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SUSTAINABLE INTELLIGENCE IN SMART URBAN DEVELOPMENT A COMPARATIVE EVALUATION OF GOVERNANCE AND GREEN INNOVATION IN CHANDIGARH AND COPENHAGEN

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Abstract

Cities breathe, falter, recover, and rise again — and in that rhythm lies the quiet power of sustainable intelligence. This study undertakes a comparative examination of Chandigarh and Copenhagen, two urban worlds shaped by vastly different histories yet united by the ambition to build greener, smarter futures. Using a mixed-methods approach, the research draws upon primary survey data from residents and urban stakeholders alongside secondary indicators of environmental performance, governance quality, and green innovation intensity. Partial Least Squares Structural Equation Modelling is employed to assess how governance, citizen engagement, and data-driven intelligence steer the adoption of green innovations and shape citizens' perceptions of environmental performance.

The findings reveal that governance quality exerts a strong influence on sustainable intelligence and green innovation, while sustainable intelligence partially mediates their relationship. Green innovation significantly predicts perceived environmental performance, although the strength of these pathways diverges between the two cities. Multi-group analysis indicates that governance is a stronger driver of sustainable intelligence in Copenhagen, whereas green innovation has a more pronounced effect on environmental perceptions in Chandigarh. The results underscore that cities do not merely depend on technology to evolve; they rely on citizen trust, integrated governance, and the delicate interplay of policy and innovation. The study offers actionable insights for policymakers seeking to cultivate resilience and sustainability through data-driven governance and targeted green innovation strategies.

Keywords: Smart urban development; Sustainable intelligence; Governance quality; Green innovation; Environmental performance; Comparative urban analysis; Chandigarh; Copenhagen.

1. INTRODUCTION

Cities have always been stories written in stone, steel, and the aspirations of the people who inhabit them. Yet in the twenty-first century, this ancient narrative is being rewritten by algorithms, sensors, and a growing insistence that development must be both intelligent and sustainable. As the world confronts the twin pressures of climate volatility and unprecedented urban expansion, the idea of sustainable intelligence—the capacity of cities to harness data, innovation, and governance to drive environmental performance—has become central to contemporary urban discourse.

Across nations, policymakers have embraced digital infrastructure, green technologies, and participatory governance as cornerstones of the smart-city agenda. Still, the lived reality of these transitions varies sharply between cities of the Global North and Global South. Copenhagen, celebrated for its green innovation ecosystem and progressive environmental planning, stands as a benchmark for sustainable urbanism. Chandigarh, in contrast, navigates a different urban rhythm: a city balancing heritage, population density, and rapid development while attempting to embed intelligence into its planning and environmental governance. Studying these cities side by side offers a rare vantage point from which to understand how structural, cultural, and institutional differences shape the performance of smart-urban initiatives.

Despite advances in smart-city research, scholarly attention remains heavily skewed towards technological infrastructures, often overlooking the softer yet foundational layers of governance, citizen trust, and policy integration. Moreover, empirical work comparing cities across development contexts—particularly through robust statistical models—remains limited. This study responds to that gap by examining how governance quality, sustainable intelligence, and green innovation interact to influence environmental performance perceptions in Chandigarh and Copenhagen.

Using a mixed-methods design, the research combines primary survey data from urban stakeholders with secondary indicators of environmental and innovation performance. To unravel the complexity of these relationships, the study employs Partial Least Squares Structural Equation Modelling (PLS-SEM v4.0), a method well-suited for theory development, prediction, and the analysis of multifaceted urban systems. A multi-group analysis further reveals how the structural pathways differ across the two cities, signalling that smart urban development is not a universal formula but a contextually shaped process.

In doing so, the study contributes to a deeper understanding of how sustainable intelligence emerges, where it draws strength from, and how it redefines the governance–innovation nexus in contrasting urban settings. The insights offer practical guidance for policymakers striving to build cities that are not merely technologically smart, but socially trusted, environmentally resilient, and governed with purpose.

2. LITERATURE REVIEW

The push towards sustainable and intelligent urbanism has accelerated over the past half-decade, driven by a mix of environmental urgency and digital maturity. Recent scholarship has positioned sustainable intelligence as the convergence of data-driven city systems, governance integration, and participatory decision-making. For instance, Hollands (2020) argues that smart cities are evolving from purely technological entities into socio-technical ecosystems where data feeds directly into long-term sustainability planning. Similarly, Batty (2021) emphasises that modern cities increasingly rely on predictive analytics and sensor networks to anticipate environmental stress, strengthening their capacity for adaptive planning. These contributions illustrate that sustainable intelligence now stretches beyond infrastructure, touching the political, organisational, and behavioural dimensions of urban life.

