a five-point Likert scale, to ope-rationalize the key constructs. The instrument, in practice, had two blocks. Block one gathered demographic markers, gender, age, occupation, monthly income, and self-assessments of digital literacy, industry, and environmental awareness. We viewed these as potentially confounding; I suspect they matter more than the literature admits. Block two attempted to capture Technical Supply Capacity (TSC), Technical Supply Quality (TSQ), and Urban Green Development (UGD). Nine items in total. A rather thin slice, I confess, for constructs so broad.

We relied on scales validated in the digital economy and environmental governance literature to secure reliability and construct validity. I find that reliance questionable. This research took these scales off the shelf, so to speak, and I worry we brought along their original blind spots. TSC was measured via digital infrastructure coverage, computational resource endowment, and talent stock. TSQ captured green scenario adaptability, cross-department data interoperability, and system running stability. UGD assessed energy efficiency, carbon mitigation intensity, and low-carbon governance optimization—a conflation of governance effort and ecological outcome that I find analytically messy. Nine items for these three constructs feels reckless.

So, three latent constructs, nine measurement dimensions—mapped directly onto nine questionnaire items.

A parsimonious mapping, some might say. I'd call it dangerously thin. Still, with this indicator system, we tried to quantify how digital innovative services might propel urban low-carbon and green transformation. The word "might" matter here—these nine items, in my view, can only hint at the mechanisms, not capture them.

3.3 Sample and data collection

Guided by SEM parameter demands and a statistical power analysis, we drafted sampling rules. We chased it by stratifying across three cities (Beijing, Hangzhou, Shenzhen) and three sectors: smart energy, smart manufacturing, smart environmental protection. Three cities, three sectors. That geometry feels too clean. Factoring in the expected invalid response rate, our initial plan called for 500 questionnaires. A round number, suspiciously so.

Data collection ran January–April 2026. A mixed-method approach: online platforms and industry associations delivered 65% of questionnaires, on-site distribution at high-tech parks and exhibitions covered the rest. We screened manually—tossing incomplete forms, perfunctory answers, and failures on embedded attention checks. But that 35% on-site return—representative, or merely convenient? We can't be sure.

Screening the research called it rigorous, though I'd say relentless, left 382 valid questionnaires, a 76.4% return. The number just clears the 350-case power threshold. Sub samples barely above 100. The data set meets textbook standards for multivariate and subgroup analysis. But 'meets standards' and 'firm foundation' are not the same thing. Still, this research may now test our models and draw inferences.

4. Results

4.1 Construct reliability and validity

The research ran reliability and validity checks on the questionnaire data. The measurement model: three latent variables, Technical Supply Capacity, Technical Supply Quality, Urban Green Development, each tapped by three observable indicators. Nine items in total. No higher-order constructs. A flat design, which I read as either prudence or under-authorization. For internal consistency, we turned to Cronbach's alpha. Then, composite reliability (CR) and average variance extracted (AVE) were layered on to gauge structural coherence and convergent validity. I find this conventional battery insufficient—more box-ticking than deep scrutiny.

Reliability run, Cronbach's α hits from 0.825 to 0.839 for latent variables. It clears the 0.8 benchmark, just barely. The narrow spread impresses me: items grip core constructs with little drift. We aren't parroting strong consistency, the measurement stands firm. Yet the research wonder if this uniformity masks overlap, though that's separate.

Table 1: Reliability and Validity Test Table

Factors	Variable	Factor Loading	Cronbach'a	CRValue	AVEValue
TSC	TSC1	0.871	0.837	0.902	0.754
	TSC2	0.867			
	TSC3	0.868			
QTS	QTS1	0.861	0.825	0.895	0.740
	QTS2	0.855			
	QTS3	0.866			
GUD	GUD1	0.877	0.839	0.903	0.757
	GUD2	0.870			
	GUD3	0.863			

Validity testing returned composite reliability (CR) values between 0.895 and 0.903 for all latent variables, consistently above the 0.80 cutoff. I see this as solid evidence of structural consistency across constructs. AVE values ranged from 0.740 to 0.757, comfortably beyond the 0.50 benchmark established by (Cheung et al., 2024). To us, this means each latent variable captures most of the variance in its indicators, confirming the measurement model's convergent validity.

From where we stand, these analytical outcomes confirm that our self-developed measurement tool possesses a coherent internal structure and can accurately capture the core constructs. The data set quality, we find, fully complies with the demands of multivariate statistical analysis. This lays a reliable groundwork for the subsequent path modeling and hypothesis verification steps.

