



Digitalization for City-Level Models, Data, and Knowledge: Enabling Trust, Transparency, and Evidence-Based Climate Action

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8.1 INTRODUCTION

By 2050, nearly 70% of people will live in cities that already account for more than 70% of global greenhouse gas emissions (Mukim et al., 2023). Urban areas, therefore, concentrate both climate risks and the capacity to

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deliver solutions, from innovation and finance to civic engagement (Yan & Cheng, 2024). The effective use of city-level models, data, and knowledge is now central to closing the gap between ambition and implementation.

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Since 2018, the Global Research and Action Agenda on Cities and Climate Change Science (GRAA) and successive Innovate4Cities (I4C) cycles have clarified what cities need from digitalization: actionable data that is trustworthy, transparent, and usable across institutions. The updated agenda organizes these needs into eight linked dimensions, or towers, that guide how information should be generated, governed, and applied. This chapter adopts those dimensions as a practical lens for strengthening city data ecosystems.

We define digitalization as the full integration of digital tools, data streams, and analytics into urban governance. City knowledge encompasses baseline inventories, scenario and risk models, real-time sensors, citizen-generated inputs, and place-based expertise that guide local decision-making. A systems approach recognizes feedback cycles, trade-offs, and path dependencies across all levels (Salehi & Sharifi, 2022). The aim is to align system demand trajectories with delivery readiness so that data translates into investable action.

Three developments motivate the analysis. First, cities are moving beyond static inventories toward longitudinal, interoperable data infrastructures that connect mitigation, adaptation, and equity. Second, digital tools such as artificial intelligence (AI), internet of things (IoT), and digital twins can shorten decision cycles when paired with clear governance and capacity. Third, investors and treasuries increasingly require transparent, reproducible models that clarify how interventions deliver outcomes over time.

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The chapter contributes in three ways. It charts how city knowledge systems have evolved, highlighting shifts in goals, roles, and technologies that change how municipalities plan and deliver. It brings to the surface persistent challenges, including interoperability gaps, algorithmic risks, uneven capacity, and the environmental footprint of digital systems. It then presents practical responses through three case studies and a systems-thinking synthesis that links open standards, participatory data, ethics-by-design, and finance readiness.

We first outline the evolution of city-level data and knowledge systems. We then use the eight GRAA towers to summarize key challenges. Next, we examine how digitalization and capacity-building enable credible, scalable responses. Three case studies illustrate implementation at city and country scales. A systems-thinking section connects the towers to considerations of delivery and justice. We close with a concise set of recommendations and metrics for governments, financiers, and civil society.

8.2 THE EVOLUTION OF CITY-LEVEL DATA AND KNOWLEDGE SYSTEMS

Since the early 2000s, cities have adopted data-driven methods for climate action, but the purpose and use of such data have changed markedly since the first GRAA in 2018. Early efforts focused mainly on mitigation, especially on greenhouse gas inventories based on the Global Protocol for Community-Scale Greenhouse-Gas Emission Inventories (GPC) (ICLEI, C40, & WRI, 2014). These provided annual snapshots of emissions but were rarely linked to adaptation, resilience, or equity (Bulkeley et al., 2014). The 2018 conference that produced the first GRAA expanded the agenda to include systemic interdependencies among infrastructure, governance, and climate risk (Hunter et al., 2023). Local governments evolved from data implementers to co-producers, using evidence to guide land-use, finance, and infrastructure choices (Taylor et al., 2021). Data became a strategic asset for decision-making rather than a compliance requirement.

Methods also shifted from linear, supply-side accounting toward dynamic, systems-based approaches. Cities now increasingly view mitigation and adaptation capacity through their ability to generate, connect, and apply knowledge across sectors (Hsu et al., 2019). Participatory

sensing, open-data portals, and community engagement allow citizen-generated data on air quality, flooding, and urban heat to complement official statistics (West et al., 2019). When such “smart” systems are transparent and inclusive, they enhance legitimacy and uptake (Jackson et al., 2022).

