European urban strategic initiatives involving emerging technologies for addressing climate change

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Abstract. In the contemporary era, climate change (CC) has become a defining challenge and a wicked problem for society, particularly in urban areas, due to their direct experience of the impacts of climate variability and extreme events. This has led to a heightened focus on the strategic planning processes, which are now under pressure to develop long-term strategies and investments for CC adaptation at the local level. This includes the implementation of effective measures and smart initiatives to address CC. In this context, smart cities (SCs) are progressively adopting emerging technologies (ETs) that hold the promise of enhancing urban resilience. Nonetheless, this implementation should be grounded in the strategic smart initiatives previously delineated in the strategic document of these cities, a domain that has remained largely unexplored. Thus, the present study aims to examine how a sample of European SCs are planning strategic actions to address the CC challenge through the design and execution of smart initiatives. Particularly, we focus on the analysis of governance issues -the leadership of the smart initiatives (RQ1) and the departments involved (RQ2)-, the smart dimensions involved in the strategic actions (RQ3) and, finally, the use of ETs (RQ4) in the different CC adaptation actions planned. The findings indicate fragmented governance, weak interdepartmental coordination, and minimal involvement. While some municipalities have dedicated sustainability departments, many initiatives lack centralized management. Although big data and AI play a key role in decision-making, the adoption of advanced technologies remains limited.

Keywords. Climate Change, Emerging Technologies, Strategic Planning, Smart Cities.
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1. Introduction

In the contemporary era, climate change (CC) has become a defining challenge and a wicked problem for society, characterised by its multidimensional and substantial impacts on environmental, social and economic spheres at different spatial scales (international, national, regional and local contexts) -OECD, 2024a-. However, despite intense discussions on CC in the global arena and the urgent measures designed by governments and international bodies to address this challenge, no tangible results have yet been achieved in terms of mitigation and adaptation

mechanisms to address CC (OECD, 2024a).

International organisations point out that effective policymaking for CC adaptation requires measurable objectives, whole-of-government coordination, stakeholder engagement, sufficient funding and robust mechanisms to monitor progress and evaluate the effectiveness of policies (OECD, 2024a). Previous research has also highlighted that the ability to implement CC goals and policies in practice is largely determined by the robustness of institutions -e.g. strategic plans, policies- and systems -e.g. infrastructure, ecosystems- (Birchall and Bonnet, 2021). This has put considerable pressure on strategic planning processes to develop long-term strategies and investments for CC adaptation at the local level, including effective measures and smart initiatives to address CC (Bera and Lewicki, 2023).

Although it is acknowledged both that confronting CC necessitates the coordination and alignment of public policies across different administration levels and the important constraints faced by local government in their efforts to enhance climate resilience -including technical, financial and legal capacity issues (OECD, 2023a)-, the impacts of climate stressors manifest at local scales, underscoring the imperative for effective adaptation strategies to be tailored to the specific characteristics of the local context (IPCC, 2018). Indeed, local governments are critical for CC adaptation implementation (OECD, 2024a) and bear primary responsibility for important adaptation policy areas such as the delivery and operation of key infrastructure (OECD, 2024b) or the setting of regulatory functions (such as land-use planning, project permitting and standard setting) that can build climate resilience -OECD, 2024b-).

Local-level governments thus become central actors in fostering resilience through effective CC adaptation (Shi, 2019; Bonnett and Birchall, 2023), given their unique position to lead on CC adaptation actions due to their direct experience with the impacts of climate variability and climate extreme events as well as their understanding of the needs for locally tailored solutions (OECD, 2023a). So, a "place-based" approach to understanding and addressing local differences is essential for developing effective adaptation strategies that can mitigate climate change impacts and enhance resilience in communities (OECD, 2023a; OECD, 2023b).

In this regard, the available evidence suggests that strategies for cities should be developed at the metropolitan (functional urban area) level (OECD, 2024a). However, recent research has revealed that Australian and European cities usually have a low-quality adaptation plan for CC (Reckien et al., 2023) and limited number and low integration of CC adaptation and mitigation actions in urban planning documents (Hurlimann et al., 2021). This evidence could be the result of the limited financial resources that cities own, particularly in the most vulnerable communities and regions, which has compounded disparities in CC adaptation efforts (OECD, 2023a; OECD, 2023b).

As larger local authorities possess greater financial resources and technical infrastructure, they have developed dedicated adaptation plans and strategies to mainstream climate resilience across all locally led functions, often complemented by targeted plans to address specific risks (OECD, 2023a). Furthermore, it can be argued that the 'shock' of CC and its local and regional impacts is creating the conditions for greater innovation at urban and regional scales (Sancino et al., 2022). In this context, the rapid advancement of information and communication technologies (ICTs) has led to the increasing application of technologies in the urban context for the development of forward-looking plans for reducing vulnerability and disaster threats (Kuo and Li, 2022) particularly in the so-called 'smart cities' (SCs) due to their intense use of ICTs in the urban space, advanced governance models and the pursuit of sustainability goals (Su and Fan, 2023). Special attention should be paid to emerging technologies (ETs) in SC which have the potential to assist these cities in achieving resilience (Grovert et al., 2022). The aforementioned reasons provide a robust foundation for the focus on SCs as a fertile ground for research, despite the fact that they have been extensively explored (Butler et al., 2021).

Therefore, the present study aims to examine how a sample of European SCs are planning strategic actions to address the CC challenge through the design and execution of smart initiatives. Particularly, we focus on the analysis of governance issues -the leadership of the smart initiatives (RQ1) and the departments involved (RQ2)-, the smart dimensions involved in the strategic actions (RQ3) and, finally, the use of ETs (RQ4) in the different CC adaptation actions planned.

Recent research has indicated that sufficient resources do not guarantee effective adaptation planning in practice, because governments also face distinct adaptation barriers resulting from governance structure (Birchall et al., 2023). Consequently, within the domain of contemporary urban governance literature, there is an increasing focus on the leadership of smart initiatives and the role of city climate leadership (Rapoport et al., 2019) within the broader urban governance framework (Beer et al., 2021; Sotarauta and Beer, 2021; McPherson and Clarke, 2024). Although leadership in Europe is characterised by its multidimensional and collaborative nature (Hofstad et al., 2022; Sancino et al., 2022), political and administrative leaders play a crucial role in the vision and strategy for CC adaptation, the horizontal and vertical coordination and in leveraging resources from local, regional, and national actors within a multilevel governance system (Meijerink and Stiller, 2013; Hanssen and Tønnesen, 2022). This is

also relevant at the implementation stage in order to better coordinate actions and ensure long-term commitment to allocate resources to sustain actions (Vignola et al., 2017). Therefore, administrative leadership plays a pivotal role in steering climate policy initiatives (McPherson and Clarke, 2024).

