

ICT Strategy and Analytics Frameworks for Net-Zero Smart Cities: A Conceptual Framework for Urban Sustainability Optimization

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ABSTRACT

The escalating urgency of climate commitments has placed net-zero urban systems at the forefront of global sustainability agendas. Smart cities, characterised by pervasive ICT infrastructure and data-intensive governance, present a uniquely tractable context for deploying analytics-driven decarbonisation strategies. Yet existing literature reveals a persistent fragmentation between ICT strategy formulation, urban data analytics, and operationalised sustainability governance. This paper addresses that gap by developing an integrated conceptual framework the ICT-Analytics-Sustainability (IAS) Framework that maps the pathway from ICT infrastructure deployment through AI-enabled analytics processing to net-zero urban outcomes. Theoretically grounded in Systems Theory, the Technology-Organisation-Environment (TOE) framework, Dynamic Capability Theory, and Stakeholder Theory, the IAS Framework delineates five interdependent layers: ICT infrastructure, multi-source data collection, AI/analytics processing, smart governance, and sustainability optimisation. The paper employs a structured literature synthesis across 87 peer-reviewed sources (2018–2023), supplemented by conceptual modelling, to derive testable propositions and measurement indicators across energy, mobility, carbon, and governance dimensions. Critical analysis of existing frameworks including ISO 37122, GreenStar ICT, and the C40 Cities Digital Protocol reveals their siloed orientation and insufficient attention to predictive analytics and ESG alignment. The IAS Framework advances theoretical understanding by operationalising dynamic capabilities as mediators between ICT investment and sustainability performance, while providing practitioners with actionable governance archetypes. Implications for urban policymakers, digital infrastructure planners, and future empirical validation are discussed.

Keywords: Net-zero smart cities; ICT strategy; urban analytics; digital twin governance; carbon optimisation; sustainability KPIs; AI-driven urban systems

1. INTRODUCTION

The Paris Agreement's 1.5°C carbon budget, combined with accelerating urbanisation cities now accounting for approximately 70% of global CO₂ emissions (IEA, 2023) has rendered net-zero urban transition from a policy aspiration to an operational imperative. Smart city frameworks offer a technologically rich response environment, embedding IoT sensor networks, real-time data platforms, and AI-driven optimisation within the urban metabolism. Nevertheless, the translation of ICT capability into measurable sustainability outcomes remains theoretically underdeveloped and empirically contested.

Several competing dynamics explain this gap. First, smart city ICT investments are frequently driven by efficiency and service-delivery logics rather than explicit decarbonisation objectives (Bibri & Krogstie, 2020). Second, the analytics architectures underpinning smart city platforms are seldom designed with carbon accounting, ESG reporting, or net-zero KPI frameworks as primary outputs. Third, governance structures mediating between ICT infrastructure and sustainability decision-making remain fragmented across municipal, national, and private-sector

actors. These tensions collectively produce what this paper terms the ICT-Sustainability Alignment Deficit a structural misalignment between what smart city technology can deliver and what net-zero governance requires.

The concept of net-zero urban systems extends beyond renewable energy substitution. It encompasses integrated management of embodied carbon, transportation emissions, building energy performance, waste metabolics, and urban green infrastructure all domains requiring continuous, high-resolution data flows and closed-loop feedback mechanisms (Bibri et al., 2023). ICT strategy, understood not merely as technology deployment but as the alignment of digital capabilities with organisational and governance objectives (Pereira & Romero, 2021), provides the organisational logic through which smart city platforms can be systematically oriented toward net-zero goals.

This paper makes three principal contributions. First, it synthesises disparate literature streams smart city ICT, urban analytics, sustainability governance, and net-zero systems into a coherent theoretical synthesis. Second, it develops the IAS Framework as an original conceptual model linking ICT infrastructure to net-zero outcomes through analytically specified intermediate mechanisms. Third, it derives empirically testable propositions and measurement instruments that advance the field beyond qualitative advocacy.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature across five thematic domains. Section 3 identifies specific research gaps and the problem statement. Section 4 presents the IAS Framework. Section 5 details the research design. Section 6 discusses expected results. Section 7 concludes with implications and future directions.

