NOVA SCHOOL OF SCIENCE & TECHNOLOGY
NOVAFCSH
FACULDADE DE CIÊNCIAS SOCIAIS E HUMANAS
UNIVERSIDADE NOVA DE LISBOA

DEPARTAMENTO DE CIÊNCIAS E ENGENHARIA DO AMBIENTE

DEPARTAMENTO DE GEOGRAFIA E PLANEAMENTO REGIONAL

Freshta Ahmadi
Bachelor's Degree in Urban Planning

Smart Cities and Climate Risk Mitigation and Adaptation: Smart Technologies and Strategies for Resilient Urban Development.

Master's Degree in Sustainable Urbanism and Territorial Planning

NOVA University Lisbon
⟨September⟩, ⟨2025⟩

DEPARTAMENTO DE CIÊNCIAS E ENGENHARIA DO AMBIENTE

DEPARTAMENTO DE GEOGRAFIA E PLANEAMENTO REGIONAL

Smart Cities and Climate Risk Mitigation and Adaptation: Smart Technologies and Strategies for Resilient Urban Development.

Freshta Ahmadi
Bacholer’s in Urban Planning

Advisor: Professor Dr, Ana Catarina Pinto de Sousa da Cruz Lopes,Assistant Professor, NOVA university Lisbon

Jury members :

Chair: Prof. Dr. José Carlos Ribeiro Ferreira, Associate Professor, NOVA University Lisbon

Examiner: Prof. Dr. José António Pereira Tenedório,Associate Professor,
NOVA University Lisbon

Member of the Jury: Professor Dr, Ana Catarina Pinto de Sousa da Cruz Lopes, Assistant Professor, NOVA university Lisbon

Master’s Degree in Sustainable Urbanism and Territorial Planning

NOVA University Lisbon
⟨September⟩, ⟨2025⟩

Smart Cities and Climate Risk Mitigation and Adaptation: Smart Technologies and Strategies for Resilient Urban Development.

Acknowledgments

I would like to express my sincere appreciation to the numerous individuals and institutions whose contributions were instrumental in the completion of my academic degree.

Foremost, I am eternally grateful to my family. Their unwavering belief in me, their profound sacrifices, and their steadfast encouragement from afar provided the emotional foundation and strength necessary to undertake this academic journey.

I am deeply indebted to my thesis supervisor, Prof. Dr. Ana Cruz Lopes, for her exceptional guidance, scholarly expertise, and continuous support throughout the research and writing process. Her insights were invaluable in shaping this work. I also extend my gratitude to Prof. Dr. José Carlos Ribeiro Ferreira, our program coordinator, for his support during this academic journey.

My appreciations extends to the distinguished faculty and administration of the MUSOT program at NOVA University Lisbon's Faculty of Science and Technology for providing a rigorous academic environment and granting me the opportunity to pursue this degree.

I also wish to specifically acknowledge the financial support provided by the Nexus organization. My special thanks to Dr. Helena Barroco for her leadership and to the entire Nexus team for their instrumental role in facilitating my studies.

I am profoundly thankful to the Government of Portugal for the educational opportunities that made this work possible.

Finally, this endeavor is dedicated to the countless Afghan women and girls persevering in their pursuit of knowledge. Their resilience amidst profound adversity is a powerful testament to the fact that building resilient futures is inextricably linked to the principles of hope, equity, and the fundamental right to education.

RESUMO

As cidades contemporâneas enfrentam riscos climáticos cada vez mais intensos, resultantes da combinação entre urbanização acelerada e alterações climáticas globais, que pressionam severamente as suas infraestruturas, sistemas sociais e ambientais. Este problema é particularmente complexo devido à dependência de soluções tecnológicas de grande escala, muitas vezes dispendiosas e de replicação difícil para municípios de média dimensão com recursos limitados, criando um vazio crítico entre as ambições climáticas e a capacidade de ação local. Perante este desafio, esta dissertação propõe que a resiliência climática eficaz depende menos da tecnologia em si e mais da sua integração estratégica .Através de uma revisão de literatura internacional e de um estudo de caso aprofundado do município de Cascais, Portugal, a investigação demonstra que o sucesso do modelo local materializado em elevadas taxas de implementação de medidas deriva de uma tríade fundamental: previsão científica robusta (através do PECAC), governação participativa (como o Fundo AdaptCascais) e inovação direcionada. Conclui-se que o conceito de cidade inteligente deve ser redefinido como um modelo de governação adaptativa e inteligente, onde a tecnologia serve como meio e não como fim, oferecendo um blueprint replicável que posiciona Cascais como um exemplo pioneiro para outras cidades costeiras enfrentarem pressões climáticas semelhantes.

Palavras-chave: Cidades inteligentes; Alterações climáticas; Resiliência urbana; Mitigação; Adaptação; Cascais; Governação participativa.

ABSTRACT

Contemporary cities face escalating climate risks, driven by the combined effects of rapid urbanization and global climate change, which exert immense pressure on urban infrastructure, social systems, and ecological networks. This problem is particularly challenging due to a prevailing overreliance on large-scale, capital-intensive technological solutions, which remain difficult to replicate for most cities, especially medium-sized municipalities with limited resources, thereby creating a critical gap between global climate ambitions and local implementation capacity. In response, this dissertation argues that effective climate resilience depends less on technology itself and more on its strategic integration. Through an international literature review and an in-depth case study of Cascais, Portugal, the research demonstrates that the municipality's success, reflected in high implementation rates of climate actions, stems from a foundational triad: scientific foresight (as established in the PECAC), participatory governance (exemplified by the AdaptCascais Fund), and targeted innovation. The study concludes that the smart city concept for climate resilience must be redefined as a model of adaptive and intelligent governance in which technology serves as an enabler rather than an end in itself. Cascais thus offers a replicable blueprint, demonstrating how medium-sized municipalities can pioneer pragmatic and strategic pathways to address mounting climate pressures.

Keywords: Smart cities; Climate change; Urban resilience; Mitigation; Adaptation; Cascais; Participatory governance.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AI	Artificial Intelligence
BEMS	Building Energy Management System
CEA	City Energy Analyst
CMC	Cascais Municipal Council (Câmara Municipal de Cascais)
CO_2	Carbon Dioxide
EWS	Early Warning System
GIS	Geographic Information System
GHG	Greenhouse Gas
ICT	Information and Communication Technology
IPCC	Intergovernmental Panel on Climate Change
IoT	Internet of Things
IDEAS	Integrated Data and Electronic Alerts System
MaaS	Mobility as a Service
NO_2	Nitrogen Dioxide
NLP	Natural Language Processing
NRW	Non-Revenue Water
PA^3C^2	Climate Adaptation Action Plan for Cascais 2030 (Plano de Ação para a Adaptação às Alterações Climáticas de Cascais 2030)
PAYT	Pay-As-You-Throw
PECAC	Strategic Plan for Cascais in the Face of Climate Change (Plano Estratégico de Cascais face às Alterações Climáticas)
PMAC2	Municipal Climate Action Plan of Cascais (Plano Municipal de Ação Climática de Cascais)
PESA	Environmental Education and Awareness Program (Programa de Educação e Sensibilização Ambiental)
SDGs	Sustainable Development Goals
SLR	Sea-Level Rise
SWM	Smart Water Management
UDT	Urban Digital Twin
UHI	Urban Heat Island
UNDRR	United Nations Office for Disaster Risk Reduction

VGI	Volunteered Geographic Information
VPP	Virtual Power Plant
WWAN	Wireless Wide Area Network
WRF	Weather Research and Forecasting

Chapter 1

Introduction

Cities serve as the foundation of human civilization, providing shelter, economic opportunities, and social infrastructure for millions of people. Yet rapid urbanization, coupled with accelerating climate change, has intensified their vulnerabilities. Urban settlements globally face a heightened and complex threat from climate change, confronting a multifaceted spectrum of acute and chronic risks that include not only extreme heatwaves, intensified storm events, and extreme precipitation, but also cascading and compound impacts such as inland flooding from heavy rainfall, coastal inundation from sea-level rise and storm surges, prolonged droughts, and acute water scarcity, which collectively jeopardize critical infrastructure systems, disrupt essential service delivery, exacerbate existing social inequities, and pose severe consequences for human health, livelihoods, and economic stability, with the most severe impacts falling disproportionately on economically and socially marginalized urban residents (IPCC, 2022).

This accelerating threat pattern necessitates a fundamental shift in urban governance and planning towards developing climate-smart cities. Consequently, this thesis argues that building effective urban resilience is contingent upon a dual strategy: it depends not only on integrating smart city technologies, such as distributed sensor arrays, advanced computational analysis, and interconnected digital communications, to mitigate emissions and enable proactive adaptation (Bibri & Krogstie, 2017; Allam & Newman, 2018), but also on the concurrent integration of sustainable spatial and ecological strategies, including nature-based solutions and part historical legacy has created participatory governance (IPCC, 2022; UN-Habitat, 2022). This synergistic approach is fundamental to safeguarding critical civic infrastructure and building truly resilient urban futures.

1.1 Objectives

This thesis examines the intersection of smart city development and climate resilience, with a focus on the municipality of Cascais, Portugal. Its primary objective is to examine how smart city strategies contribute to climate change mitigation and adaptation in urban environments by analyzing the role of digital technologies and spatial planning tools in enhancing urban resilience. The study will evaluate international smart city initiatives to identify best practices and extract transferable lessons for the Portuguese context. Based on this analysis, the research will conclude by offering strategic recommendations, identifying persistent implementation challenges, and formulating actionable insights for similar cities facing escalating climate threats.

1.2 Methodology

This thesis adopts a qualitative case study methodology to investigate how smart city strategies and technologies support climate risk mitigation and adaptation. The study emphasizes document-based analysis, drawing from academic literature, policy reports, and planning documents to examine both the technological and governance dimensions of smart urbanism in enhancing climate resilience. It begins with an extensive literature review to establish the theoretical framework for understanding the role of smart cities in addressing climate change. This review synthesizes scholarly publications, international climate strategy documents, and smart city assessments to identify key concepts, emerging technologies, and policy approaches relevant to sustainable urban development.

The core of the study is an in-depth case analysis of Cascais, Portugal. This phase relied primarily on document-based analysis, examining official planning instruments such as the Municipal Master Plan (*Plano Diretor Municipal*), the Climate Action Plan (PA^3C^2), strategic reports, and publicly available datasets from the municipality. This provided critical insights into the local implementation of smart technologies and spatial planning frameworks designed to respond to climate-related challenges.

A comparative perspective was integrated by examining international smart city initiatives selected for their innovative approaches to climate adaptation and mitigation. This benchmarking exercise contextualizes the findings from Cascais within a broader global landscape of urban resilience practices.

The ultimate objective of this methodological approach is to formulate a critically informed set of strategic recommendations. These aim to contribute to a more effective, integrated, and replicable model for smart climate governance in coastal cities, focusing on enhancing resilience through technological innovation, participatory governance, and sustainable spatial planning.