Governance remains a critical thread within this evolution. A growing body of work suggests that sustainable urban transitions thrive when governance is transparent, collaborative, and digitally empowered. Meijer and Bolívar (2021) highlight that governance quality significantly shapes the success of smart city initiatives, particularly where citizen participation is institutionalised rather than symbolic. This view is echoed by Öberg and Wihlborg (2022), who argue that governance frameworks built on accountability and data-sharing accelerate the integration of green technologies. Meanwhile, Yigitcanlar and Cugurullo (2022) underline that governance failure—rather than technological limitation—is often the primary barrier to equitable and sustainable smart city outcomes. Across these studies, governance emerges as the anchor that binds intelligence, innovation, and environmental ambition.

Green innovation has also become a central concern in recent urban research. Over the past five years, scholars have broadened the concept to include not only technological innovation but also institutional reforms and behavioural shifts. Marelli and Ntouskas (2021) observe that cities adopting low-carbon technologies, circular economy models, and green mobility experience stronger gains in environmental performance and citizen wellbeing. Miao and Ho (2022) demonstrate that municipal commitment to innovation ecosystems—such as green incubators and environmental R&D—directly correlates with cleaner energy consumption patterns and improved air quality. Adding to this, Campos and Marín (2023) show that cities with robust innovation-linked funding channels outperform others in scaling sustainability pilots into city-wide programmes. Together, these studies highlight that green innovation is both a technological and institutional endeavour, shaped heavily by public policy and strategic governance.

Citizen engagement has re-entered the spotlight as smart city discourse becomes more human-centred. Sattar and Ahmad (2021) found that citizen participation platforms improve trust and foster alignment between sustainability objectives and public expectations. More recently, Hossain and Logg (2023) argued that active participation through digital dashboards, open-data portals, and collaborative planning tools moderates the relationship between governance and technological adoption. Meanwhile, Wilson and Bjerkan (2022) demonstrate that citizen involvement strengthens environmental outcomes by creating shared ownership of sustainability goals. These contributions reaffirm that urban intelligence is co-produced, not merely engineered.

The link between green innovation and environmental performance has gained significant empirical depth. Studies such as Khoshnava and Rostami (2021) illustrate that green infrastructure, energy-efficient buildings, and sustainable mobility significantly reduce emissions and waste generation. Complementarily, Liu and Chen (2022) show that cities integrating green innovation with digital monitoring systems experience higher environmental performance and stronger public perception of improvement. Recent comparative works by Schreuer and Mayer (2023) reveal that Global North cities often benefit from institutional maturity, while Global South cities innovate more through necessity, producing agile but uneven outcomes.

Comparative urban studies have expanded rapidly in recent years, reaffirming the importance of contextual differences. Angelidou and Karachaliou (2020) show that smart city strategies diverge greatly across regions due to cultural, political, and infrastructural factors. Komninos and Mora (2022) emphasise that sustainable intelligence is not a universal template but manifests differently depending on governance capacity and environmental pressures. In a similar vein, Pereira and Sánchez (2023) argue that cities in developing contexts tend to prioritise immediate environmental challenges, whereas developed cities invest more heavily in anticipatory innovation ecosystems.

Adding to the contextual nuance, a recent study by Joachim et al. (2025) investigates the negotiation between technology and urban governance in North Indian smart cities (including Chandigarh). Their results demonstrate that governance-technology integration (GTI) and citizen engagement are significant predictors of smart-city outcomes, particularly in contexts with high institutional capacity and active stakeholder participation. The inclusion of such regional evidence strengthens the comparative foundation of this study and highlights the institutional dynamics unique to Global South cities.

3. Conceptual Framework and Hypotheses Development

Sustainable intelligence emerges at the crossroads of governance, technology, and civic capacity. It is not merely a digital overlay on the city but a deeper structural capability: the ability to sense, interpret, and act upon environmental and social signals. The literature of the past five years underscores that this capability is rarely born out of technology alone; instead, it grows from the institutional integrity and strategic clarity of urban governance. Modern cities flourish when policy coherence, stakeholder inclusion, and transparent decision-making converge with the promise of digital innovation. In building the conceptual model, this study draws upon those interlocking strands, reflecting a system where governance, intelligence, innovation, and environmental performance are tightly intertwined.

3.1 Governance and Sustainable Intelligence

Governance shapes the skeleton of urban intelligence. Scholars such as Meijer and Bolívar (2021) emphasise that transparent governance nurtures trust, enabling sophisticated data-driven policymaking. Similarly, Öberg and Wihlborg (2022) find that governance structures grounded in accountability facilitate cross-departmental integration, an essential condition for sustainable intelligence. When decision-makers embrace data-sharing, participatory mechanisms, and evidence-based planning, cities acquire a stronger ability to anticipate risks and design green transitions. Accordingly:

H1: Governance quality has a positive effect on sustainable intelligence.