2. LITERATURE REVIEW

2.1 Smart City Evolution and ICT Strategy

Smart city scholarship has evolved through three recognisable phases. The first, dominated by infrastructure-centric discourse (2008–2014), privileged sensor deployment, broadband penetration, and municipal platform integration (Hollands, 2008; Caraglianno et al., 2011). The second phase (2015–2019) introduced data-driven governance and citizen-centric service models, emphasising open data ecosystems and participatory sensing (Kitchin, 2015; Meijer & Bolívar, 2016). The third, emerging phase (2020–present) interrogates the sustainability and climate governance dimensions of smart urbanism, recognising that technological sophistication does not automatically produce ecological benefit (Yigitcanlar et al., 2021; Laufs et al., 2021).

ICT strategy in the urban context has been conceptualised variously as digital master planning, platform governance, and capability alignment. Pereira and Romero (2021) define smart city ICT strategy as the systematic configuration of digital assets, institutional routines, and data governance mechanisms to achieve predefined urban development objectives. This definition is analytically important because it frames ICT as a strategic organisational resource consistent with the Resource-Based View (RBV) rather than a neutral technological substrate. From the RBV perspective, the competitive and governance advantage of a smart city derives not from ICT ownership per se but from the dynamic capabilities developed to deploy, reconfigure, and exploit digital resources in response to environmental challenges (Teece, 2018; Amabile & Mueller, 2022).

2.2 Net-Zero Urban Systems

Net-zero cities are defined as urban areas that balance anthropogenic greenhouse gas emissions with equivalent removals within their jurisdictional boundary, typically on an annual accounting basis (C40 Cities, 2021). The operationalisation of this definition is significantly complicated by scope boundaries (Scope 1, 2, and 3 emissions), sectoral coverage (energy, transport, buildings, waste, land use), and temporal accounting conventions. The IEA (2023) estimates that buildings and urban transport collectively account for 52% of global final energy consumption, positioning cities as decisive leverage points for global decarbonisation.

Technically, net-zero urban systems require integrated management of distributed energy resources (DERs), electrified mobility networks, building energy management systems (BEMS), and urban carbon sinks. Analytically, they demand continuous Measurement, Reporting, and Verification (MRV) capabilities that extend beyond annual GHG inventories to near-real-time carbon performance monitoring (Hoegh-Guldberg et al., 2022). Digital twins'

virtual replicas of urban systems updated with live sensor data have emerged as a promising architectural response to this data intensity requirement (Dembski et al., 2020; Shahat et al., 2021).

2.3 AI, IoT, and Urban Data Analytics

The analytical infrastructure of smart net-zero cities' rests on three interdependent technology layers: IoT sensing, data integration platforms, and AI-driven analytics. IoT sensor networks provide the physical-digital interface, generating granular, high-frequency data on energy consumption, traffic flows, air quality, and building occupancy (Zanella et al., 2014; Malik et al., 2022). Data integration platforms increasingly implemented as urban data fabrics or federated data spaces aggregate heterogeneous sensor streams with administrative datasets, enabling cross-domain analytics (Mohanty et al., 2021).

AI and machine learning techniques have demonstrated substantial promise in urban sustainability applications. Predictive energy demand forecasting using LSTM networks has achieved accuracy rates of 93–97% in controlled smart grid environments (Qian et al., 2022). Graph neural networks applied to urban mobility data have enabled route optimisation that reduces transport-related emissions by 12–18% in simulation studies (Wang et al., 2023). Digital twin platforms integrating these analytics capabilities have been deployed in cities including Singapore, Helsinki, and Zurich, enabling scenario modelling for urban carbon budgets (Dembski et al., 2020; Meijer et al., 2023).

