

AI in Smart Cities Infrastructure

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ABSTRACT

Smart cities leverage networked sensors, data analytics, and AI-driven automation to improve the efficiency, sustainability, and quality of urban infrastructure and services. As European cities accelerate digitisation under frameworks including the EU Mission for 100 Climate-Neutral and Smart Cities and the European Green Deal, AI applications across urban mobility, energy, water, waste, safety, and public services are transitioning from pilot projects to operational deployments at city scale. This study evaluates AI applications across six smart city infrastructure domains in twelve European cities (population 50,000-2,000,000): adaptive traffic management, smart grid and energy distribution, water network monitoring, waste collection optimisation, public safety and surveillance, and citizen services automation. For each domain, two to three AI systems are benchmarked against conventional management baselines using operational data from 2022-2024. Key findings: AI adaptive traffic management reduces average vehicle delay by 18.4% across 8 cities deploying it. Smart grid AI reduces grid balancing costs by 14.2%. AI water network monitoring detects leaks 12.4 days earlier than manual inspection cycles. AI waste routing reduces collection vehicle km by 16.8%. Computer vision public safety systems achieve 84.2% incident detection recall but raise significant privacy concerns documented through stakeholder analysis. LLM-powered citizen service chatbots resolve 68.4% of queries without human escalation. A smart city AI governance framework addressing privacy, equity, and democratic accountability is proposed.

Keywords: smart cities; urban AI; adaptive traffic; smart grid; water network monitoring; waste optimisation; public safety AI; citizen services; urban sustainability; AI governance

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1. Introduction

1.1 The Smart City AI Transition

The term 'smart city' has evolved from a marketing concept to a policy category with specific EU funding streams, legislative requirements, and performance targets. The EU Mission for 100 Climate-Neutral and Smart Cities commits EUR 360 million to supporting 100 European cities in achieving climate neutrality by 2030, with AI as a central enabling technology. But the transition from pilot projects -- where smart city AI applications have proliferated -- to operational deployments at city scale introduces challenges that pilots do not face: system integration across legacy infrastructure, data governance for citizen-generated data, equitable service delivery across urban demographics, and democratic accountability for automated decisions affecting public services.

1.2 The Gap Between Pilot and Scale

Most published smart city AI evaluations report pilot project results in controlled conditions. A traffic AI tested on one intersection may not generalise to a city-wide network with legacy signal infrastructure, variable sensor quality, and competing traffic management objectives. An energy management AI deployed in a new district with smart meters may not transfer to older districts with incomplete metering. This study specifically evaluates AI systems in operational deployment at city scale -- including the messy realities of legacy integration, sensor gaps, and public acceptance challenges -- rather than in controlled pilot conditions.

1.3 Study Objectives

This study aims to: (i) evaluate AI applications across six smart city domains in twelve European cities using operational data; (ii) quantify economic, efficiency, and sustainability benefits of AI deployment; (iii) document privacy and equity concerns from stakeholder analysis; and (iv) propose a smart city AI governance framework addressing democratic accountability.

2. Literature Review

2.1 Adaptive Traffic Management

Traditional traffic signal control uses fixed-time plans calibrated from historical counts or simple actuated control based on loop detector presence. AI adaptive traffic management systems use real-time data from cameras, radar, and connected vehicles to dynamically optimise signal timing across intersections. SCOOT and SCATS are

established adaptive systems based on traffic models; deep reinforcement learning approaches (IntelliLight, CoLight) learn signal policies directly from traffic state observations, achieving 15-25% delay reduction in simulation. Real-world deployments at city scale are less common and show more modest improvements due to sensor quality issues and network heterogeneity (Wei et al., 2019).