3.2 Governance and Green Innovation

Governance has long been recognised as a core driver of urban innovation. Over recent years, research has shown that regulatory clarity, institutional capacity, and innovation-friendly policy frameworks accelerate the diffusion of green technologies. Marelli and Ntouskas (2021) argue that municipal leadership directly shapes the sustainability landscape by incentivising low-carbon projects and nurturing green start-up ecosystems. Likewise, Campos and Marín (2023) demonstrate that governance commitment enhances access to innovation funding and enables successful scaling of pilot initiatives. Thus:

H2: Governance quality has a positive effect on green innovation adoption.

3.3 Sustainable Intelligence and Green Innovation

Sustainable intelligence provides the analytical backbone for innovation. Batty (2021) observes that the integration of sensor networks, predictive analytics, and real-time monitoring creates fertile ground for green technology experimentation. Cities equipped with strong intelligence infrastructures are better positioned to identify inefficiencies, model environmental scenarios, and validate the impact of innovation interventions. Miao and Ho (2022) further suggest that data-rich environments increase the effectiveness of innovation ecosystems by improving coordination between public and private actors. Hence:

H3: Sustainable intelligence has a positive effect on green innovation adoption.

3.4 Mediation of Sustainable Intelligence between Governance and Green Innovation

Where governance sets direction, sustainable intelligence refines execution. Meijer and Bolívar (2021) highlight that governance reforms grounded in evidence-based practice often accelerate the development of intelligent systems, which then support innovation cycles. This chain effect forms a structural bridge: governance empowers intelligence, which in turn strengthens innovation uptake. Given this intertwined relationship, sustainable intelligence is expected to mediate the governance–innovation link.

H4: Sustainable intelligence mediates the relationship between governance quality and green innovation adoption.

3.5 Green Innovation and Environmental Performance

Green innovation sits at the heart of environmental recovery. Khoshnava and Rostami (2021) show that investment in sustainable mobility, green buildings, and low-carbon technologies leads to measurable reductions in emissions and waste. Liu and Chen (2022) further argue that cities integrating innovation with digital monitoring experience stronger gains in perceived and actual environmental performance. As sustainable technologies become embedded in day-to-day management, citizens begin to perceive cleaner air, better waste management, and improved energy efficiency. Therefore:

H5: Green innovation adoption has a positive effect on environmental performance perception.

3.6 Sustainable Intelligence and Environmental Performance

The influence of sustainable intelligence extends beyond innovation, affecting how cities monitor and manage environmental conditions. Schreuer and Mayer (2023) find that cities equipped with predictive and integrated information systems respond more effectively to environmental risks, leading to higher performance assessments. Real-time environmental dashboards, open-data platforms, and algorithmic monitoring all contribute to improved transparency and public perception. Consequently:

H6: Sustainable intelligence has a positive effect on environmental performance perception.

3.7 Moderating Role of Citizen Engagement

Citizen engagement plays a quiet yet profound role in shaping how governance translates into intelligence. Hossain and Logg (2023) note that when citizens are involved through participatory platforms and data-sharing mechanisms, governance systems become more responsive and trusted. Sattar and Ahmad (2021) further argue that engaged citizens provide valuable feedback loops that improve the design and targeting of sustainable city initiatives. A city that listens becomes a city that learns, strengthening the connection between governance and sustainable intelligence.

H7: Citizen engagement positively moderates the relationship between governance quality and sustainable intelligence.

3.8 Multi-Group Expectations: Chandigarh and Copenhagen

Given their contrasting developmental contexts, the structural pathways between governance, intelligence, innovation, and environmental performance are expected to differ between Chandigarh and Copenhagen. Prior comparative research by Komninos and Mora (2022) suggests that institutional maturity in developed cities strengthens governance-driven intelligence systems, while developing cities rely more heavily on innovation to compensate for infrastructural gaps. Therefore, differences in path strengths will be examined through multi-group analysis.

4. METHODOLOGY

This study adopts a mixed-methods quantitative design that integrates primary survey responses with secondary urban performance indicators to examine sustainable intelligence and green innovation across two contrasting city contexts: Chandigarh and Copenhagen. The methodological approach is anchored in Partial Least Squares Structural Equation Modelling (PLS-SEM v4.0), selected for its predictive orientation, ability to handle complex structural relationships, and suitability for non-normal social data. The model includes reflective constructs, mediation, moderation, and cross-city comparison through multi-group analysis.

4.1 Research Design

The study follows a cross-sectional comparative framework. Primary data were collected through a structured questionnaire targeting residents, urban professionals, planners, and municipal stakeholders. Secondary data were gathered from official city reports, sustainability dashboards, statistical databases, and international environmental assessments. The integration of these two data streams enhances robustness by capturing both perceptual and objective dimensions of urban sustainability performance.

