

Carbon Costs Without Governance Gains: Assessing Digital Participatory Sensing in Algeria's New Towns

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Abstract

Smart city initiatives are advocated throughout the Global South as a means to enhance environmental efficiency and foster democratic participation. However, the environmental and distributional implications of the digital infrastructure required for these initiatives are infrequently quantified. This research investigates the tangible outcomes of digital participatory sensing across Constantine and two of Algeria's new towns, considering the carbon footprint of this digital intervention, its adoption by urban planners, and its social outreach collectively. Employing a convergent mixed-methods approach, the study integrated a six-month sensing intervention involving 384 residents across Constantine, Ali Mendjeli, and Sidi Abdellah, yielding 18,432 geolocated reports. Additionally, the research incorporated attributional carbon accounting, convolutional neural network classification of satellite imagery, 25 stakeholder interviews, and an analysis of 1,182 pages of planning documents. The intervention produced approximately 1,247 kg CO₂e, equating to the annual electricity consumption of an Algerian household. Notably, no planning document reviewed referenced the citizen-generated datasets, and 23 out of 25 stakeholders had never reviewed them. Participation rates declined from 80% in central districts to 40% in Sidi Abdellah, with residents over 60 years contributing merely 1.8% of participants. In contexts where planning institutions are fragmented, digital participation appears to incur environmental costs without corresponding influence on redistribution. For policy considerations, low-technology engagement remains the most justifiable default, and digital tools should be implemented subsequent to institutional reforms. From a theoretical standpoint, the environmental and democratic assertions of smart cities are contingent upon governance capacity rather than technological sophistication.

Keywords

Algeria; carbon footprint; digital divide; new towns; participatory sensing; smart city governance

1. Introduction

Urban populations in the Global South are growing faster than infrastructure. Since the mid-2000s, governments and tech companies have embraced the smart city model—using sensors, data, and algorithms to improve efficiency, service, and participation (Caragliu et al., 2011; Kitchin, 2014). This model appears in national strategies and projects from Nairobi to Gujarat, promising efficiency, sustainability, and participation (Datta, 2015; Guma & Monstadt, 2021; Watson, 2014), even though such promises often function as corporate storytelling that narrows who counts as a legitimate urban actor (Söderström et al., 2014).

Algeria exemplifies digital and urban development, with initiatives like Digital Algeria 2023 (High Commission for Digitalisation, 2024) and Alger Smart City. While technological deployment has advanced (Belhocine et al., 2019, 2021, 2025), institutional coordination lags. The large-town programme aims to ease urban growth (Bounoua et al., 2023), but projects such as Sidi Abdellah and Ali Mendjeli face delays and are primarily dormitory towns with limited social infrastructure (Benlakhlef & Bergel, 2016; Berkani & Benghadbane, 2023; Bozonnet, 2017). A combined digital agenda and a weak new-towns programme test whether digital participation influences planning and whether it offers environmental benefits that offset the infrastructure footprint. If not, issues may include technological faults, governance issues, or access disparities. Research often focuses on deployments and terminology rather than outcomes (Ghidouche et al., 2019), while studies on participatory sensing seldom evaluate environmental costs alongside social and institutional impacts.

This study evaluates a six-month digital participatory sensing project in Constantine, Ali Mendjeli, and Sidi Abdellah. The main question is:

What benefits does digital participatory sensing offer in Algeria's new towns when environmental, governance, and social impacts are considered?

Three sub-questions guide the research:

SQ1: What is the carbon footprint, and how does it compare with low-tech participation?

SQ2: How do citizen-generated data influence planning decisions?

SQ3: Who participates or is excluded, and what socio-spatial and economic factors contribute to this pattern?

A process-tracing analysis compares Sidi Abdellah and Ali Mendjeli to understand the governance conditions enabling digital participation.

The article is structured as follows: Section 2 clarifies concepts and the literature context; Section 3 describes the mixed-methods design and its sampling limits; Section 4 presents findings per sub-question; Section 5 discusses them; Section 6 explores implications; Section 7 states limitations; and Section 8 concludes.

2. Conceptual Framework and Literature

2.1. *Digital, Smart, and Intelligent: A Necessary Distinction*

The terms digital, intelligent, and smart urbanism are not synonyms, and their differences matter. Following Hollands (2008), Albino et al. (2015), and Sadi and Bestandji (2020), digital refers to devices, networks, sensors, databases, and apps that capture urban data without implying data use. Intelligent pertains to processing this data for inferences, predictions, or optimisations via models or machine learning, as a system property. Smart relates to governance: digital infrastructure and analytical capacity embedded in institutions to influence decisions, with citizens exercising control. Smartness is an achievement, not just equipment. The key question is whether digital and intelligent layers connect to governance in the study areas.

2.2. *Participatory Sensing and the Ladder of Digital Participation*

Participatory sensing involves residents systematically collecting environmental and infrastructural data with personal mobile devices (Burke et al., 2006; Goodchild, 2007). It aims to expand the evidence base for planning and include diverse voices (Haklay, 2013). Critical views note that most smart participation makes residents data providers rather than co-decision-makers (Cardullo & Kitchin, 2019), and its emancipatory potential relies on integrating digital tools into everyday urban practice (Odendaal, 2021). According to Arnstein's (1969) ladder, participatory sensing supports informing and consultation but only influences decisions via institutional pathways.