4.2 Factor analysis

Prior to the formal confirmatory factor analysis, we conducted an exploratory factor analysis (EFA) to verify the scale's construct validity. All nine observed items, tied to three latent variables: technical supply capacity, technical supply quality, and urban green development, were included. We used principal component analysis (PCA) for factor extraction and Varimax orthogonal rotation to refine the factor structure. From our standpoint, this step effectively sets the stage for the measurement model.

The KMO measure returned 0.830, comfortably above the 0.7 threshold that Kaiser (1974) advocated. Bartlett's test produced $\chi^2 = 1507.825$ at $p < 0.001$—a highly significant result, in our reading. These indicators, we argue, point to strong inter-correlations among all items, confirming the data set is fully fit for factor analysis.

The research ran the principal component analysis and found the common factors aligned well with our theoretical framework. Together they account for 75.267% of the total variance, well above the 60% threshold commonly cited. To above research, this is evidence that the extracted factors are highly representative, capturing the core of the original data. The scale, in our view, presents a clear and rational structure with sound construct validity. This lays a robust statistical groundwork for subsequent hypothesis testing and model analysis.

Table 2: Results of the scale validity test

Variable	TSC	QTS	GUD
TSC1	0.838		
TSC2	0.851		
TSC3	0.816		
QTS1		0.842	
QTS2		0.820	
QTS3		0.836	
GUD1			0.829
GUD2			0.841
GUD3			0.837
KMO	0.830		
χ^2	1507.825		

Sig.	< 0.001		
Eigenvalue	4.092	1.425	1.275
Variance percentage (%)	45.346	15.791	14.130
Cumulative variance percentage (%)	45.346	61.137	75.267

4.3 Correlation analysis

This research ran a Pearson correlation analysis to map the associations among Technical Supply Capacity (TSC), Technical Supply Quality (TSQ), and Urban Green Development (UGD). In our view, this step gives us an early check on the research hypotheses and a necessary lead-in to the discriminant validity assessment.

Our correlation analysis returned something noteworthy: every latent-variable pair correlated positively, all at $p < 0.01$. TSC with TSQ gave $r = 0.380$; with UGD, $r = 0.444$. TSQ and UGD yielded $r = 0.391$. These coefficients, well below the 0.85 threshold (Kline, 2016), rule out multidisciplinary concerns—yet they confirm the expected positive associations, albeit moderate.

Correlation coefficients fall between 0.380 and 0.444, reflecting moderate positive associations. All values stay well below the 0.70 threshold for multi col linearity concerns. These results show the constructs are theoretically linked yet statistically independent, eliminating serious multi col linearity risks across variables.

The preliminary reading of the correlations lends support to the core hypothesis, that technical supply capacity and quality drive urban green development. These results, we believe, establish a solid data foundation for the structural equation modeling and empirical discussion that follow.

Table 3: Results of the correlation analysis between variables

Variable	TSC	QTS	GUD	N
TSC	1	0.380**	0.444**	382
QTS	0.380**	1	0.391**	382
GUD	0.444**	0.391**	1	382

**. At the 0.01 level (two-tailed), the correlation is significant.

*. At the 0.05 level (two-tailed), the correlation is significant.

4.4 Model development

This research analysis wants to clarify how the digital economy and innovative services facilitate urban green development—so we built a structural equation model (SEM) in Python. Grounded in theoretical deduction, we specified three direct paths: TSC → TSQ, TSC → UGD, and TSQ → UGD. Mediating effects are excluded at this stage — we aim to distinctly distinguish each dimension's independent contribution.