1.3 Organization of the document

This thesis is organized into five chapters. Chapter 1 outlines the background, research objectives, methodology, and structure of the document. Chapter 2 presents a review of relevant literature on urban development, smart cities, climate risks, and the role of smart cities in climate change mitigation and adaptation, with examples of successful initiatives from around the world. Chapter 3 introduces the case study of Cascais, examining its smart city initiatives in the context of climate resilience. Chapter 4 analyzes and discusses the findings in relation to the existing literature. Finally, Chapter 5 concludes the thesis by presenting key insights and offering strategic recommendations for urban policy and planning.

Chapter 2

Litreature review

2.1 The historical progression of urban development

Understanding the modern concept of the smart, climate-resilient city necessitates a thorough examination of the evolution of urban settlements. Cities are not static entities; they are dynamic systems that have continuously transformed in response to technological revolutions, social organizations, and environmental pressures (Mumford, 1961). This historical perspective is crucial, as the very infrastructure, spatial layouts, and socio-economic vulnerabilities of contemporary cities are legacies of their past (IPCC, 2022).

This section traces this evolution to establish a foundational context for analyzing current urban challenges. It begins by exploring the origins of urbanism in ancient societies before examining the radical transformation triggered by the Industrial Revolution. This period marked a pivotal shift, as cities became engines of economic production but also of unprecedented pollution, social inequality, and systemic disconnection from natural systems, structural legacies that continue to exacerbate climate vulnerability today (Davis, 2006).

This historical arc culminates in the 21st century, where the dual pressures of rapid urbanization and climate change have catalyzed the rise of new urban paradigms (UN-Habitat, 2020). The industrial city, once a paramount symbol of progress, is now being reimagined through the lens of the "smart" city. This contemporary model proposes leveraging digital technology, data-driven governance, and ecological design to mitigate environmental impacts and enhance adaptive capacity. Ultimately, by examining this progression, this section provides the critical background needed to assess whether smart cities represent a genuine transformation in urban development or merely a technological layer applied to persistent historical challenges.

The early humans initially relied on natural shelters, such as caves, for protection against predators and harsh climates. A pivotal shift occurred with the Neolithic Revolution (~10,000 BCE), when the advent of agriculture enabled the establishment of permanent settlements (Childe, 1950). One notable example of an early settlement that was not a true city is Çatalhöyük in present-day Turkey, characterized by densely clustered dwellings accessible via rooftops and intramural burials, which reflect strong social cohesion and ancestral veneration (Hodder, 2006).

While Neolithic settlements like Çatalhöyük demonstrated early social complexity, Childe (1950) defines true urbanism through ten revolutionary criteria, of which five are most relevant: unprecedented population density (7,000-20,000 inhabitants), full-time occupational specialization, monumental public architecture (such as temples and ziggurats), writing systems, and class stratification. These emerged in Mesopotamia, Egypt, and the Indus Valley (3500-3000 BCE) through agricultural surpluses enabled by irrigation and centralized redistribution systems (Childe, 1950).

The earliest urban empires developed in Mesopotamia during the Bronze Age (3000–1200 BCE), where prominent city-states like Ur and Babylon flourished due to sophisticated agricultural techniques and advancements in bronze production (Van De Mieroop, 2016). These technological innovations facilitated the growth of extensive trade networks, connecting distant regions from the Indus Valley to the Mediterranean. Through these connections, essential materials such as tin and copper were exchanged, alongside luxury goods like lapis lazuli. However, this thriving urban system experienced a significant decline around 1200 BCE. Severe droughts weakened agricultural productivity, while invasions by groups such as the Sea Peoples further destabilized vulnerable cities. The subsequent Iron Age (1200–500 BCE) saw the emergence of new urban powers, including the Assyrians, who built imposing imperial capitals like Nineveh, and the Phoenicians, who developed extensive maritime trade routes and established colonies such as Carthage. These civilizations laid the groundwork for the urban models that would later dominate the classical era (Van De Mieroop, 2016).

Classical antiquity produced three distinct urban forms, each reflecting its society's priorities. Greek cities grew organically around the agora, their irregular layouts embodying democratic values and adaptation to the landscape. In contrast, Roman planners enforced uniformity with rigid grid systems (castrum), prioritizing military logistics and imperial control. Persian rulers, however, designed capitals as theatrical displays of power, using colossal processional routes and elevated palaces to dominate the urban landscape. These models, the flexible Greek democracy, systematic Roman order, and monumental Persian authority they still shape cities today (Kostof, 1991).

The next period of urbanism is medieval urbanism (500-1500CE). Mumford (1961) describes medieval cities as deeply influenced by feudal and religious structures. Unlike the rigid order of classical cities, medieval cities grew organically around key institutions such as cathedrals, castles, and market squares, reflecting a society where spiritual and local governance held significant influence. Streets followed natural pathways rather than geometric plans, prioritizing defense and communal needs over formal design. Cities like Bruges and Venice thrived through guild-based economies, where trade and craftsmanship were tightly regulated by local associations rather than centralized authority.

Mumford (1961) also emphasizes that these cities, while often crowded and unsanitary, maintained a strong sense of communal identity. Walls were not just defensive but symbolic, marking the boundary between urban and rural life. The medieval city was a place of collective memory, where architecture, processions, and public rituals reinforced social cohesion.

In Mumford's view, the early modern period marks a shift toward cities as tools of state power and economic expansion. The Renaissance revival of classical ideals brought a return to geometric planning, but now in the service of absolutist monarchs and mercantile empires. Cities like Palmanova (Italy) and colonial ports (Mexico City) were designed to project authority whether through star-shaped fortifications or grid layouts imposed on conquered territories.

Mumford critiques this era for prioritizing control over organic growth. The rise of centralized states and global trade networks turned cities into nodes of exploitation, where wealth extraction and social stratification intensified. While some cities became hubs of art and learning, others reflected the darker side of early capitalism, with slums growing alongside grand palaces.

Cities have always reflected the technology, culture, and challenges of their time. In the pre-industrial era, cities were small, walkable, and centered around the markets and religious sites. Life was communal, with strong social ties despite limited infrastructure (Mumford, 1961).

The next urban evolution that had a major impact on urban history is the Industrial Revolution. During the Industrial Revolution, factories drew large numbers of workers into cities, resulting in overcrowded slums, pollution, and extreme social inequality (Engels, 1845). Later, urban thinkers like Jane Jacobs (1961) criticized how subsequent top-down planning paradigms destroyed the organic community life that had characterized older urban neighborhoods. The legacy of this approach continued with the deindustrialization of the 20th century, which left many urban cores economically hollowed out. Urban renewal projects from this era frequently displaced vulnerable residents without providing equitable alternatives, a process that has been critically documented by urban scholars (Fullilove, 2016).

The period of industrial urbanization fundamentally reconfigured the social and physical fabric of the city. As chronicled by Engels (1845), the relentless draw of factory labor catalyzed a massive and unplanned migration into urban centers, resulting in severely overcrowded slums, profound environmental pollution, and unprecedented levels of social inequality. This new industrial city prioritized production and profit over human well-being, resulting in a stark urban landscape previously unknown in prior eras. Decades later, the legacy of this disruptive model was powerfully critiqued by urbanists like Jane Jacobs (1961). She argued that the subsequent mid-20th-century planning ethos, which favored large-scale clearance and automobile-centric design, further destroyed the organic, community-based fabric that had characterized older urban neighborhoods, severing the social ties and intricate street life that fostered urban vitality.

The profound social and physical disruptions initiated by industrialization did not end with the decline of the factory. Instead, they set the stage for the next major urban crisis: deindustrialization. The flight of manufacturing capital in the latter half of the 20th century left many industrial cities economically hollowed out, grappling with massive job losses and a shrunken tax base. In this context of decline, the well-documented failures of urban renewal projects became particularly devastating. As Fullilove (2004) analyzes, these top-down redevelopment initiatives frequently displaced vulnerable, often minority, residents without providing equitable alternatives, further fracturing communities and exacerbating spatial injustice. This transition from an industrial to a post-industrial economy thus represents a critical pivot point, marking the shift from a city of concentrated production to one facing the challenges of economic transition, social fragmentation, and the search for a new identity, a search that would eventually give rise to the contemporary paradigms of the smart and sustainable city.

The smart city embodies a central paradox: it employs advanced technology to govern urban forms with deep historical roots. Its core systems often function as digital adaptations of ancient templates. For example, the smart grid is a direct successor to the classical Roman grid, swapping geometric spatial control for digital energy management while maintaining an identical principle of centralized systemic order.

This technological inheritance is complicated by the accumulated historical layers the smart city must now administer. It is constructed upon the very physical and social fabric of the industrial city, seeking to remediate the persistent landscape of inequality, environmental degradation, and post-industrial decline it inherited. Consequently, its climate-resilience objectives are a direct response to vulnerabilities cemented in the 19th century.

Simultaneously, the smart city faces a profound social challenge: to cultivate the organic, community-centric resilience reminiscent of the medieval city, while avoiding the destructive, top-down approaches that characterized later urban renewal. Therefore, the smart city does not represent a clean break from history. Rather, it constitutes a new technological stratum that attempts to optimize, and at times reconcile, these enduring and often contradictory urban legacies.

This historical progression demonstrates that the evolution of the city is fundamentally a story of adaptation to prevailing economic, technological, and social forces. Each era, from the agrarian revolutions of antiquity to the industrial explosion of the nineteenth century, bequeathed a distinct urban form, yet also generated new and often more complex vulnerabilities. The Industrial Age, in particular, established a legacy of environmental disregard and socioeconomic inequality that remains deeply embedded in the urban fabric. Today, this legacy converges with a new, unprecedented force: global climate change. The historical challenges of density, sanitation, and equity are now exponentially amplified by climate risks, demanding a radical rethinking of urban resilience. It is therefore imperative to now examine the specific nature of these climate threats, which form the critical focus of the next section.

2.2 Climate Change and Urban Risk Framework

2.2.1 The Global Climate Challenge

Anthropogenic climate change represents a paramount challenge for contemporary urban governance, a predicament deeply rooted in the industrial history of cities themselves. The modern urban form, characterized by its dense concentration of population and infrastructure, is a product of 19th and 20th-century development models that were intrinsically reliant on fossil fuels for manufacturing, energy generation, and transportation. This historical legacy has created a significant path dependency, locking metropolitan regions into high-emission systems. Consequently, although cities occupy only a small percentage of the world's landmass, they are responsible for an estimated 70% of global energy-related greenhouse gas emissions, presenting a profound challenge for decarbonization due to entrenched infrastructural and socio-technical regimes (UN-Habitat, 2022).

According to the Intergovernmental Panel on Climate Change (IPCC, 2023), climate change is defined as a long-term shift in the state of the climate, characterized by changes in the mean and/or variability of its properties that persist for decades or longer. This shift is empirically demonstrated by atmospheric carbon dioxide (CO_2) concentrations exceeding 420 parts per million, a level unprecedented in human history, which has driven a global average temperature increase of approximately 1.1°C above pre-industrial levels. This warming is unequivocally attributable to human activity, specifically the combustion of coal, oil, and natural gas. The situation is further exacerbated by positive feedback mechanisms; for instance, warming oceans have a reduced capacity to act as carbon sinks, and melting polar ice caps diminish the Earth's albedo effect, leading to greater absorption of solar radiation (National Academies of Sciences, Engineering, and Medicine, 2020).