2.3. *The Environmental Cost of Digital Participation*

The case for smart urbanism relies on digital efficiency outweighing emissions, but this is challenged. Studies by Belkhir and Elmeligi (2018), Freitag et al. (2021), and data from the International Energy Agency (2024) show rising ICT footprints and increasing energy demand. Lange et al. (2020) find that digitalisation often increases energy use rather than reduces it. Strubell et al. (2019) note that training models can produce significant emissions. Thus, the environmental impact of digital schemes depends on local electricity sources, crucially in Algeria, where thermal energy is dominant.

2.4. *Smart Urbanism, Equity, and Governance in the Global South*

Research on African and South Asian smart city projects reveals a gap between vision and delivery, mainly due to institutional fragmentation, unstable mandates, and weak coordination between authorities (Balkaran, 2019; Datta, 2015; Guma & Monstadt, 2021; Mashau & Kroeze, 2023; Watson, 2014). Algorithmic governance often concentrates decision-making (Chiappini, 2020). Algerian evidence shows that housing data systems are inaccessible at the central and local levels (Belhocine, 2021; Belhocine et al., 2019), with Belhocine-Ladaci (2025) noting similar issues with Bejaia's digital cadastre. This study evaluates the carbon cost of a digital participation intervention, its adoption by planning institutions, and social participation.

3. Methodology

3.1. Design and Epistemological Position

This study employed a convergent mixed-methods design (Creswell & Plano Clark, 2018), in which quantitative and qualitative strands were collected in parallel, analysed separately, and merged at the interpretation stage. The design was selected because the research question combines a measurement problem spanning carbon accounting and participation rates with an explanatory problem—why data were or were not used—which no single strand can address on its own. Integration followed the principles set out by Fetters et al. (2013), using joint displays and narrative weaving.

The study is grounded in critical realism (Bhaskar, 1975), which holds that observable events are generated by underlying causal mechanisms that are themselves not directly observable. This position justifies combining outcome measurement with process-oriented qualitative work to identify mechanisms, and it underpins the use of process tracing in the comparative component. Figure 1 summarises the design.

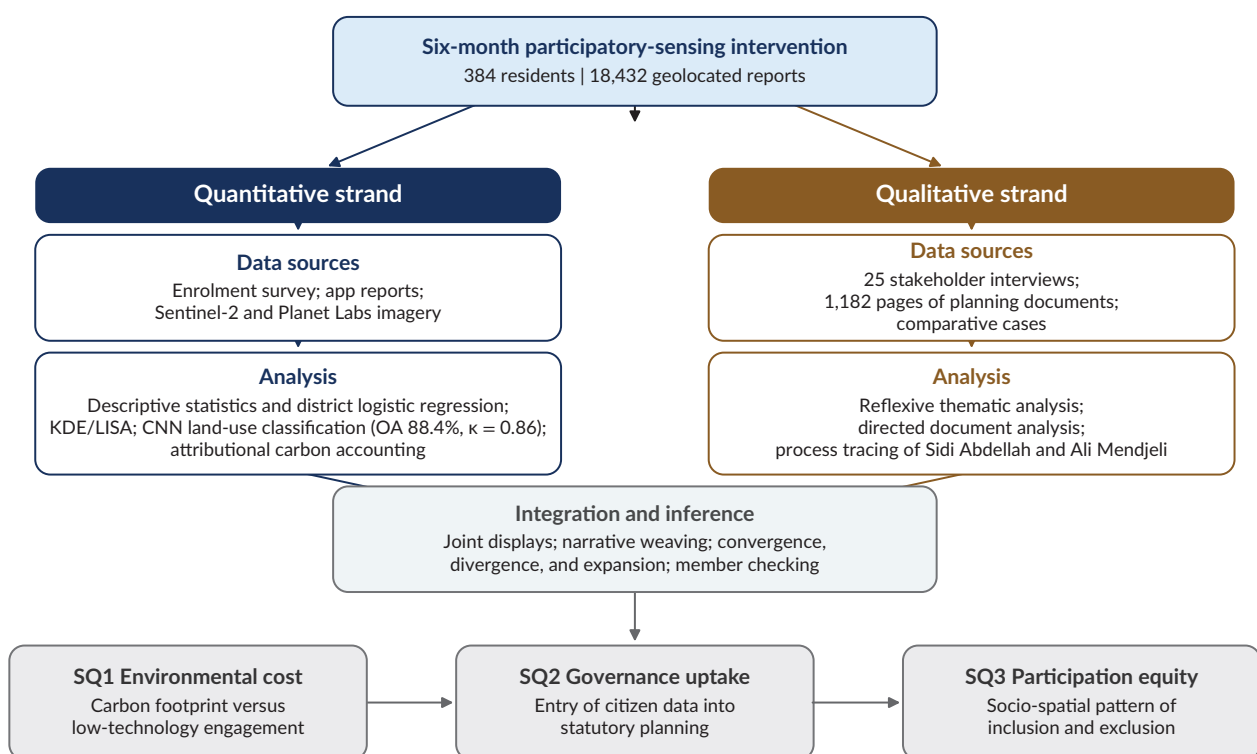


Figure 1. Integrated convergent mixed-methods framework for evaluating the environmental cost, governance uptake, and equity of digital participatory sensing. Notes: CNN = convolutional neural network; KDE = kernel density estimation; LISA = local indicators of spatial association; OA = overall accuracy.