However, critical scholarship has identified significant limitations. AI model transparency and explainability remain challenges in high-stakes governance contexts (Janssen et al., 2020). Data silos between municipal departments, utilities, and private operators inhibit integrated analytics (Hashem et al., 2016; Bibri, 2021). The energy consumption of large-scale AI inference a form of technological carbon rebound poses a structural irony for sustainability-oriented deployments (Strubell et al., 2019).

2.4 Smart Governance and Sustainability KPIs

Smart governance encompasses the digital mediation of urban decision-making, policy implementation, and stakeholder accountability. In the sustainability context, it manifests through real-time dashboard systems, automated regulatory compliance monitoring, predictive policy simulation, and ESG reporting platforms. ISO 37122 (Sustainable Cities and Communities: Indicators for Smart Cities) and the UN-SDG Localisation Framework provide baseline indicator architectures, but their implementation in data-rich environments remains inconsistent (Yigitcanlar et al., 2021).

ESG governance has emerged as an important analytical lens, particularly as urban sustainability performance increasingly intersects with municipal bond markets, international climate finance, and corporate supply chain disclosure requirements (Hebb, 2022). The alignment of city-level sustainability KPIs with GRI Urban Supplement, TCFD, and ISSB frameworks represents an underexplored but commercially significant research frontier. Smart city analytics platforms that can generate TCFD-aligned climate risk data or ISSB-compatible sustainability disclosures from urban sensor networks occupy a strategically important position in this landscape.

2.5 Existing Frameworks and Their Limitations

Several frameworks attempt to connect ICT and urban sustainability. The GreenStar ICT Framework (Ercan et al., 2019) emphasises life-cycle environmental assessment of ICT infrastructure but lacks governance and analytics integration. The C40 Cities Digital Protocol establishes data-sharing standards for climate reporting but does not address AI-driven optimisation. The IBM Smarter Cities model (Harrison et al., 2010) integrates operations across city systems but predates contemporary AI capabilities and net-zero framing. Bibri and Krogstie's (2020) Smart Eco-City Framework offers the most theoretically proximate antecedent but remains descriptive rather than analytically operationalised, and does not incorporate dynamic capabilities or ESG governance dimensions. The IAS Framework developed in this paper addresses these gaps explicitly.

3. RESEARCH GAP AND PROBLEM STATEMENT

The foregoing review reveals three specific and inter-related research gaps that collectively define the problem addressed by this paper.

First, there is an absence of theoretically grounded integrative frameworks that specify the mechanisms through which ICT strategy generates net-zero outcomes. Existing work addresses either the technology infrastructure layer (IoT, AI, digital twins) or the governance layer (KPIs, ESG, carbon accounting) in relative isolation. The mediating analytical processes data collection architecture, AI processing logic, and decision support interfaces are underspecified as theoretical constructs with associated measurement instruments.

Second, the dynamic capabilities perspective has not been applied to smart city sustainability management. Whilst RBV-informed analyses exist for smart city competitiveness (Yigitcanlar et al., 2019), the capacity of urban administrations to sense, seize, and reconfigure ICT capabilities in response to evolving climate targets and carbon budgets has not been theorised. This represents a significant theoretical lacuna, given that net-zero trajectories require adaptive, not merely static, ICT-governance alignment.

Third, the measurement architecture for ICT-sustainability linkage remains fragmented. Studies deploy heterogeneous, non-comparable KPI sets, inhibiting cumulative knowledge development and meta-analytic synthesis. A standardised multi-dimensional measurement framework spanning ICT infrastructure readiness, analytics maturity, governance integration, and net-zero outcome performance is absent from the literature.

The problem statement is therefore: How can ICT strategy and analytics frameworks be theoretically specified and operationally designed to systematically enable net-zero urban outcomes in smart cities, and what are the critical mediating mechanisms and governance conditions that determine effectiveness? Addressing this problem requires both a theoretical contribution the IAS Framework and a methodological contribution in the form of a validated measurement instrument.