These systemic climatic alterations are not future projections but present-day realities with disruptive and pervasive consequences. One of the most visible impacts is sea-level rise, with global mean sea level increasing by 20–24 centimeters since 1900. The rate of this rise is accelerating due to the rapid melting of the Greenland and Antarctic ice sheets, posing an existential threat to coastal urban centers through increased inundation, salinization of freshwater sources, and erosion (IPCC, 2023).

Furthermore, the intensification of the hydrological cycle is generating more frequent and severe compound extreme weather events. Urban centers are increasingly confronted with the paradox of simultaneous droughts and extreme precipitation, phenomena that routinely exceed the capacity of conventional water management infrastructure. The synergistic effects of these impacts extend far beyond environmental degradation, introducing severe systemic risks to global economic stability, public health, and food security. This convergence of threats ultimately constitutes one of the most comprehensive challenges faced by contemporary human civilization. Understanding the potential for damage from these global changes requires moving from planetary-scale trends to a conceptual model that explains how hazards become disasters: the framework of climate risk.

2.2.2 Defining Climate Risk

The broad patterns of global climate change manifest locally through the critical lens of climate risk, which determines the severity of impacts on human and ecological systems. Climate risk emerges not from a climatic hazard in isolation, but from the convergence of such a hazard with susceptible communities and assets. According to the Intergovernmental Panel on Climate Change (IPCC, 2022), risk is formally defined as the potential for adverse consequences where a climate-related event interacts with conditions of vulnerability and exposure. The extent of climate risk depends on three interconnected factors:

- Hazard: Refers to the climate-related event with potential to cause harm, such as a heatwave, tropical cyclone, or progressive sea-level rise (IPCC, 2022).
- Exposure: Involves the presence of people, infrastructure, housing, production capacities, or other tangible assets in zones that can be affected by hazards (IPCC, 2022).
- Vulnerability: Includes the conditions caused by physical, social, economic, and environmental factors that raise the risk of harmful effects from hazards; examples include fragile infrastructure, economic inequality, and weak governance systems (IPCC, 2022).

These components form the widely recognized risk equation, expressed as:

Risk = Hazard × Exposure × Vulnerability (UNDRR, 2017).

This formulation illustrates that a powerful hazard, such as a Category 5 hurricane, may pose minimal risk if it occurs over an unpopulated area, whereas a less intense event can produce disastrous outcomes if it affects an exposed and vulnerable population, such as a densely settled informal urban settlement with inadequate drainage and low adaptive capacity.

Climate risks can also be classified temporally The temporal scale and systemic nature of climate risks necessitate a nuanced classification framework to inform effective preparedness and response strategies, where acute risks materialize through sudden-onset events including floods, storms, and wildfires that inflict immediate damage to lives and infrastructure within abbreviated timeframes; chronic risks evolve incrementally from sustained climatic shifts such as desertification, permafrost thaw, or sea-level rise, progressively eroding ecological integrity and socio-economic stability over years or decades; and cascading risks the most complex category involve interconnected sequences where an initial climate hazard, such as severe drought, sets off a chain of secondary disasters across linked systems, for example, triggering agricultural collapse, which subsequently leads to economic instability, food scarcity, and forced migration, ultimately exacerbating urban service demand and social unrest (UNDRR, 2017).

While this risk framework applies universally, its components are powerfully intensified in urban settings, where urbanization processes significantly magnify exposure and vulnerability, thereby dramatically elevating overall climate risk.

2.2.3 Urbanization as a Risk Amplifier

Urban areas are epicenters of concentrated climate risk due to the interplay of high exposure and deeply embedded vulnerabilities. With over half the global population residing in cities, a proportion expected to grow to nearly 70% by 2050, human exposure to climatic Hazards is increasingly an urban exposure (United Nations, 2022). The very fabric of the city amplifies this risk through several mechanisms:

First, the physical infrastructure of urban areas significantly increases exposure and vulnerability. Widespread impermeable surfaces, such as concrete and asphalt, prevent natural water absorption, dramatically increasing surface runoff and flood risk during heavy precipitation events (IPCC, 2022). Second, the built environment often contains inherent vulnerabilities. Globally, a vast stock of aging buildings was constructed before modern climate resilience codes were established, making them highly susceptible to damage from events like heatwaves and floods (Global Alliance for Buildings and Construction, 2021).

Perhaps the most significant amplifier is socio-economic vulnerability. Urban areas are frequently characterized by stark inequalities. Marginalized populations are often forced into the most hazard-prone areas, such as floodplains or steep slopes, while simultaneously having the least capacity to prepare for, respond to, and recover from disasters due to limited financial resources and political power (Hallegatte, Rentschler, & Walsh, 2018; UN-Habitat, 2022). This convergence of high physical exposure and high social vulnerability creates a potent recipe for disaster when a climate hazard strikes.

It is precisely this amplification of urban climate risk that has catalyzed the emergence of the smart city model, which proposes leveraging technology and data-driven governance to systematically reduce exposure and vulnerability, a paradigm that will be explored in the following section.

2.2.4 Smart Cities as a Risk Mitigation Paradigm

Confronted with the dual pressures of global climate change and localized risk amplification, urban planners and policymakers are increasingly turning to the model of the smart city as a strategic response to these challenges. This paradigm represents a fundamental shift from the industrial-era city, which prioritized economic growth often at the expense of environmental costs, toward a model that seeks to integrate sustainability, resilience, and quality of life through technological and governance innovations (Bibri & Krogstie, 2017).

The smart city framework provides a proactive approach to addressing climate risk by strategically deploying digital technologies for enhanced monitoring and resilience. This approach, as detailed in the synthesis by Samarakkody et al. (2023), is built upon three key technological pillars:

- **IoT Sensor Networks:** Dense networks of sensors (e.g., flood, seismic, air quality, and weather sensors) are critical for capturing real-time information on environmental conditions and potential vulnerabilities before a catastrophic failure occurs.
- **Big Data Analytics:** Advanced analytics are essential for examining large, multi-source disaster-related datasets in real-time. This enables descriptive, predictive, and prescriptive insights, transforming raw data into actionable information for early warning and informed decision-making throughout the disaster management cycle.
- **Integrated Communication Systems:** Robust and resilient communication infrastructures, including Wireless Wide Area Networks (WWAN) and satellite communication, are fundamental. They interconnect sensing devices and ensure continuous data flow and crisis management services, even when terrestrial networks are compromised, thus preventing the failure of the entire monitoring system during a disaster.

Furthermore, it aims to reduce exposure through data-driven land use planning and predictive modeling that prevents new development in high-risk zones. Crucially, it seeks to diminish vulnerability by enhancing the resilience of critical infrastructure, including smart grids and adaptive water management systems, and by utilizing digital platforms to foster more participatory governance and improve service delivery to vulnerable communities (Angelidou et al., 2018).

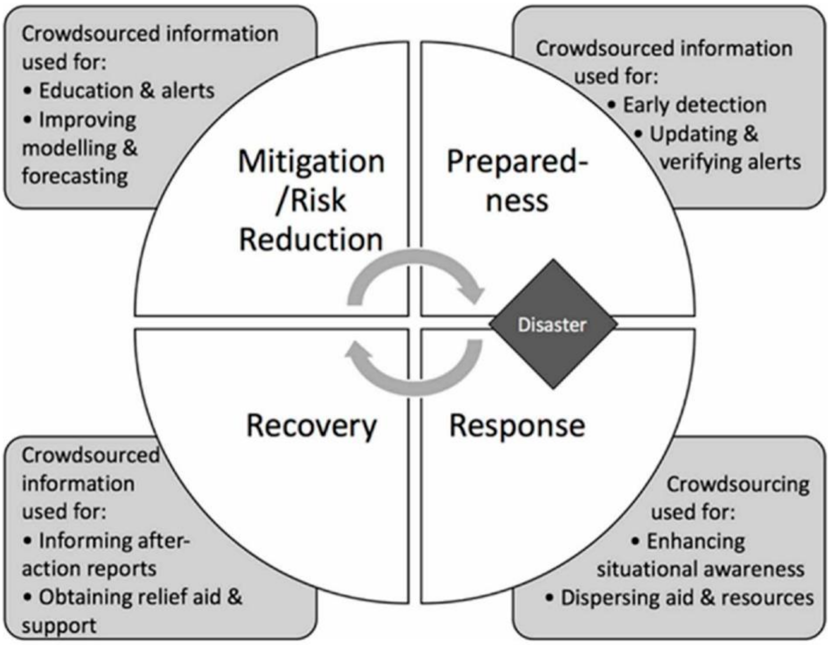


Figure 2-1: Crowdsourcing for the disaster management cycle.

(Adapted from Harrison & Johnson, 2016, as cited in Samarakkody, Amaratunga, & Haigh, 2023)

In essence, the smart city concept is being advanced as a comprehensive toolkit for urban climate adaptation and mitigation. It positions technology not as an end in itself, but as a means to build more informed, agile, and ultimately more resilient urban systems capable of managing the complex risks of the 21st century. To fully understand the potential and scope of this approach, it is first necessary to establish a clear definition of the smart city concept and examine its core components.

2.3 Smart Cities

A smart city functions as an integrated urban environment where digital infrastructure is seamlessly woven into the fabric of municipal management. This model utilizes a network of connected devices and data analytics (IoT) to optimize resource allocation, streamline public services, and foster a more responsive civic ecosystem. The ultimate objective of this technological integration extends beyond mere operational efficiency; it is fundamentally aimed at promoting inclusive socio-economic benefits and ensuring long-term environmental health. True smart urbanism is therefore defined by this dual commitment to technological innovation and sustainable, equitable development, guaranteeing that progress today does not come at the expense of future generations (ITU, 2016).

The term "smart city" has undergone a significant conceptual transformation since its emergence in the 1990s. This evolution reflects broader shifts in urban policy, technological capabilities, and scholarly criticism, moving from a narrow technocentric vision to a comprehensive urban development paradigm.

The historical development of the smart city concept can be understood through three distinct phases that illustrate its progressive maturation and expanding scope.

- **Phase 1: Technological Foundations and Conceptual Origins (1990s)**

The concept of the "smart city" first gained significant traction as a distinct urban development strategy in the 1990s, with a primary focus on information and communication technologies (ICT) as drivers of urban innovation. During this formative period, organizations such as the California Institute for Smart Communities pioneered research into how digital technologies could be integrated into urban infrastructure to improve municipal services and operational efficiency (Albino, Berardi, & Dangelico, 2015). This technologically oriented approach understood urban intelligence principally through the lens of computational systems and digital networks.

This initial technological focus soon generated scholarly critique, particularly from governance experts who argued that it overlooked essential social dimensions of urban development. Researchers at the Center for Governance at the University of Ottawa have notably contended that effective urban development requires greater attention to social capital and community relations, alongside technological implementation (Albino et al., 2015). This critical perspective established a crucial counterpoint to the prevailing technocratic vision, underscoring the need for a more balanced approach to urban innovation.