The virtual 2021 Innovate4Cities Conference saw the key cross-cutting issue of *City-level models and data* joined by *digitalization* as a dimension of consideration (this is discussed in detail in Chapter 3). These dimensions defined the structural qualities of actionable, equitable data systems, and emphasized interoperability and trust over technical sophistication alone. Digital tools moved from optional pilots to essential infrastructure for traceability and accountability (Batty, 2018). Urban digital twins, combining real-time sensors with AI-based simulations, let planners test interventions virtually before implementation, mainstreaming model-based governance (Law & Zhang, 2018; van Berlo et al., 2020). As the concept has spread, authors have suggested practical ways to differentiate digital twins based on factors like data exchange between physical and digital systems, system level, and cognitive features, with interoperability and life-cycle integration often lacking in real-world applications (Mendonça et al., 2024).

The 2024 Innovate4Cities conference advanced this agenda by formalizing eight “towers” of city-level data, models, and knowledge: communication, decentralization, digitalization, efficiency, information integrity and transparency, risk, scale, and uncertainty—that reframed city climate knowledge as a shared commons co-created among governments, citizens, and researchers (Irvin et al., 2024). This shift rejected technosolutionism and stressed that trust, transparency, and governance capacity determine digital success (Huang-Lachmann, 2019).

Recent initiatives illustrate this evolution. The Swedish ClimateView platform enables cities to link system-level demand (e.g., modal-shift targets) with interventions and forecasted outcomes, aligning strategic vision with delivery (Shalit et al., 2024). In Brazil, DUCTExplorer applies AI and spatial analytics to map heat vulnerability and collect community feedback, while the CityCatalyst stack translates national datasets into city-scale assessments. These examples show the shift from static reporting toward decision-supporting systems.

Another significant change is the convergence between digital knowledge systems and climate finance. Transparent, reproducible models that show how interventions deliver results are becoming prerequisites for

investment, connecting planners, financiers, and donors (Hughes et al., 2020; Shalit et al., 2025). As competition for resources grows, continuous monitoring of outcomes across sectors strengthens credibility and accelerates project approval.

Overall, the past decade has marked a transformation in urban climate governance. Cities act as strategic data stewards, designing and operating infrastructures that connect global goals with local action. From the early greenhouse gas inventories of the 2000s to today's AI-enabled digital twins and participatory platforms, digitalization has reshaped both technology and institutions, paving the way for more transparent and finance-ready transitions.

8.3 KEY CHALLENGES IN CITY-LEVEL MODELS AND DATA

Despite progress, major gaps persist that limit the effectiveness of urban digital systems.

8.3.1 Data Availability and Interoperability

High-quality, standardized city-scale climate data remains scarce. Many local governments -especially in the Global South- still make critical decisions with incomplete datasets, while even data-rich cities suffer from fragmentation across departments and vendors (Yang et al., 2024; Bozkurt et al., 2025). The 2021 Innovate4Cities report ranked “observations, data and modelling at the city scale” among the least developed areas of the GRAA (GCoM & UN-Habitat, 2022).

8.3.2 Capacity and Continuity

Knowledge systems depend on expertise, funding, and institutional memory that often change with election cycles and donor programs. Evidence from the 2021 Western Germany floods further illustrates this challenge in practice: disaster response across interconnected water and health systems was limited by gaps in coordination, communication, information management, and timing, worsened by physical disruptions and the legal and policy environment, leading to inadequate preparedness and response (Nick et al., 2023). Additionally, when pilots end or trained staff leave, monitoring collapses. The Tuvalu Coastal Adaptation Project,

funded by the Green Climate Fund, delivered the country's first high-resolution elevation model (UNDP, 2021), but it also illustrates how valuable datasets can degrade without long-term stewardship.

8.3.3 *Standards, Transparency, and Algorithmic Accountability*

AI-based decision tools offer analytical power, yet risk bias, and opacity. Proprietary optimization systems have disadvantaged informal settlements when training data have omitted them (Sanchez et al., 2024). Without audit protocols, cities may rely on “black-box” tools that erode trust. In safety-critical fields such as disaster risk management, practitioner guidance stresses that bias, privacy and security risks, lack of transparency and explainability, and inflated expectations can cause real harm if machine learning tools are used without safeguards and governance mechanisms (Soden et al., 2021). Open, modular frameworks such as ClimateView's Transition Elements (Shalit et al., 2024) demonstrate how transparent schemas can standardize assumptions and improve reproducibility.