3.2. Study Areas

Fieldwork covered five settings spanning the socio-spatial gradient of interest: two central districts of Constantine (El Menia and Belouizdad), the peripheral district of Ain Smara, and the new towns of Ali Mendjeli (Constantine) and Sidi Abdellah (Algiers). The two new towns serve as the comparative cases

because they are the most frequently cited demonstrations of the national new towns programme and differ in origin, scale, and timing while sharing a common institutional framework.

3.3. Participatory Sensing and Sampling

From January to June 2025, 384 residents participated in a six-month study, selected using Cochran's (1977) formula with 95% confidence and a 5% margin of error. Using location quotas (Etikan et al., 2016), participants met criteria like living locally and owning a smartphone. They used an app to report issues with infrastructure, public spaces, and services, resulting in 18,432 geolocated observations.

Two sampling limitations are noted: First, purposive quota sampling ensures location diversity but not broader representativeness; participation rates reflect this sample, not the entire population. Second, requiring smartphones excludes the most digitally marginalised, as 35% of residents lack them, highlighting the inequality SQ3 aims to assess. The gaps listed in Section 4.3 are conservative, showing inequality among smartphone owners. This asymmetry highlights digital participation issues, not just a methodological weakness.

3.4. Enrolment Questionnaire

On enrolment, participants completed a brief questionnaire on demographics (age, sex, occupation), application use, perceived usefulness, ease of use, costs, and willingness to participate in future initiatives. Aggregated responses are reported in Section 4. All items were self-reported, with response bias discussed in Section 7.

3.5. Carbon Accounting

An attributional carbon footprint was calculated for the intervention, covering participant devices, mobile network transmission, cloud hosting of the application and database, model training and inference, and research workstations. Activity data were taken from server logs, application telemetry, and recorded model-training time, and converted using Algeria's grid emission factor of 0.68 kg CO₂e/kWh, with data centre energy scaled by a power-usage-effectiveness coefficient. Parameters follow the ICT footprint literature (Belkhir & Elmelig, 2018; Freitag et al., 2021; International Energy Agency, 2024) and, for model training, Strubell et al. (2019). Table 1 reports them in full so the estimate can be recalculated under alternative assumptions.

A low-tech comparator was built for an engagement programme reaching similar residents through workshops. Its footprint relies on travel assumptions shown as two scenarios in Table 2, not a single estimate. Manufacturing and end-of-life emissions of devices are excluded because they were already owned; this scope choice is noted, as embodied emissions often dominate smartphone life-cycle footprints.

3.6. Satellite Imagery and Land-Use Classification

A convolutional neural network trained on 1,000 labelled patches from Sentinel-2 and Planet Labs imagery classified eight land-use categories: urban, agricultural, bare soil, water, forest, transport, mixed use, and

informal settlement. Following established remote sensing practices (Helber et al., 2019; Zhu et al., 2017), performance on a held-out subset showed an accuracy of 88.4% and a Cohen's (1960) kappa of 0.86. The classification helped characterise land-use hotspots but does not generate participation or governance findings, with residual error addressed in Section 7.

3.7. Spatial and Statistical Analysis

Reporting intensity was mapped using kernel density estimation with a bandwidth selected by the normal-reference rule (Silverman, 1986), and clustering was tested with local indicators of spatial association (Anselin, 1995). The correlates of participation were examined using binary logistic regression (Hosmer et al., 2013), with participation status as the outcome. Because the enrolment questionnaire was administered at the point of enrolment, age, sex, occupational status, and self-reported difficulty of application use are observed only for participants; district of residence is the sole variable recorded for both participants and non-participants. The model is therefore specified with district as its single predictor, and the remaining characteristics are reported descriptively in Section 4.3 rather than entered as covariates.

3.8. Interviews and Documentary Analysis

Semi-structured interviews with 25 stakeholders—municipal planners, architects, researchers, civil society reps, and provincial authorities—covered participatory sensing awareness, dataset access, data quality, integration barriers, and engagement modes. Transcripts were analysed via reflexive thematic analysis (Braun & Clarke, 2006).

The documentary corpus comprised 1,182 pages: a 347-page revision of the master plan (PDAU, Plan Directeur d'Aménagement et d'Urbanisme), 189 pages of land-use plans, 78 pages of budget documents, 156 pages of meeting minutes, and 412 pages of project files. Following Bowen (2009), the corpus was searched systematically for any reference to citizen-generated data, whether by dataset name, by the reporting platform, or by generic terms for resident-supplied observations, and each candidate reference was read in context.

3.9. Comparative Process Tracing

The trajectories of Sidi Abdellah and Ali Mendjeli were compared using process tracing (Beach & Pedersen, 2019), testing whether the causal steps in the hypothesis—governance fragmentation—explain the implementation failures, rather than technological issues or citizen input. The comparison focused on four aspects—vision versus practice, governance structure and mandate stability, infrastructure sequencing, and participation channels—using documents and interview evidence (Table 3).

3.10. Data Integration

Integration occurred in three steps. First, each sub-question was presented with combined quantitative and qualitative evidence; for SQ2, this included references to citizen data and reasons for not using datasets. Second, each pairing was classified as convergent, divergent, or expansive. Convergence was strongest for SQ2, where absence and interviews led to the same conclusion; expansion was strongest for SQ3, where

mechanisms explained the participation gradient, only accessible through interviews and questionnaires. Third, preliminary findings were shared with some interviewees for member checking.