- **Phase 2: Term Proliferation and Corporate Adoption (2000-2010)**

The early 2000s saw the rapid popularization of the "smart city" concept as both an urban development strategy and a marketing phenomenon. During this period, the concept gained mainstream traction through corporate initiatives such as IBM's "Smarter Cities" campaign, which conceptualized smart urban environments as "instrumented, interconnected, and intelligent" systems (Harrison et al., 2010, as cited in Albino et al., 2015). This corporate vision emphasized technological solutions for urban management through the use of sensors, data integration, and analytical systems, representing a predominantly top-down, technology-driven approach to urban development.

Concurrently, several large-scale urban developments attempted to implement this comprehensive technological vision. South Korea's Songdo International Business District, developed from 2001 onwards, represented an ambitious attempt to create a fully integrated smart environment from inception, featuring ubiquitous telecommunications infrastructure and building-integrated monitoring systems (Shwayri, 2013). These developments embodied the technological optimism characteristic of this phase while also demonstrating the practical challenges of implementing comprehensive smart city visions.

This period also generated significant critical responses from urban scholars, who questioned the substantive meaning behind the "smart city" label. Researchers such as Hollands (2008) argued that the concept risked becoming an empty marketing slogan that obscured more fundamental urban inequalities and political questions (as cited in Albino et al., 2015). This criticism reflected growing concerns about the corporate orientation of smart urbanism and its potential to prioritize technological solutions over social equity and justice.

- **Phase 3: Holistic Integration and Critical Synthesis (2010-Present)**

The most recent phase in the evolution of the smart city concept has been characterized by conceptual expansion and critical reassessment. Academic researchers developed comprehensive frameworks that moved beyond technological determinism to incorporate multiple dimensions of urban life. The seminal work of Giffinger et al. (2007) established a six-dimensional model identifying smart economy, smart mobility, smart environment, smart people, smart living, and smart governance as essential components of smart urban development. This framework represented a significant conceptual advancement by recognizing that technological innovation alone could not constitute urban smartness.

Table 2-1: The smart cities' 6 key areas of smartness.

Adapted from Giffinger et al. (2007)

Dimension	Key Factors
SMART ECONOMY (Competitiveness)	• Innovative spirit • Entrepreneurship • Economic image & trademarks • Productivity • Flexibility of the labor market • International embeddedness • Ability to transform
SMART PEOPLE (Social Capital)	• Level of qualification • Affinity to lifelong learning • Social and ethnic plurality • Flexibility • Creativity • Cosmopolitanism/Open-mindedness • Participation in public life
SMART GOVERNANCE (Participation)	• Participation in decision-making • Public and social services • Transparent governance • Political strategies & perspectives
SMART MOBILITY (Transport & ICT)	• Local accessibility • International accessibility • Availability of ICT infrastructure • Sustainable, innovative and safe transport systems
SMART ENVIRONMENT (Natural Resources)	• Attractiveness of natural conditions • Pollution • Environmental protection • Sustainable resource management
SMART LIVING (Quality of Life)	• Cultural facilities • Health conditions • Individual safety • Housing quality • Education facilities • Touristic attractiveness • Social cohesion

> This period also saw substantial critique of corporate-led smart city initiatives, with scholars like Greenfield (2013) arguing that technocratic approaches often neglected the complex social realities of urban life (Albino et al., 2015). The contemporary understanding of smart cities has consequently evolved to emphasize the synergistic combination of technological infrastructure, human capital, and institutional frameworks working to enhance urban sustainability and quality of life. This holistic perspective recognizes that true urban intelligence emerges from the effective integration of multiple systems and stakeholders rather than from technological implementation alone.

The evolution of the smart city concept shows a progressive expansion from technological experimentation toward a multifaceted urban development paradigm. This journey reflects growing recognition that sustainable urban futures require the integration of technical, human, and institutional dimensions in pursuit of more equitable and responsive cities (Giffinger et al., 2007; Albino et al., 2015). The concept continues to evolve as cities worldwide experiment with different approaches to balancing technological innovation with social equity and environmental sustainability. This holistic understanding of urban development has positioned smart cities as crucial vehicles for improving the United Nations Sustainable Development Goals (SDGs), mainly through their potential to address complex urban challenges while promoting inclusive and sustainable growth.

2.4 Smart Cites Alignment with Global Sustainability Framework

The development toward multidimensional smartness aligns with the United Nations' 2030 Agenda for Sustainable Development, a universal call to action adopted by all member states in 2015. This agenda is operationalized through 17 Sustainable Development Goals (SDGs), which are "an integrated framework that recognizes that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth, all while tackling climate change and working to preserve the oceans and forests" (United Nations, 2015).

Smart city technologies serve as a critical operational tool for achieving these goals. They directly support SDG 11 (Sustainable Cities and Communities) through improved urban planning and management, while contributing to SDG 13 (Climate Action) through emissions monitoring and reduction capabilities. Real-time monitoring systems enable more efficient energy distribution (advancing SDG 7) and water management (supporting SDG 6), while participatory digital platforms can enhance governance transparency (relating to SDG 16).

However, this alignment requires conscious effort. As UN-Habitat (2022) emphasizes, technological solutions only achieve their full potential when deployed equitably. Without inclusive governance and safeguards against digital exclusion, smart city investments risk exacerbating existing urban inequalities, which directly contradict SDG 10 (Reduced Inequalities) and undermine the inclusive aspirations of SDG 11. The most successful smart city initiatives, therefore, strike a balance between technological innovation and social consciousness, creating urban environments that are not only more efficient but also more equitable and responsive to human needs.

This foundational understanding of smart cities, grounded in their historical evolution and alignment with global sustainability imperatives, provides the necessary context for examining their practical application. The following section will analyze the specific strategies and technologies through which smart cities operationalize this potential for both climate change mitigation and adaptation.

Figure 2-2: SDGs Goals.

Resource:https://unosd.un.org/content/sustainable-development-goals-sdgs

2.5 Smart Cities and Climate Risk Mitigation and Adaptation

In recent years, climate-related events have intensified, posing severe challenges for urban environments worldwide. Characterized by high population density and complex infrastructure, cities face disproportionate exposure to the effects of climate change, including extreme temperatures, urban flooding, sea-level rise, and resource scarcity. Concurrently, urban areas are significant contributors to global greenhouse gas emissions, embodying a dual role as both drivers and victims of the climate crisis (Revi et al., 2014).

To address these issues, the smart city model has emerged as a prominent approach that leverages technological advancements, data analytics, and integrated urban planning to develop the sustainability, efficiency, and resilience of urban systems. While often associated with digital service enhancement, smart cities are increasingly being explored for their capacity to mitigate and adapt to climate-related threats. Technologies such as the Internet of Things (IoT), Geographic Information Systems (GIS), intelligent transportation networks, and Artificial Intelligence (AI) enable cities to implement more adaptive and responsive risk management strategies (Allam & Newman, 2018).

This section of the literature review explores the current academic discourse on smart cities in the context of climate resilience. It specifically examines how smart city technologies and strategies can support both the mitigation of climate risks by reducing emissions and environmental impact, as well as adaptation to those risks by enhancing the ability of urban systems to absorb, recover from, and prepare for future climate events.

2.5.1 Smart Cities' role in Climate Risk Mitigation

Climate risk mitigation encompasses strategies aimed at reducing or preventing greenhouse gas emissions to limit the magnitude of future climate change. In urban environments, these strategies include transitioning to low-carbon energy systems, enhancing building energy efficiency, promoting sustainable transportation, and integrating digital technologies for evidence-based policymaking. The smart city model provides a robust framework for implementing these measures, leveraging real-time data, digital infrastructure, and integrated systems to optimize urban operations for sustainability and efficiency (IPCC, 2022). This section examines the principal smart city strategies and technologies that contribute to climate change mitigation.

2.5.1.1 Smart Energy Systems

Smart energy systems aim to reduce greenhouse gas emissions by transforming how cities produce, distribute, and utilize energy. As analyzed by the International Energy Agency (2017), the integration of the Internet of Things (IoT), smart grids, and decentralized renewable energy sources has enabled cities to optimize energy flows, increase system flexibility, and minimize their dependence on fossil fuels.

Amsterdam’s approach to urban climate mitigation is exemplified by its pioneering smart energy systems, which integrate technology and community action to reduce greenhouse gas emissions. A central pillar of this strategy was the European Union-funded City-Zen project (2014-2019), which employed a multi-faceted, technology-driven plan. Its strategy relied on deep energy retrofits of residential buildings, using smart meters and energy modeling to identify the most effective measures for reducing demand (European Commission, 2020). Furthermore, it developed a smart grid that integrated decentralized renewables by using IoT sensors and advanced control systems to balance supply and demand in real-time. This grid created Virtual Power Plants (VPPs) by aggregating distributed energy resources and even piloted peer-to-peer energy trading using block chain technology. According to the official final report, these efforts resulted in the documented avoidance of approximately 2,600 tons of CO_2 emissions per year in Amsterdam, contributing to a broader project total of over 35,000 tons of CO_2 saved across all demonstration cities (European Commission, 2020).

Complementing these city-led technological efforts are groundbreaking citizen-led initiatives that apply these principles on a community scale. The Schoonschip floating community represents a leading model of decentralized, sustainable living. Developed over a decade by its residents, the project comprises 46 floating homes that operate as a self-sufficient micro grid (Sorkhabi et al., 2023). Its smart energy system is central to its performance: the community generates renewable electricity through 516 solar panels and meets its heating demands via 30 heat pumps that extract thermal energy from the canal water (Sorkhabi et al., 2023).A privately managed smart grid utilizes intelligent technology to optimize and redistribute energy surplus among households, while blockchain facilitates the exchange of clean energy among residents, ensuring high efficiency and autonomy (Sorkhabi et al., 2023; European Commission, 2020).

Overall, Amsterdam’s energy strategy demonstrates how smart technologies can facilitate urban climate mitigation by embedding intelligence into infrastructure and empowering communities to participate in the energy transition. The combined use of IoT, smart grids, predictive modeling, and renewable integration offers a scalable and adaptable framework for reducing emissions while enhancing urban resilience. As cities worldwide seek to decarbonize, Amsterdam's model provides a compelling example of how data-driven, inclusive, and decentralized systems can accelerate progress toward sustainable urban energy futures.

Figure 2-3: Schoonschip: A Community-built Floating Neighborhood.

Resource: https://city-changers.org/schoonschip-floating-neighbourhood/

2.5.1.2 Smart Urban Mobility

Urban mobility is a significant contributor to global greenhouse gas emissions, accounting for approximately one-quarter of worldwide totals, and presents a critical challenge for urban climate mitigation efforts (IPCC, 2022). In response, cities are increasingly turning to smart urban mobility solutions that fuse technological innovation with sustainable policy. These strategies, which integrate technology and transformative urban design to create sustainable transport ecosystems, offer a powerful means to mitigate climate change. A compelling and evidence-based model for this approach is found in Barcelona's pioneering "Superblock" (superilla) concept, which demonstrates how rethinking urban mobility can simultaneously reduce greenhouse gas emissions, enhance climate resilience, and generate profound public health co-benefits (Rueda, 2018).

