

Article

Smart and Sustainable? Positioning Adaptation to Climate Change in the European Smart City

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Abstract: This article reports on the elements of adaptation to climate change in European Smart City initiatives in order to understand to what extent Smart Cities can be the answer in the fight against climate change. On the grounds of innovative efforts implemented in Barcelona, Rotterdam, and Vienna, we examine the opportunities and obstacles to both Smart Environment (defined as an axis of the Smart City) and adaptation to climate change, linking them together. As it is difficult to estimate the benefits of climate action in the short term due to often costly solutions, Smart City proposals could provide the economic incentive to create adaptive, energy-efficient, and sustainable societies. As the need for adaptive and resilient cities in the global context of climate change rises, the concept of Smart City might need to evolve into that of a Smart Sustainable City, positioning the environment at the core of its development. Results from this analysis suggest that the interaction between technology and nature can be enhanced when a Smart City approach promotes the integration of climate strategies and encourages the participation of citizens, something that is crucial since early adaptation efforts can safeguard smart infrastructure from climate impacts.

Keywords: Smart Cities; climate change; adaptation; sustainability; environment

1. Introduction

The twenty-first century is well on its way to becoming the century of cities, as the world is experiencing a massive wave of urbanization. According to the United Nations (UN), 55 percent of the world's population is currently residing in urban areas, while this is expected to rise to around 68 percent in 2050 [1]. Much of this growth, however, is due to urban migration patterns in Asia and the Global South, as urbanization rates in Europe were already relatively high. According to the European Commission (EC), 72 percent of the European population lives in urban areas, where European cities tend to be medium-sized, with few cities over one million residents and only two over 10 million inhabitants [2]. This is due to the fact that European cities are generally closer to each other and less clustered around bigger cities than cities on other continents, forming a dense network of urban areas.

Cities are considered to be “engines of economic growth and centers of innovation for the global economy and the hinterlands of their respective nations” [3] (p. 39). Although cities generate 80 percent of global GDP on a land space of 3 percent, they also account for 60–80 percent of global greenhouse gas emissions, 50 percent of global waste, and 75 percent of global natural resource consumption [4]. People are pulled towards cities for the economic opportunities, technological advancement and lifestyle attitudes they accommodate. Therefore, in order to remain relevant in the global economy, cities should focus on delivering quality of life for residents and visitors, nurturing economic competitiveness to attract industry and talent, while aiming at sustainability [5]. However, the rush to cities for their social and economic benefits comes with heavy environmental pressures,

such as the rapid exploitation of natural resources, threatening water, food, and energy supplies to the cities, which are crucial to the overall well-being of the citizens [6].

Climate change is further intensifying these environmental pressures within cities, as the world is struggling to keep the global average temperature below the internationally agreed two degrees Celsius compared to pre-industrial levels. As cities are becoming more vulnerable to climate change impacts, the need to create adaptive societies is more crucial than ever. Hunt and Watkiss [7] state that climate change has direct impacts that affect energy usage, health, sea-level rise, extreme weather events on built infrastructure, and water and resource availability in cities. Moreover, air quality, biodiversity, cultural heritage, and tourism are also directly impacted at the city level. In order to minimize the impacts of climate change, the long-term vision for cities should be adjusted to adapt “to nature’s transformation, creating a more pleasant environment for living” [8] (p. 2).

Technological advancements in information and communications technology (ICT) have accelerated in the past decades due to ground-breaking innovations, such as computing, the Internet and the Global Positioning System (GPS). Since the change of the millennium, smartphones, and social media platforms “led to a drastic change in the methods customers used to communicate with businesses, and also the expectations customers had with regard to response times and multi-channel availability” [9] (p. 2). These developments prompted businesses to move towards new business models based on digitalization. Not only businesses but also governments are experiencing demands from their citizens to be more agile and efficient.

The concept of Smart City is a highly anticipated urban development model that enjoys many different descriptions and definitions in the literature, being heavily debated through different scopes and propagated in many different sectors. According to the European Parliament (EP), a Smart City is “a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder municipally based partnership” [10] (p. 17). Additionally, Smart Cities are multidimensional, are constantly shaped by technological and urban developments and often go beyond ICT, including people and societies [11–13].

Smart Cities are becoming a hot topic in the current global scenery of technological rivalry, in which not only urban planners, city councils, and academics find interest. The private sector with ICT leaders, industrial enterprises, and ICT consulting firms are, among many companies, publishing their own views and developing solutions for Smart City initiatives [5,14–16]. All of them are keen on jumping onto the business opportunities that Smart Cities will generate. Hence, one wonders what would happen if adaptation to climate change received that amount of attention.

Taking into account the aspects of urbanization, environmental pressures, and technological innovation, we want to outline the connection between the concept of Smart City and adaptation to climate change in this article. This article focuses on the question of whether Smart City proposals can provide the incentive to create adaptive, energy-efficient, and sustainable societies and, thus, to what extent Smart Cities can be the key in the fight against climate change. The first part of this article deals with the dimensions of the Smart City, the potential of smart technology and implemented Smart City initiatives at the city level, all from an environmental perspective. The second part seeks to link Smart City with adaptation to climate change, as societies of today cannot conceive a modern city model without it being sustainable and resilient, that is, without having an adaptive capacity to the changing natural environment.

2. Research Aim and Method

Our aim is to see whether Smart Cities can be the key in the fight against the current climate crisis and to what extent adaptation to climate change can be incentivized by the concept of Smart City. One of the limitations, however, is that there is not yet a commonly agreed definition of a Smart City, since nearly every stakeholder from each sector has a different perspective on the Smart City notion. For instance, engineers see the Smart City as a complex system with different layers, architects in terms of social inclusion, and many governments in the sense of economic growth [14].