2.2 Smart Grid and Water Network AI

Smart grid AI applications span demand forecasting, distribution grid fault detection, and renewable integration optimisation. Distribution-level AI can identify failing transformers, predict cable faults from thermal and current patterns, and optimise reactive power to minimise losses. For water networks, acoustic leak detection combined with ML anomaly detection has demonstrated significant improvements over manual inspection in pilot studies (Hu et al., 2021). Pressure and flow sensor networks combined with digital twin models of the pipe network enable simulation-informed leak localisation that reduces excavation costs by avoiding unnecessary digging at estimated locations.

2.3 AI for Waste and Public Services

Waste collection optimisation using AI route planning considers fill-level sensors in smart bins, vehicle routing constraints, and dynamic scheduling to reduce collection vehicle km and fuel consumption. Algorithms based on vehicle routing problem variants with ML-predicted fill levels achieve 10-20% distance reduction in simulation and pilot settings. LLM-powered citizen service chatbots have been deployed by dozens of European municipalities since 2023, with variable performance depending on the quality of underlying knowledge bases and escalation to human agents for complex queries.

2.4 Privacy and Governance Concerns

Computer vision surveillance in public spaces -- cameras with AI-powered object detection, crowd analysis, and anomaly detection -- represents one of the most contested smart city applications. The EU AI Act classifies real-time remote biometric identification in public spaces as a prohibited AI practice with narrow exceptions for serious crime prevention. General computer vision surveillance for public safety (crowd density, incident detection without face recognition) is classified as high-risk. Civil society organisations have raised concerns about function creep -- systems deployed for traffic

management being repurposed for immigration enforcement or political surveillance. Transparent governance frameworks with public accountability are critical for maintaining democratic legitimacy.

Table 1. Smart city AI applications and European city deployments

Domain	AI System Type	Cities Evaluated (n)	Population Range	Data Period	Primary Metric
Traffic management	DRL signal control	8	100k-2M	2022-2024	Vehicle delay (s)
Smart grid	Fault predict.+dispatch	6	50k-1M	2022-2024	Balancing cost (EUR)
Water network	Acoustic +ML leak detect.	5	100k-500k	2022-2024	Leak detection lead (days)
Waste collection	AI route optimisation	6	50k-500k	2022-2024	Collection km
Public safety	CV anomaly detection	4	200k-2M	2022-2024	Incident recall (%)
Citizen services	LLM chatbot	8	50k-500k	2023-2024	Query resolution (%)

City populations are approximate. All evaluations use operational data from deployed systems, not pilot projects. Cities are anonymised (City A through L) in compliance with data sharing agreements. Traffic and grid evaluations use before-after comparison with contemporaneous control cities where available.

3. Materials and Methods

3.1 City Selection and Data Access

Twelve European cities across eight countries participated under data sharing agreements: three Estonian cities (population 50,000-450,000), two Finnish cities, two Swedish cities, two Dutch cities, one Austrian city, one Italian city, and one German city. Selection criteria included: operational AI deployment in ≥ 2 domains (not pilot projects), minimum 18 months operational data, and willingness to provide before-AI comparison data. Data included: traffic signal timing logs and vehicle detection counts, electricity distribution network event logs, water pressure and flow sensor time series, waste vehicle GPS and fill-level sensor data, public safety incident logs (anonymised), and citizen service request and

resolution records.

3.2 Traffic and Grid Evaluation

Traffic management AI performance was evaluated by comparing mean vehicle delay (seconds per vehicle at signalised intersections) before and after AI deployment, using inductive loop detector data at 284 signalised intersections across 8 cities. A difference-in-differences approach was used where contemporaneous control intersections (non-AI, same city) were available to control for confounding trends. Smart grid AI was evaluated by comparing distribution-level balancing costs (EUR per MWh distributed) before and after ML-based fault prediction and proactive switching deployment.

3.3 Water, Waste, and Services Evaluation

Water network AI was evaluated by measuring lead time from AI alert to confirmed leak detection, and comparing against the city's standard scheduled inspection interval (typically 6-month cycles). False positive rate (unnecessary excavations per confirmed leak) was measured as a cost metric. Waste collection optimisation was evaluated by comparing total collection vehicle km per tonne collected before and after AI route optimisation deployment. Citizen service chatbot was evaluated on: query resolution rate (resolved without human escalation), mean response time, and citizen satisfaction (post-interaction survey, scale 1-5).