3.11. Ethics

Ethical approval was granted by Salah Boubnider Constantine 3 University. Written informed consent was obtained before enrolment, in Arabic and French, covering the purpose, data categories, retention, and rights to withdraw or delete reports. Geolocated data require safeguards, as repeated reports can identify residences even when names are removed (Kounadi & Leitner, 2014). Coordinates were separated from responses and linked by pseudonymous identifiers stored separately. Reports within 100 metres of participants' residences were spatially displaced before analysis; published maps used kernel-smoothed surfaces. Photographs with faces, license plates, or house numbers were cropped or discarded. Interviewees received role-based pseudonyms, and institutional details were generalised. Large language models improved the grammar and style of this manuscript's text; visualisation libraries produced its figures. All analytical decisions and conclusions are the authors' own, and all model-assisted text in the manuscript was verified by the authors.

4. Results

4.1. Sample Description

The intervention enrolled 384 participants from 612 residents approached across the five study areas, representing a 62.7% enrolment rate. Of the 228 who did not enrol, 143 were ineligible due to a lack of a smartphone, and 85 declined or did not complete enrolment.

Participants included 201 men (52.3%) and 183 women (47.7%). Most were aged 18–29 (51.6%), followed by 30–44 (35.9%), 45–60 (10.2%), over 60 (1.8%), and under 18 (0.5%). Most were employed (65.9%) or students (13.8%), with smaller groups unemployed (9.1%), trainees (4.4%), retirees (3.9%), lecturers (1.6%), doctoral candidates (0.8%), and homemakers (0.5%). Geographically, they were distributed across Constantine's central districts (39.1%), Ain Smara (28.6%), Ali Mendjeli (26.0%), and Sidi Abdellah (6.3%). Figure 2 shows sex, age, and occupational data.

The sample is therefore skewed towards younger, economically active, digitally connected residents. Residents over 60 appear at a fraction of their share of the urban population, and the Sidi Abdellah subsample is small enough that findings for that site are indicative rather than conclusive. These constraints on external validity carry over into Sections 4.3 and 5.2.

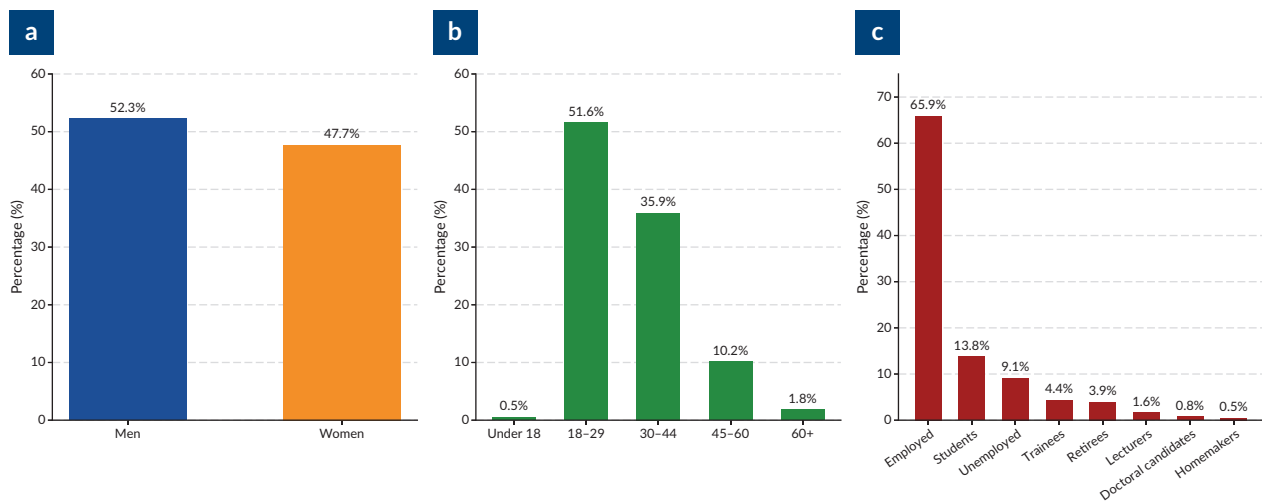


Figure 2. Sociodemographic profile of participants ($n = 384$): (a) sex distribution, (b) age distribution, and (c) occupational distribution.

4.2. Environmental Cost and Governance Uptake

The intervention produced about 1,247 kg CO₂e over six months. Table 1 outlines the sources: cloud hosting (57.3%), device charging (30.2%), model training/inference (8.7%), research workstations (3.1%), and mobile data (0.7%). The main contributor is platform maintenance, not usage volume.

Table 1. Carbon accounting of the six-month digital participatory-sensing intervention.

Source	Activity data and parameters	Energy (kWh)	Emissions (kg CO ₂ e)	Share (%)
Cloud application and database server	4,320 h × 0.160 kW × PUE 1.52	1,050.6	714.4	57.3
Participant devices	384 devices × 180 days × 0.008 kWh per device-day	553.0	376.0	30.2
Model training and inference	300 GPU-hours × 0.350 kW × PUE 1.52	159.6	108.5	8.7
Research workstations	3 units × 420 h × 0.045 kW	56.7	38.6	3.1
Mobile network transmission	96 GB × 0.14 kWh per GB	13.4	9.1	0.7
Total		1,833.3	1,246.6	100.0

Notes: Grid emission factor 0.68 kg CO₂e/kWh; embodied emissions excluded; components may not sum exactly because of rounding; GPU = graphics processing unit; PUE = power usage effectiveness.