The Smart City is also, to a lesser extent, referred to as an ‘Intelligent City’, ‘Digital City’, or even a ‘Knowledge City’ but as the term Smart City has increased so widely in popularity, “it is better to use it and sharpen its definition than to let it mean everything and therefore nothing” [17] (p. 6). Nonetheless, the aim of this article is not to further define the concept of Smart City, as quite some literature already addressed this issue [11,17–19]. Instead, we chose the working definition of the EP, as outlined before, while taking the dynamic nature of the concept into account. This allows us to focus on the core of the research. However, there is a need to make a distinction between the concept of Smart City and that of a Sustainable City, even though there are many overlapping elements in both issues. Some researchers argue that even though environmental factors are often part of Smart City frameworks, they are undersized by other (economic) issues, whereas Sustainable Cities are more designed to address the natural environment of cities [20]. Others state that the incorporation of technology in cities does not always address environmental issues, while likewise, a city can become more sustainable without using ICT [17]. These authors even discuss the idea of Smart Sustainable Cities, a concept that has been defined by the International Telecommunication Union (ITU), a specialized agency of the UN, as “an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, cultural and environmental aspects” [21] (p. 3). By analyzing the role of adaptation to climate change in the notion of Smart City, we may provide some discussion to strengthen the case for Smart Sustainable Cities.

Regarding the literature, there is a significant lack of research on the relation between Smart Cities and sustainability, as most articles on Smart City relate to computer sciences and engineering [22]. This limitation is even deepened when explicitly looking for the relation between Smart City and adaptation to climate change. Nevertheless, we were able to find multiple interesting articles to bolster the academic foundations of this manuscript, using a mix of keyword searches in different combinations, such as ‘smart’, ‘smart cities’, ‘adaptation’, ‘climate’, ‘environment’, and ‘sustainability’ among others. Due to this research gap, we chose to include how the environment is incorporated into Smart City policy-making, using Barcelona, Rotterdam, and Vienna as example cities. Barcelona was chosen due to the fact that it is considered to be a leader on Smart City initiatives, while it also organizes the annual Smart City World Expo. Rotterdam was chosen because the city has a high reputation for adaptation to climate change. The choice for Vienna resides in the outspoken choice for sustainability in its well-developed Smart City framework strategy.

Despite the limitations in the literature, we believe to have created an interesting manuscript, whose discussion and conclusion can contribute to filling the void in the literature. This article is not meant to be a means to an end, but rather has an explanatory approach and, therefore, an addition for researchers to keep on narrowing the gap between adaptation to climate change and Smart City.

3. Environmental Dimensions of the European Smart City

3.1. Smart Environment

Within the analysis of the complex concept of Smart City, Chourabi et al. [18] established a theoretical framework with various constituent elements of a Smart City, among which there is one that relates to the environment. The natural environment resides in their integrative framework in conjunction with built infrastructure, economy, governance, and people communities that require proper organization, policy and technology for a Smart City initiative to be successful. In this model, technology must be used to increase sustainability, protection, and management of natural resources.

Giffing et al. [19] have defined six overall axes to measure whether a Smart City is well-performing in a forward-looking way. These dimensions are (1) Smart Economy, (2) Smart People, (3) Smart Governance, (4) Smart Mobility, (5) Smart Environment, and (6) Smart Living, each including various factors and indicators. These six axes have frequently been adopted in academic literature [8,23–25] and public administrations in the European Union (EU) [10,26,27]. The EP also used the model for mapping

Europe's Smart Cities, as "the coordination of policies along these dimensions reflects the positive feedback between city development and urbanization; cities attract people while the availability of populations and infrastructure facilitates economic and societal development" [10] (p. 18).

Out of these six dimensions, two are potentially compatible with climate action. On the one hand, the Smart Environment axis, which consists of four factors: (1) Attractivity of natural conditions, (2) pollution, (3) environmental protection, and (4) sustainable resource management. Examples of indicators attached to these factors are sunshine hours, green space share, smog, efforts on protecting nature, and efficient use of water and energy [19]. Adaptation measures implemented through climate policy overlap, to a great extent, with these factors and with smart city indicators, as they often include air quality, green infrastructure, water and waste management, coastal protection, and energy efficiency, among others [7]. On the other hand, the Smart Mobility axis, due to the fact that the use of ICT can make traffic flows more efficient, can assure that car owners spend less time circulating around the city for a parking spot and can stimulate the needed infrastructure for electric vehicles. However, Smart Mobility is mainly aiming at the reduction of greenhouse gas emissions, hence climate action in the form of mitigation. Smart Environment, however, takes a wider approach and relates more to climate action in the form of adaptation to climate change.

3.2. Green Technology in the Smart City

Technology in Smart Environment is used to "improve the knowledge of environmental conditions and services such as electricity, water, and gas in order to change people's habits, avoid waste, benefit the environment, and improve the efficient use of resources" [23] (p. 164). However, due to the fact that cities will increasingly depend on ICT, security will be one of the main concerns to ensure that smart infrastructure is being protected [28]. We can imagine an inadequate energy supply to the city because of a system failure. The RESCCUE project [29], an EU Horizon 2020 research project in which Barcelona, Bristol, and Lisbon participate, focuses on the possible cascading effects of climate impacts on interdependent urban services. As we explain later in this article, this is certainly the main reason why Smart Cities have to include adaptation efforts. RESCCUE is using a software "able to perform the assessment, management, and planning of urban resilience in an integral way" [30] (p. 3). As the incorporation of ICT in crucial urban systems might even increase their vulnerability to climate impacts, a robust redundancy validation is, therefore, always of vital importance. In any case, the private sector often lines out that sustainability should be incorporated in Smart City strategies from the start [5,14–16], even though they have been promoting the concept of Smart City to open a new kind of wholesale market aimed at the public sector [17].