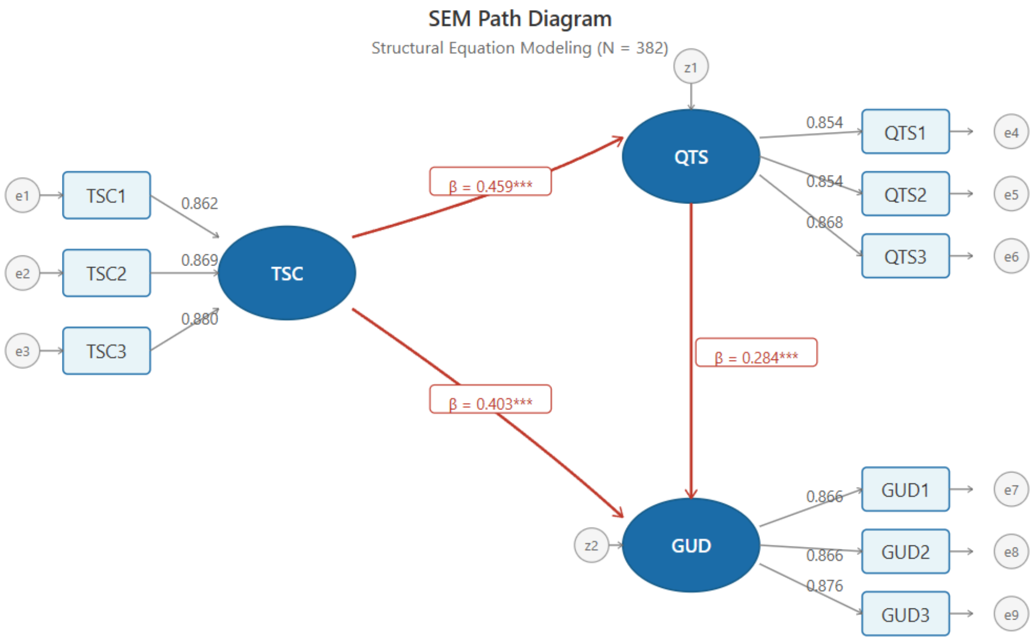

Figure 1: Structural Equation Model

For parameter estimation, we adopted bootstrap resampling, specifically 1,000 bootstrap samples drawn to mitigate biases from non-normal data and strengthen the empirical tests. Path coefficients were judged significant when their 95% confidence intervals excluded zero, a convention that has served us well in prior modeling work.

Prior to formal path analysis, we comprehensively assessed the overall goodness-of-fit of the SEM. The outcomes present ideal values across all core indicators: the chi-square-to-degrees-of-freedom ratio (χ^2/df) is 1.206; the Goodness-of-Fit Index (GFI) stands at 0.981; the Adjusted Goodness-of-Fit Index (AGFI) is 0.972; and the Comparative Fit Index (CFI) hits 0.997, all exceeding the widely recognized threshold of 0.90. To our eyes, these numbers confirm the model is well-specified. Meanwhile, the root mean square error of approximation (RMSEA) is only 0.023, which falls into the excellent fit range. These findings prove the theoretical model matches the actual observed data closely and fully satisfies strict statistical standards for follow-up hypothesis testing.

Table 4: Goodness-of-fit indices for the structural equation model (n=382)

Measurement model	X^2/df	GFI	AGFI	NFI	CFI	RMSEA
Evaluation indicators	< 5	> 0.90	> 0.90	> 0.90	< 0.08	< 5
Outcome model	1.206	0.981	0.972	0.997	0.023	1.206

4.5 Analysis of Effects

Given the model achieves an ideal overall fitting effect, this study further leverages Python software to conduct empirical tests on all preset influence pathways. The final estimation results clearly demonstrate that the collected empirical data fully validate and support the three proposed direct effect hypotheses in this research.

First, Technical Supply Capacity (TSC) delivers a prominent positive influence on Technical Supply Quality (TSQ) ($\beta = 0.459$, $p < 0.001$, 95% CI [0.313, 0.567]). This outcome reveals that improving urban digital infrastructure and expanding professional talent teams can effectively elevate the overall quality of innovative services, which fully verifies Hypothesis H1. Second, TSC also generates a strong direct driving effect on Urban Green Development (UGD) ($\beta = 0.403$, $p < 0.001$, 95% CI [0.268, 0.576]). Our analysis confirms Hypothesis H2 — stronger technical capabilities directly boost urban energy conservation, carbon reduction, and energy efficiency. Technical Supply Quality also significantly promotes urban green development ($\beta = 0.284$, $p < 0.001$, 95% CI [0.165, 0.467]). We view this as evidence that well-adapted digital service systems play a key role in optimizing green governance mechanisms, validating Hypothesis H3.

Taken together, the path coefficients hold significance and stability across Bootstrap replications, provides compelling evidence: digital economy and innovative service components effectively advance urban green transformation, lending robust empirical support to our theoretical framework.

Table 5: Analysis of main effects of variables

Path	**Non-standardized coefficient**	**Standardized coefficient (β)**	**Lower limit of 95% CI**	**Upper limit of 95% CI**	**P-value**	**Conclusion**
TSC → QTS	0.437	0.459	0.313	0.567	< 0.001	Support
TSC → GUD	0.416	0.403	0.268	0.576	< 0.001	Support
QTS → GUD	0.308	0.284	0.165	0.467	< 0.001	Support

5. Conclusion

Through systematic conceptual work and empirical testing, we categorized digital economy innovative services into two core dimensions, technical supply capacity and technical supply quality, which meaningfully extends the research boundary at the intersection of digital economy and urban green development. The empirical findings further uncover their differentiated driving roles in advancing urban green development. Technical supply capacity delivers a stronger direct effect ($\beta = 0.403$), suggesting to us that digital infrastructure construction and large-scale technological support serve as essential hard guarantees for urban digital-green transformation. Technical supply quality, meanwhile, plays a noteworthy positive role ($\beta = 0.284$), reflecting the long-term practical value of technological adaptability, in-depth service provision, and refined urban governance. Our analysis suggests these results validate the theoretical rationality of dividing digital innovative services into a dual capacity-quality structure—rather than treating them as a single undifferentiated construct.