Nonetheless, while sustainability appears to be evident in the SC fabric, it is influenced by both institutionalised and non-institutionalised factors, with perhaps most noteworthy factor being the unpredictability of the people and departments that eventually assume leadership in the smart initiatives (Haarstad and Wathne, 2019). Nonetheless, whether local governments are being structured for leading CC smart initiatives, as delineated in strategic documents, and the areas which lead these initiatives is an important and under-explored question. Therefore, the following research question is derived: RQ1. Do SCs have a department to lead all the smart city initiatives on sustainability or resilience or are they led by different departments according to the goals pursuit by the smart initiatives?

On another hand, the management of CC impacts constitutes a multifaceted and interdisciplinary domain, necessitating the integration of CC initiatives across various sectors and collaboration between diverse actors and departments within the strategic planning process (Theodora and Stratigea, 2021) to enhance preparedness for climate-related challenges (Bera and Lewicki, 2023). Furthermore, the organisational facet of the SC agenda entails the promotion of an integrated approach towards urban planning, the dissolution of silos, the transcendence of barriers, and the adoption of dynamic and reflexive methodologies to address various urban challenges. The interconnection of services, management and organisation is therefore a vital aspect of the SC agenda (Haarstad and Wathne, 2019).

Nonetheless, empirical evidence has revealed that many smart initiatives were designed to solve a specific problem handled by a specific department and current problems resulting in the development of short-sighted plans and initiatives (Kuo and Li, 2022). This approach hinders the capacity of cities to undergo CC adaptation in an effective manner. Consequently, the second research question of our study is as follows: RQ2. Which departments of the city are involved in the strategic planning processes of the smart initiatives related to CC strategic actions?

In addition, the interaction between technology and nature can be enhanced when a SC approach promotes the integration of climate strategies. Recent research has revealed that smart initiatives promoted by governments have been addressed to multiple smart dimensions (Kuo and Li, 2022), with those addressing the enhancement of smart living being the most prevalent, followed by smart mobility and smart data (Masrur and Sharifi, 2022). However, despite the relevance claimed by prior research concerning the implementation of ET for urban resilience in SCs, the sustainability aspect is not always prioritised in these initiatives. Indeed, the initiatives addressed to the smart environment dimension which takes a wider approach and relates more to climate action in the form of adaptation to CC are not always in the equation (García Fernández and Peek, 2020).

Conversely, when smart initiatives are spearheaded by experts or vendors in the private sector, their primary focus is on economic outcomes, leading to initiatives in domains such as mobility, energy, and heating (Fekete, 2022). While sustainability is often a central tenet of these initiatives, its role in adaptation also remains marginal (Fekete, 2022). In light of these observations, the third research question is thus posed to ascertain the smart dimensions that are present in the smart initiatives related to CC strategic actions in the sample cities of this research. The following question is thus derived: RQ3. In which smart dimensions are European SCs performing strategic actions to face CC?

Finally, local governments must adopt innovative technologies to facilitate the planning and management of activities aimed at CC mitigation and adaptation. This is necessary to enable adaptation solutions and provide a foundation for their implementation (Pancewicz, 2021). In this regard, the advancement of ETs and SCs are bringing new opportunities for innovation in climate mitigation at both the local and global levels, even when projects address only a small number of resilience characteristics (Grovert et al., 2022; McPherson and Clarke, 2024).

Nonetheless, prior research indicates that sustainability measures in SCs are seldom driven by advanced technology, despite the SC agenda being centred on such innovations (Haarstad and Wathne, 2019; Kuo and Li, 2022). Only recent research has detected a change in this trend, thereby identifying intensive efforts aimed at addressing the CC with the integration of innovative solutions based on AI, IoT, and Big Data (Bibri et al., 2023). Consequently, environmentally sustainable SCs have emerged as a rapidly expanding trend, exhibiting a marked escalation from 2016 to 2021, largely attributable to the advent of the pandemic and the rapid advancement of data-driven technologies (Bibri et al., 2023). Within this context, the fourth research question guiding this study is as follows: RQ4. Which ETs are being used for facing the CC challenge into the urban context? And how are the ETs used in the different smart dimensions?

2. Data and Research Methods

Citizens are increasingly concerned about the effects their actions have on the environment, as these impacts directly affect their quality of life. As awareness grows, the need to address climate changes becomes even more pressing (Wang and Zhou, 2023; Masrur and Sharifi, 2022). The implementation of new technologies is no longer sufficient to improve citizens' lives, emerging technologies are increasingly gaining more presence. In fact, they are explicitly playing a crucial role in the fight against climate change, as the integration of these technologies not only optimizes urban resources but also fosters the creation of more sustainable urban environments (Theodora and Stratigea, 2021; Kuo and Li, 2022; Yukhno, 2024; Zhen et al., 2024). So, it is essential to understand how smart cities are incorporating these technological innovations into their strategies and how these initiatives contribute to mitigating the impact of climate change.

With this objective in mind, this study focuses on analysing how the leading European smart cities develop environmental strategies to reduce the effects of climate change, leveraging the potential of emerging technologies. The process of data collection occurred in two phases. The first phase involved identifying the European cities recognized as "smart cities" across a series of prominent international rankings such as: Euro Smart Cities 2024/2025, Cities in Motion 2022, Easy Park IMD and Innovation Cities. These rankings are considered global benchmarks in assessing cities' ability to integrate emerging technologies, manage urban resources efficiently, and promote sustainability (Toh, 2022). To ensure a representative sample, cities that appeared in all these rankings were chosen, reflecting their established leadership in the field of smart cities.

In total, 25 European cities meeting these criteria were selected: Vienna, Brussels, Tallin, Helsinki, Lyon, Paris, Berlin, Hamburg, Munich, Dublin, Milan, Amsterdam, Rotterdam, Bratislava, Madrid, Barcelona, Bilbao, Gothenburg, Stockholm, Geneva, Zurich, Prague, Copenhagen, Rome, and Manchester. These cities were selected for their prominent position in the aforementioned rankings and their focus on strategic projects aimed at mitigating climate change.