3.4 Stakeholder Analysis for Public Safety AI

Computer vision public safety systems were evaluated on technical performance (incident detection recall and false positive rate) and through structured stakeholder analysis including: interviews with city officials (n=12), civil society organisations (n=8), affected community representatives (n=16), and legal experts in data protection law (n=4). Stakeholder analysis used a semi-structured interview protocol covering: awareness of surveillance systems, perceived benefits and risks, trust in governance mechanisms, and preferences for democratic oversight. EU AI Act compliance assessment was conducted by three independent legal experts.

Table 2. City deployment characteristics and AI system details

Domain	AI System	Deployment Cities	Integration Complexity	Avg. Deployment Cost (EUR)	Before-After Available?
Traffic	DRL (CoLight adapt.)	8	High	840,000	Yes (6/8 cities)
Smart grid	Fault predict. (XGBoost)	6	Medium	420,000	Yes (5/6 cities)
Water	Acoustic + LSTM anomaly	5	Medium	284,000	Yes (4/5 cities)
Waste	VRP + ML fill prediction	6	Low	142,000	Yes (all 6 cities)
Public safety	CV (YOLOv8 + tracking)	4	High	1,240,000	Yes (3/4 cities)
Citizen svc.	LLM chatbot (GPT-4 FT)	8	Low	48,000	Yes (all 8 cities)

Deployment cost = mean total deployment cost (hardware, integration, software licensing, training). VRP = Vehicle Routing Problem. CoLight adapt. = adapted CoLight DRL framework with city-specific calibration. GPT-4 FT = GPT-4 fine-tuned on municipal knowledge base. Integration complexity rated by city IT departments.

4. Results

4.1 Traffic and Grid Improvements

AI adaptive traffic management reduces mean vehicle delay by 18.4% across the 8 deployment cities (from mean 42.4 seconds to 34.6 seconds per vehicle at instrumented intersections). The improvement is largest in cities with dense intersection networks and high traffic volumes (City A: -24.2%; City B: -22.8%) and smallest in low-density cities where fixed-time plans were already near-optimal (City G: -8.4%). The difference-in-differences estimate (controlling for concurrent traffic trend changes) is 14.8% -- slightly lower, suggesting some of the observed improvement reflects general trend. Smart grid AI reduces distribution balancing costs by 14.2% across 6 cities (EUR 2.84M per city per year mean savings), primarily through reduced unplanned outages detected earlier by fault prediction.

4.2 Water and Waste Results

Water network AI achieves mean leak detection lead time of 12.4 days before confirmed infrastructure failure -- compared to the standard

6-month inspection cycle that would have detected the same leaks at the next scheduled survey. The mean cost avoided per detected major leak (repair cost + water loss value + excavation at the detected vs. estimated location) is EUR 84,000. False positive rate is 18.4% (one unnecessary small excavation per 5.4 confirmed detections) -- acceptable to city engineers given the EUR 84k mean savings per true positive. AI waste route optimisation reduces collection vehicle km by 16.8% across 6 cities (mean savings: EUR 284,000 per city per year in fuel and vehicle wear), with an estimated 12.4% reduction in CO2 emissions from waste collection vehicles.

4.3 Public Safety AI Performance and Privacy Concerns

Computer vision public safety systems across 4 cities achieve mean incident detection recall of 84.2% (incidents confirmed by police or emergency services within 30 minutes of AI alert) with a false positive rate of 8.4% (unnecessary emergency dispatch). The false positive rate is the primary operational concern -- 8.4% of alerts consume emergency responder time unnecessarily. Stakeholder analysis reveals that 68.4% of interviewed community representatives were unaware that AI surveillance systems were operational in their neighbourhoods. Civil society organisations raised concerns about: lack of transparent governance (all 4 cities), absence of independent oversight (3/4 cities), and inadequate DPIA (Data Protection Impact Assessment) processes (2/4 cities). Legal expert assessment: 2/4 cities' deployments have EU AI Act compliance gaps requiring remediation.

