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Practical implementation of artificial intelligence for climate change mitigation in cities – priorities, collaborations and challenges

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ABSTRACT

European cities are increasingly exploring artificial intelligence (AI) applications to achieve their climate goals. Yet, how European city administrations implement AI-for-climate projects remains unclear. To address this gap, we interviewed city staff and urban innovation experts (n=15 interviewees) from Amsterdam, Berlin, Copenhagen, Greater Paris, Helsinki, and Vienna about their motivations, challenges, solutions, and partnerships when deploying AI tools. We found that city administrations were driven by different priorities that extend beyond accelerating climate action, such as improving decision-making, providing better services to residents, reducing costs, and showcasing innovation. We also identified implementation challenges for city administrations, for instance, socio-technical interoperability with existing systems or increasing AI literacy among city staff who work on climate action. We characterized three implementation arrangements through which cities deployed AI, highlighting the plural roles of city administrations in shaping AI deployment. Our analysis indicates that the European Commission, start-ups, researchers, and innovation labs were key partners for implementation, unlike civil society and large technology firms. Our study also reveals substantial challenges even for large, affluent cities, creating doubt about the applicability of AI projects for climate change mitigation in small and medium-sized cities.

1. Introduction

Cities increasingly use artificial intelligence (AI) as a means to reach their climate targets. While not a silver bullet, AI offers many opportunities to address climate change through mitigation and adaptation actions [1,2]. As identified in a recent systematic map of peer-reviewed research with a focus on mitigation, cities can use AI and machine learning (ML) predominantly in the transport and buildings sectors, but also for urban form and waste-related actions [3]. Heavily researched ML applications include optimizing heat supply in district heating networks, generating insights from building data to inform retrofitting, and assisting with managing shared mobility systems.

Research on the use of AI in the public sector and for urban climate change mitigation is increasing [3–5]. While the gap between research and adoption of these approaches has not been systematically studied, it is known that the implementation of AI applications by city administrations is slow – it often stops at the stage of small-scale pilots [6,7]. Empirical evidence, particularly on first-hand experiences of city administrations, remains scarce, because existing studies about the implementation of AI at the city-level are largely based on academic literature [5], policy documents [8], or surveys among academic researchers [9]. Improving understanding of deployment and causes of slow impetus may help researchers and practitioners resolve bottlenecks and unlock promising AI projects for climate change mitigation (hereafter, AI-for-climate) in cities.

Within public sector AI, AI-for-climate in cities presents a specific case of applications, which is distinct in core objectives, type of data, and the implementation contexts. For example, AI applications used in the automation of administrative processes are based on text data from legal documents or bureaucratic forms [10]. In turn, AI applications used to address urban climate issues often involve data on physical infrastructure and the built environment, such as energy use, weather, traffic flow, or occupancy rates [1]. Focusing the analysis on AI-for-climate may lead to revealing distinct priorities, challenges, and associated solutions, as well as collaboration needs.

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In addition, we narrowed the scope of analysis to Europe to keep a comparable regional implementation context. European cities are a main focus of research on AI for urban climate change mitigation [3], and they may spearhead the implementation of AI-for-climate projects. The European Commission has a joint agenda for a low-carbon transition and digital development, and positions the local public sector as a pivotal actor to shape AI deployment [11].

Implementing AI-for-climate applications is often driven by efforts to mitigate greenhouse gas (GHG) emissions [1]. In reality, however, AI-for-climate action may be motivated by several political agendas whose objectives have been observed as both complementary and, at times, competing [12,13]. For instance, AI-for-climate may be connected to city administrations' overall responsibility to create public value and localize policy objectives such as environmental protection and economic development [14]. City administrations may be motivated to use AI-for-climate to realize their commitment to implement effective measures to achieve pledged climate neutrality targets [15]. Additionally, public sector organizations may use AI within digitization efforts to increase efficiency of administrative processes, but also in support of decision making for services and management [16,17]. Previous studies have looked into the motivations to adopt AI in public administrations, with a focus on the trade-offs between values, such as economic and social benefits [17]. Yet, research has not assessed which specific, potentially conflicting priorities lead city administrations to use AI-for-climate applications.

City administrations are considered essential actors for driving AI-for-climate in urban settings [18,19], but their specific role in shaping AI deployment is not yet fully understood. So far, city administrations, as part of the public sector more broadly, are positioned as a key actor [11,20] through their role as a 'regulator' and a 'user' [17,21]. As a 'user', for example, they are typically involved in project implementation. This role implies that city administrations tend not to implement AI-for-climate alone but rely on partnerships. City administrations' collaboration with multiple actors, for instance, civil society or businesses, is a key trait of successful urban climate governance [19]. Yet, evidence about collaborators for AI-for-climate projects is lacking. Here, the analytical lens of 'implementation arrangements' might help to investigate city administrations' (potentially diverse) roles and partnerships with external actors, when implementing AI-for climate [22–24]. Implementation arrangements are commonly used in public policy research and implementation studies to determine the institutional setting and organizational form of implementation [25]. By combining insights about the conditions under which a policy and linked projects are implemented [26]. Implementation arrangements can also help reveal particular implementation challenges and associated solutions [27].

Implementation challenges, particularly across multiple AI application areas, have been investigated by previous research, such as automating administrative tasks or identity analytics [5], but not yet specifically for climate change mitigation in cities. It is also well understood that digital innovation processes in smart cities face barriers related to administrative processes or IT infrastructure [28–30]. Provided the slow pace of adoption, we expect that AI-for-climate projects similarly face such challenges. The climate-specific context, however, may yield additional challenges that result, for example, from the interdisciplinary nature of the problems to be addressed or the fact that most applications concern (critical) infrastructure. Revealing deployment challenges in this setting can help to understand both urban and climate-specific barriers to AI adoption, while solutions might offer promising pathways to tackle them.

Here, we investigate the use of AI for urban climate change mitigation based on first-hand experiences of European city administrations. Our analysis is based on cities that best fulfilled the selection criteria for climate leadership, AI-for-climate projects, and digitalization capacity (see Methods), enabling promising insights. The cities include Amsterdam, Berlin, Copenhagen, Greater Paris, Helsinki, and Vienna. To better understand how city administrations deploy AI-for-climate actions and through which implementation arrangements, we seek to answer the following research questions (RQs):

1. Which priorities drive city administrations to use AI-for-climate?
2. Which challenges do city administrations encounter around using AI-for-climate? And what are potential solutions to address those challenges?
3. What are the roles of the city administration, and who are key collaborators, in the implementation of urban AI-for-climate?

Our main contribution lies in assessing first-hand implementation experiences in practice, which is vital for understanding and shaping the deployment of AI-for-climate applications. The analysis specifies priorities and roles for the local public sector, providing insights into the initiating circumstances and different tasks that enable the implementation of AI-for-climate through city administrations. We also identify implementation challenges and incorporate them alongside roles and partnerships into implementation arrangements to capture the different conditions under which practitioners were able to realize AI-for-climate projects. Finally, we provide implications for city administrations and avenues for future research on AI-for-climate.

2. Methods

2.1. Selecting six European cities as cases

European cities provide an excellent opportunity to explore AI-for-climate implementation experiences since they are committed to achieving climate neutrality, recognizing their historical responsibility for a large share of GHG emissions [31,32]. In addition, European cities are supported by the European Commission's supra-national policies and programs to engage in projects that connect climate change mitigation with digital technologies. For example, the European Union (EU) not only declared the twin challenge of low-carbon transition and digital transformation in 2022 [33] but also established related funding programs, like the Digital Europe Program or the EU Mission: Climate-Neutral and Smart Cities.

To select cities in the EU that can help us answer our research questions, we developed three selection criteria that selected cities all had to meet: (1) climate action leadership, (2) past or currently implemented AI-for-climate project/s, that is, first-hand experience, and (3) digitalization capacity. We operationalized these selection criteria through several sub-criteria (see Supplementary Information A, potential cities). For example, for (1) climate action leadership (five sub-criteria in total), we checked whether a city declared a climate emergency or is part of the EU-mission Climate-Neutral and Smart Cities. For (2) (two sub-criteria), we identified whether an AI project has been implemented with relevance for climate change mitigation. For (3) (six sub-criteria), we assessed, for instance, if a city administration has relevant in-house staff, an open data platform, or a connection to digital innovation institutions. Through desk research, we first identified 30 European cities potentially relevant to provide first-hand experiences into AI-for-climate. Second, we assessed which of these cities met all selection criteria and at least 10 of the 13 sub-criteria and filtered for accessibility to interviewees, resulting in the following cities: Amsterdam, Berlin, Copenhagen, Helsinki, Paris, and Vienna (see Table 1 and Supplementary Information A for how the six cities fulfilled the selection (sub-)criteria).