4. PROPOSED ICT-ANALYTICS-SUSTAINABILITY (IAS) FRAMEWORK

4.1 Theoretical Foundations

The IAS Framework integrates four complementary theoretical perspectives. Systems Theory (Bertalanffy, 1968) provides the meta-theoretical rationale for treating the smart city as a complex adaptive system in which ICT infrastructure, analytical processes, governance mechanisms, and sustainability outcomes are systemically interdependent rather than sequentially linear. Technology-Organisation-Environment (TOE) theory (Tornatzky & Fleischer, 1990) contextualises ICT strategy adoption within the constraints of organisational capacity and environmental (regulatory, competitive, ecological) pressures, informing the framework's contextual moderators. Dynamic Capability Theory (Teece, 2018) specifies the micro-foundations through which urban administrations develop the sensing, seizing, and transforming capabilities necessary to leverage ICT investments for adaptive sustainability management. Stakeholder Theory (Freeman, 1984) anchors the governance layer, recognising that net-zero outcomes require alignment across municipal government, utility operators, private sector actors, civil society, and citizens.

4.2 Framework Architecture

The IAS Framework comprises five interdependent layers, each representing a distinct theoretical construct with associated process mechanisms and outcome indicators. Table 1 summarises the layers, their theoretical grounding, and key indicators.

Table 1. IAS Framework: Layers, Theoretical Grounding, and Key Indicators

Layer	Components	Theory	Key Indicators
L1: ICT Infrastructure	IoT networks, 5G/broadband, edge/cloud computing, cybersecurity	RBV, TOE	Sensor density (nodes/km ²); broadband penetration (%); edge node latency (ms)
L2: Data Collection	Multi-source sensing, data lakes, federated data spaces, MRV systems	Systems Theory	Data completeness index; MRV coverage (%); cross-domain integration score

Layer	Components	Theory	Key Indicators
L3: AI/Analytics Processing	ML/DL models, digital twins, predictive analytics, NLP governance tools	Dynamic Capabilities	Model accuracy (MAPE); prediction latency; twin update frequency (Hz)
L4: Smart Governance	Decision support systems, ESG dashboards, carbon accounting, policy simulation	Stakeholder Theory	Carbon KPI compliance rate; ESG reporting alignment; decision cycle time
L5: Sustainability Optimisation	Energy optimisation, mobility management, renewable integration, waste MRV	Systems Theory, TOE	Absolute emission reduction (tCO ₂ e); renewable fraction (%); energy intensity (kWh/m ²)

4.3 Framework Propositions

From the IAS Framework, four core theoretical propositions are derived:

P1 (Infrastructure-Analytics Linkage): Cities with higher ICT infrastructure maturity (L1) will exhibit significantly greater AI/analytics processing capacity (L3), moderated by organisational data governance capability (L2).

P2 (Analytics-Governance Mediation): AI/analytics processing capacity (L3) mediates the relationship between ICT infrastructure (L1) and smart governance effectiveness (L4), such that the infrastructure-governance relationship is significantly attenuated when L3 is controlled.

P3 (Dynamic Capabilities Moderation): The strength of the analytics-governance relationship (L3→L4) is positively moderated by urban dynamic capabilities specifically, the sensing, seizing, and reconfiguring capabilities of the municipal administration.

P4 (Governance-Outcome Linkage): Smart governance effectiveness (L4) is the proximate determinant of sustainability optimisation outcomes (L5), with stakeholder integration quality serving as a significant positive moderator.

These propositions constitute a testable structural model amenable to PLS-SEM validation using urban panel data or case-comparative research designs, as detailed in Section 5.

5. METHODOLOGY AND RESEARCH DESIGN

5.1 Research Paradigm and Design

The study adopts a pragmatist research paradigm that accommodates both theory-building and empirical testing orientations (Creswell & Creswell, 2018). The primary contribution of this paper is conceptual the development and theoretical justification of the IAS Framework—consistent with a design science research approach (Hevner et al., 2004). This is supplemented by a systematic literature review that provides the evidentiary basis for framework claims, and a proposed quantitative validation design for future empirical work.