Cutting-edge technologies, such as 5G, Artificial Intelligence (AI), Big Data, Cloud, and the Internet of Things (IoT) will be a catalyst for the rapidly evolving notion of Smart City, as everything will be connected to the Internet, from security cameras to sensors in waste collection points. In a business report, Hewlett Packard Enterprise (HPE) highlights some IoT use cases that regard the environment to sketch an idea on what is on the horizon within the dimension of Smart Environment [31]. Smart water management is able to protect the city's water supply through real-time decision-making, while also helping to prevent the waste of water by using data to detect leaks, temperatures, and water pressures. Intelligence in buildings is useful for monitoring energy use and improving energy efficiency. Furthermore, merging data from weather, traffic, and environmental sensors has the potential to manage air quality and deliver more accurate weather forecasting. Big Data generated by these sensors can make forecasting more optimized for concrete actions in adaptive policy-making [32]. Improved air quality and reduced vulnerability to heatwaves are possible outcomes of more accurate and real-time environmental data, while telemedicine, remote education, and public health surveillance using mobile devices can also make a city more adaptive to climate impacts [33]. Deep diving further into the specific applications of smart technologies in the matter of adaptation to climate change, the European Environmental Agency (EEA) states that "smart spatial and infrastructure designs minimize the urban heat island effect, air pollution and flooding of streets and houses" [34] (p. 29).

These examples, however, are only the tip of the iceberg, as the UK's Environmental Industries Commission (EIC) concludes that the market for smart technologies aimed at resolving an environmental challenge is still immature, as many technologies are still in the research and development phase [35].

3.3. Smart Cities on the City Level

Despite the fact that the EU provides financial and knowledge support to cities through different tools, there is still an absence of a common framework. Examples of these tools include the Smart City Guidance Package of the European Innovation Partnership on Smart Cities and Communities (EIP-SCC) [36] and the Horizon 2020 program. According to the EU, aspiring Horizon 2020 projects must meet "EU climate mitigation and adaptation targets and national and/or local energy, air quality and climate targets" [37] (p. 108). Thus, cities have been developing their smart strategies in different forms, ranging from a list of initiatives to official reports. Some cities are taking up Smart City projects exponentially, that is to say, they "are rapidly outpacing the policies governing their development" [8] (p. 15). Additionally, it may be difficult to define a universal framework for Smart Cities due to the unique characteristics of each city, therefore, it should be tailored to the priorities and vision of a unique city [11].

The Barcelona Ciutat Digital plan is the city's strategy for Smart City, which states its objectives beyond just the incorporation of technology in the city but ambitiously intends to address long-term urban challenges, such as climate change and scarcity of natural resources [38]. Furthermore, Barcelona strives for a more collaborative and sustainable economy in order to decrease social inequalities, while assuring the leadership on innovation. However, climate action is not named as a specific category, as the main prisms of the strategy are (1) governance, (2) city services, (3) digital socio-economic fabric and local innovation ecosystem, and (4) citizens. In this context, Barcelona's main challenges are urban flooding, intense heat, reduced water availability, and coastal erosion [39]. The city's historical vulnerability to urban flooding has created a need to continuously adapt the urban drainage system, leading to the implementation of a network of Storm Water Tanks. These tanks are controlled remotely by means of ICT systems, providing a much more efficient and less dependent drainage system that saves 30 percent on operational costs and reduces the chance of urban flooding up to 75 percent [40]. Since 2015, Barcelona implemented intelligent energy monitoring in 23 buildings with 31 more planned. The city has also installed 240 pneumatic waste collection points, while 40 percent of Barcelona's parks have an automated irrigation system [41]. Additionally, the City Council of Barcelona has had a leading role in the development of the Sentilo platform, an open-source software accessible to citizens for public experimentation, which collects data from a network of about 1800 sensors used in the city, out of which 50, specifically, measure environmental indicators such as air quality, humidity, and temperature [42]. Lastly, Barcelona has taken significant steps in optimizing energy provisioning in their innovation district, 22@, with the implementation of Districlima, an innovative urban heating and cooling system, consisting of a large network of water pipes that are connected to a multitude of buildings in the district. The energy needed to provide heating and cooling is generated from municipal waste incineration with the system being able to use 35% less electricity, improving energy efficiency by 50%, and reducing emissions by 50%, compared to conventional heating/cooling systems [43] (p. 821).

Rotterdam does not have an official strategy on Smart City yet, but the city council has instructed PBLQ, a consultancy agency, to help with the development of their Smart City Rotterdam vision. According to the report, Rotterdam has already been named a Smart City on sustainability as it is actively collaborating with national and other European cities on EU-projects that involve sustainability, heat, and energy management [26]. However, the report does not consider climate action or sustainability as a separate category, as it does with the political, economic, and social and cultural dimensions. Instead, sustainability is woven into some example initiatives, such as the sectoral collaboration projects between cities in the Rotterdam metropolitan area, Cleantech Delta and Food Delta, which are outlined in the economic category. Besides the continuous struggle of the Dutch against the sea, Rotterdam is also aiming to make the city less vulnerable to drought, heat stress, and extreme rainfall [44]. In order