To contextualise, 1,247 kg CO₂e equals an Algerian household's annual electricity use or about 6,850 km of car travel. Table 2 compares it with a low-tech programme that reaches similar residents through neighbourhood workshops. Under walking access, the comparator produces 50.7 kg CO₂e, a 95.9% reduction. If 30% of attendees travel 5 km by car, it results in 148.5 kg CO₂e, an 88.1% reduction. The key point is that low-tech engagement with similar coverage emits roughly 10 times less carbon, though the figures depend on travel assumptions.

Table 2. Carbon emissions of low-technology engagement under two travel scenarios.

Component	Scenario A: walking access (kg CO ₂ e)	Scenario B: 30% travel 5 km by car (kg CO ₂ e)
Venue electricity (6 workshops × 3 h × 1.2 kW)	14.7	14.7
Printed materials (1,200 A4 sheets)	5.4	5.4
Facilitator travel (6 × 30 km by car)	30.6	30.6
Participant travel	0.0	97.8
Total	50.7	148.5
Reduction relative to the digital intervention	95.9%	88.1%

Notes: Both scenarios assume comparable resident coverage; road transport factor 0.17 kg CO₂e per vehicle-kilometre.

The evidence of governance uptake is uniformly negative across three sources. None of the 1,182 planning pages mentioned citizen datasets by name, platform, or description. Of 25 stakeholders, 23 never accessed the data, and 19 found it irrelevant to statutory decisions. Interviewees explained non-use: Planning procedures lack steps that require or accept resident observations, and no unit handles them. Planners see datasets as interesting but institutionally homeless.

This third element strengthens the inference. A conclusion of no uptake based solely on silence is weak, as the absence of a written trace can be informal. When silent documents, self-reported non-consultation, and no receiving mechanism coincide, the negative finding is more robust and indicates the mechanism, not just the outcome.

Figure 3 shows the environmental cost alongside uptake measures, a cost with no governance return. This is an empirical finding about this intervention in this setting, not a claim that digital participation is always worth its carbon cost; potential conditions are discussed in Section 6.

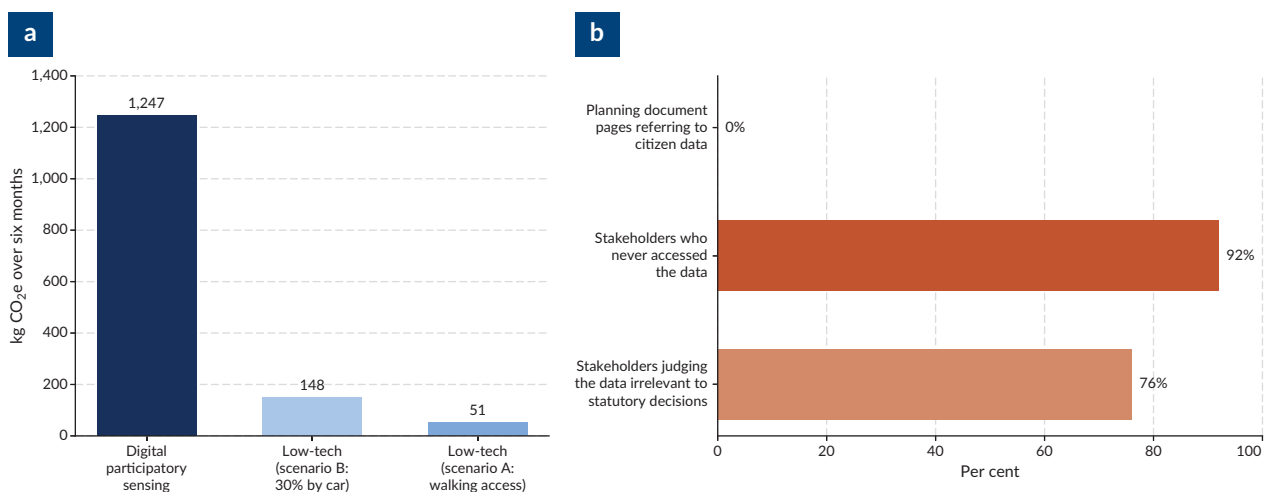


Figure 3. Environmental footprint of the six-month digital participatory-sensing intervention and its institutional uptake: (a) comparison between the intervention's carbon footprint and two low-technology engagement scenarios of comparable coverage; (b) extent to which citizen-generated data were accessed and considered relevant within statutory planning processes.

4.3. Equity of Participation

Participation varied across the areas: 80% in Constantine's centre, 55% in Ain Smara, 60% in Ali Mendjeli, and 40% in Sidi Abdellah, decreasing toward newer, less-served edges. Figure 4 details participation by district, age, and digital access.