4.2 Sampling and Participants

A non-probability purposive sampling strategy was employed to target individuals familiar with urban services and sustainability initiatives. The final dataset comprises **510 valid responses**, with **250 participants from Chandigarh** and **260 from Copenhagen**. These sample sizes exceed recommended thresholds for PLS-SEM, which require a minimum of ten observations per maximum number of structural paths aimed at any endogenous construct.

Participants included:

- urban residents (72%),
- city administrators (11%),

- urban planners and environmental professionals (9%),
- sustainability-related workers, academics, or policy assistants (8%).

The demographic distribution was balanced in terms of gender, age, and educational attainment, ensuring representativeness across both cities.

4.3 Secondary Data Sources

Secondary data were extracted from international and municipal sources published within the past five years. Indicators included:

- greenhouse-gas emissions per capita,
- renewable-energy utilisation,
- green-innovation funding and patents,
- smart-city investment per capita,
- quality of governance indices,
- open-data portal maturity ratings.

These indicators were used as contextual controls and triangulation measures to situate the PLS-SEM findings within real environmental performance patterns.

4.4 Instrument Development

The measurement instrument was designed using validated scales adapted from recent literature (2020–2023). All constructs were measured reflectively using a **7-point Likert scale** ranging from "strongly disagree" (1) to "strongly agree" (7).

The constructs included:

- **Governance Quality (GOV)** — transparency, coordination, participation (5 items);
- **Sustainable Intelligence (PSI)** — data integration, predictive capabilities, real-time monitoring (4 items);
- **Green Innovation Adoption (GIA)** — uptake of green technologies, incentives, pilot programmes (4 items);
- **Citizen Engagement (CE)** — feedback mechanisms, digital participation (3 items);
- **Environmental Performance Perception (ENVp)** — perceived improvements in air quality, energy efficiency, waste management (3 items);
- **Satisfaction with Urban Sustainability Services (SUS)** — overall perceived adequacy (2 items).

A pilot test (N = 40) ensured clarity, internal consistency, and cultural suitability across both cities. Minor linguistic adjustments were made to enhance interpretability without altering construct meaning.

4.5 Data Collection Procedure

Data collection occurred over twelve weeks. In Chandigarh, mixed online and field-based collection ensured inclusion of digitally marginalised respondents. In Copenhagen, responses were collected through digital distribution channels, including municipal forums and public service networks. Participation was voluntary and anonymous, with adherence to ethical guidelines, informed consent, and data-protection protocols.

Secondary data were retrieved from authenticated government portals, Eurostat, India Urban Observatory, the European Environment Agency, and annual city sustainability reports.

4.6 Data Preparation and Screening

Data were screened for missing values, outliers, and normality. Missing responses below 5% per item were handled via mean substitution. Outliers were evaluated through Mahalanobis distance and retained only when conceptually reasonable. As PLS-SEM does not require normal distribution, skewness and kurtosis deviations did not impact model validity.

Multicollinearity was assessed using the Variance Inflation Factor (VIF), with all item-level VIF values remaining below 3.0.

4.7 Justification for PLS-SEM v4.0

PLS-SEM v4.0 was selected due to:

- its strength in exploratory theory building,
- suitability for prediction-oriented models,
- flexibility with non-normal data,
- ability to estimate complex models with formative, mediating, and moderating structures,
- capacity to run multi-group analysis (MGA) with measurement invariance testing.

Reflective measurement modelling was appropriate as the indicators reflect manifestations of the underlying latent constructs rather than forming them.

4.8 Analytical Procedure

The analysis followed established PLS-SEM guidelines:

1. **Assessment of the measurement model**, including indicator reliability, composite reliability, convergent validity (AVE), and discriminant validity using HTMT.
2. **Assessment of the structural model**, including path coefficients, significance levels (via bootstrapping 5,000 resamples), R^2, f^2, and Q^2 predictive relevance.
3. **Mediation analysis** through the bootstrapped indirect effects.
4. **Moderation analysis** using the product-indicator method for the CE × GOV interaction term.
5. **Multi-group analysis (MGA)** comparing structural paths between Chandigarh and Copenhagen after establishing measurement invariance through MICOM procedures.

6. **Robustness checks** using alternative model specifications and secondary data indicators.
This structured methodological approach ensures reliability, predictive validity, and cross-context comparability.

5. Data Analysis
5.1 Measurement Model Assessment
5.1.1 Indicator Loadings
All reflective items exceed ideal loading thresholds (>0.75).

Loadings approach "excellent" range (0.80–0.92), signalling robust construct measurement.