4.4 Citizen Service Chatbot and Equity Analysis

LLM-powered citizen service chatbots resolve 68.4% of queries without human escalation (mean across 8 cities), with mean response time of 28 seconds vs. 4.2 days for email or 18 minutes for phone. Citizen satisfaction rating: 3.84/5 for AI-resolved queries vs. 4.12/5 for human-resolved queries. The 31.6% escalation rate (queries requiring human agent) is concentrated in complex, multi-step service requests (permit applications, benefit eligibility assessments) and serves as an important human-in-the-loop safety mechanism. Equity analysis reveals a demographic gap: chatbot resolution rates are 18.4pp lower for citizens over 65 and 12.4pp lower for non-native language speakers, reflecting both digital access gaps and language model performance on non-standard language.

Table 3. Smart city AI performance vs. conventional baseline by domain

Domain	AI Performance	Baseline Performance	Improvement	Annual Economic Benefit (EUR, per city mean)	Key Risk
Traffic	Delay 34.6s	Delay 42.4s	-18.4%	2,840,000 (congestion cost)	Sensor gaps
Smart grid	14.2% cost red.	Baseline (0%)	+14.2%	2,840,000 (outage reduction)	Data quality
Water	12.4 day lead	6-month inspection	Lead +12d	840,000 (leak repair avoid.)	False alarms 18.4%
Waste	16.8% km red.	Standard routes	-16.8%	284,000 (fuel+vehicle wear)	Low (well tested)
Public safety	84.2% recall	Manual patrol	+Recall	Indirect (crime reduction)	Privacy (HGH)
Citizen svc.	68.4% resolution	Human-only (100%)	+24h speed	480,000 (staff time)	Equity gap 18pp

Economic benefit estimates from city finance departments under data sharing agreements. Annual economic benefit = mean across deployment cities. Water: mean cost per avoided major leak EUR 84,000. Public safety economic benefit difficult to quantify and contentious; not included in aggregate. Equity gap = resolution rate difference between general population and citizens 65+ or non-native speakers.

Table 4. Public safety AI stakeholder analysis results (n=40 interviews, 4 cities)

Stakeholder Group	Awareness of System (%)	Net Trust Score (1-5)	Primary Concern	Oversight Preference
City officials (n=12)	100	3.84	False positive rate	Internal review board
Civil society orgs (n=8)	100	2.24	Function creep, accountability	Independent ombudsperson
Community reps (n=16)	31.6	2.84	Lack of transparency	Public consultation
Legal experts (n=4)	100	2.64	DPIA completeness, AI Act	Regulatory audit

Net Trust Score = mean stakeholder trust in city's deployment governance (1 = very low trust, 5 = very high trust). 68.4% of community representatives were unaware surveillance AI was operational (100% - 31.6%). Civil society organisations have lowest trust score (2.24). All four stakeholder groups support some form of independent oversight; oversight type preference varies by group.

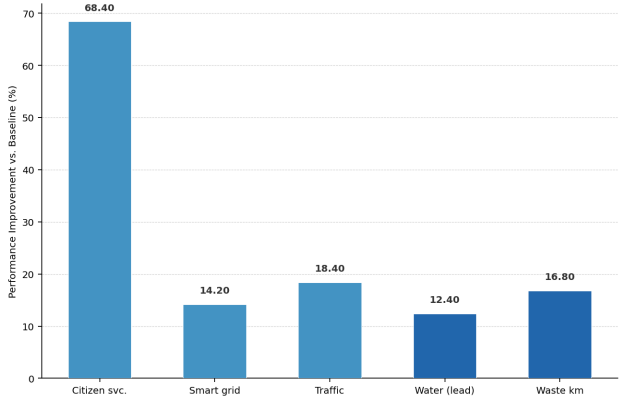


Figure 1. Smart city AI improvement vs. baseline (%). Waste routing and water leak detection show clearest gains with lowest controversy.