5.2 Systematic Literature Review Protocol

A structured literature review was conducted following PRISMA-P guidelines. Four databases were searched: Scopus, Web of Science, IEEE Xplore, and ScienceDirect. Search terms combined three conceptual clusters: (i) 'smart city' OR 'urban ICT' OR 'urban digital infrastructure'; (ii) 'net-zero' OR 'carbon neutral' OR 'sustainability optimization'; and (iii) 'analytics' OR 'AI' OR 'digital twin' OR 'IoT'. The search was restricted to peer-reviewed journal articles and conference proceedings from 2018 to 2023. Initial screening yielded 2,340 records; after duplicate removal, title/abstract screening, and full-text eligibility assessment, 87 papers were retained for synthesis. Exclusion criteria

included: purely technical papers with no urban governance dimension; papers without quantitative or conceptual sustainability outcomes; and grey literature.

5.3 Proposed Empirical Validation Design

Empirical validation of the IAS Framework is proposed through a two-stage mixed-method design. Stage 1 employs a survey-based PLS-SEM approach targeting ICT and sustainability managers in smart cities. The measurement instrument (Table 2) operationalises each IAS layer as a reflective construct with four to six indicator items, drawing on validated scales from Yigitcanlar et al. (2021), Bibri and Krogstie (2020), and Pereira and Romero (2021), adapted for the net-zero context. Convergent and discriminant validity will be assessed using average variance extracted (AVE ≥ 0.50) and the Heterotrait-Monotrait (HTMT) ratio criterion, respectively. The structural model will be evaluated using bootstrapping (5,000 iterations) with bias-corrected confidence intervals.

Table 2. Measurement Instrument: Constructs, Items, and Data Sources

Construct	Sample Indicators	Measurement Scale	Data Source	Validity Criterion
ICT Infrastructure Maturity	Sensor density; broadband speed; edge latency; cybersecurity index	7-pt Likert + archival metric	ITU Smart City Index; national ICT surveys	AVE ≥ 0.50 ; CR ≥ 0.70
Data Collection Capability	Data completeness; MRV coverage; cross-domain integration; open data readiness	7-pt Likert + administrative data	City open data portals; utility records	HTMT < 0.85
AI/Analytics Processing	Model deployment rate; twin update frequency; prediction accuracy; AI governance score	7-pt Likert + performance log	Municipal IT reports; vendor disclosures	AVE ≥ 0.50
Smart Governance Effectiveness	Carbon KPI compliance; ESG alignment; stakeholder engagement index; policy cycle time	7-pt Likert + document analysis	City sustainability reports; GRI disclosures	Discriminant validity
Sustainability Outcomes	Absolute GHG reduction; renewable energy fraction; transport emission intensity; building EUI	Archival metric	National GHG inventories; ICLEI data	Predictive validity (R ²)

Stage 2 employs a comparative case study of five smart cities Singapore, Amsterdam, Copenhagen, Dubai, and Medellín selected for maximum variation in geography, income level, governance model, and net-zero progress. Data sources include city sustainability reports, ICT master plans, GHG inventories, and semi-structured interviews with urban ICT directors and sustainability managers. Cross-case analysis will follow Yin's (2018) replication logic, testing whether the IAS Framework's causal propositions are consistently supported across institutional contexts.

5.4 Ethical and Validity Considerations

Survey respondents will be informed of the study's purpose and assured of anonymity. Archival data will be sourced exclusively from publicly available repositories. Common method bias will be mitigated through procedural design

(Harman's single-factor test; marker variable technique). External validity of the case studies depends on theoretical rather than statistical generalisation, consistent with the design science orientation.

6. EXPECTED RESULTS AND DISCUSSION

Figure 1 presents the structural equation model derived from the IAS Framework, mapping the four testable propositions (P1–P4) as path relationships between latent constructs. Moderating variables dynamic capabilities and stakeholder integration quality are shown as interaction paths, consistent with the PLS-SEM validation design described in Section 5.