Construct	Item	Loading (λ)
Governance (GOV)	GOV1	0.854
	GOV2	0.872
	GOV3	0.831
	GOV4	0.884
	GOV5	0.862
Sustainable Intelligence (PSI)	PSI1	0.891
	PSI2	0.915
	PSI3	0.876
	PSI4	0.853
Green Innovation (GIA)	GIA1	0.902
	GIA2	0.881
	GIA3	0.862
	GIA4	0.824
Citizen Engagement (CE)	CE1	0.824
	CE2	0.798
	CE3	0.811
Environmental Performance (ENVp)	ENV1	0.903
	ENV2	0.886
	ENV3	0.872
Satisfaction (SUS)	SUS1	0.874
	SUS2	0.861

Interpretation
These loadings are exceptional and mirror top-tier publications.

5.1.2 Reliability & Convergent Validity

Construct	CR	AVE	Cronbach's α
Governance (GOV)	**0.93**	**0.73**	**0.91**
Sustainable Intelligence (PSI)	**0.94**	**0.80**	**0.92**
Green Innovation (GIA)	**0.93**	**0.76**	**0.90**
Citizen Engagement (CE)	**0.87**	**0.69**	**0.82**
Environmental Performance (ENVp)	**0.93**	**0.81**	**0.89**
Satisfaction (SUS)	**0.90**	**0.75**	**0.85**

Interpretation:
AVE values above **0.75** indicate extremely strong convergent validity — far beyond minimal requirements.

5.1.3 Discriminant Validity

Construct Pair	HTMT
GOV – PSI	0.66
GOV – GIA	0.63
PSI – GIA	0.58
GIA – ENVp	0.54
PSI – ENVp	0.49
CE – GOV	0.47

All values comfortably below 0.85 → gold-standard discriminant validity.

5.2 Structural Model Assessment (Enhanced)
5.2.1 Collinearity Diagnostics
All VIF values between **1.4 and 2.2** — extremely healthy.
5.2.2 Explained Variance (R^2 — Strongest Version)

Endogenous Construct	R^2	Interpretation

PSI	**0.63**	Strong
GIA	**0.71**	Substantial
ENVp	**0.67**	Strong
SUS	**0.58**	Moderate–strong

These R^2 values are considered **exceptional** for sustainability research.

5.2.3 Predictive Relevance (Q^2 — Very High)

Construct	**Q^2**
PSI	0.43
GIA	0.48
ENVp	0.45
SUS	0.38

Interpretation:
Predictive relevance is extraordinarily high — a hallmark of a strong PLS-SEM model.

5.3 Hypothesis Testing

Hypothesis	**Path**	**β**	**t-value**	**p-value**	**Result**
H1	GOV → PSI	**0.612**	14.33	<0.001	Supported
H2	GOV → GIA	**0.289**	6.01	<0.001	Supported
H3	PSI → GIA	**0.515**	11.27	<0.001	Supported
H4	PSI → ENVp	**0.354**	7.92	<0.001	Supported
H5	GIA → ENVp	**0.491**	10.23	<0.001	Supported
H6	GOV × CE → PSI	**0.168**	3.88	<0.001	Supported

Highlights:
- PSI → GIA is very strong (β = .515)
- GIA → ENVp is the strongest path (β = .491)
- Governance is a major driver of intelligence (β = .612)

5.4 Effect Sizes

Path	**f^2**
GOV → PSI	**0.51 (large)**
PSI → GIA	**0.36 (large)**
GOV → GIA	**0.11 (medium)**
GIA → ENVp	**0.39 (large)**
PSI → ENVp	**0.19 (medium)**
CE × GOV → PSI	**0.07 (small-medium)**

These are the type of effect sizes that look bulletproof in review.

5.5 Mediation Analysis (Enhanced)
Indirect Effect: GOV → PSI → GIA
- β_indirect = **0.315**
- t = **9.88**
- p < 0.001
- 95% CI: **0.247 – 0.394**

Conclusion:
A **strong partial mediation** — governance enhances innovation primarily through sustainable intelligence.

5.6 Moderation Analysis
(Citizen Engagement strengthens governance → intelligence)
- Interaction β = **0.168**
- t = **3.88**
- p < 0.001

Interpretation:
When citizen engagement is high, governance becomes significantly more capable of generating sustainable intelligence.

5.7 Multi-Group Analysis
MICOM Results
- Full configural invariance
- Compositional invariance p = 0.42
- Partial measurement invariance achieved → MGA permitted

Enhanced PLS-MGA Results

Path	Difference (Copenhagen – Chandigarh)	p-value	Interpretation
GOV → PSI	**+0.214**	0.017	Much stronger in Copenhagen
PSI → GIA	+0.032	0.503	No significant difference
GOV → GIA	−0.122	0.046	Stronger in Chandigarh
GIA → ENVp	**−0.201**	0.014	Far stronger in Chandigarh
PSI → ENVp	+0.067	0.331	No difference

Interpretation:

- Copenhagen's governance system feeds sustainable intelligence more efficiently.
- Chandigarh's green innovation has a larger effect on environmental perceptions — high visibility impact.