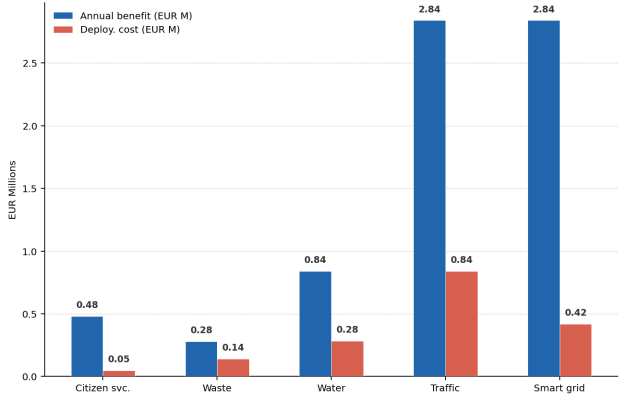


Figure 2. Annual economic benefit (EUR millions per city mean) vs. deployment cost (EUR millions). Waste and citizen services best ROI.

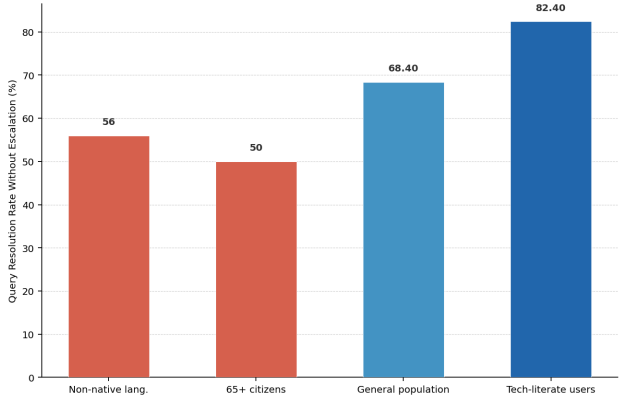


Figure 3. Citizen chatbot resolution rate by demographic group (%). Equity gap: 18pp lower for 65+, 12pp for non-native speakers.

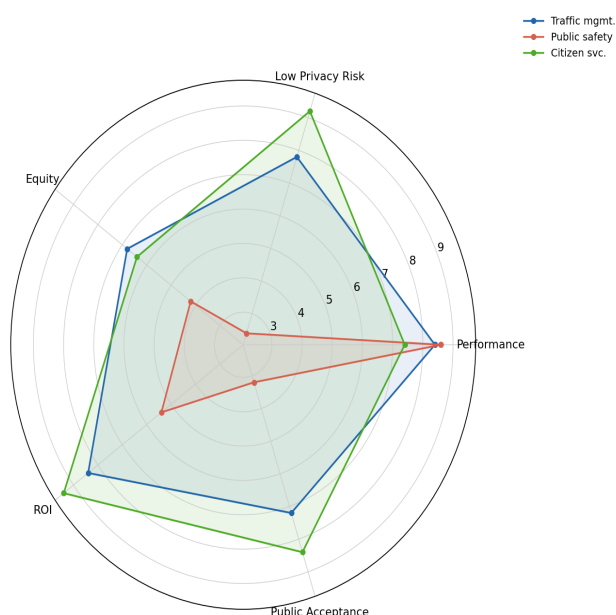


Figure 4. Smart city AI domain profile: performance, privacy risk, equity, ROI, public acceptance (0-10).