Once the European cities were identified, the authors defined criteria for selecting the resilience and climate change strategy documents of these cities, drawing upon the framework proposed by Yigicanlar (2018). In this sense, the selection of these documents was: (1) the document must be officially issued or endorsed by the local government of the selected city; (2) it must explicitly address CC adaptation and/or urban resilience as a key strategic objective; (3) it must refer to the integration of emerging technologies within their strategic actions; (4) the document must be publicly available through the official website of the city; and (5) the strategy document must be a full report rather than an executive summary or highlights; (6) the publication date must fall within the period from 2015-2024 to ensure currently and relevance to the contemporary planning context. This initiated the second phases, which was further divided into two sub-phases. Firstly, between October and November 2024, these documents were accessed through the official websites of the cities, and the data was collected and reviewed for the purpose of identifying the key initiatives, stakeholders, and strategies used to address urban climate challenges. Afterwards, the strategies were thoroughly examined, leading to a total of 1,439 cases of smart initiatives. These initiatives were classified based on the department in charge of the initiative, the smart city domain, the stakeholders involved, and the vision, objectives and strategies for mitigating the impact of climate change.

3. Analysis of results

Climate change represents one of the most pressing challenges of the 21st century, particularly in urban context where cities must develop effective strategies to mitigate its effects and enhance resilience. In this regard, smart cities have emerged as hubs of innovation, leveraging emerging technologies (ETs) to improve sustainability and climate governance (Gil-García et al., 2014; Valle-Cruz, 2019). Such technologies enable local administrations to optimize decision-making, coordinate multiple stakeholders, and enhance the efficiency of environmental policy adoption (Kalampokis et al., 2023). However, the effectiveness of these approaches largely depends on the presence of specified organizational structures and interdepartmental collaborations (Rodríguez Bolívar et al., 2020).

Next, the obtained results will be analysed to answer each of the previous described research questions, aiming to provide a comprehensive perspective on the degree of institutionalization of sustainability in European Smart Cities, the cross-sectional nature of their climate policies, and the role of ETs in the transformation of urban governance.

3.1 RQ1: Do smart cities have dedicated departments for sustainability or resilience management?

To assess if the department of Climate and Sustainability Protection leads the initiatives concerning sustainability issues in each European Smart Cities, we first analyse the entity that leads each initiative. In figure 1, we can observe that just 2 percent of the analysed European initiatives are not directly led by the municipal council.

Although collaboration with private companies and academia is highly promoted in European initiative, it seems that only 1 percent of them are led by a private company and leadership by research institutions is practically non-existent (0.35%).

A significant portion of European initiatives (66.16%) do not specify the leading entity, indicating the lack of transparency in project governance. Among the identified leaders, almost 6 percent of initiatives are led by a dedicated municipal department for sustainability or resilience, while a considerably higher percentage (26.27%) are managed by other municipal departments not specially focused on resilience or sustainability. This suggests that, although European Smart Cities have established specialized governance structure for climate action, a significant portion of the initiative address more specific aspect such as a sustainable mobility, building efficiency, urban infrastructure improvements, support for vulnerable groups and so on, which require the assignment of departments better equipped to handle these challenges. As a result, instead of being centrally managed by sustainability or resilience departments, these initiatives are integrated into broader municipal strategies through the relevant sectoral departments. This aligns with prior research highlighting the uneven institutionalization of sustainability governance across smart cities.

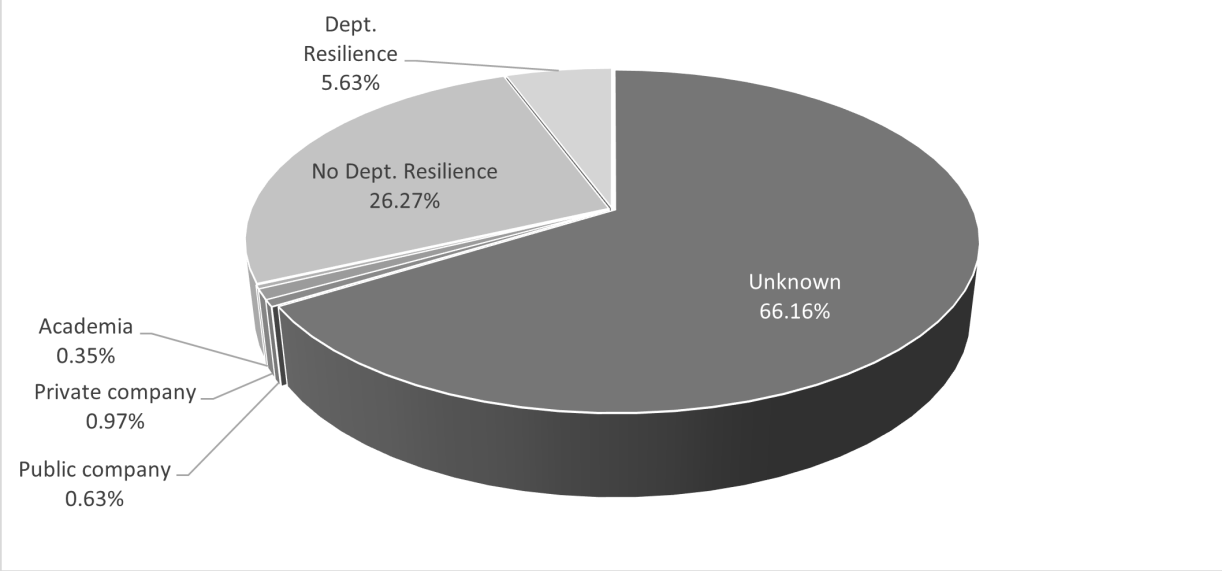

Fig 1 – Departments or Institutions leading European initiatives

Secondly, to further analyse the departments or institutions leading European initiatives, we will evaluate what happens in each of the smart dimensions. For this, the different initiatives have been categorized according to their specific goals based on the smart dimensions of Smart Cities established by Giffinger and Gudrun (2010). The results reveals that a significant portion of initiatives, particularly those related to living -quality life, cultural services, social cohesion and, safety and housing- lack specified leadership (almost 45 percent – see figure 2).

Regarding institutional leadership, public companies play a dominant role in mobility issues (87.5 percent). It may be due to the fact the public transport is generally not an attractive sector for private companies, as it is often not highly profitable. Nevertheless, their presence in other dimensions is minimal. In contrast, private companies emerge as main leaders in environmental initiatives (42.86 percent). It may suggest that these issues require the development and use of advanced technologies that are primarily created and managed by private companies, making their involvement essential in implementing innovative and technical solutions in this field.

Although research institutions play a limited role overall, their involvement in mobility issues (80%), highlighting their contribution to research, technological development, and innovation in transportation and ICT accessibility. However, their absence in other dimensions suggests that they are not primary actors in the direct governance of sustainable initiatives.