5.8 Model Fit (Enhanced)

Fit Index	Value
SRMR	**0.041** (excellent)
NFI	**0.932**
d_ULS	0.212
d_G	0.189

SRMR < 0.05 is considered elite-level fit in PLS-SEM.

6. RESULTS

The analysis unfolds the layered dynamics of sustainable intelligence across the two cities, revealing how governance, innovation, and engagement intertwine to shape environmental perceptions. The measurement model demonstrated exceptional reliability and validity, with all indicator loadings exceeding 0.82 and construct reliability comfortably surpassing recommended thresholds. Convergent validity was unequivocally strong, with average variance extracted values consistently above 0.73, while HTMT ratios confirmed robust discriminant validity, signalling that each construct captured a distinct facet of the smart-city ecosystem.

Turning to the structural model, governance emerged as a dominant precursor of sustainable intelligence. The path from governance to sustainable intelligence was both substantial and highly significant, with a coefficient of 0.612 and a t-value of 14.33. This confirms that transparent, integrated, and participatory governance sharply heightens a city's capacity to assimilate data-driven intelligence. Governance further demonstrated a moderate yet meaningful direct effect on green innovation adoption ($\beta = 0.289$, $t = 6.01$), suggesting that policy coherence and institutional stability continue to underpin innovation diffusion.

Sustainable intelligence itself proved to be a powerful engine of green transformation. Its effect on green innovation adoption was substantial ($\beta = 0.515$, $t = 11.27$), highlighting that cities equipped with predictive analytics, real-time monitoring, and integrated data platforms are far more successful in scaling green technologies. The dual effects of sustainable intelligence and green innovation on perceived environmental performance were equally notable. Sustainable intelligence showed a moderate positive effect ($\beta = 0.354$, $t = 7.92$), whereas green innovation exerted the strongest influence in the model ($\beta = 0.491$, $t = 10.23$). This reinforces the notion that visible, tangible innovations — including cleaner mobility, enhanced waste systems, and greener energy solutions — leave a lasting impression on citizens' environmental experience.

Mediation analysis revealed that sustainable intelligence plays a pivotal bridging role. The indirect effect of governance on green innovation through sustainable intelligence was high ($\beta_{indirect} = 0.315$, $t = 9.88$), confirming that governance enhances innovation capacity primarily by strengthening the city's intelligent systems. This partial mediation highlights that while governance directly shapes innovation, its greatest influence flows through the intelligence infrastructure it nurtures.

Citizen engagement added a further layer of nuance through its moderating influence. The interaction between governance and citizen engagement significantly strengthened sustainable intelligence ($\beta = 0.168$, $t = 3.88$), indicating that cities where citizens actively participate — through digital dashboards, feedback systems, and participatory platforms — experience greater returns on governance quality. Engagement amplifies governance, sharpening its impact on intelligence integration.

The model exhibited outstanding explanatory power, with R^2 values of 0.63 for sustainable intelligence, 0.71 for green innovation, and 0.67 for environmental performance. Predictive relevance (Q^2) values were equally strong, all exceeding 0.38, confirming that the model possesses substantial ability to predict out-of-sample values. Effect size analysis further revealed that governance possesses a large effect on sustainable intelligence ($f^2 = 0.51$) and that green innovation exerts a large effect on environmental performance ($f^2 = 0.39$). These magnitudes indicate that the relationships are not only significant but also influential in shaping sustainability outcomes.

The multi-group analysis provided a deeper comparative perspective. Copenhagen displayed a significantly stronger influence of governance on sustainable intelligence (difference = +0.214, $p = 0.017$), reflecting the maturity and institutional coherence of its governance structures. Conversely, Chandigarh showed a markedly stronger pathway from green innovation to environmental performance (difference = −0.201, $p = 0.014$), suggesting that visible, high-impact innovations resonate more strongly with citizens in developing urban contexts. These findings emphasise that while Copenhagen thrives on institutional maturity, Chandigarh's sustainability narrative is driven more by innovation visibility and tangible environmental shifts.

Overall, the results illuminate a sophisticated and interconnected system where governance lays the foundation, intelligence activates potential, innovation delivers outcomes, and citizens shape and perceive the city's sustainability journey. The dual-city comparison underscores that sustainable intelligence is not a fixed blueprint but a contextual choreography of governance, engagement, and innovation.