8.3.4 *Risk, Uncertainty, and Downscaling*

Translating national or global models to neighborhood scales is complex. Simplifying land-use or socio-economic patterns can cause maladaptation (Wilby et al., 2014). Many cities are shifting to opportunity-based scenario planning that co-creates desirable futures, backcasting to identify enabling actions (Haasnoot et al., 2013). These approaches require participatory tools and a cultural shift from risk avoidance to adaptive learning.

8.3.5 *Decentralization Versus Efficiency*

Distributed sensors and citizen science enhance local insight but raise questions about data quality and validation. Studies show that wearable air-quality sensors can achieve reference-grade accuracy through clustering and calibration (Nguyen et al., 2025). Yet such methods can exceed municipal capacity, while vendor-locked centralized platforms restrict flexibility. Balanced governance should encourage experimentation within interoperable standards.

8.3.6 *Environmental Footprint of Digitalization*

Running complex AI models and digital twins consumes significant energy; AI data centers could reach 3.4% of global electricity demand by 2030 (de Vries, 2023). Hardware production also carries embodied carbon and resource costs (Zewe, 2025). Quantifying and offsetting this footprint is crucial to ensure that digital tools support, rather than undermine, mitigation goals.

8.3.7 *Data Ethics and Epistemic Justice*

Informal, Local, and Indigenous Knowledge remain under-represented in formal datasets. A review of planetary-health citizen-science projects found that institutions in the Global North funded 87% of projects, potentially skewing priorities (Ambole et al., 2025). Recognizing diverse epistemologies prevents inequities and enriches understanding of place-specific resilience.

These challenges are institutional, ethical, and technical. Interoperability without transparency can reproduce inequality, and hidden carbon costs may offset efficiency gains. Operating the eight GRAA towers using mutually reinforcing principles—openness, accountability, fairness, and continuity—will allow cities to transform fragmented initiatives into inclusive, enduring knowledge systems.

8.4 DIGITALIZATION AND CAPACITY-BUILDING FOR CITY CLIMATE ACTION

Digitalization has moved to the center of urban climate governance. AI optimizes transport routes in real time, IoT sensors stream micro-climate data, and digital twins allow policy scenarios to be tested before implementation (Argyroudis et al., 2022; Helmi et al., 2024). When used strategically, such tools shorten decision cycles and build the evidence base that financiers need. Their success, however, depends on human and institutional capacities that remain uneven.

AI analytics now turn raw sensor data into hourly emissions baselines, enabling carbon budgets to be managed like ledgers (Shen et al., 2023). IoT networks track heat islands, groundwater, and building energy use, feeding early-warning dashboards for adaptation (Balogun et al., 2020). Continuous digital-twin operation can deliver up to 18% energy savings

in retrofit programs (Bortolini et al., 2022). These systems transform episodic inventories into living knowledge platforms.

However, technical innovation must be matched by skills and governance. Many municipalities lack personnel with statistical or coding expertise; audits show that fewer than one in 10 climate-staff positions in African and Asian cities require such skills (Bastidas et al., 2024). Broader training frameworks like DC2-CF combine data competence with systems thinking, stakeholder engagement, and ethics-by-design (Helmi et al., 2024). Roles should be defined by function: compliance analysts need methodological rigor, while transition modelers need facilitation and prototyping abilities.

Financing remains a major constraint. Sensors, cloud services, and expert staff entail high upfront costs. Positive net benefits emerge only when technology upgrades coincide with governance reforms that streamline project pipelines and enable blended finance (OECD, World Bank, & UN Environment, 2018). Mechanisms such as outcome-linked bonds or pooled procurement can improve affordability. The WHO Small Island Developing States initiative showed how harmonized procurement yielded average savings of 56% (World Health Organization [WHO] Regional Office for Africa, 2024).

Digital platforms also connect fragmented project pipelines with climate-aligned capital. When data demonstrates system-wide interactions, such as e-buses cutting CO₂ while freeing grid capacity, treasuries can present program-level business cases that align with investors' risk appetites. Transition portfolios combining multiple measures under shared metrics can reduce transaction costs by 30% and attract larger investments (Monasterolo & Battiston, 2022; Shalit et al., 2025).

Ethics and trust are central. Public-private data-trust models pool municipal and citizen data under neutral charters guaranteeing anonymity, open-access derivatives, and transparent governance (Verhulst, 2024). Participatory ethics boards enable civil society to review algorithms and address privacy and surveillance risks (Sanchez et al., 2024). Such safeguards strengthen legitimacy and encourage long-term data sharing.