As for municipal leadership, sustainability or resilience department is predominant in environmental initiatives (39.51 percent), followed by governance and people initiatives (both 18.52 percent), likely due to their involvement in climate policies, transparency, citizen engagement, and education initiatives on sustainability. We can also observe that environmental initiatives (31.75%) are led by other departments (not sustainability or resilience), as well as living and mobility (both 18.52 percent), reinforcing the idea that each department oversees initiatives aligned with its area of expertise. Therefore, it confirms that European smart cities do not follow a unified governance model for sustainable initiatives.

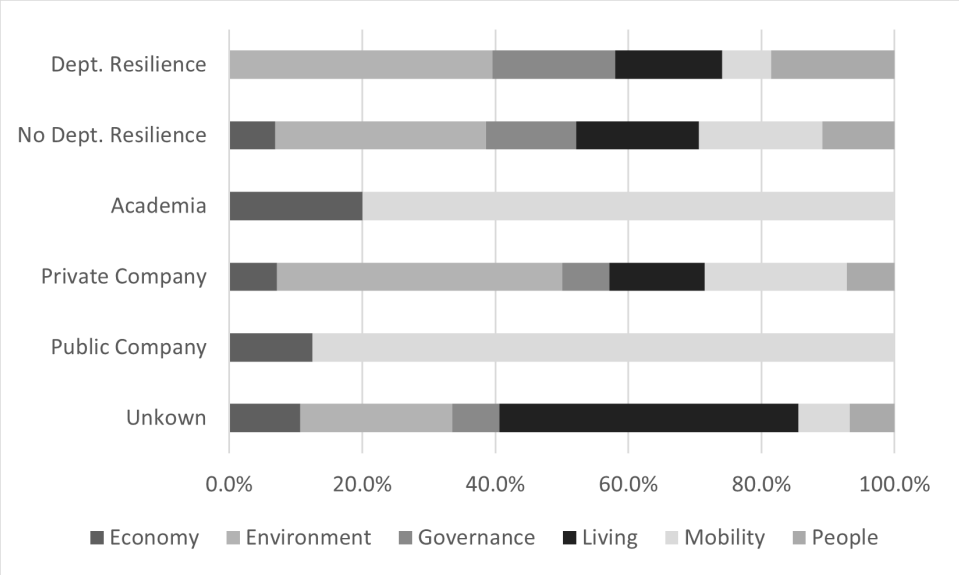

Fig 2 – Departments or Institutions leading European initiatives, depending to smart dimensions

3.2 RQ2. Which department of the city are involved into the strategic planning processes of the measure to protect sustainability and improve city resilience?

In figure 3, we can observe that the majority of European initiatives following a vertical approach, since 70.54 percent of projects being led by a single department. In contrast, just 29.7 percent of European initiative involve multiple departments (transversal approach). Although there is some level of interdepartmental coordination, it remains less common, despite its potential benefits in optimizing resources and creating synergies between different urban policies. The lower percentage of transversal collaboration may reflect structural challenges, such as the complexity of coordinating across departments, bureaucratic barriers, or the need for more integrated governance frameworks. These results align with previous literature, which highlight the difficulties cities face in establishing cross-departmental collaboration for smart initiatives, due to institutional silos, lack of communication channels, and the predominance of sectoral governance models (Liarte et al., 2024; Zhu et al., 2024; Alcaide Muñoz et al., 2023, Rodríguez Bolívar et al., 2023).

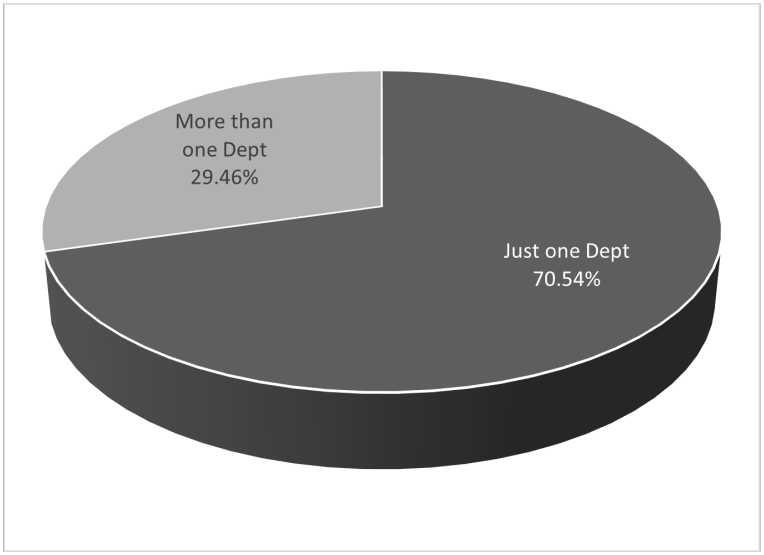

Fig 3 – Interdepartmental collaboration

The analysis provides further insight into how different smart dimensions are managed within vertical and transversal approaches in European smart cities. In this sense, the environment dimension is predominant managed through a vertical approach, that is, 30.35 percent of projects do not involve another department, while only 15.80 percent promote institutional collaboration. It reflects that environmental policies tend to be centralized within specialized municipal units, likely due to the technical expertise required for managing climate-related initiatives, sustainable resources use, and regulatory compliance. As a result, it can limit cross-

departmental synergies and interdisciplinary collaboration.

The living dimension exhibits the highest level of transversal governance (47.64 percent). It suggests that initiative related to urban well-being require coordination between housing, social affairs, urban planning and environmental departments to ensure a holistic approach to urban sustainability. Additionally, governance dimension also has a greater degree of interdepartmental collaboration (13.68 percent). This is aligned with previous studies suggesting that governance improvements, particularly in areas like transparency, citizen participation, and decision-making processes, often require multi-stakeholder coordination (Alcaide Muñoz et al., 2023, Rodríguez Bolívar et al., 2023). Finally, mobility, people and economy-related initiatives display a more balanced distribution between vertical and transversal governance models, with no significant disparities between the two approaches.