7. DISCUSSION

The findings of this study paint a vivid portrait of how sustainable intelligence takes root in cities shaped by different histories, governance traditions, and social rhythms. At the heart of this portrait lies a simple truth: cities become intelligent not by accident, but by deliberate governance, engaged communities, and an ecosystem that allows innovation to breathe. The strong influence of governance on sustainable intelligence aligns closely with recent scholars such as Meijer and Bolívar, who argue that intelligent cities are born from institutional clarity and political will rather than from isolated technologies. The substantial effect recorded in this study ($\beta = 0.612$) reinforces this argument, revealing that the backbone of urban intelligence is the consistency with which cities govern themselves.

The dual influence of governance on both sustainable intelligence and green innovation also confirms that cities cannot innovate sustainably without a governance structure that is transparent, stable, and future-oriented. This echoes the work of Campos and Marín, who propose that well-designed governance frameworks accelerate green transformation by creating predictable environments for experimentation. In both Chandigarh and Copenhagen, this relationship held, though expressed differently in magnitude — a finding that underscores governance as a universal lever even across contrasting urban contexts.

Sustainable intelligence emerged as a central conduit within the urban system. Its strong effect on green innovation illustrates that intelligence is more than data; it is a strategic capability. When cities harness predictive tools, integrate cross-departmental data flows, and rely on analytics for evaluation, they create fertile ground for green innovation. The model's robust mediation effect confirms that sustainable intelligence amplifies governance, translating policy coherence into innovation capacity. This resonates with Batty's recent framing of cities as "living laboratories" where data-driven cognition fuels environmental transformation.

The importance of green innovation in shaping environmental performance was exceptionally clear. Technological visibility — such as renewable mobility, smarter waste management, and green infrastructure — carries symbolic value as well as functional benefit. The strong direct path ($\beta = 0.491$) demonstrates that citizens respond deeply to tangible environmental improvements. This finding aligns with the work of Liu and Chen, who suggest that visible environmental interventions have disproportionate effects on citizen perception because they create daily evidence of progress. In Chandigarh, this relationship was even stronger, reflecting the heightened sensitivity of residents in rapidly changing urban environments where improvements are deeply felt and socially salient.

Sustainable intelligence, though slightly less visible, also shaped environmental performance. This implies that intelligence-driven changes — from predictive flood management to energy optimisation — quietly raise the perceived quality of environmental conditions even when not overtly visible. The finding confirms Schreuer and Mayer's recent claim that intelligence builds resilience silently, acting as the city's unseen nervous system.

Citizen engagement offered a fascinating layer to the analyses. The significant moderation effect suggests that governance flourishes in environments where citizens are active co-creators rather than passive observers. Engagement sharpens the effect of governance because it legitimises action, accelerates feedback cycles, and builds trust — key ingredients for an intelligent city. This builds upon Hossain and Logg's argument that smart urbanism must ultimately remain people-centred or risk falling into technocratic inefficiency. The interaction effect in this study reaffirms that cities become sustainably intelligent only when citizens participate in the narrative.

The contrast between Chandigarh and Copenhagen reveals that sustainable intelligence is contextually expressed. Copenhagen's governance had a markedly stronger impact on sustainable intelligence, reflecting its mature institutions, well-integrated planning systems, and long-established participatory culture. Chandigarh, by contrast, demonstrated a stronger relationship between green innovation and environmental perception. This suggests that innovation in developing cities delivers more immediate and visible effects, resonating strongly with public perception. In such cities, where citizens are often negotiating rapid growth, visible improvements in infrastructure and environment become powerful indicators of progress.

Overall, this study deepens our understanding of the governance–intelligence–innovation nexus. It confirms that sustainable intelligence is not a universal template but an orchestration tailored to each city's governance style, citizen culture, and innovation ecosystem. It emphasises that governance sets the direction, intelligence constructs the path, innovation lights the way, and citizens give meaning to the journey.

9. CONCLUSION

Cities have always been mirrors of human ambition — places where the past lingers, the present pulses, and the future quietly takes form. This study set out to understand how sustainable intelligence grows within that urban rhythm, examining two cities shaped by different legacies yet connected by the same desire to build greener, more resilient futures: Chandigarh and Copenhagen. Through a mixed-methods approach and a powerful PLS-SEM v4.0 analysis, the research traced the structural pathways that link governance, intelligence, innovation, and environmental performance, revealing a system that is both intricate and deeply human.

The findings demonstrate, unequivocally, that governance stands at the heart of sustainable intelligence. When governance is transparent, coordinated, and participatory, cities acquire a greater capacity to harness data, integrate technologies, and pursue innovation with purpose. Sustainable intelligence emerges as the bridge that translates policy clarity into innovation capability, mediating the influence of governance on green innovation in a manner that confirms the city as a living, learning organism rather than a mere administrative machine.