The Human Needs-Based Climate Innovation Framework (UNFCCC, 2021) reinforces people-centered evaluation by measuring technology through outcomes such as clean energy, safe mobility, and resilient shelter, rather than hardware counts. Linking each digital indicator to a needs-based result translates technical progress into social benefit. RiskScape, for

example, prioritizes flood-mitigation investments for residents of informal settlements, aligning adaptation with equity.

Four enabling conditions support responsible digitalization:

1. *Open standards* that let cities integrate new datasets without re-engineering (e.g., Transition Element Framework, GPC).
2. *Outcome-based finance* that ties funding to independently verified data.
3. *Ethics-by-design training* covering privacy, bias auditing, and life-cycle carbon accounting.
4. *Interoperable governance* via data trusts and citizen oversight that balance innovation with accountability.

With these capabilities in place, cities can move from pilots to adaptive, scalable, and socially responsive digital climate practice.

8.5 CASE-STUDY EXAMPLES: DIGITAL STRATEGIES FOR CLIMATE-RESPONSIVE CITIES

The rapid development of digital tools has transformed how cities understand, plan, and monitor climate action. While early climate tools mainly focused on creating emissions inventories or tracking individual projects, today's platforms are increasingly designed to support systemic planning, integrate with financial frameworks, and enable ongoing assessment. At the same time, new forms of digital infrastructure, such as participatory mapping and interoperable data standards, are allowing cities to transition from single assessments to adaptive, evidence-based decision-making. This section presents three examples of digital tools used to support climate-conscious urban governance. Each example follows a standard structure: context and motivation, approach and features, emerging impacts, and lessons learned. Collectively, these cases demonstrate how cities and their partners are developing the next generation of digital climate strategies. After the case studies, we examine the growing role of co-production in shaping city knowledge systems, including a snapshot from Tuvalu's coastal-resilience initiative.

8.5.1 Case Study 1: ClimateView

Context and Motivation

Cities are facing growing pressure not only to demonstrate that their climate strategies yield tangible results but also to use data to drive and inform their decisions. Traditional methods often depend on emissions inventories and sector-specific plans that are disconnected from actual implementation or investment plans. The gap between strategic goals and operating capacity has created a need for specialized platforms that take a holistic approach, aligning data, roles, funding, and monitoring (Lonergan et al., 2025). The ClimateView platform, now adopted in more than 250 cities worldwide, was developed to address this need, helping cities structure and model their climate transition as a series of activity shifts based on IPCC mitigation options, monitor implementation readiness, build investment confidence, and share knowledge with other cities.

Approach and Features

The architecture of ClimateView takes a systems-based approach to structuring transition efforts by defining goals, understanding the current status, identifying needed shifts in activities and their requirements to occur, developing, and logging interventions to fulfill the requirements to achieve those shifts, and using custom indicators to monitor change and inform iteration. The method is grounded in the Transition Element Framework (TEF), which provides a standardized approach (DIN SPEC 91637¹) for defining, comparing, and monitoring activity shifts across sectors, including transportation, energy, and housing. Using this framework, cities can collaborate more effectively to develop and implement evidence-based transition pathways grounded in IPCC science and tailored to local constraints and opportunities (Colona, 2023).

The platform supports the operationalization of systems thinking and multi-level governance. For example, in Scotland, the Scottish Climate Intelligence Service (SCIS) uses ClimateView to help all 32 local authorities coordinate their climate plans while maintaining local context. In Germany's Ruhr region, 53 municipalities are digitizing local interventions that, together, form a regional scenario, enabling spatial-planning

¹ <https://www.din.de/en/innovation-and-research/din-spec-en/current-din-specs/wdc-beuth:din21:393817040>.

agencies to identify gaps, align actions, and make a case for state-level support. The platform features live dashboards, intervention mapping, and integration with reporting standards.

Emerging Impacts

Results indicate improvements in both internal and external coordination. Cities and regions using ClimateView report better alignment between departments, stakeholders, and levels of government (Scottish Climate Intelligence Service, n.d.). From a finance perspective, ClimateView supports clear monitoring and communication of impact, as well as the aggregation of smaller actions into portfolio-level investment cases. For example, cities in the Netherlands are using ClimateView to standardize their housing and mobility plans under a national data playbook, resulting in comparable outputs that may enhance investor confidence.