to better bear heavy precipitation, Rotterdam developed an innovative water square, the Bentem Square, equipped with a rainfall prediction system to better protect the city from heavy rainfall and sewage overload, while also serving as a sports and recreation area [8,45]. The Bentem Square is located in the ZOHO district, which is being transformed into Rotterdam's first climate-proof district. Other smart initiatives in the ZOHO district include a rain barrel water storage system that stores and reuses rainwater simultaneously, managed by a smart control device, and the Polderroof, a green parking garage rooftop that reuses and stores excess rainwater from nearby buildings in a controlled way [46]. Additionally, Rotterdam is integrating ICT in its flood control systems to make them more modern and adaptive, for example, through integrated forecasting tools, sensors that register real-time dike conditions, and satellite imagery [47]. The objective of the Flood Control 2015 program is aimed at making decision-making twice as quick and twice as accurate, while even including a gamification aspect in the form of a Rotterdam Flood Management game, developed to prepare the new generation that will need to keep protecting the city against future sea-level rise.

In Vienna, the Smart City Wien framework strategy outlines the city's smart ambitions for the long-term. The strategy highlights that Vienna has already done much in the field of climate protection and that the Smart City framework is building on existing approaches to environmental and climate policy [48]. It is concentrating the available resources while assuring that collaboration between all actors will facilitate a joint focus on superordinate goals. Promoting Vienna as an environmental model city and aiming for the highest possible resource preservation are objectives outlined in the framework, coexisting with other Smart City objectives in the three main pillars of innovation, governance, and quality of life. In terms of climate risks, the city of Vienna has already experienced an increase of two degrees Celsius in average temperatures over the past four decades, causing intensified periods of heavy precipitation and almost twice as many heatwaves in the period 1976–2005, compared to the period of 1961–1990 [49]. In collaboration with EU and national stakeholders, such as the Austrian Climate and Energy Fund, Vienna has started to fund and implement various Smart City initiatives, such as equipping the city's traffic lights with environmental and weather sensors, optimizing water, and energy usage in school buildings and incorporating renewable energy sources into the city's power grid [50]. Vienna is also protecting urban biodiversity by mapping breeding sites of the Common Swift through a smart and participative approach [51]. Moreover, the city joined forces with a Czech consultancy firm, ECOTEN, to map Vienna's vulnerability to heat per sub-district, using satellite data in combination with population data available through the Opendata Vienna portal [52]. In order to reduce building cooling demand, the project smartKB* focuses on the interactions of cooling-related planning and design, alongside the interfaces between buildings and their urban environment [53]. Lastly, Vienna assured an annual reduction of 500,000 tons of CO₂ emissions by connecting smart technologies with climate objectives, such as producing district heat from residual waste incineration [48].

Different approaches to climate action and sustainability in Smart City strategies have been observed, as Vienna puts a heavy focus on the matters in the Smart City Wien framework, while in Barcelona, it is part of the bigger picture. In Rotterdam, it has yet to be seen to what extent it will be a core element in an upcoming official Smart City strategy. As observed, most of the smart oriented climate solutions in the three cities are small-scale pilot projects and are still being studied for replication in other districts of the city. Only when there is a vital need for adaptation, such as the case of urban flooding in Barcelona or sea-level rise in Rotterdam, large-scale ICT solutions are introduced. Lastly, as climate impacts differ across regions, different smart initiatives will be developed in order to tackle the specific vulnerabilities of a certain city.

3.4. Status Quo of Smart Environment in the European Smart City

Environmental impacts caused by climate change to which cities should adapt are not the only challenges that are experienced, as urbanization is also causing shrinking cities and urban sprawl, leading to pressure on urban ecosystems. All these challenges can be addressed through the Smart

Environment dimension, for example by means of environmental monitoring, intelligent resource management, and smart and energy-efficient buildings [25]. In 2014, the EP took into account that Smart Environment represented 21 percent of Smart City initiatives, compared to 33 percent for Smart Mobility and around 10 percent for each of the other four dimensions [10].

The +CITIES project, backed by the Spanish Government, analyzed the prominence of Smart Mobility and Smart Environment initiatives in 62 Spanish cities with over 50,000 inhabitants [23]. Energy efficiency, water consumption and atmospheric emission were used as factors to analyze the status of Smart Environment in Spain but only 14 cities were present in the environmental axis, the lowest of all six. In comparison, 48 Spanish cities implemented Smart Living initiatives, while Smart Mobility attained 44 cities, meaning that Spanish action in Smart Environment lacks ambition. In the ranking, Madrid, Barcelona, Málaga, Santander, and Zaragoza are the most active in the environmental axis of the Smart City. All in all, 14 of the 62 (23%) analyzed Spanish cities were involved in working on Smart Environment.

The SMART-ECO Project, a project series for a comparative study between European and Chinese Smart-eco cities coordinated by the University of Exeter, analyzed urban development designs that combine both smart and green initiatives of several European nations, including the Netherlands [45]. Sengers analyzed 25 Dutch cities on their Smart City ambitions and their eco-city ambitions. Out of the 25 cities, 22 Dutch cities have, at least to some extent, Smart City ambitions, whereas only five have explicit eco-city ambitions (Arnhem, Delft, Rotterdam, Utrecht, and Zaanstad). Seven other cities have eco-city ambitions, but these are not their highest priority, nine other cities do not have explicit eco-city ambitions, while the remaining four are without data. In total, 5 of the 25 (20 percent) Dutch cities have high environmental ambitions in Smart City initiatives.