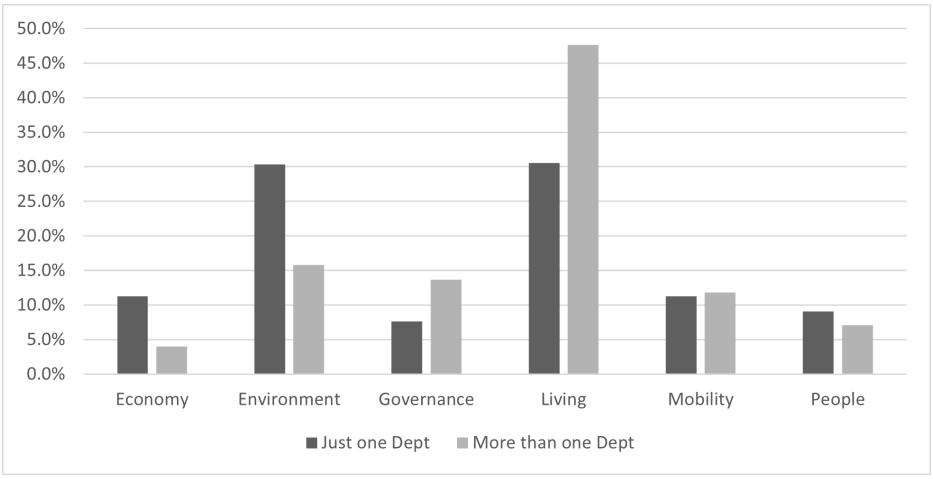

Fig 4 – Interdepartmental collaboration, depending to smart dimensions

To further explore the governance of sustainability initiatives, we will analyse the departments involved specifically in initiative directly focused on environmental issues (see figure 5). So, we can identify municipal departments that play a central role in environmental governance and how different sectors contribute to the implementation of sustainability policies within European smart cities. In this term, the department of Urban Planning and the department of Climate and Environmental Protection (28.18 percent and 23.02 percent, respectively) play the most significant roles, reflecting the importance of land use planning, infrastructure adaptation, and environmental regulation in addressing sustainability challenges. It suggests that urban planning initiatives are deeply integrated with environmental policies to ensure sustainable urban development.

Alongside these main departments, others contribute to environmental initiatives, revealing the interdisciplinary nature of sustainability efforts. There is a growing emphasis on technological solutions and digital engagement in environmental initiatives due to their involvement of the department of innovation and digital transformation and the department of digital governance and citizen participation (10.99 percent and 5.84 percent, respectively). This in line with previous research on the trend of cities to improve citizens' lives through the adoption of use of technology (Alcaide Muñoz et al., 2023; Wang and Zhou, 2023; Sari, 2023).

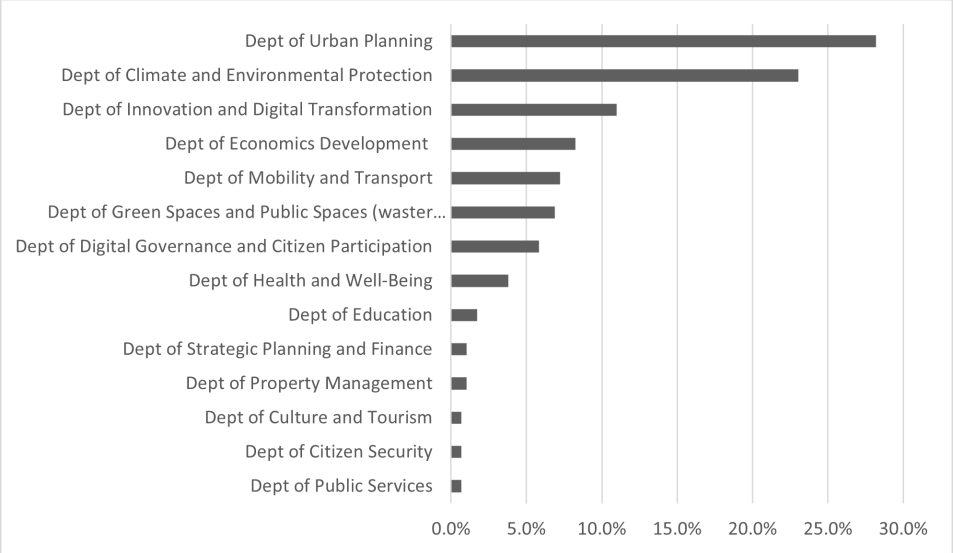

Fig 5 – Department involved in environmental initiatives

Another noteworthy aspect is the involvement of economics and mobility-related departments in environmental initiatives (8.25 percent and 7.21 percent, respectively), which reveals the significant link between environmental sustainability and both economic and mobility issues. Additionally, the existence of a broad scope of environmental initiatives in public health, green infrastructure and education programs issues is also revealed -the department of health and well-being with 3.78 percent, the department of green spaces and public services with 6.87 percent and the department of education with only 1.72 percent-. Nevertheless, the lower involvement of public services, culture and tourism, and citizen security departments (each below 1 percent) suggests their indirect role in climate change affairs.

3.3. RQ3. In which smart dimensions are European Smart Cities performing strategic actions to face climate change?

Figure 6 shows the key actions and thematic areas promoted by European smart cities in their efforts to tackle climate changes. So, we can determine which aspects of sustainability and resilience are being prioritized by such cities under study. It will provide insight into the specific themes and initiatives that are most significant to European smart cities, highlighting their approaches to creating sustainable and resilient urban environments and mitigating their impacts of climate changes.

The main priority of European smart cities is the improvement of quality of life, urban spaces, social cohesion, and safety and housing issues (living dimension-33.56 percent-), as well as the mitigation of climate change via the improvement of energy efficiency and green infrastructure, and the promotion and adoption of sustainable resources (environment dimension-25.16 percent-). Both dimensions involved actions aimed at creation more resilient urban environments and climate adaptation, which reinforces the commitment of cities to adopt eco-friendly initiatives.