Lessons Learned

ClimateView shows the importance of combining scientific accuracy with planning usability. Cities need tools that not only track emissions but also map interdependencies, measure system demands, and show how they achieve results, unlocking innovative financing options and enabling implementation. Instead of having an isolated impact, ClimateView enables cities to navigate their entire transition through a comprehensive, integrated approach. The platform proves that when system-wide readiness indicators and co-benefit tracking are integrated into a single digital environment, it becomes easier for cities to secure funding, coordinate stakeholders, and adjust their plans based on real-world feedback. Therefore, ClimateView functions as an operational infrastructure for multi-level governance and climate action.

8.5.2 Case Study 2: Brazil's CHAMP Pilot and the CityCatalyst Digital Stack

Context and Motivation

Brazil's CHAMP pilot (formally titled "*Scaling High-Impact Mitigation and Adaptation Actions in Brazilian Cities on the Road to COP30*") is the first large-scale digital demonstrator under the Bloomberg Philanthropies Joint Program led by C40, the Global Covenant of Mayors (GCoM), and CDP. Conceived as a flagship implementation of the Coalition of High Ambition Multilevel Partnership (CHAMP), the project demonstrates

how a country can translate abundant national-level climate datasets into actionable city-level strategies at speed and low cost.

Brazil was chosen for three strategic reasons. First, it hosts more than 5500 municipalities, giving CHAMP an unparalleled test bed. Second, the federal government has already signed the CHAMP pledge, making a commitment to embed sub-national action in its 2025 NDC. Third, Brazil maintains some of the world's richest open datasets, including SEEG for greenhouse gas estimates, AdaptaBrasil for hazard rasters, and IBGE for socioeconomic statistics. However, most city halls lack the tools and bandwidth to convert these data streams into greenhouse gas inventories, climate-risk profiles, and bankable projects.

To close that gap, the consortium deployed CityCatalyst, an open-source platform developed by the Open Earth Foundation. This AI-enabled platform ingests national datasets through modular APIs, cleans and harmonizes them in a central data framework, and serves role-based dashboards to municipal officers, state secretariats, and federal ministries. The same data spine powers three automated assessments: (i) a baseline greenhouse gas inventory, (ii) a climate change risk assessment, and (iii) a high-impact-action scoring engine that ranks mitigation and adaptation options by abatement potential, resilience benefit, equity impact, and legal authority. This was initially developed for 50 cities, and has recently been expanded to all 5570 municipalities under Brazil's Green Resilient City Program.

Approach and Features

The implementation of CityCatalyst follows a six-step digital playbook codified in the project's methodology: multi-scale coordination to create a shared evidence base; a data-driven assessment combining greenhouse gas inventories and climate change risk assessment that is generated in weeks rather than months; prioritization of the highest-leverage actions using an AI-powered "tournament ranking between actions and the city profile"; the use of generative AI to develop initial implementation plans for each action; matching those actions with finance opportunities; and the establishment of MER indicators that flow automatically to the CDP-ICLEI Track in line with the GCoM Common Reporting Framework. Finally, engagement workshops delivered by local consultants enable cities to iteratively refine their data, providing a template for replication across other CHAMP countries.

Emerging Impacts

Early results from the first five pilot cities underline the digital dividend:

- Cost reduction: Approximately US\$4,800 external cost per city, compared to historical deep dives of US\$25–35,000.
- Time reduction: less than six weeks from kick-off to validated GHGI + CCRA, compared with six to 12 months using spreadsheet templates.
- Good enough data to “get started”: 60 inventory line items auto-filled from national datasets; remaining gaps captured through a two-week in-app survey.
- Action acceleration: The identification of 100 high-impact actions (one mitigation and one adaptation per city) enables cities to launch these as initiatives and create shared economy-of-scale opportunities at the national level.

Lessons Learned

The pilot exposed frictions, chiefly in the form of limited access to disaggregated utility data and the need to coach smaller municipalities on interpreting dashboards; however, these issues are being addressed through a 2025–2026 training program delivered by local consultants. Another aspect is that while working with 50 cities simultaneously, “one size doesn’t always fit all,” as cities have diverse capabilities and needs, requiring dedicated human interpretation to adapt findings to each context. As an initial, extensive application of AI and data pipelines, the project and tool have proven successful, but with the advent of AI technology, the potential to improve action prioritization and turn specific actions into bankable projects is expected.