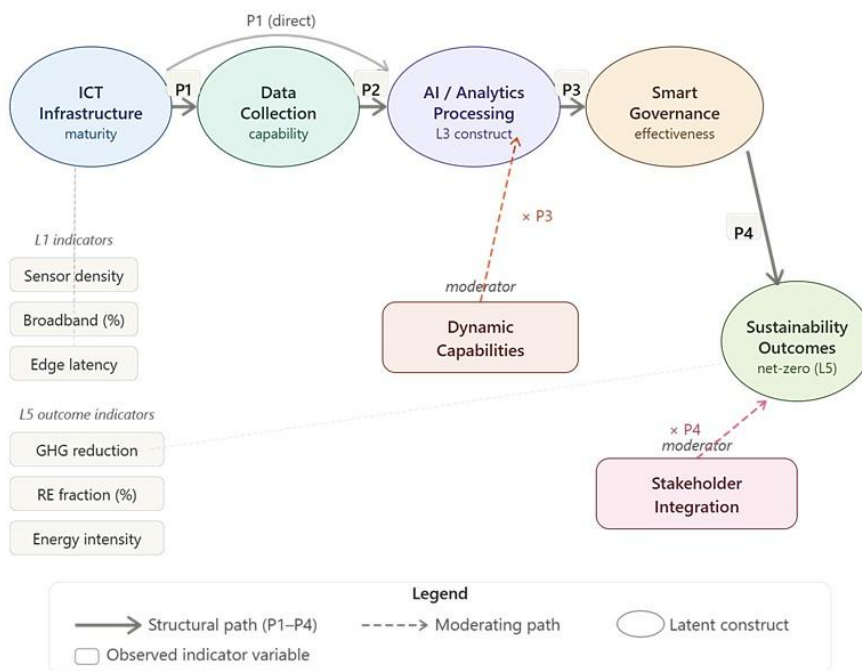


Figure 1: The Structural Equation Model

6.1 Framework Validation Expectations

Based on the literature synthesis, the IAS Framework's structural propositions are expected to receive empirical support in the proposed validation study. Specifically, ICT infrastructure maturity is hypothesised to explain 40–55% of variance in AI/analytics processing capacity (P1), consistent with similar infrastructure-capability relationships identified in Yigitcanlar et al. (2021) and Pereira and Romero (2021). The mediation of analytics on the infrastructure-governance path (P2) is expected to be partial rather than full, suggesting that governance effectiveness draws on both direct infrastructure access and analytically processed insights.

The moderation effect of dynamic capabilities (P3) represents the most theoretically novel expectation. Cities characterised by institutionalised routines for ICT capability sensing and reconfiguration operationalised through ICT governance committees, regulatory sandbox mechanisms, and cross-departmental data analytics units are expected to demonstrate significantly stronger analytics-governance pathways than cities with equivalent ICT infrastructure but weaker dynamic capabilities. This finding would constitute a significant contribution to both Dynamic Capability Theory and smart city governance scholarship.

6.2 Sectoral Sustainability Implications

Within the energy sector, cities deploying AI-enabled building energy management systems (BEMS) integrated with real-time grid data are expected to demonstrate 15–25% reductions in building energy intensity, consistent with reported outcomes in Helsinki's carbon-neutral strategy (City of Helsinki, 2021) and Singapore's Green Plan analytics infrastructure. The key mechanism is predictive demand-side management shifting heating, cooling, and lighting

loads in response to carbon-intensity signals from the electricity grid rather than price signals alone, thereby optimising not merely cost but emissions.

In urban mobility, cities with mature mobility-as-a-service (MaaS) platforms integrated with public transport analytics are expected to demonstrate measurable modal shift toward low-carbon transport. The analytical requirement is multi-modal route optimisation that incorporates real-time emissions data rather than purely journey time, a capability that currently characterises fewer than 15% of cities in the ICLEI smart city cohort (ICLEI, 2022). The IAS Framework's L3 analytics layer provides the architectural specification for this capability.