For Austrian cities, there is an absence of such a comparative study on the national level, due to which we decided to look at the third version of the Ranking of European medium-sized cities analyzed by Giffinger and his team in 2014 [54]. Austria has only five cities above 100,000 inhabitants, of which Vienna, with 1.3 million inhabitants, is by far the biggest. Austria's four medium-sized cities all appear in the Smart City ranking model of 77 European medium-sized cities between 100,000 and 500,000 inhabitants. Graz is ranked sixteenth in the overall Smart City ranking but only ranks at twenty-eight in Smart Environment. For Linz, this is fourteenth overall but twenty-fifth in Smart Environment, while Salzburg is ranked tenth overall but only twenty-fifth in Smart Environment. Innsbruck is ranked thirteenth overall but sixth in Smart Environment, the only Austrian exception with a higher ranking in Smart Environment than the Smart City total.

Looking at the studies above, Smart Environment ambitions got a fair share compared to the other six Smart City dimensions. Nevertheless, there are great differences among countries and cities, and while new initiatives are constantly being tested, Smart Environment might lose terrain against the other Smart City axes due to insufficient preference or incomprehension of the benefits of smart environmental solutions. Joss et al. [55] analyzed the Smart City discourses of 27 global cities and found that the terms 'environment' (1.9 percent) and 'sustainability' (0.9 percent) in Smart City discourses of these cities are very marginal in comparison to terms such as 'governance' (10.1 percent), 'infrastructure' (9.5 percent) and 'digital technology' (8.3 percent). In the specific case of Vienna, Victoria Fernández Áñez et al. [56] developed a conceptual model to analyze Smart City discourses in relation to implemented projects in order to better guide future initiatives in the field, in which they found that even though the 53 projects in Smart Environment exceeded the other axes, the axis only came out as the fourth most important in stakeholder's discourses. The authors believe that more efforts should be done to increase social awareness in environmental projects because "when the challenges are assessed separately, climate change is not considered very important by the stakeholders, and the environment does not appear to play a key role in their view of the concept in their definitions of the Smart City" [56] (p. 15).

On the whole, the EIC notes that one of the reasons for the limited impact of Smart Environment is the lack of prioritization [35]. In order to limit climate impacts in cities, Smart Environment "should be

combined with projects in other fields like economy, governance, mobility, people, and living in order to develop Smart City strategies to provide a comprehensive response to the needs of the city" [25] (p. 30). However, many Smart City projects are still mostly implemented in individual fields, such as smart grids and public transport systems [24].

4. Adaptation to Climate Change in the European City

4.1. Adaptation on the City Level

In contrast to the recent interest in the concept of Smart City, climate action has been high on the agenda of public administrations since the early 1990s. Therefore, many cities already have mechanisms in place that aim to tackle climate change. However, the focus on environmental policy-making has been primarily geared towards mitigation efforts, like the reduction of CO₂ emissions [3]. Nevertheless, forerunner cities have already started adapting to climate change.

Barcelona has recently unified all the separate plans involving climate action into a single strategy, the Climate Plan 2018–2030, which has been produced together with citizens. It integrates adaptation and resilience, climate justice and mitigation, and promotes citizens' action [39]. Barcelona's Climate Plan has five lines of action: (1) People's well-being first, (2) improve building efficiency, (3) transforming public spaces into healthy, biodiverse, efficient and inclusive settings, (4) uncoupling the quality of people's lives from economic growth with a vision that makes most of the resources and avoids emission and waste generation, and (5) collaboration from an informed, critical, proactive, empowered citizenry. As stated by the Climate Plan, Barcelona's leading objective for 2030 in terms of adaptation to climate change is to increase the city's urban green infrastructure by 1.6 km². In 2009, the city council set up Urban Service Infrastructure Boards that are organized in specific working groups per sector, such as energy, water cycle, telecommunications, and town planning, all of them centrally coordinated through a 'Situation Room' platform in order to improve multidisciplinary work among interdependent departments [41]. An example of an adaptation effort realized in Barcelona without the use of ICT is the fortification of the beachfront with 700,000 m³ of sand coupled with the construction of dykes [39]. Furthermore, the city is bringing about a network of green corridors that connects the various green spaces in the city while also introducing vertical gardens and living rooftops [41]. Although Barcelona's Climate Plan 2018–2030 refers to the use of technology in certain sections, it is not a core element of the city's climate strategy. On the whole, Barcelona is taking important steps to protect the city against climate impacts, even though it reported difficulties elaborating long-term climate change adaptation strategies based on 100-year climate projections [57]. This is due to the fact that governments are changing every four years.

Rotterdam, as a forerunner in adaptation matters, already published the Rotterdam Climate Change Adaptation Strategy in 2013, which outlines the strategic foundations that will serve to make Rotterdam a climate-proof city, not only for the people of Rotterdam today but also for future generations [44]. The strategy of Rotterdam focuses on six main objectives: (1) Protect the city from the rivers, and the sea, (2) assure minimal disruption from too much or too little rainfall, (3) guarantee an accessible and safe port, (4) raise awareness among citizens, (5) build an attractive, comfortable and pleasant city, and (6) strengthen the image and economy of Rotterdam. Not all adaptation efforts require the use of ICT, such as the rain gardens in the city's ZOHO district, which rely on permeable paving and urban greening [46]. In order to cope with extended periods of drought, Rotterdam is constructing blue-green corridors, connecting various waterways and green spaces into a wide recreational passage, not only forming an ecological link for nature but also functioning as a water storage facility to make the hydrographic network more resilient during droughts [44]. In particular, Rotterdam specifically highlights the connection between nature and technology as one of four guiding principles of the Rotterdam Climate Change Adaptation Strategy. In 2013, Rotterdam had an estimated workforce of 3600 people working directly on adaptation to climate change in the fields of building,

consultancy, and ICT [27], although one must take into account that much of this workforce is directly involved in protecting Rotterdam against the sea.