2.2. Short description of the climate and AI contexts in selected cities

The six selected cities were unique in implementing AI-for-climate, and hence, allowed us to explore a variety of contexts for the implementation of AI-for-climate projects (see Supplementary Information B for detailed descriptions of the context for each selected city). For example, the city of Amsterdam has been jointly advancing the sustainability and digitalization agenda by putting in place open ethical AI procurement standards and fostering innovation partnerships with academic and civic networks dedicated to solving the city's challenges related to, for

Table 1
Overview of the European cities selected as examples with evidence for fulfilling the selection criteria (1)–(3) based on desk research.

City	Country	Aims to be carbon neutral by	(1) Climate action leadership	(2) Implementation of AI climate projects	(3) Digitalization capacity
Amsterdam	Netherlands	2050	Member of 100 climate neutral cities, Covenant of Mayors for Climate & energy	Multiple pilot projects, AI4Cities consortium city	AI team, uses AI registry, established AI procurement clauses, AI strategy
Berlin	Germany	2045	Member of Covenant of Mayors for Climate & energy, active civil society	Few pilot projects, AI4Cities follower city	Digital and smart city strategy, strong collaboration with the innovation lab, Chief Digital Officer with team
Copenhagen	Denmark	2035	Member of 100 climate neutral cities, Covenant of Mayors for Climate & energy	Multiple pilot projects, AI4Cities consortium city	Copenhagen Solutions lab, Digital champions unit
Greater Paris	France	2050	Member of 100 climate neutral cities, Covenant of Mayors for Climate & energy	Few pilot projects, AI4Cities consortium city	AI strategy, city as test-bed, Cap Digital as innovation hub for digital and ecological transformation
Helsinki	Finland	2030	Member of 100 climate neutral cities, Covenant of Mayors for Climate & energy	Few pilot projects, AI4Cities consortium city	Uses AI registry, member of Finnish Center for AI, runs AI upskilling programs for staff, Chief Digital Officer and digitalization unit, data strategy and digitalization program in place
Vienna	Austria	2040	Member of Covenant of Mayors for Climate, following a set of inter-generational solidarity principles, collaborative climate governance	Multiple pilot projects	Chief Technology Officer (CTO) with a team, Digitalization principles, AI strategy and compass

example, mobility or building energy consumption. The city of Berlin integrated climate targets into its smart city strategy and invests in innovation hubs to experiment with AI as a means to meet digitalization and sustainability goals. The city of Copenhagen established AI literacy in climate-relevant departments, that is, in properties and building management, while fostering innovation through market collaboration and resident-oriented experimentation via the Copenhagen Solutions Lab. The city of Helsinki develops digital tools for public services through its digitalization unit, internal upskilling programs, open data platform, and close partnerships with innovation actors like Forum Virium and Mobility Lab Helsinki. Greater Paris clearly outlines the sustainable and ethical use of AI for the public interest in the AI strategy. Their interest in using AI for climate action is driven by climate leadership and urban development agencies like Cap Digital, with local initiatives—such as the city of Meudon's experimentation with AI for traffic optimization. Finally, the city of Vienna aims to become both climate-neutral by 2040 and Europe's digital capital through a unified Smart Climate City Strategy, climate-conscious digital principles, and strong internal expertise, guided by, for instance, the generative AI compass.

2.3. Interviewing city staff members and urban innovation experts

To gather first-hand implementation experiences, we conducted semi-structured interviews with 15 city staff members and urban innovation experts between January and November 2023 (see Supplementary Information C for the interview guide). The interviews entailed open-ended questions about priorities, roles, collaborators, challenges, and solutions for the implementation of AI-for-climate projects. We asked interviewees to elaborate with details, using a specific project as an example. The interview guide was pre-tested with two city staff members in iterative rounds. We selected suitable interviewees from staff members of each city administration and, in three cities, additionally, experts of the urban innovation lab, who were closely involved in the cities' activities on AI and climate action (Table 2). Specifically, we focused on project managers, technical leadership, data scientists, and digital advisors based in environmental teams to capture first-hand implementation experiences. Before conducting the interview, we explained the purpose of the research to each interviewee (Written information sheet and verbal explanation in Supplementary Information D) and asked for written consent (Declaration of Consent in Supplementary Information D), which each interviewee granted. All interviews were conducted online by the first author, took between 42 to 67 min (54 min on average), and were recorded and transcribed for analysis. We stopped recruiting more interviewees once conceptual patterns started to repeat themselves, indicating data saturation [34,35].

2.4. Conducting qualitative content analysis

All transcripts were imported into Atlas.ti (version 23.4.0) [36] to conduct a qualitative content analysis [35,37]. Two authors created the coding framework through an inductive and iterative process, guided by the research questions (see Table 3 for an overview of RQs with coding categories and figures and Supplementary Information E for the coding framework) [35,38,39]. To maximize inter-coder reliability [40], both authors discussed and resolved conflicts, and consolidated the categories into a final version of the coding scheme, which the first author then applied to all interviews. We noticed that interviewees mainly used the term 'AI', although the deployed systems are technically based on machine learning (ML). To align with interviewees' expressions and maintain consistency in terminology, we decided to use the term 'AI' throughout the study.

In addition to coding the categories priorities, challenges, solutions, roles, and key collaborators in the interviews, we gathered information on the key traits of the six AI-for-climate projects, including the objective, tasks for AI, and contribution to climate change mitigation to characterize the projects (see Table 4 for a comparative overview and Supplementary Information B for more detailed project descriptions). For example, the AI applications include object recognition in waste management, forecasting of tree suction tension to safeguard street trees, prediction and automated control for heating-ventilation-air conditioning systems in public buildings or text classification to accelerate approval of sustainable design permits. Next, we developed implementation arrangements in two steps (see Supplementary Information F). First, we identified similarities between the projects with

Table 2
Interviewee details across the six cities.

City	Department or institution	Role	City staff	Urban innovation expert	Interviewee ID
Amsterdam	Urban Innovation & Procurement	Project manager	x		A
	Digitalization & Innovation	Project manager	x		B
Berlin	Berlin partner for economy and technology	Leadership		x	H1
		Project manager		x	H2
	City lab (Innovation lab)	Leadership		x	I
	City administration - Environment and sustainability policy	Leadership	x		M1
		Digital policy advisor	x		M2
Copenhagen	Energy and technology	Procurement advisor	x		C
	Building economic administration, Properties and purchases	Digital policy advisor	x		D
Greater Paris	Digitalization (Meudon)	Leadership	x		K
	Climate & Ecological transition directorate (City of Paris)	Leadership	x		L
Helsinki	Forum virium (Innovation company)	Project manager		x	E
		Data scientist, Project manager		x	F
	Data analytics	Data Scientist	x		G
Vienna	IT & Digitalization	Leadership, data scientist	x		J

Table 3
Overview of research questions, methods, (sub-)categories from coding framework, and synthesis of results.

Research question	Categories and sub-categories from coding framework (Supplementary Information E)	Results synthesized in
(1) Which priorities drive city administrations to use AI-for-climate?	**Priorities:** Accelerating climate action progress; Improving information; Enhancing decision-making; Providing new or improved services to residents or users; Reducing costs for the organization; Shaping or supporting the (local) AI market; Showcasing a data-driven, innovative approach; Using automation for a more effective use of human labor.	Table 5, Supplementary Information E
(2) Which challenges do city administrations encounter around using AI-for-climate? And what are potential solutions to address those challenges?	**Challenges and solutions** across five themes: Administrative and regulatory processes; Capacity and skills; Data and IT infrastructure; Environmental impact and ethics; Political agenda and attitude	Fig. 2, Supplementary Information G
(3) What are the roles of the city administration, and who are key collaborators, in the implementation of urban AI-for-climate?	**Roles of city administrations:** Ownership and authorization responsibilities; User of AI; Developer of AI; Providing domain expertise; Enabling private sector innovation; Co-creator or designer of code or application; Regulator **Key collaborators driving uptake of AI:** City administration (AI/Data team, Climate/Sustainability team, Innovation, R&D team, Domain experts, Leadership); Public utility companies; Private sector (Start-ups, SMEs, Consultants).	Table 7, Fig. 1, Fig. 2, Supplementary Information E

regards to, for instance, the collaborators involved, and among key characteristics in the six cities, iteratively grouping information to form a typology of implementation arrangement. Second, we applied the interview data to the arrangements through inductive evaluation of the role of the city administration, AI capacity, and character of the AI project. Complementing the interviews, we also use project documentation, for example, presentation decks, blog posts, and technical summaries. These were helpful to characterize the projects better, however, insufficient to systematically triangulate findings.