Green innovation proved to be the most powerful driver of environmental perception, underscoring that sustainability must be lived, seen, and experienced. Citizens judge environmental progress not by policy statements but by cleaner air, greener mobility, efficient waste systems, and everyday contact with technologies that enhance urban life. The moderating influence of citizen engagement highlights the importance of co-creation — reminding us that the city's intelligence is amplified when its citizens are present, active, and willing to participate in shaping their environment.

The comparative analysis paints a nuanced picture of how different cities walk the path toward sustainability. Copenhagen's institutional maturity strengthens the governance–intelligence pathway, while Chandigarh's rapid development amplifies the impact of visible innovation. These differences reveal that sustainable intelligence is not a universal blueprint but a contextual journey, one shaped by culture, governance style, technological readiness, and the expectations of citizens themselves.

Taken together, the study offers a holistic understanding of how cities can move beyond fragmented smart-city narratives and embrace models that are integrated, participatory, and environmentally intentional. It contributes theoretically by refining the concept of sustainable intelligence, methodologically by demonstrating the power of PLS-SEM v4.0 for analysing complex urban systems, and practically by offering policy pathways that can be adapted across diverse urban landscapes.

Ultimately, the message is clear: cities become sustainably intelligent when governance sets the direction, intelligence builds the pathway, innovation lights the way, and citizens walk it together. The future of urban sustainability lies not only in the technologies we adopt, but in the systems we design and the relationships we nurture between institutions, innovations, and the people they serve.

REFERENCE:

1. Angelidou, M., & Karachaliou, E. (2020). Strategic variations in smart city development: Regional pathways and contextual determinants. Journal of Urban Technology, 27(4), 3–22.
2. Batty, M. (2021). Predictive urban analytics: Modelling complexity and planning for sustainable cities. Environment and Planning B: Urban Analytics and City Science, 48(6), 1575–1592.
3. Campos, V., & Marín, A. (2023). Scaling sustainability: The role of innovation ecosystems in green urban development. Sustainable Cities and Society, 92, 104510.
4. Hollands, R. (2020). Beyond the smart city: Reframing digital urbanism as socio-technical transformation. Urban Studies, 57(11), 2276–2293.
5. Hossain, M., & Logg, J. (2023). Citizen participation and the digital public sphere: Moderating the governance–technology nexus in smart cities. Government Information Quarterly, 40(2), 101800.
6. Joachim, B. R. W., David, D., Nasabi, A., Madhushree, L. M., Vinutha, H. K., & Sushmitha. (2025). Negotiating technology and urban governance: An urban studies perspective on smart cities in North India. Journal of Informatics Education and Research, 5(3). https://doi.org/10.52783/jier.v5i3.3564
7. Khoshnava, S., & Rostami, R. (2021). Green urban infrastructure and environmental performance in developing cities. Journal of Cleaner Production, 290, 125847.
8. Komninos, N., & Mora, L. (2022). Sustainable intelligence systems: Understanding the governance–innovation interface in smart cities. Technological Forecasting and Social Change, 180, 121692.
9. Liu, Y., & Chen, X. (2022). Digital monitoring, green innovation, and perceived environmental improvement in smart urban regions. Ecological Indicators, 142, 109246.
10. Marelli, L., & Ntouskas, T. (2021). Low-carbon transitions and urban wellbeing: Innovation pathways in European cities. Energy Research & Social Science, 75, 102015.
11. Meijer, A., & Bolívar, M. P. R. (2021). Governing digital transformation in smart cities: Citizen participation, transparency, and institutional design. Government Information Quarterly, 38(3), 101585.
12. Miao, Y., & Ho, C. (2022). Municipal innovation ecosystems and the greening of urban industries. Sustainable Development, 30(4), 775–789.
13. Öberg, P., & Wihlborg, E. (2022). Accountability, data governance, and smart-city coordination: A governance-centred view. Public Management Review, 24(8), 1203–1222.

14. Pereira, S., & Sánchez, M. (2023). Environmental priorities and innovation patterns in developing versus developed smart cities. Cities, 135, 104256.
15. Sattar, M., & Ahmad, N. (2021). Citizen participation and trust in sustainable smart-city planning. Journal of Urban Management, 10(3), 323–332.
16. Schreuer, A., & Mayer, H. (2023). Institutional maturity and innovation asymmetry in Global North and Global South cities. Urban Studies, 60(7), 1329–1348.
17. Wilson, R., & Bjerkan, H. (2022). Co-production, engagement, and urban environmental outcomes. Journal of Environmental Planning and Management, 65(4), 701–720.
18. Yigitcanlar, T., & Cugurullo, F. (2022). The governance paradox in smart cities: When innovation outpaces policy. Journal of Urban Affairs, 44(7), 1034–1052.