At its core, the superblock model is founded on the radical reclamation of public space from private vehicles. By transforming a 3x3 city block area into a pacified cell where interior streets are dedicated to low-speed traffic for pedestrians and cyclists, while through-traffic is redirected to a perimeter network, the design directly targets the root cause of urban transport emissions. This restructuring is projected to engineer a significant modal shift, with Barcelona's Urban Mobility Plan estimating a 19.2%

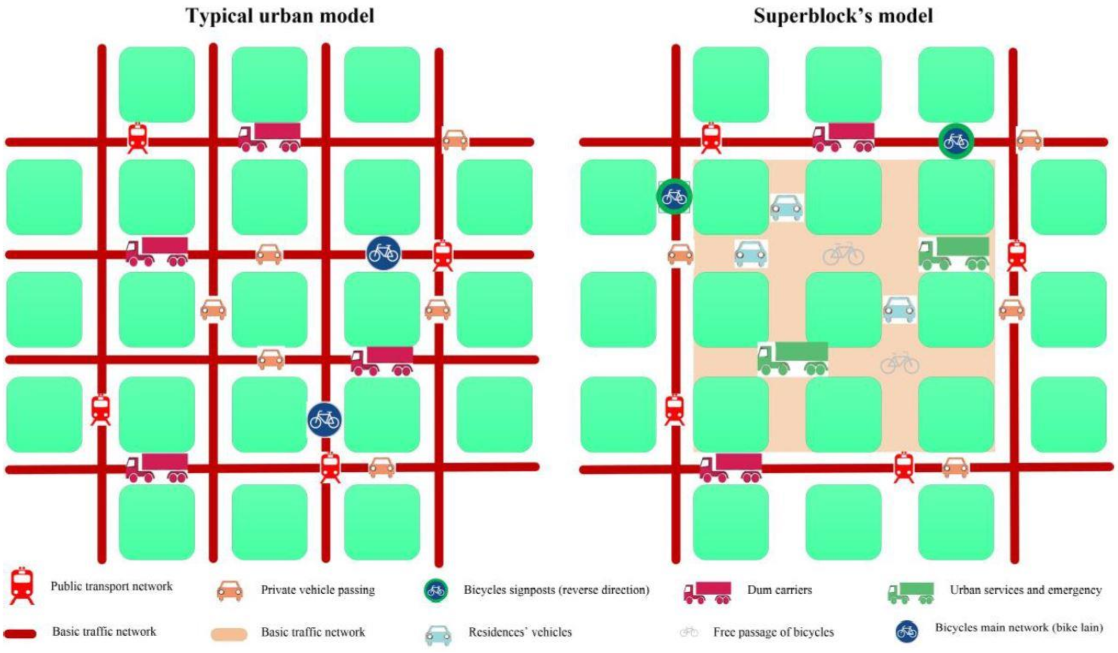


Figure 2-4:Barcelona supper block.

Source: (Vardakas et al., 2018)

reduction in private car and motorcycle trips across the city upon the full implementation of 503 Superblocks (Mueller et al., 2020). This reduction in vehicle kilometers traveled is the primary driver behind the model's climate benefits.

The direct environmental outcomes of this reduced traffic are both significant and quantifiable. Modeling for the Superblock scenario indicates a substantial 24.3% improvement in air quality, with city-wide annual mean Nitrogen Dioxide (NO_2) levels estimated to fall (Mueller et al., 2020). While NO_2 is a local pollutant, its reduction is a clear marker of decreased fossil fuel combustion, directly correlating with lower carbon dioxide emissions. Furthermore, the model effectively counters the urban heat island effect, a phenomenon in which cities become significantly warmer than their surroundings due to the heat-absorbing properties of asphalt and the waste heat generated by vehicles and buildings. The strategy involves replacing swathes of asphalt with vegetation and semi-permeable materials. Thermal simulations conducted for a central superblock demonstrated a notable 2°C reduction in heat transfer from surfaces, with a conservative city-wide estimate pointing to a 1°C reduction in ambient air temperature during summer (Mueller et al., 2020).

This not only lessens the city's vulnerability to heatwaves, a key climate adaptation goal, but also reduces the energy demand for air conditioning, creating a positive feedback loop for further emission reductions.

Critically, the success of this physical urban redesign is amplified by the integration of smart technology. The superblock provides the ideal framework for Mobility as a Service (MaaS), a digital platform that consolidates various transport options such as public transit, bike-sharing, car-sharing, and taxis into a single, accessible service on a smartphone (Jittrapirom et al., 2017). By offering tailored mobility packages and seamless payment options, MaaS reduces the convenience gap between private car ownership and sustainable transportation, thereby reinforcing the essential modal shift.

Beyond mobility, technology enables energy cooperation within the Superblock's building cluster. A study of the Poblenou pilot area in Barcelona showed that a system where buildings equipped with solar panels and energy storage share excess energy can drastically reduce grid dependence. This cooperative model resulted in staggering reductions in the CO_2 footprint of up to 74% for certain building types (Vardakas et al., 2018), showcasing how local renewable energy generation can decarbonize the urban ecosystem that powers new forms of electric mobility, themselves supported by city policies like the Electric Vehicle Masterplan with its network of charging points and financial incentives (Ajuntament de Barcelona, n.d.).

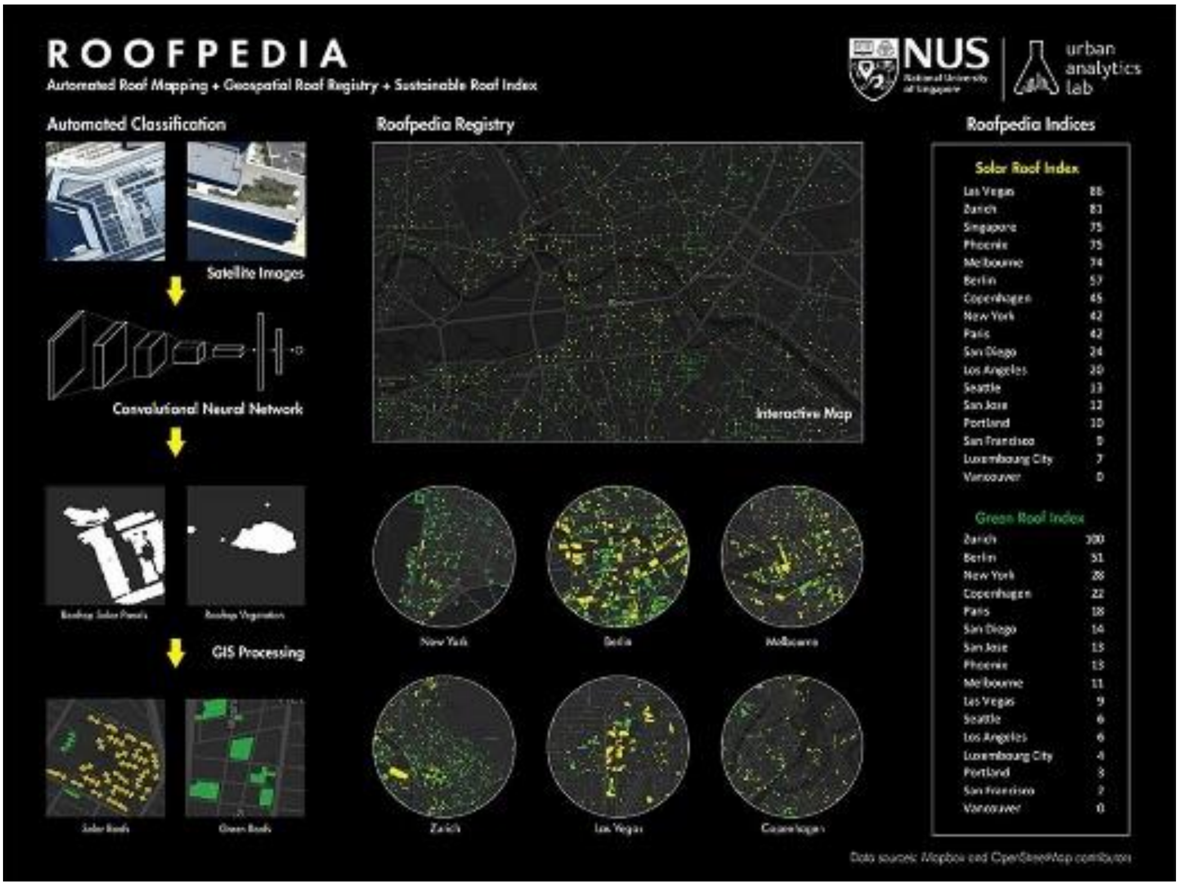
Perhaps the most powerful argument for this integrated approach lies in its immense co-benefits for public health, which serve as a proxy for its overall success. A comprehensive health impact assessment of the 503-Superblock plan calculated that 667 premature deaths could be prevented annually in Barcelona (Mueller et al., 2020). This staggering figure is attributed to the cumulative effect of reduced air pollution, less traffic noise, a cooler urban climate, and increased physical activity from walking and cycling. This translates to an estimated increase in average life expectancy of nearly 200 days for the adult population and an annual economic benefit of €1.7 billion (Mueller et al., 2020).

These figures irrefutably demonstrate that climate action through smart mobility is not an economic burden but a monumental investment in urban well-being. In conclusion, Barcelona's Superblock model exemplifies a holistic path forward. It moves beyond merely restricting cars to proactively creating a more efficient, healthy, and resilient urban environment. By strategically reconfiguring space, leveraging technology for integration, and prioritizing human health, it provides a robust blueprint for how cities can directly combat climate change while building a higher quality of life for their residents, proving that sustainability and urban vitality are fundamentally interconnected.

2.5.1.3 Green Infrastructure and Smart Water Management for Urban Climate Mitigation

In the quest to reduce urban carbon emissions, green buildings and infrastructure offer compelling pathways through passive design strategies, digital systems, and ecological integration. In Singapore, a globally influential leader in sustainable urban development, innovative approaches such as smart building management systems, high-performance envelopes, and vegetated structures are driving significant progress in mitigating urban climate risks. Building energy management systems (BEMS) use real-time data from IoT sensors to optimize heating, cooling, and lighting systems while ensuring occupant comfort and minimizing energy use (Hodson et al., 2023). The integration of such systems enables intelligent, automated control that accounts for occupancy, weather, and energy price signals, delivering climate and cost benefits

Recent advances in geospatial technology have enabled automated systems to track urban sustainability features, such as green and solar roofs. Roofpedia is a digital platform that addresses this need by employing satellite imagery and 3D city models to create standardized inventories of roof types across global cities. The system classifies rooftops based on vegetation cover and solar panel installation through deep learning algorithms, compiling the data into an open-access registry. This approach allows cities to benchmark their progress, identify underutilized roof space, and develop targeted policies for renewable energy expansion (Wu & Biljecki, 2022).