3. Results

3.1. City administrations use AI-for-climate to fulfill multiple priorities

All interviewees explicitly mentioned the role of AI to advance climate change mitigation efforts, alongside seven other priorities (Table 5): 'Enhancing decision-making', 'improving information on the city/project region', 'providing new or improved services to residents or users', 'reducing costs for the organization', 'shaping or supporting the (local) AI market', 'showcasing a data-driven, innovative approach', and 'using automation for more effective use of human labor'. Interviewees reported that AI-for-climate projects were implemented to tackle multiple priorities at once. They explained that achieving climate targets is linked to improving energy efficiency and reducing costs. Some interviewees observed that decision-makers in AI projects place less importance on CO_2 reduction potential compared to increasing the efficiency of processes, linked to the priority of reducing costs for the organization. For example, a Project Manager working for the city of Amsterdam (interviewee ID: B) described it as *"(…) the start point is*

Table 4
Overview of an exemplary AI-for-climate project per city (in columns) with categories (in rows); descriptions are based on case study descriptions.

Project title, City	Area	Specific AI task/s	Type of AI (name of model)	Training data	Data sources & data privacy	Key collaborators	Project type	Project status	Climate impact
The Urban Detection Kit, Amsterdam	Waste collection route optimization	Object classification & recognition	Reinforcement learning (You only look once (YOLO))	Annotated street-level images	Real-time data collection, municipal data; privacy filter for faces and license plates	City administration (AI team), University, Waste company	Research to city-owned spin-off	Deployed at urban scale	Reduced mileage and energy
Quantified Trees, Berlin	Street tree safeguarding and watering route optimization	Tree suction tension forecasting	Supervised learning (Random forest)	Sensor data from trees	Open source municipal data and private company data; no personal data involved	City administration, Federal agency, Innovation lab, Start-up	Research project	Completed prototype test	NA
SPIKE, Copenhagen	Heating-ventilation-air conditioning (HVAC) system optimization in public buildings	Cause-effect dynamics prediction, automated control	Supervised and reinforcement learning (NA)	Historical sensor data from buildings	Municipal and private company data; GDPR compliant	City administration, European Commission, Start-up	Innovation procurement	Completed pilot	Reduced energy consumption
Ix3, Greater Paris – Meudon	Traffic management via automated traffic light control	Object classification & recognition, automated control	Deep learning (Convolutional neural network (CNN))	Annotated traffic video	Real-time data collection, private company data; no personal identifiers used, video footage is not stored	City administration, European Commission, Start-up	Innovation procurement	Completed pilot	2% reduction in traffic emissions
BEE System, Helsinki	Renewable energy use in public buildings	24h utilization forecast (energy, weather, room use), control for HVAC, water heating, EV charging	Deep learning (Neural prophet)	Energy consumption data	Publicly available data, municipal and utility company data; no personal data	City administration, Consultants, European Commission, Innovation lab, Start-up	Innovation procurement	Completed pilot	20% reduction in energy use
BRISE, Vienna	Support in sustainable neighborhood design approval	Text classification & recognition	Deep learning (NLP)	NA	Not publicly available, municipal and research institute data; NA	City administration, Consultants, University	Research project	Scaled and deployed pilot	Enabled ecological standards in buildings

always efficiency. You try to make your work more efficient or aka smart (. . .) the start point is never really hey, I want to do some climate action".

3.2. Multiple challenges to deploying AI in cities

Interviewees reported challenges for implementing AI-for-climate projects related to five domains: environmental impact and ethics, administrative processes and budget planning, capacity and skills, data and IT infrastructure, as well as political agenda and attitude. For some of the challenges, interviewees also suggested solutions (see Table 6, extended in Supplementary Information G, Table 1).

Uncertainty around the environmental impact and ethics of AI. Uncertainty around the environmental impact of AI models – in particular, the potential for GHG emissions reduction and the direct footprint – challenged the implementation of projects (see Supplementary Information G). For example, some city administrations included the CO_2 emission reduction potential as an award criterion in the procurement process. While such integration signals the importance of climate action to potential suppliers, estimating the reduction potential is difficult. For example, a project manager from Helsinki's innovation company (E) explained that: *"these results [for CO_2 emission reduction] were more or less like estimations, but some of them were able to show some real figures. (...) But anyway, it was very complicated, and that was one of our problems that how we can measure".*

Regarding AI's direct environmental footprint, we found different levels of experience among interviewees. A Project Manager from the city of Amsterdam (B) shared their perspective: *"Just to stress again, I think the importance of figuring out at some point how much CO_2 does the AI emit itself. It's incredibly understudied. And I really think that answer needs to be answered first before you go in full mode on using it for all kinds of things".* A data scientist from the city of Helsinki (G) describes that for most AI-for-climate models, the direct footprint is less of an issue [41] by saying, *"at the moment our computational services are it's still quite light. [...] I don't think that's a very, very large issue at the moment. [...] A lot of the hype is going for the very large models, NLP models, or something. So yeah, they consume a lot of resources, but our scale is much, much smaller. If you think of the big tech global corporations, that Google, Amazon, Netflix, their services are consuming a huge proportion of all the computational power in the world, and they have millions, hundreds of millions, or even billions of users daily, and they process image data, and they process video data. All of this. [...] Whereas the city has only, well, we have about 2 million potential customers for any of our services. That's the maximum that's 600 or 700,000 inhabitants in the city. So the scale is much smaller. [...] So it's really not that big of an issue".*

Interviewees were challenged by addressing ethical and safety risks associated with AI. For instance, they reported struggling with assuring

Table 5
Eight priorities that lead city administrations to deploy AI-for-climate change mitigation emerged from the interviews.

Priority	Description	Example quote (Interviewee ID – City)	Prioritized in the following cities
Accelerating climate action progress	Deploying AI to accelerate the implementation of actions that reduce CO_2 emissions in various sectors effectively towards achieving climate neutrality targets.	*"First thing is that we have very ambitious climate goals, so we want to have a 50% CO_2 reduction in 2030, 95% in 2050. I think that looking at our policy goals, that we're very ambitious, but then looking at the practical side of it, I think we're running behind. (. . .) one of the ways to solve it is to actually use the data that we have to make more intelligent predictions and really see how we can incorporate artificial intelligence to contribute to these types of goals."* (A–AMS)	All
Enhancing decision-making	Using AI for better informed, fact-based decision making, both for operational and strategic contexts.	*"Probably more for monitoring to achieve climate goals, to know exactly where we stand and where adjustments might be necessary."* (H1 –BER)	BER, PAR
Improving information on the city/project region	Filling knowledge gaps on climate-related issues, making use of a large amount of unanalyzed information, insights that are beyond human analytical capacity, including the impact of climate policies.	*"To make the nexus with social data, environmental data, economics data and not only, for example, of GHG emissions data, to have the consequences of all the co-benefits and all the consequences of the policy of the climate change policy of for the background of the city. That can be useful for the future."* (L –PAR)	AMS, CPH, HEL
Providing new or improved services to residents or users	Offering new services or optimizing operations based on demand or residents' behavior e.g. creating comfort.	*"And of course to create better services, it's not always about just saving money, but it's also about creating better services."* (G –HEL)	AMS, CPH, HEL, PAR, VIE
Reducing costs for the organization	Reducing costs, navigating austerity, tight municipal budgets, fiscal policy, e.g. through energy efficiency.	*"And right now it looks like AI as a tool can assist us in becoming more efficient. So that is the key driver for us. That is always to look at efficiency."* (D –CPH)	BER, CPH, PAR, VIE
Shaping or supporting the (local) AI market	Actively participating in market dynamics, communicating needs to the private sector, influencing through urban public sector demand, co-creating applications that are on the market.	*"AI is coming and they are looking for that kind of area that what it can serve to the city and what kind of advantages it will give for the city."* (E –HEL)	AMS, BER, CPH, HEL, PAR
Showcasing a data-driven, innovative approach	Creating data-driven innovation, being an early adopter of AI, exploring AI's relevance in an urban context, implementing the smart city agenda.	*"AI will help us to do what was not possible."* (K –PAR) *"I think what I mentioned earlier, with all of the data that is being locked and currently not analyzed. I think there's a huge potential in that."* (C –CPH)	AMS, BER, HEL, PAR
Using automation for more effective use of human labor	Conducting tasks that thus far could not be done (by humans), automation of processes to free up human capacity, which can then be used for less repetitive tasks, and more resource-efficient use of human labor.	*"There are many opportunities to cover routine tasks where human intervention is not necessarily required."* (H2 –BER) *"Because it gives us the possibility to automate procedures and processes."* (J –VIE)	AMS, BER, HEL, PAR, VIE