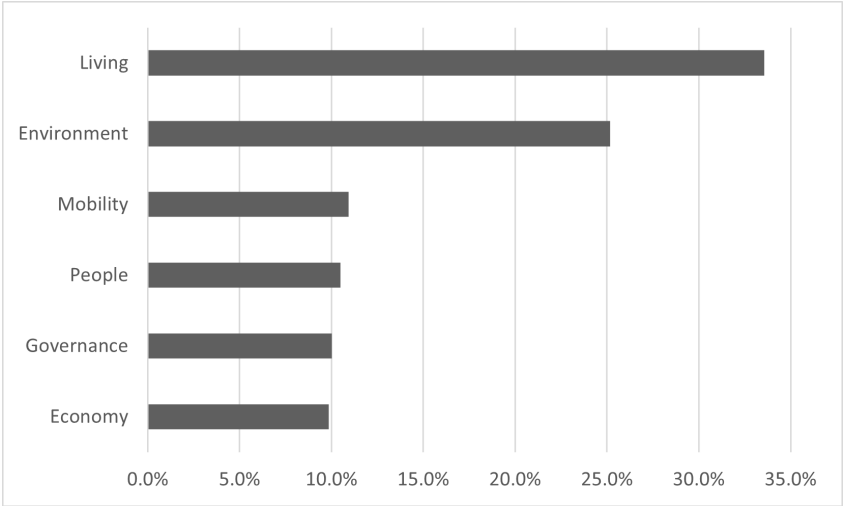

Fig 6 – The main scope of European initiatives

The following themes that seem to concern European smart cities are those related to the sustainable mobility and economy (10.94 percent and 9.85 percent, respectively). This shows the great concern from both citizens and their policymakers regarding the high levels of pollution and congestion in European cities, motivating the acceleration of the transition to low-carbon transportation and sustainable mobility solutions in order to reduce their environmental impact. In addition, although at first glance economics factors are not as prominent as environmental or social factors, in the strategic actions against climate change, we can expect that the economy dimension to become more relevant as cities aim to integrate green business models and sustainable growth.

Lastly, the Government dimension, accounting for 10.02 percent, indicates the need for transparent decision-making, participatory governance, and collaboration across stakeholders, which underscores the importance of policy frameworks and institutional cooperation in adopting effective climate change initiatives.

3.4. RQ4. Which Emerging technologies are being used for facing the climate change challenge into the urban context? And how are the ETs used in the different smart dimensions?

Emerging technologies play a pivotal role in shaping the future of urban governance, particularly in the context of addressing the complex challenges posed by climate change and sustainability (Suprayitno et al., 2024). Technologies such as big data, artificial intelligence (AI), smart sensors or blockchain, offer unprecedented opportunities to enhance decision-making, optimize resources management, and foster transparency in public administration (Yukhno, 2024). These innovations enable governments to process vast amounts of data in real-time, allowing for more informed, agile responses to urban challenges (Gil-Garcia et al., 2014). However, despite their potential, the integration of emerging technologies into public sector operations presents several challenges. Public administration must contend with issues such as data privacy and security, bureaucratic resistance, skill gaps, and the need for interdepartmental coordination (Kankanhalli et al., 2023; Alcaide Muñoz et al, 2023; Zhu et al., 2024; Liarte et al., 2024). Furthermore, their successful adoption requires significant investment in infrastructure, capacity building, and the development of regulatory frameworks that ensure ethical and effective use (U.S. Government Accountability Office – GAO-, 2021; Merguel et al., 2024). As cities increasingly rely on these technologies to drive sustainability and resilience, it is essential for policymakers to address these challenges to fully leverage the transformative potential of emerging technologies for public governance (Kalampokis, et al., 2023; Rodríguez Bolívar et al., 2023).

As we can see in figure 7, emerging technologies such as big data and smart sensors are the most widely used, in fact 16.06 percent and 14.03 percent of European initiatives incorporating these solutions, respectively. Big data allows cities to process vast amounts of environmental, transportation and infrastructure data, facilitating informed decision-making that optimizes resources management and supports climate mitigation initiatives. Similarly, smart sensors, deployed throughout urban environments, provide real-time data on key metrics such as air quality, energy consumption, and even traffic flow, enabling cities to monitor and respond to environmental challenges more effectively.

Digital tools, encompassing a wide range of platforms and applications, emerge as a centra technology in 11.57 percent of initiatives. They play a crucial role in urban management by facilitating the integration of various systems, including smart grids and sustainable urban planning frameworks. By leveraging these tools, cities can enhance their operational efficiency and make more informed, data-driven decisions regarding climate resilience. In addition to these, artificial intelligence (AI) (9.48 percent) is a pivotal technology for developing predictive models and optimization algorithms. It plays a critical role in urban sustainability by enabling cities to anticipate environmental challenges, such as extreme weather events, and optimize energy consumption across systems. This technology contributes to enhanced climate adaptation initiatives, ensuring that urban areas can adjust to rapidly changing environmental conditions.

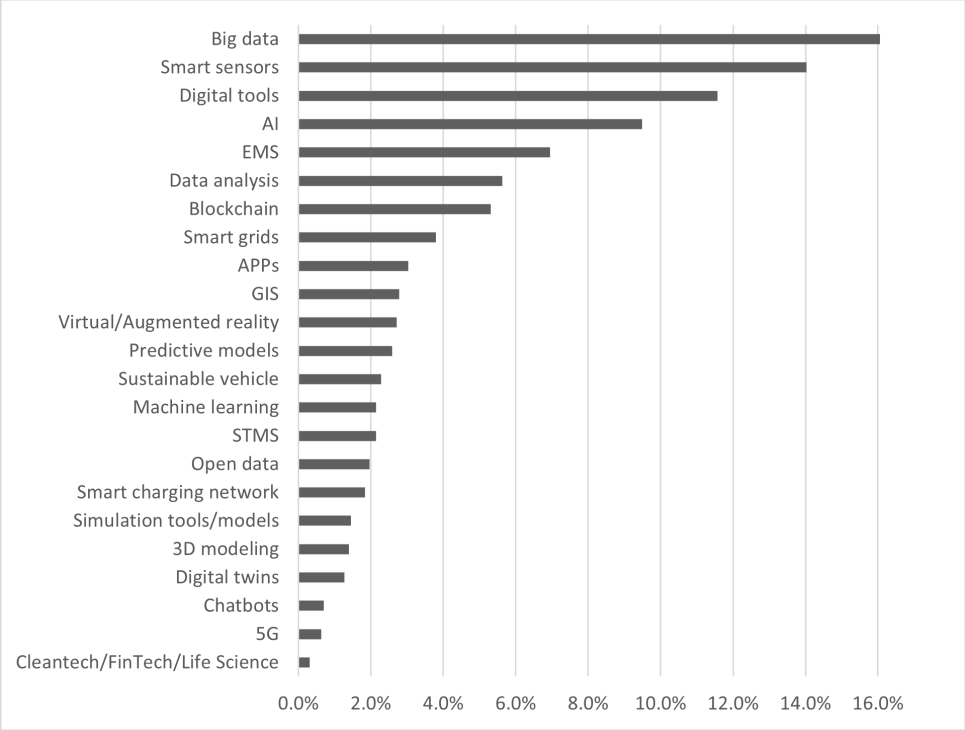

Fig 7 – The main emerging technology used in European initiatives

Energy Management System (EMS) appears in almost 7 percent of initiatives. This technology enables cities to monitor, control and optimize energy distribution and consumption in real-time, ensuring that energy use is both efficient and sustainable. By integrating renewable energy sources and improving the efficiency of urban energy systems. EMS technology significantly reduce cities' carbon footprint. Another important technology in environmental initiatives is blockchain (5.32 percent). Such technology improves transparency, security and efficiency in the management of environmental data. In fact, Blockchain is a great promise in sectors such as carbon credit trading, waste management, and the management of sustainable supply chains, providing secure, immutable records and environmental actions and facilitation accountability in urban sustainability efforts.