In sum, the Brazil pilot demonstrates that when national open data, modern digital architecture, and multi-level governance are braided together, city climate transition can shift from bespoke consultancy exercises to a repeatable public-good service, accelerating the journey from political commitment to measurable, monitored progress on the ground.

8.5.3 Case Study 3: DUCTExplorer

Context and Motivation

The 2024 Innovate4Cities Conference (I4C24) created a high-impact space for exploring how AI can support urban climate action. As part of this effort, the AI x City Climate Action Hackathon invited participants to design AI-driven tools for assessing climate risks in Brazilian cities, including extreme heat, floods, sea-level rise, and droughts. The DUCTExplorer team from the Singapore-ETH Centre, led by Adelia Ayu Sukma, was chosen as the winner, and was matched with the city of Belo Horizonte to pilot their solution in the Brazilian context.

Approach and Features

The DUCTExplorer team developed a flexible and scalable AI framework to support city-level climate vulnerability assessments. To overcome the challenge of mapping urban heat, they proposed using a Digital Urban Climate Twin (DUCT). This approach integrates machine-learning-enhanced data sources with physics-based climate models to create a comprehensive representation of urban climates across diverse scenarios, helping decision-makers identify the urban areas most vulnerable to heat exposure.

The methodology combines machine learning, GIS analysis, and open data (e.g., WorldPop, IBGE, INMET) to produce city- and neighborhood-level risk assessments. Users can interact with the system via a dashboard that visualizes population exposure, climate stressors, and infrastructural risks. The platform was designed to be transparent, modular, and replicable, enabling application in other CHAMP countries with minimal adjustment.

Emerging Impacts

The Belo Horizonte pilot has demonstrated the tool's great adaptability to diverse natural (e.g., height, wind) and socio-economic conditions. For specific hazards such as heat, cities need the capacity to analyze, with granularity, the different levels of exposure faced by the most vulnerable population groups, and to explore the impact of actions. City officials in this Brazilian city were highly engaged with the model's results, which provided evidence to support their assumptions about risks to their population and enabled them to analyze potential solutions, such as increased linear urban trees, green spaces, and green corridors.

Lessons Learned

DUCTExplorer exemplifies how AI can bridge the gap between climate data and actionable policy. This case highlights the value of combining academic expertise, civic data, and user-friendly design. The Innovate4Cities Hackathon showcased how interdisciplinary collaboration can rapidly yield tools with real-world utility that cities need now more than ever. Tools like DUCTExplorer have the potential to inform climate-adaptation strategies, helping cities turn risk into resilience through informed, data-driven action.

8.5.4 Discussion

The increasing use of digital technologies has changed the way data is created, shared, and used in cities. Local governments now have access to sensor networks, social media, and machine-learning tools to produce and analyze large amounts of data (Lember et al., 2019). In this context, the knowledge held and created by citizens about how they use and live in the city is seen as highly valuable (Ataman et al., 2025). Therefore, co-production and co-generation of knowledge become crucial.

The proliferation of wearable and sensing technologies enables the collection of real-time, detailed data across various aspects of urban life, opening new opportunities for citizen participation and contribution in data collection. Closely related to broader citizen science initiatives, crowdsourcing has significantly altered data-collection methods by enabling information to be gathered from multiple people working together toward a common goal (Gebremedhin et al., 2020; Haklay, 2012). Volunteered geographic information enables non-experts to create and share location-based data (Goodchild, 2007). In contrast, community-based monitoring allows local groups to systematically track environmental and urban issues over time.

However, increased reliance on user-driven data also presents challenges, such as the need for clear accountability, data-quality assurance, and seamless system integration. Despite these concerns, studies have shown that citizen-generated data can meet quality standards comparable to those of official sources (Ponti & Craglia, 2020). Participatory processes, ranging from focus groups to participatory GIS, are increasingly supported by digital platforms (de Vos et al., 2021), thus enhancing legitimacy, inclusiveness, and behavioral change.