Note: see Table 2 for interviewee details. Abbreviations: AMS: Amsterdam, BER: Berlin, CPH: Copenhagen, HEL: Helsinki, PAR: Paris, VIE: Vienna.

the trustworthiness of AI models. A data scientist from Helsinki's innovation company (F) reflected that *"Some part of decision making is taking away from the human and given to the AI. Even if the AI would only provide suggestions instead of, like, actual actions or commands, the users have to be able to trust the AI, or the AI has to be trustworthy. So they have to be adequate safeguards that the AI doesn't accidentally do something that is not wanted"*. Interviewees suggested solving the former by certifying AI models that could help the administration assess a model's performance and the developers' risk management. For example, an interviewee (K) who works in the leadership team of the city of Meudon, Greater Paris, shared: *"As we had a lot of security to manage with the AI system, I said maybe it could be useful to have an algorithm certification of the red light management. Because today we have used AI to manage the red light traffic. But we had no certification. So we don't know exactly how the company managed the AI"*. A digital policy advisor working for the city of Berlin (M2) framed the challenge of AI ethics and safety as *"(...) an issue of data governance, because in order to find meaningful solutions in the interests of the common good, there should also be regulation, for example with regard to data availability at companies"*.

In addition, navigating data sharing and compliance with GDPR when deploying AI projects was challenging for interviewees. For example, a digital policy advisor (M2) from the city of Berlin illustrated this challenge as *"either you find a technical way to operate these models locally, for example, and then somehow guarantee data protection, or you just have to think about what data protection actually means in concrete terms"*. Yet, city administrations choose to use AI specifically on climate issues as these projects tend not to involve personal data. For example, a data scientist from the city of Helsinki (G) states that *"if you use it [AI] for environmental issues, then mostly it's not about personal data and you don't have the sort of limitations. But that's been the sort of driving factor for our decisions"*. Next to data protection, interviewees described that data sharing is a challenge for city administrations that deploy AI-for-climate

Table 6
Summary of implementation challenges and potential solutions described by interviewees.

Domain	Challenges	Solutions
Environmental impact and ethics	Assuring the trustworthiness of AI	Certification of AI models
	Uncertainty around AI's direct footprint	Clean energy for datacenters
	Calculating the emission reduction potential	
	Navigating data sharing and compliance with GDPR	–
	Negative system-level impact	–
Administrative processes, budget planning, and readiness	Existing bureaucratic processes or lack thereof	Centralize digitalization expertise
	Financial limitations, too high or uncertain initial costs	Allocate budget for pilot projects
	Lack of influence on regulation from cities	More agile forms of partnership
	Lack of technological readiness	Pivoting to a different approach
Capacity and skills	Lack of (interdisciplinary) collaboration	Collaborative project design
	Lack of AI literacy	AI knowledge development for decision-makers
		Developing roles with interdisciplinary profiles
		Subcontract consultants
		Upskilling of the administrative workforce
		User-friendly AI applications
	Cannot compete with AI jobs in the private sector	–
	Operation and maintenance of AI systems	–
Data and IT infrastructure	Lack of ML-ready data	Data collection and management
		Using AI itself to generate data
	AI is not required	–
	Lack of socio-technical interoperability and agility around existing systems	–
Political agenda and attitude	Hesitant attitude towards AI adoption	Communication material
		Precise definition of problem and tasks
	Unsupportive political agenda	Showcase the benefits of using AI
		Realizing the city's agency to shape AI development

Note: '–' indicates that we did not detect a solution for the challenge in the interviews. This, however, does not mean that the challenge, per se, cannot be resolved.

projects with private companies. A data scientist and project manager at Helsinki's innovation company (F) explained that *"(…) might be a bit difficult or it requires a lot of work and time to get all the necessary permissions to share data"*

Administrative processes, budget planning, and technological readiness not (yet) supportive of AI-for-climate in practice. Interviewees stated that missing or conflicting bureaucratic processes and a mismatch in the pace between private and public sector processes were challenges for city administrations to deploy AI-for-climate projects (see Supplementary Information G). As AI is a nascent tool for many city administrations, staff often have to improvise steps to navigate the lack of established bureaucratic processes that would bring together relevant staff and resources. They also struggle with existing processes and a culture that can hinder AI-for-climate implementation. For instance, a project manager from the City of Amsterdam (B) describes that *"people get scared if you are like, oh, I'm looking for a certain data and then you need to call this guy who knows another guy who maybe knows where this data is. So that's terrible still"*. Interviewees described that setting up a centralized digitalization and AI team within the administration's structure was helpful. Notably, a centralized AI team differed from the established IT (service) team as it drove the work on digital technologies on specific use cases, and acted as a contact point for project ideas and inquiries about digital technologies internally and externally.

We detected hesitation among city staff to invest in AI due to prevailing austerity, high costs, and budget plans not (yet) including AI-related projects with related staff capacity and infrastructure. A member of Vienna's city leadership (J) emphasized that *"[AI applications] will have to become a bit cheaper until we are really ready to say, okay, we can manage to carry out this more or less frequent, high-frequency or actually permanent use and also build up the pipeline"*. Since investing in AI-for-climate implied high costs or diverting the budget away from other measures, city administrations tread lightly. Interviewees shared that allocating budget or acquiring third-party funding to conduct AI pilot projects, instead, enables the build-up of experience and careful performance evaluation. A Digital Policy Advisor of the city of Copenhagen (D) suggests to *"Ensure that you have enough money and that you have enough resources internally that you can allocate to this […]"*.

Interviewees stated that the mismatch between slow public procurement and rapid AI development led to friction between city administrations and solution providers. Slow procurement processes may cause companies not to do business with public sector entities, as described by a Procurement Advisor working for the city of Copenhagen (C): *"Really changing anything within a public government, it just takes a while. And it's my experience that companies are not usually that patient. Probably due to funding as well"*. In turn, interviewees described that city administrations, for instance, Helsinki, held off on purchasing AI applications, as they struggled to assess the long-term applicability of an AI model and aimed to avoid the risk of infrastructure lock-ins, given the rapid pace of development and innovation for some AI applications. Interviewees identified the creation of more agile partnerships between city administrations and the private sector, for example, through innovation procurement, as a solution. Through these partnership approaches, start-ups develop AI applications based on city administrations' needs for GHG emission reduction. However, these partnerships bear their own challenges, as a project manager from Berlin Partner (H) described *"Innovative procurement is too slow because it is just too complicated; no one dares to do it properly"*.

Interviewees detected a lack of technological readiness in the market, preventing city administrations from purchasing an AI application. Many AI products and services are available on the market, but they do not necessarily match the demand of city administration or match the

scale of urban infrastructure. A Project Manager working for the city of Amsterdam (B) emphasizes that: *"I don't really think that there's anything there yet that's advanced enough"*. Interviewees described insufficient performance against promised objectives, such as energy savings or safety concerns, including security breaches, as key reasons not to scale a tested solution offered by a start-up and instead develop the AI model internally.

Low AI literacy and lack of interdisciplinary expertise in city administrations limit implementation. Interviewees stated the lack of AI literacy of staff across departments, including the climate team, as a challenge for deploying AI-for-climate (see Supplementary Information G). The lack of AI literacy, here, refers to insufficient expertise or skill in the city administration to initiate or manage an AI-for-climate project. This left city staff unable to evaluate the potential of an AI application for solving a climate action problem and to coordinate a project, given the ethics and safety dimensions of AI. A data scientist from the city of Helsinki (G) highlighted *"[…] We don't have those people who would be able to actually like [sic] convert these problems into AI and machine learning problems"*. and *" someone has to actually decide what to procure from them [supplier of AI applications.] […] then you don't need to have skills to actually develop AI, but you need to understand it on a very technical level to be able to actually make these decisions"*. Similarly, a member of Berlin Partner leadership (H1) shares that *"I think people just haven't connected the dots yet. Artificial intelligence as a technology is in one cluster, and climate protection is in another. I believe they just haven't thought about it together"*. Once up and running, interviewees shared that AI systems required oversight and maintenance, that is, staff with the skill and capacity to manage and fix emerging errors in AI systems. While some cities, for example, Amsterdam, Helsinki, and Vienna, created roles such as a Chief Technology Officer (CTO) or built up an AI team, other administrative staff, including procurers and leadership, require AI literacy, too. An employee at the city of Paris, working in the leadership of the Climate and Ecological Transition Directorate (L), shared that *"to help the decision makers is to know what is really possible with AI. It is not so easy to understand if you don't […] know what you can do"*.