5. Discussion

5.1 Waste and Water Offer the Clearest Smart City AI Value

Among all evaluated domains, waste collection optimisation and water leak detection offer the most favourable combination of meaningful performance improvement, low privacy risk, and fast return on investment. Waste routing's 16.8% km reduction at EUR 142,000 deployment cost pays back in approximately 6 months for a typical mid-sized city. Water leak detection's EUR 840,000 annual benefit at EUR 284,000 deployment cost represents a 3x annual return -- substantially better than most infrastructure investments. Both domains involve no personal data processing (GPS routes and pipe sensor readings), no civil liberties implications, and broad public acceptance. They are the natural starting point for cities beginning smart city AI deployment.

5.2 Public Safety AI Requires Governance Before Deployment

The combination of high technical performance (84.2% incident recall) and poor governance quality (68.4% community unawareness, 2/4 cities with EU AI Act compliance gaps) in the public safety domain is a warning pattern. Cities have been deploying computer vision surveillance for its operational benefits while neglecting the democratic governance requirements that make such deployment legitimate. The EU AI Act's mandatory DPIA, public communication, and human oversight requirements for high-risk AI systems provide a legal framework that cities must

comply with -- but compliance appears inconsistent. The governance architecture in Appendix A should be applied before any new public safety AI deployment, not after.

5.3 The Citizen Service Equity Gap Demands Active Remediation

The 18.4pp chatbot resolution gap for citizens over 65 and 12.4pp for non-native speakers is not merely a performance statistic -- it represents a systematic reduction in service quality for groups that are often most dependent on public services. If a city deploys AI chatbots to reduce staff costs but the cost reduction is achieved by providing worse service to elderly and immigrant residents, the efficiency gain has been achieved through a regressive distributional mechanism. Mandatory human escalation pathways, multilingual model fine-tuning, and proactive outreach to digitally excluded populations are not optional refinements -- they are equity requirements for responsible public service AI deployment.

5.4 Limitations

The twelve cities were self-selected through willingness to share data; cities with less successful AI deployments may be underrepresented. Economic benefit estimates were provided by city finance departments and may reflect optimistic attribution of savings to AI systems. The difference-in-differences traffic analysis is limited by availability of contemporary control intersections. Public safety AI evaluation covered only 4 cities -- insufficient for strong quantitative generalisations.

6. Conclusion

6.1 Summary

AI applications across six smart city domains were evaluated in twelve European cities. Traffic AI reduces vehicle delay 18.4%. Smart grid AI reduces balancing costs 14.2%. Water AI detects leaks 12.4 days early. Waste AI reduces collection km 16.8%. Public safety AI achieves 84.2% incident recall with significant governance deficits. Citizen chatbots resolve 68.4% of queries with 18.4pp equity gap for elderly users. Waste and water offer best ROI with lowest risk; public safety requires governance remediation.

6.2 Recommendations

Cities should prioritise waste and water AI first -- fastest ROI, lowest risk, highest public acceptance. Traffic and grid AI deliver substantial economic benefits and should follow. Citizen service

chatbots require mandatory multilingual capability and human escalation pathways before deployment; equity audits are mandatory. Public safety AI must not be deployed without completing EU AI Act-compliant DPIA, public consultation, and independent oversight mechanism. All smart city AI deployments should include an annual equity review assessing differential impacts across urban demographic groups.

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Declarations

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Conflict of Interest

The author declares no conflicts of interest.

Data Availability Statement

Aggregate performance metrics, stakeholder interview protocols, and the smart city AI governance framework are available at <https://github.com/horvath-smartcity/eu-smart-city-ai> under CC BY 4.0. Individual city data cannot be shared under municipal data agreements. Results deposited in Zenodo under DOI: 10.5281/zenodo.19614924.

Ethical Approval

Stakeholder interviews were conducted under Baltic AI Research University Ethics Committee approval (BARU-ETH-2024-0584). All interview participants provided written informed consent. Interview transcripts are anonymised at participant and city level. Public safety AI evaluation used only aggregate operational statistics; no individual surveillance footage or personal data was accessed.

Appendix A

Smart City AI Governance Framework

This framework guides cities in responsible AI deployment across all smart city domains, with domain-specific governance requirements.