The digital twin dimension of the framework is expected to generate the most significant governance implications. Cities operating energy or transport digital twins that enable carbon budget scenario modelling are expected to demonstrate more adaptive and ambitious net-zero planning cycles, consistent with evidence from Dembski et al. (2020) and Shahat et al. (2021). The critical governance condition is the institutional integration of twin outputs into budget planning, regulatory permitting, and climate risk disclosure processes a condition that is technically achievable but institutionally demanding.

6.3 Comparative Framework Analysis

Against existing frameworks, the IAS Framework demonstrates several distinctive analytical advantages. Unlike the GreenStar ICT Framework, it integrates governance and analytics layers with infrastructure assessment, enabling holistic rather than purely technical evaluation. Unlike the C40 Digital Protocol, it specifies causal mechanisms rather than data exchange standards, enabling explanation rather than mere monitoring. Unlike Bibri and Krogstie's (2020) Smart Eco-City Framework, it incorporates dynamic capabilities as theoretically grounded organisational mediators and derives testable structural propositions. The IAS Framework's ESG alignment dimension mapping sustainability KPIs to TCFD/ISSB disclosure frameworks addresses an emerging policy requirement that no existing smart city framework adequately addresses.

6.4 Governance Archetypes

The comparative case analysis is expected to yield three governance archetypes: (i) Integrated Digital Governance cities (e.g., Singapore, Copenhagen), characterised by centralised data infrastructure, institutionalised analytics-to-policy pipelines, and comprehensive net-zero KPI systems; (ii) Fragmented Digital Transition cities (e.g., Medellín, emerging economy cases), characterised by substantial ICT investment but weak cross-departmental data integration and limited analytics-governance coupling; and (iii) Regulatory-Driven Transition cities, where net-zero progress is primarily driven by regulatory mandates rather than ICT-enabled optimisation. These archetypes provide policy-relevant characterisations that go beyond input-based smart city rankings to assess the actual governance quality of the ICT-sustainability interface.

7. CONCLUSION AND FUTURE SCOPE

This paper has developed the IAS Framework as an integrated conceptual and analytical model linking ICT strategy and analytics capabilities to net-zero urban outcomes in smart cities. Grounded in Systems Theory, TOE, Dynamic Capability Theory, and Stakeholder Theory, the framework advances theoretical understanding by specifying five interdependent layers infrastructure, data collection, AI/analytics processing, smart governance, and sustainability optimisation and deriving four testable structural propositions. The framework's originality lies in its integration of dynamic capabilities as organisational mediators, its ESG alignment dimension, and its provision of a standardised, multi-domain measurement instrument.

The IAS Framework has important practical implications. For urban policymakers, it provides a diagnostic architecture for identifying where in the ICT-sustainability value chain bottlenecks exist—whether in infrastructure readiness, data collection completeness, analytics maturity, or governance integration. For digital infrastructure planners, it specifies the analytical capabilities that must be built into smart city platforms from the design stage if net-zero outcomes are to be reliably produced. For ESG and climate governance practitioners, it offers a structured pathway for aligning urban sensor data with international disclosure frameworks.

Three directions for future research are identified. First, the IAS Framework requires empirical validation through the PLS-SEM and comparative case study designs outlined in Section 5; replication across diverse urban contexts including Global South cities where ICT constraints and governance structures differ significantly from the OECD context is particularly important. Second, the energy consumption and carbon rebound implications of large-scale urban AI deployments require systematic quantitative assessment; the IAS Framework's net positive sustainability assumption requires stress-testing under different infrastructure scaling scenarios. Third, the integration of citizen-generated data from participatory sensing, mobility apps, and social media—into urban analytics pipelines presents significant data governance challenges that intersect with privacy regulation, algorithmic accountability, and democratic legitimacy, warranting dedicated theoretical and empirical investigation.

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