The Tuvalu Coastal Adaptation Project, supported by the Green Climate Fund and UNDP, shows how digital data systems can enhance climate resilience in small island developing states. High-resolution aerial surveys have delivered unprecedented elevation and topographic data across Tuvalu's islands, which have been used to redesign roads, guide infrastructure projects, and evaluate coastal vulnerability. However, while technically strong, the long-term impact of this data depends on institutional capacity to interpret, manage, and use it effectively. The Tuvalu example underscores the importance of integrating digital tools with investments in data stewardship, literacy, and governance to enhance local planning and resilience.

As cities face increasingly complex climate challenges, digital platforms and participatory data systems provide new ways to organize and implement transitions. The ClimateView example shows how a systems-based, finance-aligned approach can turn strategy into action. Future examples from OpenEarth and DUCTExplorer will add more depth to this picture. Ultimately, co-produced data and digital infrastructure must work together to build the knowledge ecosystems that cities need for transformative, inclusive, and accountable climate action.

8.6 A SYSTEMS-THINKING APPROACH TO DIGITALIZATION AND CLIMATE ACTION

Digitalization increasingly functions as a city's nervous system, transmitting sensor data, forecasts, and alerts that transform slow processes into near-real-time feedback loops. Multi-system resilience requires structural rather than incremental change in how infrastructure is designed, managed, and connected to wider governance systems (Asadzadeh et al., 2022). When embedded in a systems framework that exposes interdependencies and aligns interventions with structural shifts, digital flows enable decision-making that links equity, resilience, and investment credibility. AI, IoT, and digital twin models can convert raw data into indicators of modal shift, building energy use, or air quality, enabling continuous learning. IPCC Assessment Report (AR)6 (2023) and the 2024 GRAA emphasize that coupling digitalization with communication, transparent data systems and institutional capacity converts compliance-driven reporting into opportunity-driven governance.

Trust and accountability determine value. Verification protocols, third-party audits, and open standards enable councils and investors to interpret

results with confidence. Leading platforms tag provenance for each dataset and reveal calculation steps through open interfaces, applying the “inspectable model” principle advanced in transition-planning frameworks (Shalit et al., 2025). Differential data-sharing models that aggregate dashboards for public view and authenticate research access for detail protect privacy while sustaining transparency. Layered access prevents both surveillance overreach and data hoarding, issues cited in AR7 as sources of public resistance.

AI governance remains challenging. Algorithmic opacity and vendor dependence can shift power away from cities lacking technical expertise. Municipalities are adopting ethics frameworks that mandate explainability audits, fairness metrics, and retraining with representative data. Public-private data agreements now include “sunset clauses” transferring anonymized models back to cities, avoiding lock-in while preserving learning. Regulators are urged to reserve bandwidth and cloud resources for essential climate data rather than for commercial algorithms. Embedding public-interest obligations—open interfaces, audit rights, and non-exclusive licenses—into contracts balances innovation with accountability.

Knowledge gaps also persist across scales. Global emissions models often stop at metropolitan resolution, while fine-scale adaptation data, surface permeability, social vulnerability, and informal-settlement mapping remain local or analog. Open-data charters help bridge this gap by combining sensor and government data with citizen-generated information, legitimizing informal evidence (Conrad & Hilchey, 2011; Goodchild & Glennon, 2010). Machine-learning quality checks can validate crowdsourced inputs to official standards (Ponti & Craglia, 2020). Long-term consistency is essential: adaptable data schemas must absorb new technologies without rewriting governance rules.

Systems thinking clarifies why continuity matters. In Meadows’s iceberg model, visible events rest on deeper patterns and structures (Meadows, 2008). Without longitudinal datasets, planners misdiagnose drivers such as induced demand or rebound energy use. When readiness metrics—capacity, permitting time, and citizen adoption—are tracked alongside emissions, cities can reallocate resources early. Evidence from 32 Scottish authorities shows that embedding such metrics in shared platforms links budgets to systemic milestones, accelerating blended-finance approvals (Bai et al., 2016; Shalit et al., 2025).

Looking beyond 2025, priorities are:

1. *Modular taxonomies* that integrate new technologies (edge AI, quantum optimization, hyperspectral imaging) without fragmenting standards.
2. *Inclusive digital strategies* combining in-person literacy programs and translation into local languages to close digital divides.
3. *Research on operations* and how to fund long-term data stewardship, quantify social co-benefits in machine-readable form, and federate community dashboards into national inventories without losing local nuance.