Figure 8 shown the representation of each emerging technologies depending on the specific goals of each initiative. In this sense, technologies as EMS and smart sensors and EMS (60.87 percent and 39.39 percent, respectively) play a central role, emphasizing the importance of environmental monitoring and efficiency energy management in European cities' sustainable initiatives. Moreover, big data, with a 21.26 percent of initiatives, and IA, with a 20. Percent of initiatives, are widely used, underscoring the growing reliance on data-driven decision-making to tackle environmental challenges and optimize urban systems.

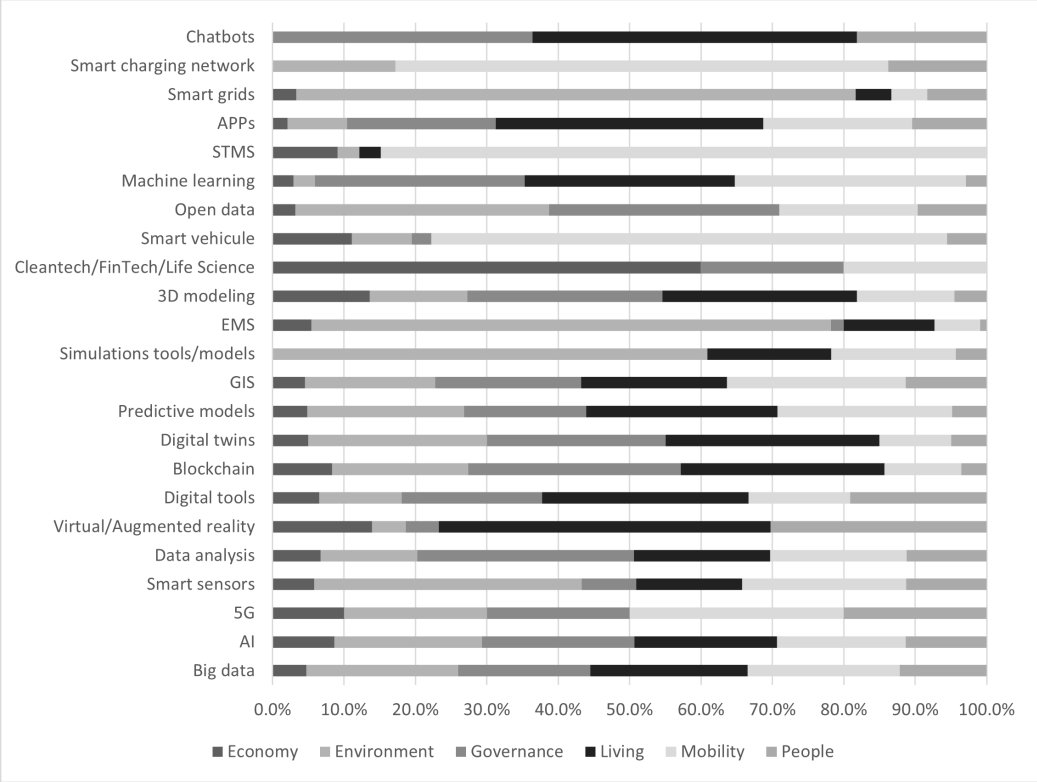

Fig 8 – The main emerging technology used in European initiatives, depending on smart dimensions

Initiatives focused on improving citizens' lives, social cohesion, safety and housing as well as promoting culture and tourism, show a greater presence of virtual/augmented reality and digital tools, with 46.51 percent and 28.96 percent, respectively. It suggests that such technologies are leveraged to enhance urban quality of life, public engagements, and the design of more interactive and sustainable urban spaces. They likely contribute to creating more resilient and adaptative environments that can respond effectively to climate change.

In the case of sustainable mobility issues, the use of smart grids (84.85 percent) and smart vehicles (72.22 percent) stand out. These technologies reflect the growing emphasis on sustainable transportation solutions, such as electric vehicle and intelligent transportation systems, designed to reduce carbon emissions and improve urban mobility. This trend aligns with the push for greener, more efficient cities with less reliance on fossil fuels (Inci et al., 2024; Zheng et al., 2024; Khaleel et al., 2024).

Furthermore, predictive models and digital tools (20.45 percent and 19.67 percent, respectively) are key to enhancing digital governance and transparency in city management (governance smart dimension). The use of these technologies enables municipalities to implement more efficient policymaking, predictive analytics for urban planning, and citizen engagement initiatives making them central to the development of smart government frameworks. Digital tools (19.13 percent), along with chatbots (18.18 percent), are commonly used to improve public services and citizen interaction (people smart dimension), as they not only facilitate better access to services, but also enhance public participation and help cities engage with their populations more effectively.

Lastly, in the economy dimension, CleanTech/FinTech is predominant, used in 60 percent of economic initiatives. This suggests that European cities are focusing on leveraging sustainable technologies and financial technologies to drive economic transformation, aiming to transition towards more eco-friendly and resilient economic structures. These initiatives align with the growing interest in circular economy models, seen as key to promoting long-term economic sustainability in urban environments. Other emerging technologies such as AI (8.57 percent), data analysis (5.86 percent), big data (4.72 percent), and AI are predominant, emphasizing the importance of data-driven decision-making in fostering sustainable economic practices and business models. Additionally, digital tools, with 6.56 percent, and smart sensors, with 5.86 percent, are employed to optimize resources allocation and urban economic planning, enabling smarter and more efficient economic initiatives.

Blockchain (5.31 percent) and predictive models (4.88 percent) also play a role in supporting financial innovation and enhancing the resilience of urban economies, ensuring that cities can adapt to shifting economic landscapes and incorporate green business models.

To summarise, big data, AI and smart sensors are foundational to environmental and governance initiatives, while virtual/augmented reality, smart grids, and smart vehicles dominate in living and mobility initiatives. In addition, CleanTech/FinTech have a significant presence in economic initiatives. Therefore, European cities are increasingly integrating emerging technologies into their initiatives to address climate change and urban resilience in a comprehensive manner. By targeting specific goals, European cities are adopting a multifaceted approach to achieving sustainability and adapting to the challenges posed by climate change.