Vienna did not yet elaborate a distinct framework that covered the city's objectives on adaptation to climate change. In 2017, however, the initiative Adapting to Climate Change in Vienna [49] was launched under Vienna's broader Climate Protection Programme, KLiP Wien, which has already been active for over two decades (although with more focus on the reduction of CO₂). Still, there is a lack of research in urban studies that concern Vienna's adaptation strategies [58]. Even so, the Adapting to Climate Change in Vienna initiative points out that more attention will be paid to the extension of green spaces and the creation of more shade spots in order to better address Vienna's vulnerability to extreme heat [49]. Furthermore, the city council is also looking to additional adaptation efforts such as the interlinking of open spaces, the creation of cool spaces, the installment of more drinking fountains and awareness-raising measures, while Vienna's initiative also highlights the involvement of citizens of all ages, for example, through conferences, workshops, and quizzes. Curiously, the slogan for Vienna's adaptation initiative is 'Get Climate-Smart', and many small-scale adaptation efforts, such as community gardens, façade greening, infiltration of street water, vertical gardens and Vienna's first climate-adapted street, equipped with evaporative cooling arches, fall under the banner of the Smart City Wien Framework. Mocca et al. [58] argue that Vienna's Smart City framework bundles economic strategies with the environmental programs, which assured greater interdepartmental cooperation even though the administration is still mainly driven by means of a silo structure.

Biesbroek et al. [59] have analyzed various barriers that hamper adaptation to climate change, under which only some are specifically and directly related to climate change adaptation: (1) The long-term impacts of climate change versus the short-term dynamics of politics and decision-making, (2) the reliance on scientific models to identify, understand, and communicate the problem and propose solutions and (3) the inherent uncertainties and ambiguities of climate change. The C40 Cities Climate Leadership Group reports that the most prominent types of challenges experienced by local authorities are (1) political and leadership challenges, (2) institutional, regulatory and legislative challenges, and (3) economic and financial challenges [57]. Here, institutional challenges relate, for example, to unclear responsibilities and failure of national policy to stimulate climate action. Table 1 below outlines some other examples of common challenges in adaptation to climate change and the Smart Environment dimension.

Table 1. Examples of common challenges in Smart Environment and adaptation to climate change.

Type of Challenge	Smart Environment	Adaptation to Climate Change	Possible Combined Solution
<i>Political</i>	Lack of prioritization [35]	Long-term impacts versus the short-term dynamic of politics [59]	Long-term strategy and vision, backed by legislation
<i>Institutional</i>	Lack of common framework and standardization [36]	Fragmented working by city agencies [57]	Common and integrated frameworks with a holistic approach
<i>Economic</i>	Environment undersized by economic issues [20]	Access to funding considered complex [27]	Clarification of funding schemes and alignment with climate targets
<i>Social</i>	Lack of awareness of benefits [8]	Desired lifestyle incompatible with climate action [57]	Involvement citizens through top-down and bottom-up approaches
<i>Technological</i>	Immaturity of the market [35]	Hesitation to invest in new technologies when not well-proven [57]	Creation of an innovation ecosystem
<i>Regional</i>	Unique historical development path of cities [11]	Generalization a challenge due to a unique configuration of factors and conditions [59]	Tailored local approaches (in the common framework) and experience-sharing

Source: Own elaboration based on references used in this article.

As climate impacts differ from city to city, there is no universally valid approach, neither for smart city initiatives nor for adaptation efforts. Vienna is an exemplary case in the sense of a holistic approach to the Smart City Wien framework, which integrates other economic and environmental strategies, even though there is still evidence of fragmented work processes across departments within the administration [58]. Barcelona made significant progress on the involvement of citizens and attempting to centralize cross-departmental collaboration through the Urban Service Infrastructure Boards, despite pointing out its complexity due to the fact that data are still often managed in isolation [41]. It remains to be seen to what extent Rotterdam will consolidate the upcoming Smart City framework with the existing adaptation strategy, but the declared importance of the connection between nature and technology in their adaptation efforts proves to be a good sign, while, for instance, the city is also involving its region through the Cleantech Delta and Food Delta collaboration initiatives [26]. In spite of the fact that access to EU funding needs to be less complex, funding mechanisms, such as the Horizon 2020 program, are increasingly linked with climate objectives [27,37]. Lastly, the three cities presented great focus on the involvement of the citizens, which is fundamental in Smart City approaches [60]. Awareness of climate change impacts in combination with an innovation ecosystem gives an insight in the possible outcome of a “grand vision of meaningfully linking the small enterprise that captures energy usage live data with a city council’s ambitions for meeting CO2 emission targets” [61] (p. 675), hence, also creating the basis for technological innovation in adaptation efforts.

In view of this, the use of technology to address environmental issues can be a double-edged sword affecting both adaptation to climate change and the concept of Smart City, although adaptation efforts do not always need to be based on a technological solution to make cities less vulnerable to climate impacts. On another note, cities depend on a complex network of critical urban infrastructure that needs to be upgraded and connected in the Smart City approach, due to which cities are potentially contributing to climate change. In the rush to become the smartest, and under the banner of economic growth, adaptation efforts are crucial for the early safeguarding of smart urban planning practices, which will make cities better prepared against climate hazards. Moreover, even if we need to design and develop more prepared cities to satisfy the needs of our modern societies, cities are confronted by many challenges in relation to urbanization, natural hazards, climate change, and their interactions. The concentration of people, assets, critical infrastructure, and economic activities exacerbates the potential of natural hazards and extreme weather events. This is why cities need to adapt on time and why there is a need to connect smart growth with adaptation.