City administrations struggled to address the lack of AI literacy by hiring AI experts to their internal staff since they could not compete with private sector job conditions, including high salaries, attractive benefits, and personal development perspectives. Some city administrations, that is, Helsinki, Paris, and Vienna, instead subcontracted from a pool of AI consultants for specific input. For example, a consultant supported the evaluation of AI project proposals, as described by a Project Manager (E), working at Forum Virium, Helsinki's innovation company: *"We need to find external experts to help us with how to calculate, and how to ask from the companies, for example, the reduction potential"*. AI literacy was also introduced to project teams through external collaborators. Partnerships with universities, different departments within the administration, or the private sector ensured to fulfill all of the required areas of expertise, for instance, on urban mobility, project management, and AI development. Amsterdam, for example, found what was described by a project manager (B) as a "winning formula": *"work together with the university, get the Ph.D. students in-house, get a couple of people that you hire, make a small team. Give them an innovative environment and come with cases for which they need to develop something for"*. In turn, interviewees pointed out that collaboration among multiple actors across disciplines requires additional coordination capacity, especially when working in an experimental environment, with (sometimes still) unclear AI regulation.

While collaboration with AI-literate partners could enable the implementation of AI-for-climate projects, as interviewees outlined, city administrations nevertheless benefited from building up AI literacy internally. Interviewees identified that up-skilling the administrative workforce, developing roles with interdisciplinary profiles, and AI knowledge development for decision-makers were key to addressing the AI literacy challenge. Educational efforts included training programs, certifications, and workshops, designed for leadership or specific staff across departments. For example, in 2021, the city of Helsinki teamed up with a local university to organize a year-long training course on AI for 20 staff members of the administration. Another training course was geared towards equipping procurers with an understanding of data engineering to improve procurement of digital services, including AI applications. As a means to be accessible to city administrations with low AI literacy, interviewees found that suppliers of AI applications would need to offer user-friendly interfaces and descriptions. Staff working in the leadership team of the city of Meudon, Greater Paris (K), described this as follows: *"And as we are not going to have very qualified people in the city because we cannot pay them, then it has to be easy to use"*.

Implementing AI projects is challenged by insufficient AI-ready data and IT infrastructure. Interviewees also identified technical hurdles (see Supplementary Information G), including the lack of or access to sufficient data in machine-readable formats, the amount or quality for developing a project. For example, the city of Copenhagen had datasets with data points on indoor temperature of buildings in two-hour and two-day intervals, which conflicted with suppliers' need for data points collected every 15 min and 24 h. Improving data collection efforts and continuous management of databases in conjunction with the development of the AI model helped overcome this challenge.

Most of the AI-for-climate prototypes in the selected cities were not scaled up due to the lack of socio-technical interoperability and agility around existing (digital) systems, for instance, sensors and applications for the management of a building's energy consumption. Integrating AI models into daily operations at scale required a shift in system settings and organization of collaboration. Interviewee A from the city of Amsterdam shared that *"you need some subcontractors to actually help do the installations. We have a house installer that's maintaining the indoor infrastructure. So I think it's really about working together with different stakeholders in this trajectory. So it's not only about 'does the solution technically do what it has to do', but also, can you work together with the supplier and do they fit into the existing infrastructure of entities involved"*. A Procurement Advisor from the city of Copenhagen (C) reflected on how *"it's not an easy process to begin this because going in with artificial intelligence and changing operation is a quite deep interference […] so it's not just a plug and play or a fix. You almost always need like [sic] quite a long process to make sure everything sort of fits"*. However, if the design of existing systems or the proposed AI model lacked agility, the transaction costs became very high. For example, the shift required additional expertise and resources around control and system integration, which is reinforced as a challenge by the previously mentioned lack of AI literacy and high costs.

Unsupportive political agendas and hesitant attitude hinder the use of AI-for-climate in practice. Interviewees shared that opposing views among involved staff and decision-makers delay or hinder the implementation of AI-for-climate. For example, the innovation department or innovation lab (a creative space that fosters experimentation specific to a local context) saw the potential of using AI to achieve the city's goals, but other teams doubted the use of AI, especially for assisting in climate change mitigation efforts (see Supplementary Information G). For instance, Leadership staff at Berlin Partner (H1) shared that *"the new Berlin Energy and Climate Protection concept is not finalized yet, and the specific directions are not completely defined. We are still unsure about the use of AI for climate monitoring, for instance"*.

A Digital Policy Advisor working for the city of Copenhagen (D) explained that *"There could be persons who just subjectively can be against it or don't believe in it, and that's like a culture thing. And you can always have [such] a person in the project group"*. Interviewees reflected that providing communication material that, for instance, explained which datasets the AI model was trained on and how privacy was protected helped to address critical views. Communicating clearly about the type

Table 7
Seven roles of city administrations for implementing AI-for-climate projects emerged from interviews.

Role	Description	Example quote (Interviewee ID)
Co-creator	Actively involved in the development process as one of the multiple actors, i.e. also companies and universities; engages in dialogue and provides feedback.	*"Normally, we should have been only a user. But as there were, as mentioned, a lot of roadblocks, we had to participate in the solution design."* (K)
Data owner and authorizing body	Decides over data access, has responsibility for allowing and coordinating piloting of AI, owns and maintains urban infrastructure or buildings.	*"Who had access and can make (…) decisions on behalf of the city when needed and confirm those pilots."* (E)
Developer	Identifies opportunities, develops ideas, creates AI models, and creates service products in-house.	*"Most algorithms, algorithms that we use, have been developed by ourselves."* (B)
Domain expert	Feeds in specific expertise when and where needed, e.g., on existing building management systems.	*"So we were looking for experts in different areas that were related to our project, like in energy, in mobility (…) So as a matter of just finding those people and getting them interested about our project."* (F)
Enabler of innovation	Gives opportunities to AI start-ups, provides a test bed for new, off-market AI applications.	*"To support those companies in developing their solutions [AI application] by offering contracts to the cities and in the end, offer them a place to pilot."* (F)
Regulator	Steers the use of AI in the city context, works with an AI strategy or localizes EU regulation.	*"We have our own AI strategy, which basically sets out what framework conditions we have for AI systems. Which systems do we want to use, which do we not want to use? Yes, well, we have a de facto guideline that describes the AI systems and regulates their use."* (J)
User	Contracts out a service; the city is a customer of a company that provides AI applications.	*"But we are like the user of the platform and they (the company) provide the platform."* (D)

of problem, purpose, and tasks the AI model would be deployed for was helpful in convincing decision-makers, or as a Project Manager at Forum Virium Helsinki (E) put it: *"Know beforehand what you are actually trying to achieve, what is your exact problem? I think it would be still easier to find good results or good, new ideas. Because otherwise, it can be very [sic] it's hard to convince your colleagues to take part in those experiments or pilots if it's not so clear what are the benefits of it"*. Interviewees emphasized that for the implementation of AI-for-climate projects, often political support was needed. Building an AI team, for example, required political willpower. Showcasing the potential benefits of using AI for specific tasks to accelerate climate action helped get political leadership on board. And the implementation of AI-for-climate can be described as an opportunity for a city's leadership to shape AI development and fulfill multiple priorities at once (Table 5). For example, a Data Scientist working in the city of Vienna's leadership (J) highlights that *"the municipal directorate [is] very strong, is itself talking about some initiatives such as the AI strategy or working groups to look at the topic [sic]"*.

3.3. Plural roles and arrangements for implementing AI-for-climate projects

We identified seven roles for city administrations, across the different departments that are involved in implementing AI-for-climate projects (Table 7): 'Co-creator', 'data owner and authorizing body', 'developer', 'domain expert', 'enabler of innovation', 'regulator', and 'user'. Interviewees shared that multiple departments from the same administration can simultaneously take on several roles in one (or multiple) project(s). For example, they can grant access to data or approve the use of AI in the city ('data owner and authorizing body'), or work on technical tasks related to AI models, such as their integration into existing systems ('co-creator'). City administrations also work on enabling AI innovation by providing means to start-ups to test prototypes.