Solar Roof Index	
Las Vegas	86
Zurich	83
Singapore	75
Phoenix	75
Melbourne	74
Berlin	57
Copenhagen	45
New York	42
Paris	42
San Diego	24
Los Angeles	20
Seattle	13
San Jose	12
Portland	10
San Francisco	9
Luxembourg City	7
Vancouver	0

Green Roof Index	
Zurich	100
Berlin	51
New York	28
Copenhagen	22
Paris	18
San Diego	14
San Jose	13
Phoenix	13
Melbourne	11
Las Vegas	9
Seattle	6
Los Angeles	6
Luxembourg City	4
Portland	3
San Francisco	2
Vancouver	0

Figure 2-5: Roofpedia automatic mapping of green and solar roofs for an open roofs cape registry and evaluation of urban sustainability.
Source (Wu & Biljecki, 2022)

The platform's evaluation of global cities revealed Zurich as a leader in both green and solar roof adoption. Local building regulations in Zurich played a significant role in this achievement, particularly requirements for green roofs on flat-roofed structures. Roofpedia's data demonstrates how combining geospatial technology with policy driven initiatives can accelerate the implementation of climate-friendly infrastructure.

By providing transparent, comparable metrics on roofs cape sustainability, the tool supports evidence-based decision-making for urban carbon reduction strategies (Wu & Biljecki, 2022).

Another key area where smart cities' contribution is noticeable is water management. Efficient resource management is a core pillar of smart city initiatives, designed to mitigate climate change by optimizing natural resource utilization and reducing greenhouse gas emissions. Smart water systems and IoT-driven waste management technologies exemplify key areas where digital tools advance sustainability objectives.

Smart water management systems in cities utilize advanced technologies, including IoT sensors, real-time data analytics, and automated control systems, to optimize water distribution, detect leaks, and monitor water quality. These systems integrate pressure, flow, and water quality sensors across distribution networks to identify inefficiencies and reduce non-revenue water losses. For instance, Singapore’s Smart Water Grid utilizes an Integrated Data and Electronic Alerts System (IDEAS) to detect pipeline bursts and manage demand, resulting in a 50% reduction in water losses (Gupta et al., 2020). Such innovations enhance water security while minimizing energy consumption in pumping and treatment, thereby lowering carbon emissions.

Additionally, smart water technologies contribute to climate risk mitigation by improving resilience against extreme weather events. Real-time monitoring of water bodies helps detect contamination and flood risks, enabling timely interventions to mitigate these risks. In agriculture, sensor-based irrigation systems reduce water waste, conserving resources in drought-prone regions. The study highlights that smart metering and demand prediction further curb excessive water use, aligning with sustainable urban development goals (Gupta et al., 2020).

Collectively, the evidence from leading smart cities demonstrates that integrating technology with urban planning is a powerful strategy for climate mitigation. Amsterdam's smart energy grid, which employs IoT sensors and block chain to create virtual power plants, shows how data-driven systems can optimize energy distribution and significantly reduce emissions (European Commission, 2020; Sorkhabi et al., 2023). Similarly, Barcelona's Superblocks model demonstrates how reclaiming public space from cars can cut transport-related pollution and generate substantial public health co-benefits (Mueller et al., 2020; Rueda, 2018). These approaches are strengthened by complementary innovations in green infrastructure, as seen in Zurich's policy-driven green roofs mapped by platforms like Roofpedia (Wu & Biljecki, 2022), and smart water management, exemplified by Singapore's sensor-based systems that drastically reduce non-revenue water loss and associated energy waste (Gupta et al., 2020).

However, the success of these technological interventions is not automatic. As scholars note, their effectiveness depends on supportive policy frameworks and community engagement; they must also address challenges such as high implementation costs and concerns about data privacy (Hodson et al., 2023). The most effective smart city strategies are those that embed technology within a broader commitment to equity and institutional capacity, ensuring climate solutions also advance social sustainability. By learning from these pioneering examples and adapting their lessons to local contexts, cities can harness smart technologies as essential tools for building a low-carbon, resilient future. This synthesis affirms that smart city strategies are critical for global climate action, offering scalable models for emission reduction while smart cites also have the capacity to adapt the climate change which will be disused in details in the next section.

2.5.2 Smart Cities' role in Climate Risk Adaptation

Climate change adaptation constitutes a critical and ongoing process of adjustment in response to actual manifestations and projected impacts of a changing climate. Its central objective is to mitigate potential damages to human and natural systems, while also strategically capitalizing on any emergent beneficial opportunities (IPCC, 2022). Within the complex and densely populated context of urban environments, this process demands transformative changes that extend beyond mere technical fixes. Effective urban adaptation necessitates the fundamental modification of physical infrastructure, the evolution of governance and institutional frameworks, and the empowerment of community practices. This multi-faceted approach is essential to build systemic resilience against a suite of intensifying climate hazards, including increased frequency and severity of flooding, debilitating extreme heat events, coastal inundation from sea-level rise, and more destructive storms (Revi et al., 2014).

The profound urgency of this endeavor is unequivocally underscored by the IPCC’s Sixth Assessment Report. The report confirms that climate risks are escalating at an accelerating pace and are disproportionately concentrated in urban areas. This heightened vulnerability is a direct function of cities' high population density, their concentration of critical economic assets, and the interconnected fragility of their complex infrastructure networks, making them both contributors to and casualties of climate change (IPCC, 2022).

Consequently, developing robust adaptation strategies is not merely a planning option but an imperative for sustainable urban survival and prosperity. Confronted with these escalating and concentrated risks, cities are increasingly turning to innovative paradigms to bolster their resilience. In this context, the smart city model emerges as a critical enabler of effective climate adaptation. Moving beyond the foundational capabilities of real-time monitoring and predictive planning, the smart city approach is distinguished by its capacity to integrate these technological functions into a cohesive, city-wide resilience strategy. This integration is achieved through a layered architecture of interconnected systems. For instance, data from IoT sensors deployed to monitor storm water drainage can be fused with Geographic Information Systems (GIS) to create dynamic flood inundation models, while AI-driven analytics processes this data to predict blockages or overflows before they occur (Batty et al., 2012).

This transforms urban management from a reactive to a profoundly anticipatory practice. Furthermore, the principle of multi-scalar integration is vital; data gathered at the microscale—such as from a network of soil moisture sensors in a park—can inform mesoscale decisions about city-wide green infrastructure investment, which in turn supports macroscale goals of reducing the urban heat island effect and managing storm water runoff (Kitchin, 2014).

Critically, this technological infrastructure is not an end in itself but a platform to strengthen socio-ecological systems. The true resilience of a smart city is realized when digital tools facilitate robust citizen engagement and cross-sector collaboration. Open data platforms, for example, can provide residents and businesses with accessible information on local heat risks or flood zones, empowering community-led adaptation actions and fostering a shared culture of preparedness (Kitchin, 2014). This interplay between digital intelligence, engineered infrastructure, and social capital is what constitutes the systemic nature of smart climate adaptation.

Therefore, examining the specific technologies and strategies through which this interplay is operationalized is fundamental to understanding the future of urban climate resilience. The following sections detail the primary applications that define this approach.

2.5.2.1 Enhances Early Warning System as a Foundation for Urban Climate Adaptation

Early warning systems (EWS) serve as a critical component of urban climate risk adaptation, substantially mitigating potential losses from natural disasters by providing timely information to at-risk populations and authorities (UNDRR, 2019). These systems function through integrated processes of hazard detection, risk analysis, public communication, and coordinated response, enabling the protection of vulnerable communities and critical infrastructure through preventive action and evacuation (Basher, 2006). The effectiveness of EWS is demonstrated through both reduced mortality rates and decreased economic impacts from climate-related disasters when implemented with comprehensive community engagement and institutional support (UNDRR, 2019).

The emergence of smart city technologies has significantly advanced the capabilities of traditional early warning systems through digital innovation. The deployment of Internet of Things (IoT) sensor networks enables continuous environmental monitoring, capturing real-time data on hydrological, meteorological, and geophysical variables, including precipitation, river levels, wind patterns, and ground saturation (Perera et al., 2014). This dense network of environmental sensors generates granular data streams that form the foundational input for predictive analytics. Through sophisticated big data processing and machine learning algorithms, these systems can identify precursor patterns to climate hazards, substantially improving both the accuracy and lead time of warnings (Khalid et al., 2017).

Concurrently, remote sensing technologies and Geographic Information Systems (GIS) enable spatially precise hazard mapping, identifying high-risk zones and optimizing the planning of evacuation routes and emergency resource deployment (Goodchild, 2007). This integration of sensing, analytics, and visualization technologies creates a comprehensive decision-support system for climate risk management. A representative example of advanced EWS implementation is found in Florida's coastal communities, which face increasing threats from sea-level rise and intensifying storm systems. Chen et al. (2024) document the development of an integrated resilience platform that combines urban digital twins (UDTs) with cloud-based geospatial dashboards. This system incorporates LiDAR topography and drone photogrammetry to enable monitoring of environmental conditions with high spatial resolution. The platform's analytical capabilities, powered by GPU-accelerated rendering through platforms like Deck.gl, facilitate the integration of predictive flood models and infrastructure vulnerability assessments (Chen et al., 2024).

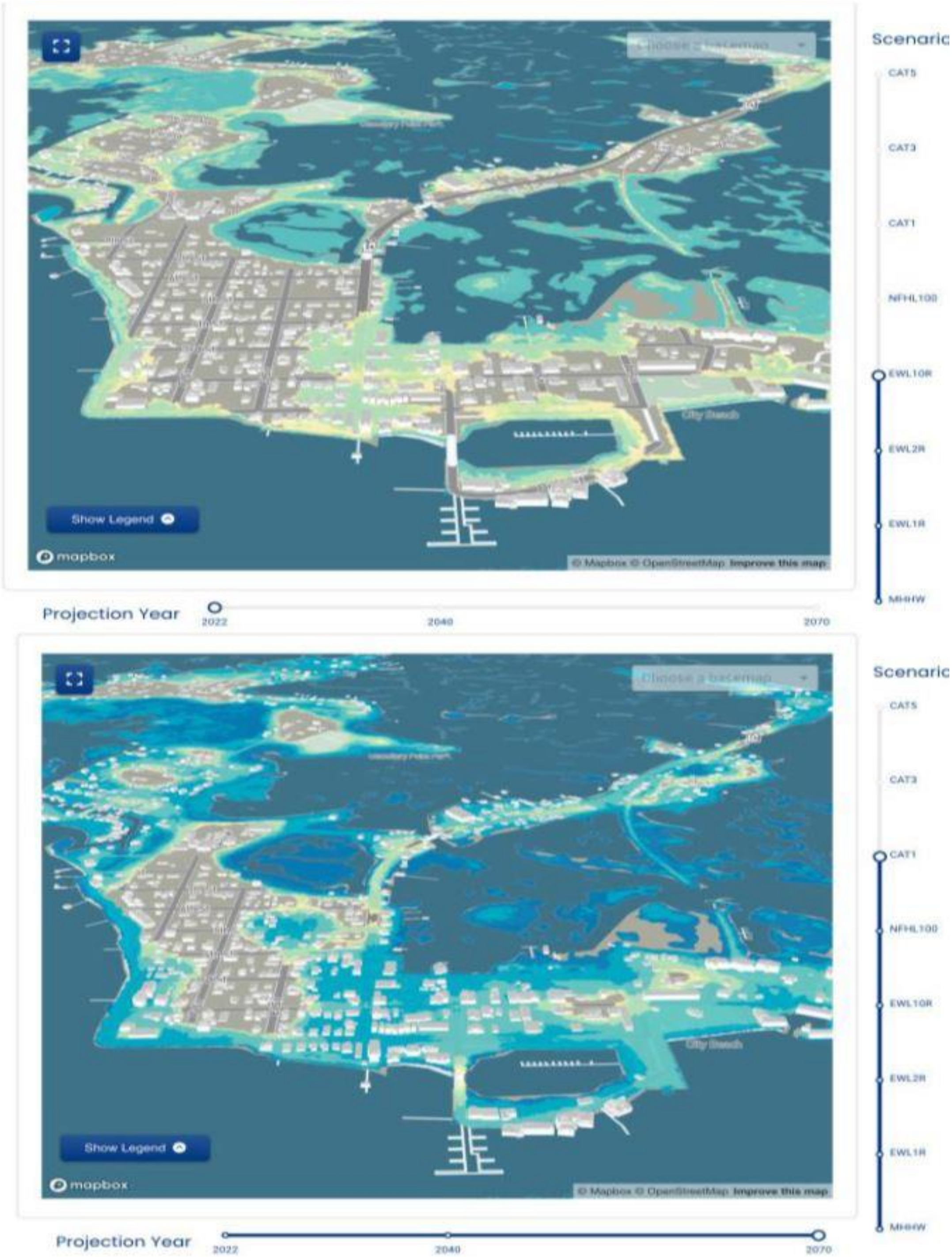


Figure 2-6: Projected flood inundation maps for a Florida coastal community.