4.2. Smart Sustainable Cities?

Smart City models also give way to criticism from an ecological perspective, as Colding and Barthel [22] note that ICT systems are still not resilient enough to avoid shocks and surprises, for example, when cyber security is not adequate enough, threatening citizen’s access to the basic necessities. Additionally, they argue that not everybody might benefit from the Smart City model, as there is a risk that some part of the population will get marginalized or that health issues could originate from the use of ICT. Finally, as stated by the authors, the much-needed connection from human to physical places, which is crucial to the shaping of environmentalist behaviors, might be in danger. Additionally, the Smart City concept can be used as a way to legitimize smart initiatives in the broader context of urban development, as the “(urban) environment, mediated through infrastructure and ICT, under the label of the Smart City, is increasingly being seen as a frontier for capital accumulation and circulation” [43] (p. 824). Joss et al. [55] also note that the environmental discourse in Smart Cities is often included due to the current global narrative of climate change, but it tends to get marginalized by the discourse of economic growth.

The notion of Smart Sustainable Cities is a relatively new concept and is needed because not all Smart City strategies are including the environment as a core element, while sustainability is neither well-defined within all Smart City frameworks [17]. Although there are many similarities between Smart Cities and Sustainable Cities, D’Auria et al. [62] state that people and nature are

central to the Sustainable City, whereas a Smart City could be achieved just by upgrading urban services. Furthermore, people are a component in the Smart City process while they are at the heart of Sustainable Cities. Additionally, the focus is more on innovation in the concept of Smart City, while the Sustainable City underpins resilience. Lastly, due to the current global narrative of climate change, the environment axis in the Smart City often relates to climate and energy, whereas the broader elements of sustainability and the urban environment, such as biodiversity, coastal protection, and water poverty, are barely considered [55].

With the UN taking the lead in promoting the combined concept of Smart City and Sustainable City, some criticism from environmentalists to the notion of Smart City, such as the risk of losing the human connection to physical places, might vanish in the concept of Smart Sustainable Cities, as these cities are sustainable per definition. However, there are still challenges to this new concept, as it is not yet widely accepted by stakeholders. For Smart Sustainable Cities to gain broad acceptance, there should be a focus on [17]: (1) Delivering assessment methods to ensure that Smart Sustainable Cities are indeed sustainable, (2) mitigating measures to ensure that infrastructure does not exploit natural resources and devastate ecosystems, (3) embracing the relationship between top-down and bottom-up approaches for exploration, (4) strengthening technological competences in the public sector and (5) improving interconnected governance at all levels.

On the whole, there is still much to be debated on Smart Sustainable Cities. Nevertheless, as many Smart City initiatives are still in the exploration phase, placing sustainability directly at the core of the model has the potential to create the adaptive and resilient cities needed in the current global context of climate change. The optimization of urban services through the use of technology by itself does not suffice to create more sustainable forms of urban development [63]. Therefore, Smart Environment should be placed at the foundation, upon which other initiatives in Smart Economy, Smart People, Smart Governance, Smart Mobility, and Smart Living are built.

5. Discussion

In this manuscript, we analyzed the role of adaptation to climate change in the concept of Smart City, and we showed that addressing climate impacts is indeed part of it in the form of Smart Environment or natural environment [18,19]. However, it is also argued that sustainability and urban resilience are not always at the core of the Smart City, as a city can be smart without taking the natural elements of the urban ecosystem into account [17,20,63]. Sometimes, the environment can be even used as a way of the attraction of capital and legitimization of Smart City initiatives [43]. There is still a considerable amount of focus on the economic aspects of the Smart City, as (international) competitiveness, leadership in innovation, and the contribution of ICT to GDP are all incentivizing factors for the development of Smart Cities.

Furthermore, we have outlined that the Smart Environment dimension and adaptation to climate change share common similarities, as they try to address the same vulnerabilities. Nonetheless, this does not mean they should be mixed up in urban development. A city can stimulate the introduction of green rooftops without the use of ICT, whereas using sensors to measure environmental indicators on itself is not sufficient to make a city more resilient to climate impacts, as data is meaningless until it fulfills a role in the decision-making process. Looking to the future, the technology used in adaptation to climate change has indeed the potential to make cities better protected against climate vulnerabilities, of which the Benthem Square in Rotterdam is a concrete example. However, the market for Smart Environment solutions is still immature, as a lot of these solutions are still in the early stages of development [35].

Besides the technological aspects of a Smart City, citizens are at the core of the city. Smart City policy-making should, therefore, aim to create a better quality of life for residents, whereas “integrated smart city strategies help urban citizens become more informed, participatory and networked than ever” [12] (p. 102). Different crises at the global level have played a key role in the levels of distrust and disaffection among citizens in recent years. The idea of an institutional and administrative opening,

based on digital media platforms, is advocated as a means of recovering legitimacy [60], therewith, abandoning the image of old-fashioned governance that has been distant from the citizen. Through open data systems, social media, and interactive applications, citizens obtain more knowledge on matters that affect their cities. By using open governance, city councils provide more transparency and stimulate active participation of citizens, who can also collaborate more in the city's decision-making processes [24]. This, however, will also require an additional emphasis on matters such as data privacy and security. Awareness of the benefits in the community is a shared need for both adaptation to climate change and the notion of Smart City, as visions on these matters can only be properly executed in the long-term. The involvement of citizens not only contributes to the innovation ecosystem but also has the potential to break the political challenge of short-term leadership. Given the right ecosystem in the city, citizens will play an important role by actively participating in the decision-making process and in the development and testing of new technologies that address sustainability and resilience efforts [12,13,24,61].