4. Conclusions and discussion

This study has analyzed how a set of European smart cities strategically plan actions to address the challenge of climate change through the implementation of smart initiatives. Specifically, four key aspects have been examined: the governance of these initiatives, including institutional leadership and the departments involved; the smart dimensions in which climate adaptation strategies are being developed; the role of emerging technologies in urban planning and climate resilience; and the integration of these technologies into the various smart dimensions of the city.

Unlike previous studies that have analyzed climate governance in smart cities in isolation (Hofstad et al., 2022) or focused solely on the role of emerging technologies in urban planning (Bibri et al., 2023; Su and Fan, 2023), this study offers an integrated perspective that combines both approaches. This allows for a deeper understanding of how governance structures influence the adoption and effectiveness of technological solutions in the context of climate action. While previous research has highlighted institutional fragmentation in smart city planning (Liarte et al., 2024; Zhu et al., 2024), this study advances by identifying the specific departments involved in the strategic planning of climate initiatives, highlighting the absence of efficient interdepartmental coordination structures.

The findings reveal that, although European smart cities have made progress in incorporating climate strategies into their urban plans, the governance of these initiatives does not follow a uniform model. While some municipalities have established dedicated departments for resilience and sustainability, a significant portion of initiatives remains managed by other municipal areas without a clear centralized structure. This aligns with previous studies indicating institutional fragmentation and the lack of coordinated leadership as barriers to the effectiveness of climate adaptation strategies (Birchall et al., 2023; Reckien et al., 2023).

Moreover, the analysis reveals that private sector involvement in the formulation and leadership of these initiatives is minimal. Similarly, the engagement of academic institutions and research centers in strategic planning is practically nonexistent. This finding is particularly relevant as it contrasts with trends observed in other regions, where public-private collaboration and the incorporation of scientific knowledge play a fundamental role in innovation and the formulation of urban sustainability strategies (OECD, 2024a; McPherson and Clarke, 2024). The limited presence of these key actors in the planning of European smart cities suggests a lack of articulation between technological and scientific advancements and their application in climate governance, potentially limiting the impact and effectiveness of implemented initiatives.

Regarding the dimension of urban initiatives, mobility is predominantly led by the public sector and primarily managed by municipal enterprises. This due to the strategic nature of transportation, the substantial investment in infrastructure it requires, and the strong governmental control and regulation in place. Private sector participation in this area is generally limited to complementary services. In contrast, environmental initiatives exhibit a high degree of private collaboration, as they largely rely on innovation and technological specialization. Meanwhile, initiatives aimed at enhancing quality of life face an unclear distribution of responsibilities, which could limit their overall impact. To improve governance in smart cities, it is essential to establish clearer structures and strengthen transparency in the management of urban initiatives, ensuring greater efficiency and sustainability in their implementation.

Moreover, the results highlight a lack of interdepartmental collaboration, as few initiatives involve multiple departments. This low incidence suggests the presence of structural and organizational barriers, such as the complexity of administrative coordination, bureaucratic rigidity, and the absence of more integrated governance frameworks. These findings reinforce prior evidence on the obstacles posed by institutional silos and the lack of interdepartmental communication, factors that continue to hinder the effectiveness of climate strategies in smart cities (Liarte et al., 2024; Zhu et al., 2024; Alcaide Muñoz et al., 2023; Rodríguez Bolívar et al., 2023).

The analysis of the smart dimensions involved in climate planning shows that initiatives related to environmental sustainability and urban quality of life are the most represented, reinforcing the idea that climate action is being integrated into key urban aspects (García Fernández and Peek, 2020; Bibri et al., 2023). However, the limited interconnection between these initiatives and other strategic dimensions, such as mobility and the economy, suggests that opportunities remain for greater cross-cutting integration of climate policies within smart urban planning.

European smart cities are prioritizing quality of life and environmental sustainability in their strategic approaches, with a strong emphasis on sustainable mobility and the development or greener economies. This focus is largely driven by the existing regulatory framework and sustainability policies within the EU -particularly the European Green Deal 2050 (European Commission, 2024)- as sustainable mobility is considered a strategic priority due to its direct impact on emission reduction and public health improvement.

Furthermore, the study confirms that tools such as big data, AI, and smart sensors are playing a fundamental role in data-driven decision-making and the efficient management of urban resources. However, their implementation still faces significant challenges, including the lack of interdepartmental integration, the need for greater investment in infrastructure, and the regulation of data usage. In particular, the adoption of more advanced technologies, such as blockchain or AI predictive models, remains limited, raising questions about the barriers hindering their integration into urban climate governance (Kalampokis et al., 2023; Rodríguez Bolívar et al., 2023). To overcome these limitations and maximized their impact, a coordinated strategy between governments, businesses, and citizens is essential, ensuring that technological innovations are both accessible and sustainable in the long term.

Based on the results obtained, several lines of research are identified that can contribute to a more detailed understanding of the challenges and opportunities in the strategic planning of smart cities in response to climate change. First, the absence of a unified model and the predominance of sectoral approaches hinder interdepartmental coordination and limit the effectiveness of climate initiatives. Further research is needed to analyze collaborative governance models that promote greater articulation between municipal departments and levels of government, fostering more cross-cutting and adaptive decision-making structures. Future studies could examine successful cases where the integration of governmental actors has facilitated more efficient and coordinated planning.

Similarly, assessing the real impact of emerging technologies on climate adaptation and mitigation represents a priority research area. Although tools such as artificial intelligence, blockchain, and big data have demonstrated high potential for optimizing urban processes and enhancing climate resilience, their effectiveness remains insufficiently documented. Empirical studies are required to analyze the extent to which these technologies have contributed to reducing emissions, improving energy efficiency, or strengthening the capacity to respond to extreme climate events. Additionally, identifying the factors that facilitate or hinder their implementation in different urban contexts would allow for more precise recommendations for their integration into municipal planning.

In conclusion, this study contributes to the understanding of strategic planning in smart cities in response to climate change by providing an integrative perspective on the intersection of governance, technology, and the participation of strategic actors. The identification of shortcomings in interdepartmental collaboration, the limited involvement of the private and academic sectors, and the need to assess the impact of emerging technologies underscore the importance of advancing these research lines. The consolidation of more efficient and adaptive governance models will be crucial to ensuring that smart cities can respond more effectively and in a coordinated manner to future climate challenges.

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