Top: Extreme water level scenario with 10-year return period (2022 conditions). Bottom: Category-1 hurricane storm surge scenario un-der projected 2070 sea-level rise conditions. Source: Adapted from Chen et al. (2024).

The practical implementation of this technology was demonstrated during Hurricane Idalia (2023), when the system provided critical decision support for emergency management in Cedar Key, Florida. By simulating flood scenarios and projecting infrastructure impacts, the platform enabled authorities to optimize evacuation plans and resource deployment (Chen et al., 2024). This case illustrates the transformative potential of smart EWS in converting static planning tools into dynamic adaptive systems that can respond to evolving climate risks, ultimately enhancing community resilience through technology-enabled anticipatory governance.

2.5.2.2 Green Infrastructure and Urban Heat Island

Green infrastructure is widely recognized as a multifunctional adaptation approach that enhances urban climate resilience. Unlike traditional “grey” infrastructure, green infrastructure encompasses natural or semi-natural systems, such as parks, vegetated swales, and permeable pavements that manage storm water and reduce urban temperatures. By promoting water infiltration and retention, green infrastructure alleviates urban flooding and decreases runoff pollution, while vegetative cover mitigates the urban heat island effect, improving microclimate conditions (Oberndorfer et al., 2007). Importantly, green infrastructure also enhances urban biodiversity and social well-being, reinforcing ecological and community resilience simultaneously.

Meanwhile, the Urban Heat Island (UHI) is another climate risk that needs to be considered. Cities, particularly in tropical regions like Singapore, experience higher temperatures than surrounding rural areas due to energy consumption, reduced vegetation, and heat-absorbing materials (Pignatta et al., 2018). This phenomenon, known as the Urban Heat Island (UHI) effect, can elevate temperatures by 4°C or more, negatively impacting public health, energy demand, and outdoor livability (Pignatta et al., 2018).To combat this, smart cities employ sophisticated simulation tools that enable precise assessment and mitigation of climate-related threats. The *Cooling Singapore* initiative exemplifies this approach by utilizing computational models to develop resilient urban strategies, ensuring sustainable and livable environments (Pignatta et al., 2018).

Central to this effort are three categories of simulation tools, each serving distinct yet complementary roles in climate adaptation: **Microscale tools**, such as the three-dimensional microclimate model ENVI-met which provides granular insights into how buildings and infrastructure interact with their immediate surroundings. These tools are indispensable for evaluating localized cooling interventions, including green roofs, shade structures, and reflective pavements, which collectively reduce surface temperatures and enhance pedestrian comfort (Pignatta et al., 2018).

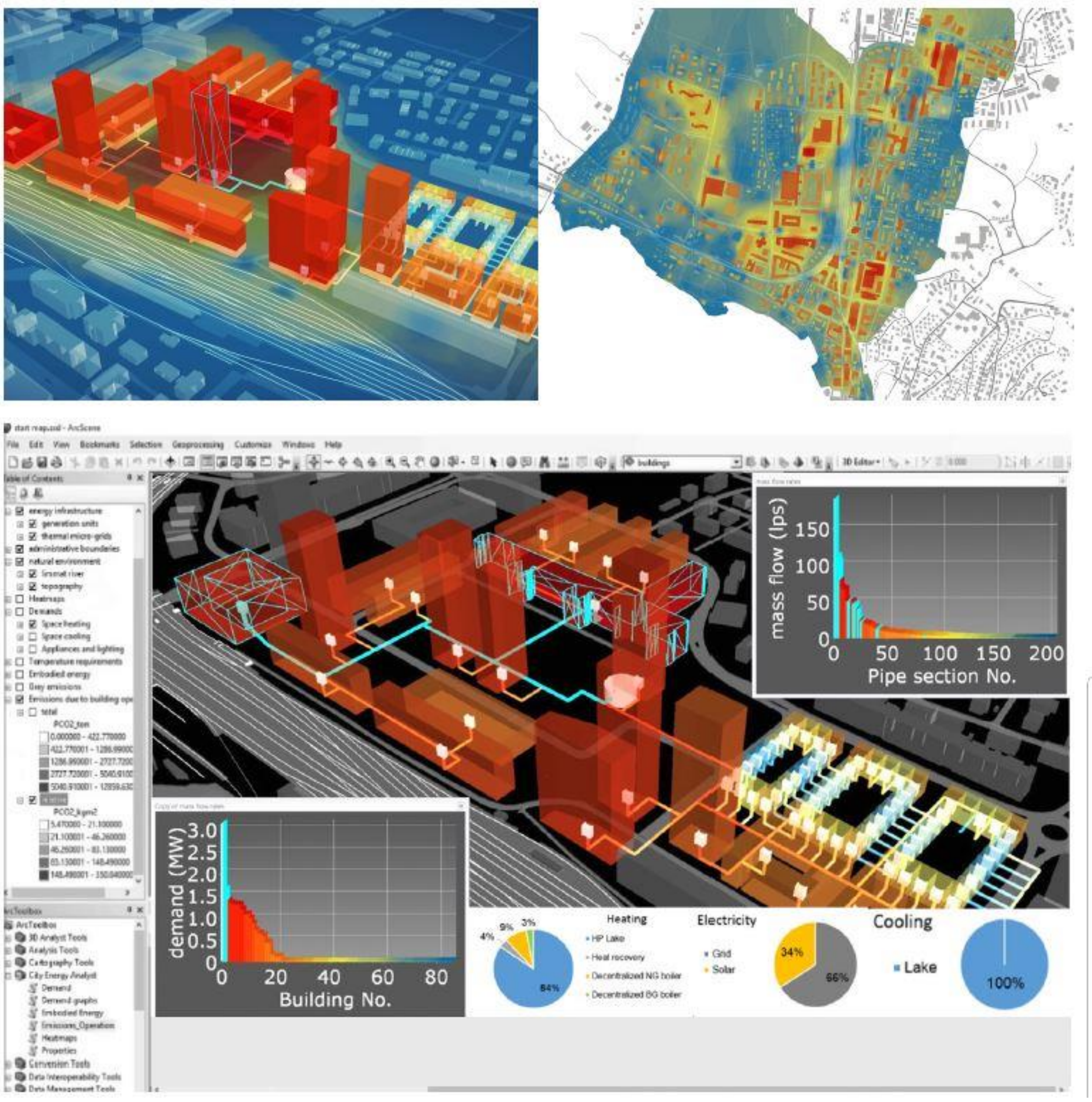


Figure 2-7: Interface of the City Energy Analyst (CEA) tool.

This image illustrates the CEA software's capability to model urban energy systems. The top portion shows a 3D visualization of a city district's energy demand, while the bottom displays the user interface with various data outputs, including energy demand charts and cooling source breakdowns. *Source: (Pignatta et al., 2018).*

At a broader scale, **mesoscale tools** or numerical weather prediction models like the Weather Research and Forecasting (WRF) system and the urban surface model TEB-SURFEX analyze city-wide or regional climate patterns, offering policymakers a macro-level understanding of heat distribution. By simulating urban airflow and temperature variations, these tools inform large-scale strategies such as the creation of green corridors and optimized ventilation pathways, which are critical for mitigating heat accumulation across densely built environments (Pignatta et al., 2018).

Complementing these are **supporting tools** such as the whole-building energy simulation program EnergyPlus and the urban forest analysis suite i-Tree Eco, which focus on targeted adaptation measures. Energy Plus aids in designing energy-efficient buildings that minimize heat emissions, while i-Tree Eco quantifies the cooling benefits of urban forestry, helping planners optimize tree placement for maximum climate resilience (Pignatta et al., 2018).

To sum up, Smart city technologies provide tools to monitor and manage these effects through real-time data from sensor networks and IoT devices. These systems allow for precise identification of heat hotspots and support targeted cooling strategies such as urban greening (parks, green roofs), which reduce temperatures by providing shade and enhancing evapotranspiration (Bowler et al., 2010).

2.5.2.3 Smart Water Management (SWM)

In the previous section that discussed climate risk mitigation and smart water management, it is also worth noting that smart cities must not only mitigate climate change through water management but also adapt to it. Smart water management (SWM) represents a critical component of climate-resilient urban planning, leveraging advanced technologies like IoT, AI, and digital twins to enhance adaptive capacity. Unlike traditional approaches, SWM enables real-time monitoring, predictive analytics, and automated decision-making, which are essential for mitigating climate risks such as floods, droughts, and water scarcity. For instance, Singapore’s Smart Water Grid integrates over 50,000 IoT sensors and digital twin modeling to optimize water distribution, reducing non-revenue water (NRW) by 54.4% and improving leak detection response times by 91.7% (Dai et al., 2025).

These systems not only enhance operational efficiency but also strengthen resilience by simulating climate scenarios, such as extreme rainfall or sea-level rise to preemptively adjust infrastructure performance. This schematic illustrates Singapore's integrated smart water management system, which connects IoT sensors, cloud analytics, and digital twin modeling across water infrastructure. The digital twin environment (center) simulates scenarios using real-time data from reservoirs, treatment plants, and pumping stations, while the public-facing 'MyWater' app promotes citizen engagement. This closed-loop system enables predictive maintenance and climate adaptation planning (Dai et al., 2025).