Indeed, drawing on the path analysis, technical supply capacity underpins improvements in technical supply quality ($\beta=0.459$). Our analysis suggests this reveals an internal logic: the digital economy's shift from scale expansion to quality improvement. Drawing on empirical data from typical digital development cities including Beijing, Hangzhou and Shenzhen, this research further enriches the understanding of how urban green transformation operates in China. In the fields of smart energy and intelligent environmental governance, digital innovation is no longer merely a tool for industrial upgrading, but has evolved into a core driver to tackle ecological governance issues in a systematic way. Accordingly, follow-up research on urban sustainable development needs to integrate both the scale and quality of digital supply into a unified theoretical and analytical framework.

This research delivers practical implications for urban administrators and policymakers striving to advance high-quality urban green transition. Given that technical supply capacity strongly facilitates quality improvement and green development, local governments and enterprises should prioritize consolidating the digital economy's foundations, including upgrading computing infrastructure and cultivating professional talent teams. That said, the most effective approach lies in the coordinated development of capacity and quality. While robust supply capacity serves as a fundamental underpinning, supply quality deserves to be the core focus of strategic planning. Practitioners should enhance the applicability and precision of digital technologies in carbon monitoring, energy dispatching and other related fields.Ding et al. (2025) essential to avoid blind investment in hardware facilities, so that technological innovations can be fully translated into tangible outcomes for ecological governance.

At the policy level, optimizing the digital ecosystem should be regarded as a core task to accelerate regional sustainable development (Luo et al., 2023). To begin with, authorities need to formulate and refine unified standards and evaluation systems for digital-driven green development, so as to bridge data gaps between government departments and enterprises. In addition, fiscal tools including tax preferences and targeted subsidies can be adopted to motivate firms to scale up investment in the research and development of high-value green technologies. Moreover, relevant policies should work to narrow the regional digital divide. It is necessary to offer technical guidance and financial support to less developed regions as well as small and medium-sized enterprises, advance the inclusive application of digital innovative services and remove obstacles in technology promotion. In this way, cities can steadily achieve green and high-quality transformation in a comprehensive manner.

6. Declarations

6.1 Study Limitations

This research is aware of some limitations. The empirical analysis is based on a static cross-sectional data. Although the SEM results are consistent with theory, such data cannot allow for strict causal inference; a limitation that, quite frankly, restricts the strength of our claims. Considering the fast iteration of digital technologies and the changing characteristics of urban green governance, the empowerment effect of digital innovative services on green development may have dynamic characteristics that cannot be captured in a single snapshot. Furthermore, our latent variables were measured by subjective questionnaire scales, including technical supply capacity. There may still be a slight bias in the assessment even after controlling for statistical factors. Future work should include objective archival data, carbon emission monitoring indicator, green patent statistic for cross-verification. But doing so faces practical obstacles: data fusion from multiple sources, incomplete disclosure from enterprises, and inconsistent statistical calibers at the city level all make it difficult. Our analysis shows how digital innovative services work through a differentiated capacity-quality structure, which is in contrast to the prevailing assumption of them being a homogeneous, linear driver of green outcomes.

6.2 Future Research Directions

These limitations suggest future work. We argue that longitudinal panel data can be used to trace the dynamic transformation of digital innovative services on urban green development, revealing long-term mechanisms and potential non linearity. Spatial econometric models could test whether there are spillover effects across urban agglomerations, i.e., whether core cities affect coordinated green outcomes in neighbouring regions. Targeted comparative work on cities with different resource endowments and industrial structure could reveal differentiated paths of transformation. But there are practical constraints: fragmented data systems, inconsistent urban monitoring indicators. We argue that such efforts, if undertaken, would offer a more refined theoretical basis for the development of context-specific green policies, although the path is not at all clear.

6.3 Acknowledgement

Ting Yao is the initiator of the research topic, the builder of the theoretical structure, and is responsible for full drafting and revision. ALIZA ABU HASSIM Review and proof reading. Checking content, optimizing

details. This comprehensive review of the integrity, logic and expression of the whole text ensured the academic quality and rigour of the study. HAROON SHAHID's main job is to review the references and polish the grammar.

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