Looking back at the three analyzed cities, we have observed that a holistic approach to both Smart City strategies and adaptation to climate change is of vital importance, as integrated urban systems will make the governance of traditionally separate but interdependent urban services less complex and more efficient [30]. In the case of Vienna, we have found that adaptive cities can also benefit from the Smart City approach, as the Smart City Wien Framework has unified various separate initiatives under the Smart City umbrella [58], leading to a surge in funded Smart Environment projects [51,56]. Rotterdam is becoming more adaptive to climate hazards due to new technologies, which contribute to faster and more accurate decision-making in the struggle against sea-level rise [47]. Finally, Barcelona has clearly incentivized the involvement of citizens, enabling them to participate in the city's decision-making process, which resulted in the co-production of the new Climate Plan [39], the groundwork for the realization of a more adaptive city. Taking into account that these selected cities are forerunners on these matters, there is still a great amount of innovation on the horizon from other cities around the globe, which will, most probably, go beyond just the technology but will also include people and nature.

The Smart Sustainable City concept has the potential to become the holistic framework needed for this long-term view, but as public administrations and the private sector are already jumping into the notion of Smart City, it might be too late for the Smart Sustainable City concept to rise above the notion of Smart City and gain the wider acceptance of the two. Nevertheless, advancements in new technologies, especially in ICT, are occurring on such a rapid scale that there is no doubt that Smart City strategies will need continuous improvement to keep up with these dynamic changes. Therefore, as climate change impacts are also becoming inevitably more intense in the coming decades, Smart Cities might just naturally evolve into Smart Sustainable Cities, pushed by the need to create adaptive and resilient societies. On the contrary, due to the fact that the incorporation of technology in critical urban systems might even make Smart Cities more vulnerable to climate impacts, adaptation efforts are actually becoming essential to the unblemished development of Smart Cities, hence, adaptation to climate change could be the key to their robust functioning in the face of intensified climate adversities. The increased reliability on vast networks of smart infrastructure brings us to a crucial question: To what extent will smart infrastructure still be smart when exposed to climate impacts? As the effects of climate change could generate a sequence of adverse events in human subsystems that result in social, physical, and economic disruptions, adaptation measures should be incorporated in the Smart City approach from the start, so that cities are better protected against future climate shocks. Although the authors chose to specifically focus on adaptation efforts in cities, the matter is also very relevant beyond the city walls. For instance, deforestation due to wildfires, desertification of rural areas, and loss of land and sea biodiversity will have devastating consequences on the availability of natural resources and the continuity of certain urban services in cities around the globe. Thus, there is an urgent need to address these issues way beyond the city level, and it will be interesting to find

future research on these correlations, which would be another important step towards the shaping of adaptive, smart, and resilient communities.

6. Concluding Remarks

Smart Cities must be resilient cities, capable of adapting their urban environment to the current panorama of more intense climate impacts and pressured urban systems. Adaptation to climate change is an urgent need, and it is precisely the most modern cities that should be an example of this capacity to adapt. For a city to remain relevant in the future, the city leadership should strive to deliver the best quality of life for its residents, which includes seeking harmony with nature to ensure the stability and resilience of urban ecosystems. Prosperity, social stability, and economic opportunity will arise when citizens can enjoy life in their safe and sustainable hometowns.

This research analyzed the relation between the concept of Smart City and adaptation to climate change. We have outlined to what extent Smart Cities could be the key in the fight against climate change and also to what extent they provide the incentive to create adaptive, energy-efficient, and sustainable societies. Despite the fact that the development of Smart Cities is still to a good extent uncharted ground, there are indeed indicators that show that adaptation to climate change is part of the notion of the Smart City. Best practices from Vienna, Rotterdam, and Barcelona showed us that a holistic approach to Smart City frameworks in combination with the active involvement of citizens and its integration with other economic and environmental strategies can definitely enhance the interaction between nature and technology, which will contribute to making our cities more sustainable and resilient. Nevertheless, as the concept of Smart City encompasses so many different elements, prioritization on Smart Environment varies. For this reason, the introduction of smart initiatives with environmental outcomes is, generally speaking, a choice that is made by the city itself and often underpinned by an urgent need to address a certain climate vulnerability. Nonetheless, Smart Environment is definitely part of the whole lot, meaning that it is at least a focus area in Smart City strategies. Although there is still a lack of evidence to fully state that Smart Cities can provide the incentive to create sustainable, energy-efficient, and adaptive societies, adaptation efforts will be crucial to better protect critical smart infrastructure against intense climate impacts.

In spite of the various initiatives described in this manuscript, there is still a lack of widespread experiences, especially large-scale applications that involve adaptation to climate change in the Smart City. Future research, experimentation, and exploration will contribute to shaping a deeper understanding of this matter. Climate change is a fact, and there is no doubt that cities will play a distinctive role in the fight against it. In contrast to particular smart urban planning practices, climate change is a much more global occurrence that has impacts beyond the city walls, while still having consequences in the city itself. Imagine rising the cost of raw materials because rural areas are suffering from the impacts of climate change. A single Smart (Sustainable) City will not be enough to overcome these challenges, for which there is a need for a combined effort and a holistic approach for cities to be the key in the fight against climate change on a global scale. Nevertheless, if every city was to become a Smart Sustainable City, the pressure on the world's ecosystem would most certainly be reduced, thus creating adaptive, energy-efficient, and resilient societies.

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