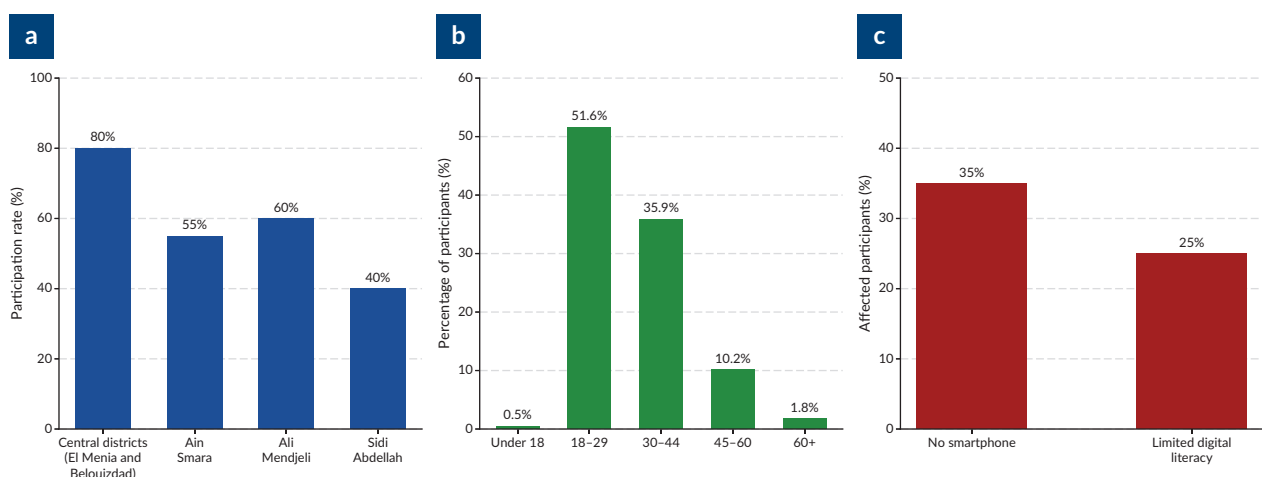


Figure 4. Socio-spatial inequalities in digital participation: (a) participation rates across central, peripheral, and new-town districts; (b) age distribution of participants; (c) key barriers to digital inclusion, namely lack of smartphone access and limited digital literacy.

Three barriers explain the gradient: access, competence, and cost. First, 35% of residents in Constantine lacked smartphones, especially older and lower-income groups in peripheral areas. Second, 25% found digital apps hard to use, mainly older and less educated respondents. Third, mobile data costs 10–15% of some low-income households' monthly budgets, making ongoing use expensive. These barriers combine; a retired resident on a fixed income may face all three, while a young, employed resident in the centre typically faces none. This explains the age distribution: Residents over 60 make up 1.8%, compared to 51.6% for those aged 18–29.

The equity model's scope should be stated before its results. District of residence is the only recorded characteristic for both participants and non-participants, as the enrolment questionnaire was completed at enrolment and captured only age, sex, occupational status, and perceived ease of use for participants. The correlates of participation are estimated using a binary logistic model with district as the only predictor. This model is saturated, so its coefficients are exactly determined by the district participation table and match the odds ratios (ORs) from observed counts. District denominators are based on reported participation rates and have a rounding uncertainty of 1 to 2 residents per district; re-estimation within the plausible rounding range leaves all ORs unchanged to two decimal places and does not affect the direction or significance of contrasts.

Taking Constantine's central districts as the reference, the odds of participation were lower at every peripheral site: Ain Smara, OR = 0.31; Ali Mendjeli, OR = 0.38; and Sidi Abdellah, OR = 0.17. The model significantly improves on the intercept-only model, $\chi^2(3) = 43.89$, $p < .001$, with a McFadden pseudo- R^2 of 0.054—a modest gain, since district alone doesn't explain most of the individual variation. A resident of Sidi Abdellah had about one-sixth the odds of participating as a resident of the centre; residents of Ain Smara and Ali Mendjeli had between roughly a third and two-fifths.

Two qualifications apply to these estimates. First, the district contrast conflates two processes: ineligibility due to the lack of a smartphone and declining to enrol when eligible. The ORs measure the combined effect of a digital-only recruitment channel, not willingness to participate, which is the policy focus but should not be seen as civic disposition. Second, the age gradient isn't modelled and is only described: Over-60s made up 1.8% of the sample, below Algeria's 7.4% in 2008 (Office National des Statistiques, 2008). This comparison is indicative, not age-standardised, as census data don't match the study areas' adult populations. The patterns are convergent, not mutually adjusted, consistent with the cumulative-barrier account in Section 5.2, but the design can't allocate weight between mechanisms or claim to do so.

Two considerations clarify the interpretation. First, eligibility required smartphone ownership, so these rates are within a selected group; including non-owners would widen the central-peripheral gap and underestimate inequality. Second, barriers are not just technical: Data cost relates to income, competence to education and age, and device ownership to both. Digital participation reflects existing socio-economic stratification, shaping its influence over urban evidence.

4.4. Comparative Case Analysis

Process tracing of Sidi Abdellah and Ali Mendjeli tested whether governance fragmentation, not technological or participatory issues, explains the implementation failures. Table 3 compares four dimensions. Figure 5 summarises the two trajectories.

Table 3. Cross-case comparison of development trajectories in Sidi Abdellah and Ali Mendjeli, based on the documentary corpus and stakeholder interviews.