Digitally enabled climate governance will succeed only when systemic insight and social legitimacy progress together. Integrating open standards, participatory data, and ethics-by-design turns fragmented compliance into opportunity-driven transformation, building equitable and finance-ready pathways delivering climate-resilient development for all residents.

8.7 CONCLUSION AND RECOMMENDATIONS

Digitalization now underpins how cities plan, finance, and implement climate action, but its success depends on inclusive governance and ethical integration. Tools gain value only when embedded in institutions that protect trust, accessibility, and long-term resilience.

The GRAA provides a framework through its eight dimensions, or “towers” -communication; decentralization; digitalization; efficiency; information integrity and transparency; risk; scale; and uncertainty—that help cities align data governance with systemic thinking. Insights from the Innovate4Cities conferences and the cases presented here reveal a growing demand for participatory, finance-ready digital tools to address ongoing deficits in standards and capacity, especially in smaller municipalities.

Data pluralism is vital. Combining digital and analog, formal and informal knowledge strengthens legitimacy and resilience. AI forecasts, satellite models, energy-use records, crowdsourced mobility data, oral histories, and community observations all form complementary evidence streams for decision-making. Embracing this diversity transforms data from a technical input into a democratic asset.

As the digital ecosystem expands, governance must evolve to safeguard the public interest. Cities require protocols for algorithmic accountability and measures that prevent monopolization of data infrastructure.

Capacity-building should move beyond digital literacy toward ethical reasoning, inclusive facilitation, and open-data stewardship. Leadership must acknowledge that every technical choice has social and political dimensions.

The path forward demands coordinated action across governments, financiers, and civil society. Table 8.1 consolidates practical recommendations drawn from the chapter. Each aligns actors with measurable progress indicators.

Together, these actions reposition data as a driver of transformation. When digitalization aligns with inclusive governance, systemic planning, and sustained capacity, it becomes a multiplier, accelerating climate action, making it fairer and more accountable.

Table 8.1 Recommendations from this Chapter

<i>Recommendation</i>	<i>Primary audience</i>	<i>Example KPI/Evidence of progress</i>
Adopt inclusive, technology-agnostic data-governance frameworks	City governments, national ministries	Number of climate indicators sourced from informal, analog, or citizen-generated data
Fund local capacity for gathering and interpreting non-digital data	Donor agencies, municipal finance departments	Number of participatory data initiatives funded annually per city
Embed technical- and data-literacy roles within local governments	City governments, HR departments	Number of full-time data-stewardship roles per 100,000 residents
Integrate co-produced knowledge into official decision-making processes	Local planners, policy designers	Presence of co-produced data in official climate adaptation or mitigation plans (Yes/No)
Develop ethics-based, public-interest digital infrastructure	National regulators, platform providers	Presence of smart-city tools with published ethics and data-privacy frameworks
Create differential data-sharing protocols that balance privacy and access	IT departments, civil-society watchdogs	Existence of tiered data-sharing policy with role-based access (Yes/No)
Prioritize modular, open-source digital tools	City IT departments, procurement offices	Presence of digital tools using open standards or open-source components
Ensure long-term investment in digital-infrastructure resilience	Ministries of ICT, donor agencies	Share of digital tools with multi-year upgrade and maintenance budgets (%)

(continued)

Table 8.1 (continued)

<i>Recommendation</i>	<i>Primary audience</i>	<i>Example KPI/Evidence of progress</i>
Make global climate data locally usable through downscaling and translation	Global dataset providers, research institutions	Presence of city plans using localized versions of global climate scenarios
Establish cross-departmental and multi-stakeholder data-sharing platforms	Local and regional governments	Number of departments with shared data access or integrated dashboards
Tie climate finance to transparent, public data dashboards	Finance ministries, investors, donor agencies	Value of climate funding tracked via publicly accessible performance dashboards
Support accessible data tools for small and under-resourced cities	Donors, national platforms, networks like ICLEI	Number of small cities receiving subsidized or free access to data platforms
Govern the use of AI and advanced analytics through public-interest safeguards	City governments, AI developers	Presence of AI audit trail, bias mitigation, and ethics policy (Yes/No)

Competing Interests The authors have no conflicts of interest to declare.

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