Interviewees described the implementation of AI-for-climate as a nascent, experimental space in which city administrations collaborate internally and externally with research, the private sector, civil society, and other governmental entities to implement pilot projects. Our results did not show collaboration with residents or any big tech firms — referring to the largest IT companies in the world [42]. Three of the six projects in the selected cities received funding through the EU project 'AI4Cities' (Helsinki, Copenhagen, Meudon). The scope of implementation is small, with pilot projects typically lasting between a few months to a few years, testing an off-market approach that is applied at a small scale with multiple rounds of iteration. Interviewees explained that in current pilot projects (Table 4) they understand the impact on GHG emission reduction equal to the reduction of energy consumption or vehicle mileage. In some cases, interviewees were able to share quantified impact, such as a 20% reduction in energy use (Amsterdam), and a 2% reduction in traffic emissions (Meudon, Greater Paris).

We identified three implementation arrangements: 'Frontrunner', 'Partner-reliant', and 'Nascent' (Fig. 2). They were distinct in their role and AI capacity of city administrations, key collaborators (Fig. 1), challenges, and solutions for implementation. We defined them without hierarchy and described them as simplified stereotypes, assuming variations to occur. Circumstances may inform which arrangement is most suited for implementing AI-for-climate projects; at times, it may be with the 'Frontrunner' and on other occasions with the 'Partner-reliant' or the 'Nascent' arrangement.

In the 'Frontrunner' arrangement, the city administration was the driving force for the project. With high AI literacy among city staff, for example, in the city's AI team, the administration coordinates the project and is in charge of identifying relevant use cases. The implementation of the project relied on the city administration's existing IT infrastructure (hardware and software) and AI governance. Examples of the latter included an AI registry (City of Amsterdam), or a set of principles around the use of AI with a guidebook for staff (City of Vienna). The city's political leadership decided to invest in AI deployment by funding an AI team and putting it in charge of initiating and coordinating, for instance, AI-for-climate projects. The city's AI team was well-connected with relevant actors and collaborated with the climate team and domain experts. Selectively, the city administration collaborated with external experts, such as scientists or consultants. High AI literacy enabled the city administration to be both the developer and the user of the AI technology. The AI team developed AI

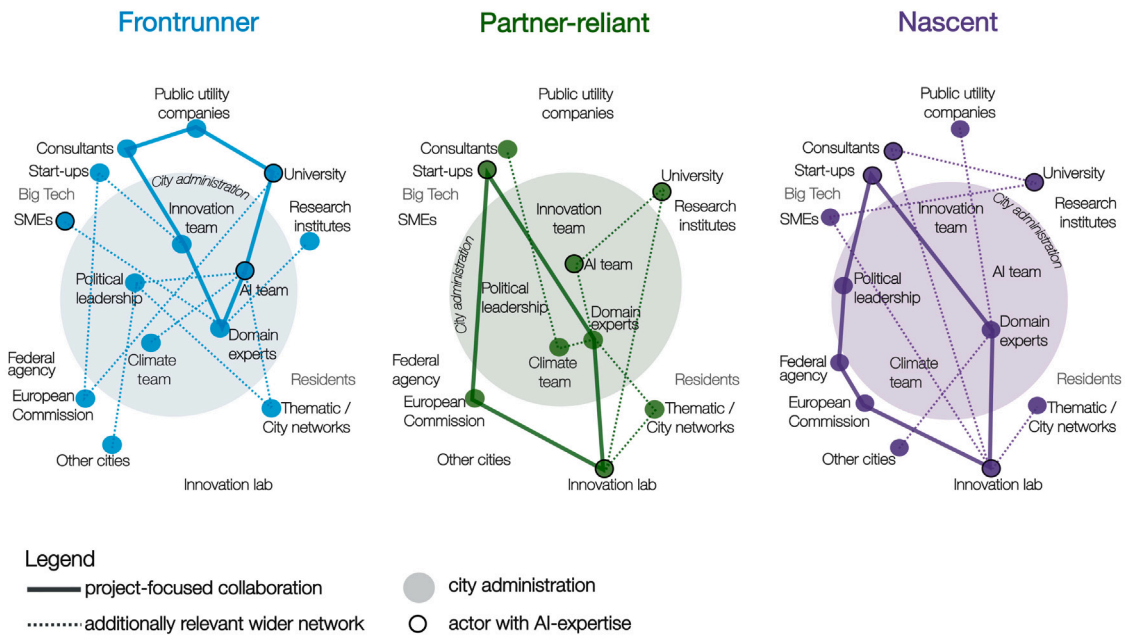

Fig. 1. Collaborators across three arrangements for the implementation of AI in climate change mitigation based on interviews and project documentation. In 'Frontrunner', the city administration is the key driver for internal and external collaboration. In 'Partner-reliant', a start-up or an innovation lab is creating a collaboration with the city administration. In 'Nascent', non-administrative actors collaborate, occasionally with the city administration. The lines indicate collaborations specific to projects (Table 4) and the dotted connections capture collaboration between relevant actors more broadly. Abbreviation: SMEs: Small-Medium Enterprises.

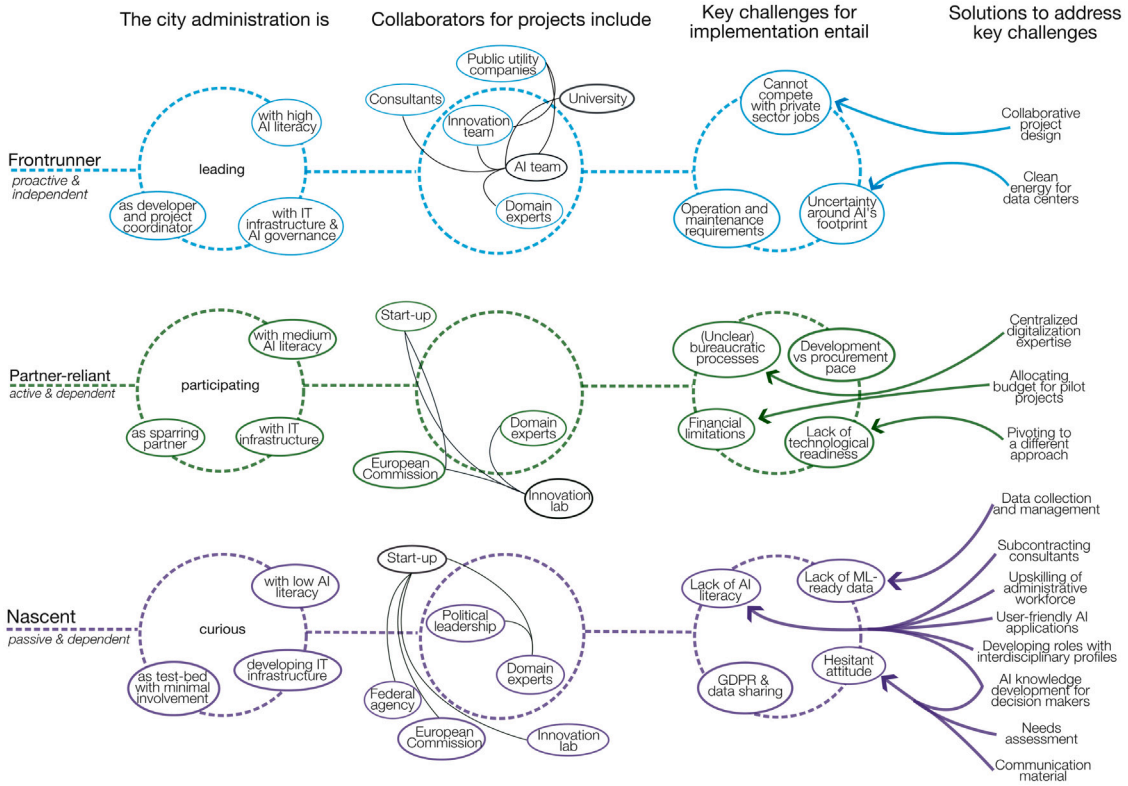

Fig. 2. Three AI project implementation arrangements for city administrations in the context of urban climate change mitigation. For collaborators, we provide more depth in Fig. 1, and for challenges and solutions in Supplementary Information G Table 1. Notably, different projects in one city can be characterized by different implementation arrangements.

models with the ambition to scale them, for example, within the public building portfolio, public vehicle fleet, or utility operations. The city administration is active in localizing AI regulation (Table 7). Implementing projects with this arrangement may have been challenging because of difficulties in attracting or keeping AI staff talent due to difficulty competing with the (financial) conditions of private sector jobs. Yet, creating longer-term collaboration for multiple AI projects between partners, such as researchers and the city administration, may be a solution. Once deployed, implementation at scale was challenged due to the operation and maintenance work, which requires additional IT infrastructure, expertise, and capacity among city staff. Examples for this implementation arrangement from our sampled projects were the 'Urban Detection Kit' in Amsterdam and 'BRISE' in Vienna.