Dimension	Sidi Abdellah (Algiers)	Ali Mendjeli (Constantine)
Founding vision and date	Science and technology hub, 1994	Planned satellite town relieving Constantine, 1999
Elapsed time	22 years to the inauguration in 2016	25 years and incomplete in 2024
Vision-practice alignment	The original programme was displaced by housing quotas	The master plan was repeatedly modified without revision of the underlying programme
Governance structure	Shifting ministerial priorities; no stable lead authority	Unresolved jurisdiction between national ministries and local authorities
Infrastructure sequencing	Housing delivered ahead of services; infrastructure now deteriorating	Schools, health and community facilities behind housing; university pole built outside the planned perimeter
Institutionalised participation	None identified in corpus or interviews	None identified in corpus or interviews
Documented use of citizen data	None in the reviewed corpus	None in the reviewed corpus
Observed outcome	Largely a dormitory town	Incomplete and fragmented

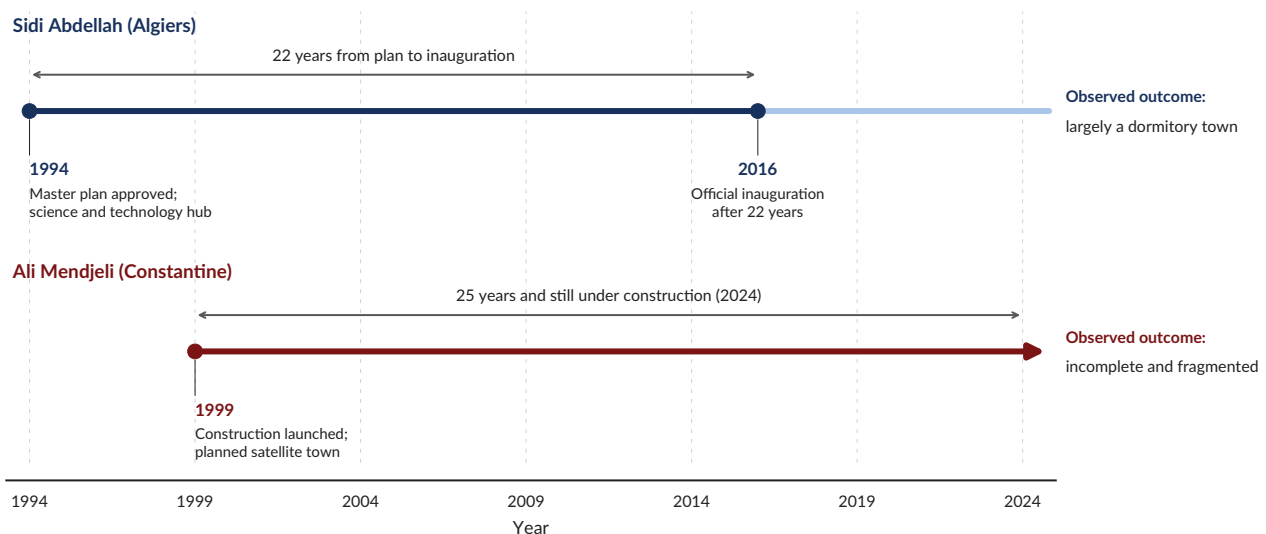


Figure 5. Comparative development trajectories of Sidi Abdellah and Ali Mendjeli, Algeria, contrasting each town's founding vision, implementation pathway, and observed outcome.

The cases share outcomes but differ in origin, strengthening the inference. Sidi Abdellah, conceived in 1994 as a science and technology hub and inaugurated in 2016, shifted from its original programme to housing quotas and now functions as a dormitory town with poor infrastructure. Ali Mendjeli, launched in 1999 to relieve Constantine, remains incomplete after 25 years, with the master plan repeatedly modified, unresolved jurisdiction issues, and social infrastructure lagging behind housing. The governance-fragmentation hypothesis is supported by observable indicators: a founding vision not matched by delivered practice, changes in authority or priority, plan revisions without programme updates, and housing-service mismatches. These are absent in other hypotheses. No technical failure or citizen input occurred, as participation channels were missing and their quality untested. Awareness of digital initiatives was low, with no decisions based on them. Both cases lack institutional participatory input, mirroring the absence noted at the project level.

5. Discussion

5.1. Carbon Cost in Context

A modest digital participation intervention had a small environmental cost—1,247 kg CO₂e—without any governance benefits. While this is minor compared to urban interventions, the significance lies in three factors: The cost was for a non-decision-making output; the footprint results from infrastructure, not usage, scaling with deployment duration; and in fossil-fuel-heavy grids, emissions per kWh are high, so low-carbon energy doesn't transfer. The key point is that digital tools' environmental impact must be assessed based on actual benefits, not projections.

5.2. The Mechanisms Behind Unequal Participation

The second finding is that digital participation often reproduces rather than reduces socio-spatial inequality. Access, competence, and cost are interconnected, influenced by income, age, and education. Income affects device ownership and data costs; age and education impact confidence in using applications; location

influences network quality and social networks for recruitment. Cultural factors also play a role, as reporting on deficient public services can be sensitive, potentially reducing participation regardless of access. These patterns align with global evidence on connectivity disparities (International Telecommunication Union, 2024), other Global South studies (Datta, 2015; Guma & Monstadt, 2021; Haklay, 2013), and the tendency for participatory tech to be adopted first by those with the most social voice.

5.3. Governance Fragmentation as the Binding Constraint

The third finding is that the binding constraint is institutional. Process-tracing shows a specific, remediable issue: No procedural point requires citizen evidence, no unit is mandated to receive it, and there's no record of how it's considered. This is a stronger claim than a governance weakness and aligns with Algerian data from sectors such as housing, where systems produced data that the structures weren't organised to use (Belhocine, 2021; Belhocine et al., 2019; Belhocine-Ladaci, 2025). It also supports the literature arguing that institutional reform must precede technological deployment (Hollands, 2008; Mora & Deakin, 2020; Vanolo, 2014).

5.4. The Feasibility of Low-Technology Engagement

Low-technology engagement cannot stand alone as the policy response; the recommendation requires more than simply substituting low-tech options for digital ones. While neighbourhood workshops, ward committees, and meetings have a lower carbon footprint and include excluded residents, they are labour-intensive, depend on facilitator availability, and are affected by income, gender, and mobility. Sustainability hinges on stable budgets and trained staff, not just platforms. A better approach is to establish institutional functions first, then use low-tech channels for broad engagement, and add digital tools selectively for infrastructure monitoring, fault detection, or enabling participation for residents unable to attend meetings. Digital engagement should complement face-to-face methods, balancing environmental and equity costs with its added capabilities.

6. Theoretical and Policy Implications

6.1. Theoretical Contributions

This study makes three contributions. First, it supplies an integrated evaluation in which the environmental cost, institutional uptake, and social reach of a digital participation intervention are measured in the same case. The smart city literature has developed each critique separately; measuring them jointly shows they are not independent. The carbon cost is objectionable *because* the governance return was nil, and the governance return was nil *because* no institutional pathway existed, which is also why extending social reach would not, on its own, have changed the outcome.

Second, it gives empirical content to the distinction drawn in Section 2.1. The setting studied was digital and, through the classification model, analytically intelligent, yet not smart in any governance sense. Smartness is better treated as a property of the coupling between technical systems and decision-making institutions than as an attribute of the systems themselves.

Third, it identifies a missing rung in the participation literature. Arnstein's (1969) ladder presupposes an institution that receives citizen input and can be pushed to share decision-making power with citizens.

Where no receiving function exists, the ladder has no base, and interventions that increase the volume or sophistication of citizen data cannot move participation up that ladder. Assessments of digital participation should therefore begin with institutional receiving capacity rather than with the participatory instrument.

6.2. Policy Implications

For Algerian authorities and similar contexts, four key implications emerge from the evidence. First, establish the platform's receiving function before procurement, including revisions and land-use plans to review residents' observations and assign responsibility, costing little but establishing a crucial pathway. Without this, digital investments risk replicating past issues. Second, record responses to promote accountability, with authorities publishing how resident submissions are managed. Third, maintain a recurring budget for neighbourhood engagement, not just project-based funding, and ensure procurement policies specify how data influence decisions. Fourth, design for inclusion by avoiding device-dependent channels, using zero-rated data, accessible reporting points, and tracking participation by district, age, and income. For new towns, social infrastructure should accompany housing to encourage participation, not digital tools alone.

7. Limitations

Five limitations qualify these findings. First, the sample comprised smartphone owners recruited through purposive quota sampling, describing a self-selected, connected population not generalisable to the entire urban population; the Sidi Abdellah subgroup ($n = 24$) is too small for definitive conclusions. Second, the six-month window doesn't capture seasonal or long-term trends in platform use, which declines after an initial peak; longer studies may yield different results. Third, carbon estimates rely on assumptions about device and server energy use, power efficiency, and electricity sources, which are not directly observable; Tables 1 and 2 provide recalculations and ranges. Embodied emissions from manufacturing are excluded, underestimating the footprint. Fourth, the land-use classifier's 88.4% accuracy, with errors mainly in mixed-use zones, makes hotspot mapping approximate and not conclusive. Fifth, self-reported data on app use, difficulty, and expenditure are subject to recall and social desirability bias, potentially overstating engagement. These self-reports were cross-checked against interview accounts, but no independent verification was possible.

8. Conclusion

This article evaluates a six-month digital participatory sensing intervention in Constantine and the new towns of Ali Mendjeli and Sidi Abdellah, measuring its carbon footprint, uptake by planning institutions, and social reach in a single case study.

The intervention produced about 1,247 kg CO₂e, significantly more than similar low-tech efforts. Planning documents rarely mentioned citizen datasets; 23 of 25 stakeholders never consulted them, citing a lack of procedural points for such data. Participation varied from 80% in central districts to 40% in Sidi Abdellah, with almost none among residents over 60, reflecting the socio-economic stratification it aimed to address.

These results are limited to a specific six-month intervention in one institutional context. They do not prove that smart city initiatives or digital participation are unsuccessful in general. The key finding is that, in this

setting, the challenge was not technology but the lack of an institutional pathway for citizen input. Under these conditions, digital participation causes environmental costs and inequality without increasing influence. Different outcomes could occur with a functioning reception system, highlighting the setting's importance.

Four implications follow. Planning authorities should: establish a mandated resident input point with a responsible unit and record of submissions; fund neighbourhood engagement as a recurring line with trained facilitators instead of periodic platforms; restrict digital investments to decisions with a contractual evaluation of use; and publish participation data disaggregated by district, age, and income to measure exclusion. In Algeria's new towns, sequencing social infrastructure with housing would better promote participation than any application. Digital tools are useful only after these conditions are met; before then, they are an expense without return.

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Conflict of Interests

The authors declare no conflicts of interest.

Data Availability

Data are restricted to protect participants' privacy and are available from the corresponding author upon reasonable, justified request.

LLMs Disclosure

Grammarly (with its Authorship feature enabled) was used to improve the grammar and language style of the manuscript. All analytical decisions, interpretations, and conclusions are the authors' own, and all model-assisted text was reviewed and verified by the authors before submission. Claude (Anthropic) was used to redraw all five figures as editable vector graphics reproducing the original layouts, data, and values. The authors reviewed, verified, and remain fully responsible for the content, data, and interpretation of every figure.

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