In the 'Partner-reliant' arrangement, collaboration between the innovation lab and domain experts was central to project implementation. The innovation lab may facilitate the initiation of a project or identify new technology for testing, and the domain experts contribute with city-specific expertise, such as on local mobility or energy consumption. As partners, they then identified additional collaborators and external funding, for example, from the Horizon Europe programs. In some instances, the city may have created an AI team or hired individuals with AI expertise, but their work is not well-connected to relevant internal teams, for instance, the climate team. Instead, the AI expertise in this collaboration is external and situated with start-ups, the university, or the innovation lab. The city administration was a co-creator throughout the project and the authorizing body, giving access to data that external partners may want to use. Projects were designed to test a prototype for a new AI-for-climate product or service based on collaboration between public and private sector entities, as well as exchanges between cities. This implementation arrangement faced a few key challenges, such as (unclear) bureaucratic processes, which could be partly remedied by centralizing the digitalization expertise within the city administration, as suggested by interviewees. As a result, staff members and external partners would have had clarity about, for example, who to contact for AI-related projects. Testing a prototype may also enable the city administration to realize that there is a lack of market-ready AI applications for public sector needs, leading to discontinuing the project for the time being. Our sample comprised two project examples for this implementation arrangement – 'SPIKE' in Copenhagen and 'BEE System' in Helsinki.

Under the 'Nascent' arrangement, non-administration actors collaboratively drove the implementation of AI projects, especially private sector actors. Dedicated funding, for example, from EU programs, enables SMEs, start-ups, and consultants to initiate AI applications with the innovation lab, who reach out to city staff, for example, for prototype testing. Collaboration between actors was facilitated by the innovation lab. Political leadership is supportive of experimenting with the deployment of AI to tackle urban issues. Here, the city administration was new to AI innovation and interested in eventually becoming a user of AI applications, contracting products, and services from the private sector. Typically, the focus of the project lay on prototype testing, enabling solution providers to improve their model and for the city administration to learn about AI and key deployment challenges. The projects in this implementation arrangement faced fundamental technical and knowledge-related challenges. For instance, the city administration often lacked AI-ready data, struggled with low or no AI literacy among city staff who did not know how to remedy concerns around GDPR and data sharing. Examples of the 'Nascent' arrangement included 'Quantified trees' in Berlin and 'Ix3' in Meudon, Greater Paris.

4. Discussion and conclusion

In the following, we discuss how cities navigate potentially conflicting priorities and enable the implementation of AI-for-climate in practice. We highlight the need for sufficient resources, socio-technical interoperability, and market-readiness for the implementation of projects to advance. Further, we critically reflect on key collaborators and the absence of residents and big tech firms. To reduce implementation challenges, we point to the core issues induced by the current mode of experimentation. Finally, we share implications for city administrations and four avenues for future research.

4.1. Priorities beyond climate change enable implementation of AI-for-climate projects

Our results show that city administrations are motivated to deploy AI-for-climate applications because they can accelerate climate action and reduce costs at the same time. Alongside rising energy prices, prevailing austerity tightens cities' budgets [43]. Approaches that can increase energy efficiency, or enable energy savings, and reduce public spending are of high interest to city administrations. However, careful balancing between the priorities is required to ensure the potential for cost reduction does not outweigh the importance of CO_2 reduction. If working with the private sector, public procurement processes may enable a helpful approach for securing effective contributions to mitigation. For example, cities in the EU-funded AI4Cities project experimented with operationalizing the importance of CO_2 emission reduction through public procurement criteria. Specifically, the cities built the award criteria in a way so that the CO_2 emission reduction potential had the highest overall weight, with 19%, compared to price, which was weighted around 10%. We see a need for future research to evaluate processes or approaches city administrations can leverage to ensure CO_2 emission reduction is placed at the center of AI deployment.

Our study shows that opportunities to receive more information, make better decisions, and showcase innovative approaches also lead city administrations to use AI-for-climate applications. Deploying AI in ways that provide city staff with insights they would not detect on their own may add value. For example, better or more fine-grained information about, for instance, a neighborhood, can provide crucial insights for planning of cycling infrastructure [44]. Oftentimes, however, better decision-making for climate action is hindered due to a lack of willingness, induced by prevailing neoliberal thinking, to tackle the root causes of climate change [16,19,45–48] – not because of a lack of information. Similarly, experimenting with AI to showcase an innovative image of the city administration can easily overrule effective climate change mitigation approaches [49,50]. This may also be a symptom of blame avoidance, meaning city administrations prioritize appearing to do something rather than to do nothing [51]. To reconcile conflicting priorities, city administrations may benefit from responsible AI governance. The AI strategy of the city of Vienna provides an example (https://www.wien.gv.at/spezial/ki-strategie/). In the strategy, the city outlines digital innovation not as an end in itself, but places human needs, which include sustainability, at the core. As a result, city staff can implement AI-for-climate projects based on guiding principles for responsible innovation. To address any ethical concerns, the city of Amsterdam created several instruments to enable trustworthy AI, such as ethical contract clauses. These apply whenever the city purchases algorithms from external companies and encompass information on technical, procedural transparency, and explainability. The city of Helsinki has established eight ethical principles that apply to all AI applications, for instance, people-centredness, privacy, fairness, and equality. Jointly, Amsterdam and Helsinki created an online AI registry that introduces the public to all the algorithms used in the cities. These examples demonstrate the potential for European city administrations to play an active role in steering responsible AI deployment.

4.2. Implementing AI-for-climate projects in cities requires resources, socio-technical interoperability, and market-readiness

Our study foregrounds a nuanced understanding of city administrations' agency in shaping AI deployment. We detect additional roles for city administrations next to those mentioned in previous

studies, for instance, 'regulator' and 'user' [7]. Our results suggest that city administrations actively engage in creating and deploying AI applications, which aligns with research on urban climate action more broadly, where the city administrations' role has been described as multi-faceted, too. For example, roles can entail facilitator and coordinator of actions [48], manager of buildings and infrastructure, and regulator through urban planning [52]. Some roles that we identified for the city administration require a relatively high budget, AI literacy, and innovation capacity, for example, 'developer', 'co-creator', or 'enabler of innovation'. All six cities in our sample are capital cities, located in high-income and innovation-strong regions [53]. While in our sample, all cities assumed multiple roles, we hypothesize that less affluent city administrations may not have the capacity to choose freely between their roles and implementation arrangements. For example, cities located in low-income EU regions tend to engage with technologies that are simple to learn [54], whereas more complex economic activities, such as AI innovation, concentrate in large, affluent cities [55].

Our findings indicate that a lack of socio-technical interoperability with existing digital systems in physical infrastructure and a lack of technological and market readiness hinder city administrations from procuring scalable AI-for-climate applications from private companies. Instead, city administrations often need to develop their own AI application, which leads to taking on several roles simultaneously. For example, the city-internal climate team, in the role of the prospective 'user', approaches the internal AI team to be the 'developer' of an AI system. Together with a relevant 'domain expert' – a staff member with specific expertise on, for instance, energy systems of public buildings — the climate team and the AI team co-create the AI-for-climate application. This suggests that city administrations need to take on multiple roles to navigate the experimental, emerging space of urban AI-for-climate. The interdisciplinary nature of this space also requires new connections between potentially disparate departments in the administration. Fostering horizontal collaboration, however, is a challenge that can only be resolved by changing the management of public administrations in general [56].

4.3. Implementation of AI-for-climate in European cities relies on the EU Commission, but not on big tech

Our study emphasizes that collaboration with external partnerships is essential for the implementation of AI-for-climate projects. This finding aligns with the importance of collaboration for fruitful climate action, through formats such as science-policy-practice partnerships [57]. The European Commission is a key collaborator by providing seed funding for AI-for-climate projects, indicating a strategic connection to the realization of the twin transitions agenda [33] and Cohesion Policy objectives (https://ec.europa.eu/regional_policy/policy/what/investment-policy_en). However, EU funding for high-tech projects reproduces existing regional inequalities of technological capabilities [53], leading to already advanced regions benefiting economically [54]. Creating a spatial concentration of AI innovation in a few European cities and regions may support the EU's competitiveness with the USA and China [54]. While this may apply to exporting AI-based products and services, it is a major limitation for using AI in urban climate change mitigation. If only a few, affluent, well-staffed, and AI-literate city administrations engage with AI-for-climate, deployment will remain slow, unevenly distributed, and with a limited impact on mitigation overall. Implementation of urban AI-for-climate projects may provide an opportunity to iterate on EU twin-transition strategies and funding mechanisms, closing the gap between conceptual and operational coherence [58].

The EU Commission and city administrations are not the only ones exploring AI-for-climate projects. Big tech firms have identified AI-for-climate as a business opportunity, initiating and operating projects on their terms [59]. However, we did not identify big tech as a key collaborator for project implementation, that is, big tech firms were neither involved as consultants nor as developers. This is a surprising finding given the dominant role big tech plays in developing and deploying AI tools [60]. We hypothesize that big tech firms may not (yet) collaborate with city administrations in this area because of low profit margins and long administrative processes. Urban AI-for-climate applications are just emerging. They require plenty of iteration for each context and are susceptible to slow public procurement processes. Across the EU, for all public procurement, on average, the duration of the decision-making period until contract award has increased from 63 days in 2011 to 95 days in 2021 [61]. Such conditions are unattractive for firms with already established AI products and services [62], and involvement in the rapid pace of AI development [63]. City administrations aiming for independence from big tech (for instance, Amsterdam or Copenhagen) may interpret big tech's absence from the implementation of small-scale pilot projects as proof of concept. Our findings show that independent implementation of AI-for-climate projects is possible under the 'Frontrunner' implementation arrangement. This, however, requires additional resources, for instance, high AI literacy, IT infrastructure, and AI governance, as well as collaboration within and beyond the city administration. Many cities need to resolve bottlenecks beforehand, such as securing support from political leadership for digital self-determination or improving data collection first. This finding may look different for projects deployed at a large spatial scale and across cities, for which big tech's technical, financial, and personnel capacities may be vital. For example, in 2022, the city of Meudon, Greater Paris, together with a start-up, tested the use of AI for traffic management via automated traffic light control (Table 4). The pilot project focused on one intersection for a couple of months with the intention to scale the approach to more intersections and other cities, yet was discontinued due to socio-technical incompatibility, security concerns, and lack of funding. In 2024, Google started to test a similar product, and scaled it to a global research project on multiple cities by mid-2025 (https://sites.research.google/gr/greenlight/). Who is involved in urban projects matters, within and beyond the AI-for-climate context, because it influences who establishes or maintains power and control in a city, for example, changing mobility options or communication infrastructure [64]. Previous studies have detected big tech's involvement in the urban sphere [65,66], and criticized the growing dependency on their cloud infrastructure [60], introducing further financialization of urban life [62], and rolling out infrastructure programs or services that place profit over the well-being of people [67]. The production of (digital) urban infrastructure with deployment of AI applications must be understood together with actors' financial, engineering, and governance practices, which are embedded in contemporary capitalism's power relations [68].

4.4. Experimentation is not enough to resolve implementation challenges

Implementation challenges cannot be overcome in a setting of permanent experimentation [69]. City administrations need substantial funding and foundational infrastructure to establish AI governance, maintain extensive databases on well-managed data portals, and nurture connections to relevant collaborators, such as the innovation lab or a local university. The challenge of data protection and sharing requires not a one-off solution but a revised data governance approach from city administrations in line with trustworthy AI as defined in the EU AI Act [70,71]. Specifically, creating AI governance that complies with bureaucratic processes or designing new sets of procedural steps that take into account aspects such as fairness, or data protection [21], calls for long-term effort and resources [72].

Our results demonstrate that creating AI literacy among decision-makers and across teams, for instance, the innovation team and climate team, is vital for the implementation of AI-for-climate. Upskilling city

staff across departments, who will have the ability to connect a climate project to an AI solution, requires a large-scale and long-lasting effort independent of single experiments. We also detected that city staff have misconceptions about the environmental impact of AI. In particular, since the large footprint of large language models is a known concern [73], the direct footprint of AI can present a perceived barrier, although such large models are less relevant in the climate context [41]. A continued lack of AI literacy in municipal governments risks sustaining such misconceptions, which, in turn, make it difficult to justify potentially high investment costs — fundamentally challenging the implementation of AI-for-climate. Upskilling formats are an opportunity for staff to resolve perceived barriers to AI deployment and to learn about AI-for-climate beyond individual experiments.

Our findings show that creating better services for residents was a key motivation for city administrations to use AI-for-climate applications, yet none of the projects included forms of public participation. The current lack of AI literacy may have limited city staff's capacity to engage or facilitate in-depth dialogue around the use of AI with residents. Successful public participation not only depends on organizational structures or cultural aspects but also availability of resources, including staff with sufficient knowledge on the given topic [74]. The absence of residents in AI pilot projects is concerning because genuine opportunities for civil society to participate can help to align project goals with the actual needs of residents [75,76]. Whether and how residents are being involved in the implementation of AI-for-climate projects is a question of AI governance [76]. Vienna, Amsterdam, and Helsinki, for example, deploy AI-for-climate projects and are committed to ethical AI principles. Looking ahead, it will be vital for city administrations to operationalize such principles at the project level and to integrate the topic of AI into existing fora of public participation for climate action.

4.5. Implications for city administrations

Our analysis of practitioners' experiences reveals that city administrations can pave the way for AI-for-climate in cities — provided they are well-prepared. City administrations that lead in climate action and are technologically advanced experiment with AI-for-climate through different arrangements to test feasibility. However, based on our study, we cannot yet determine which AI applications are effective for climate change mitigation. At the time of research, few AI-for-climate projects emerged, often as pilot projects with seldom quantified GHG emission reduction, limiting the generalizability of findings. At this early stage, city administrations face multi-faceted challenges for implementation, suggesting that AI-for-climate demands continued testing, careful weighing of costs and benefits, and good practice examples. Based on our study, we suggest the following three points to city administrations working on AI-for-climate projects.

Upskill city staff and establish positions for AI-for-climate. Establish AI training programs for different staff members. Such training should enable staff to determine whether AI is needed to solve a climate problem, to learn about environmental and ethical issues, and how to navigate those in the city's context. Expand or create designated positions among staff that are responsible for identifying, shaping, and managing AI applications in service of the city's policy goals. Integrate the topic of AI into fora of public participation.

Be precise on the purpose and the reasons for using AI. For each project, create a clear understanding of the problem, the objective, and the reasons for using AI compared to other analytical approaches. Keep track of available and accessible datasets to determine if they fit the purpose or if other data is required.

Experiment and ensure that AI systems can be maintained before scaling. Allocate budget and personnel for experimentation and the maintenance of AI systems. Build partnerships with local research institutions and innovation labs for experimentation. Build on lessons learned, with emphasis on how to build and maintain ethical AI-for-climate applications at scale.

4.6. Four avenues for future research

We suggest that researchers interested in the implementation of AI for climate focus on the following four avenues.

Analyze the implementation of AI-for-climate in other world regions. Apply a similar study design in other socio-political contexts and investigate AI applications that have been deployed at scale. The actor constellations may look different, for instance, with big tech firms directly involved. Then, comparing and contrasting at the level of implementation arrangements potentially reveals additional sets of challenges and insights for the applicability of AI-for-climate across contexts.

Contribute to responsible AI governance. Develop tools and guidance that can help practitioners build responsible AI governance, including addressing environmental impact and ethical issues. Disseminate research findings in formats that are accessible to city administrations.

Include perspectives from social sciences. Conducting studies on the topic through lenses of political geography and STS may allow further understanding of narratives, collaboration dynamics, and vested interest among actors involved in the implementation of AI-for-climate in cities.

Focus on climate change adaptation. Investigate the implementation of AI-for-climate in adaptation contexts, for instance, disaster response. Likely, implementation arrangements with linked challenges will look different, adding to the experiences on the practical implementation of AI-for-climate.

CRediT authorship contribution statement

Marie Josefine Hintz: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Milena Gross:** Writing – review & editing, Methodology, Formal analysis. **Felix Creutzig:** Writing – review & editing, Supervision, Conceptualization. **Lynn H. Kaack:** Writing – review & editing, Supervision, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.erss.2025.104498.

Data availability

The data that has been used is confidential.

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