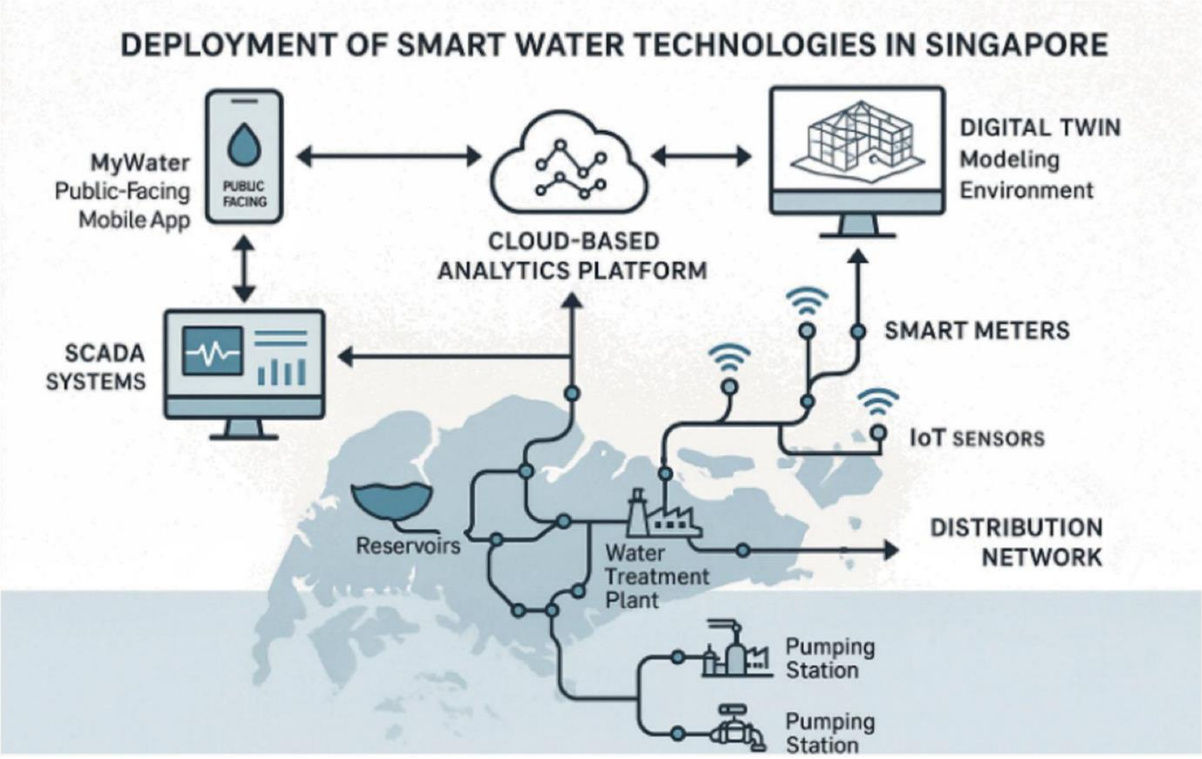


Figure 2-8: Integrated Digital Twin Process for Scenario-Based Planning and Real-Time Control.

Source :(Dai et al., 2025)

The role of SWM in climate adaptation is further demonstrated in China’s pilot projects, where AI-driven flood-risk digital twins in Beijing and smart metering in Shenzhen address urbanization pressures and pollution control. By aligning with the Sustainable Development Goals (SDGs), these technologies reduce energy consumption (e.g., achieving 15% savings in Singapore’s pumping systems) and minimize ecological damage through precise demand forecasting and contamination tracking (Dai et al., 2025).

2.5.2.4 Public Participation in Smart City Climate Action

Smart cities represent a new approach to urban governance, moving beyond a purely technocratic model to one that recognizes civic participation as a critical social infrastructure for tackling complex challenges, such as climate change. This approach integrates citizens not as passive recipients of top-down solutions but as active sensors, co-creators, and stewards in both mitigating greenhouse gas emissions and adapting to inevitable climatic impacts. The integration of the public happens through a multi-faceted framework that leverages technology, data, and innovative governance models (Moreno-Ibarra & Torres-Ruiz, 2019; Ministry of Sustainability and the Environment [MSE], 2021).

The foundation of this integration is the concept of the citizen as a sensor. As detailed by Moreno-Ibarra and Torres-Ruiz (2019), mobile devices and social media have turned the populace into a distributed network for generating real-time, geo-referenced data. This Volunteered Geographic Information (VGI), such as tweets about localized flooding, traffic congestion due to extreme weather, or photos of urban heat islands, provides a granular, dynamic picture of climate events that traditional static sensors cannot capture. For instance, the analysis of traffic-related tweets in Mexico City demonstrates how citizen reports can be processed using natural language processing (NLP) and machine learning to classify events, validate them against authoritative data, and map them geographically. This transforms noisy social media data into actionable intelligence for urban managers, enabling a more responsive and adaptive city system.

This data-driven approach is central to climate adaptation. By monitoring citizen-reported events, cities can identify climate vulnerabilities, such as neighborhoods prone to flash flooding or corridors with dangerously high temperatures, with unprecedented speed and precision. This enables targeted infrastructure upgrades, optimized resource deployment for emergency services, and validation of predictive climate models. On the other hand, Singapore’s overall strategy, as outlined in its Green Plan 2030, exemplifies this. The educational programs that teach children in academic institutions about sustainability and waste management are a long-term investment in cultivating an environmentally conscious citizenry that actively participates in waste reduction and circular economy initiatives, core components of climate mitigation (MSE, 2021).

However, simply collecting data is insufficient. The true power of public participation is unlocked through co-creative governance structures that empower citizens to have a say in decision-making. This involves moving from sensing to meaningful engagement. Singapore’s Green Plan promotes community involvement in initiatives such as the transformation of Pulau Semakau into a sustainability hub and the development of additional green spaces, ensuring that adaptation measures align with community needs and values. This mirrors the framework proposed by Moreno-Ibarra and Torres-Ruiz (2019), which culminates in the "use and exploitation" of validated citizen data for spatial analysis and policymaking. Digital platforms can facilitate this by enabling participatory budgeting for climate resilience projects or crowdsourcing ideas for low-carbon urban mobility solutions.

Ultimately, the integration of the public in smart cities for climate action creates a virtuous cycle. Citizens contribute data that improves the city's adaptive capacity and provides insights for effective mitigation strategies. In return, transparent governments provide citizens with information, platforms, and a sense of agency, fostering trust and legitimizing climate actions. This integration between a city's "hard" digital and physical infrastructure and its "soft" social and governance infrastructure is what transforms a merely automated city into a truly resilient, sustainable, and smart community capable of facing the profound challenges of climate change.

In summary, the role of smart cities in climate risk adaptation lies in their ability to integrate advanced technology with proactive planning and inclusive governance. Rather than offering a single solution, smart cities provide a multifaceted approach that combines real-time monitoring, data-driven forecasting, and community engagement to address climate challenges. Key tools, such as enhanced early warning systems, green infrastructure planning, smart water management, and digital platforms for public participation, help cities transition from reactive to anticipatory adaptation. These approaches enable more efficient resource utilization, improved risk preparedness, and stronger collaborative action among governments, communities, and technical experts.

Ultimately, smart cities are not defined by technology alone, but by how they use it to support both ecological and social resilience. By linking digital systems with meaningful public involvement, cities can better adapt to climate threats while maintaining livability and equity for all residents. While these strategies provide a blueprint for urban climate resilience, their practical effectiveness is best demonstrated through local implementation. This is exemplified by Cascais, Portugal, a coastal municipality in the Lisbon Metropolitan Area, where tailored smart city initiatives are directly addressing region-specific climate vulnerabilities. The following section will explore Cascais innovative solutions in detail.

Chapter 3

Case Study of Cascais, Portugal

3.1 Background Information

Cascais is a coastal municipality in Portugal's Lisbon District, situated on the Portuguese Riviera approximately 30 kilometers west of Lisbon. It occupies a strategic location between the Sintra mountains and the Atlantic Ocean, bordered by the municipality of Sintra to the north, the ocean to the south and west, and Oeiras to the east. Encompassing an area of 97.40 km² with a coastline of 30 km, the municipality has a population of 214,124 inhabitants (Câmara Municipal de Cascais, 2024a).

The municipality is administratively divided into four civil parishes: Alcabideche; the union of Carcavelos and Parede; the union of Cascais and Estoril; and São Domingos de Rana. All are governed by the Cascais Municipal Council (CMC) (Câmara Municipal de Cascais, 2024). Demographically, the population is characterized by 53% women and 47% men, and includes 31,037 children and young adults living within 86,484 families (Câmara Municipal de Cascais, 2024a).

Cascais has established itself as a center of innovation, demonstrating a strong commitment to sustainability and environmental quality. This is reflected in a wide range of initiatives and projects aimed at environmental protection and promoting a healthy, balanced urban life, aligning with its strategic commitment to the United Nations' 2030 Agenda for Sustainable Development (Câmara Municipal de Cascais, 2024a).

Cascais was selected as a pivotal case study for this research due to its exemplary and pioneering role in operationalizing local climate adaptation frameworks. The municipality's approach is distinguished by its early adoption of IPCC assessment methodologies to downscale global climate projections, specifically for sea-level rise, increased temperatures, and precipitation changes, into actionable municipal policy. This scientific foundation was instrumental in developing Portugal's first comprehensive municipal climate adaptation strategy, an effort that transitioned from the strategic diagnosis of the 2010 PECAC to the actionable, implementation-focused (PA3C2) *Plano de Ação para a Adaptação às Alterações Climáticas de Cascais 2030* (Cascais Ambiente, 2021).

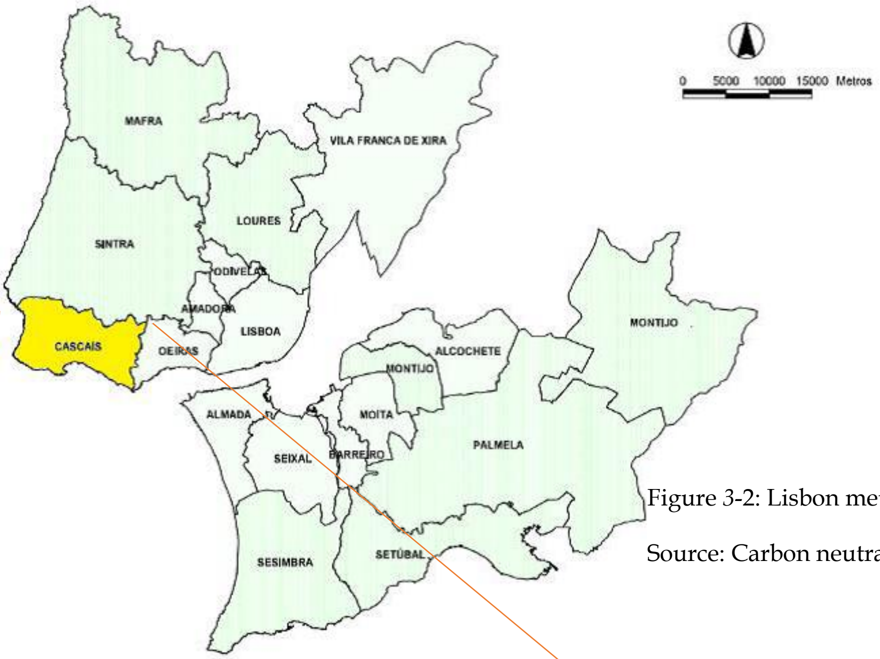


Figure 3-2: Lisbon metropolitan area.

Source: Carbon neutrality plan (CMC, 2020)

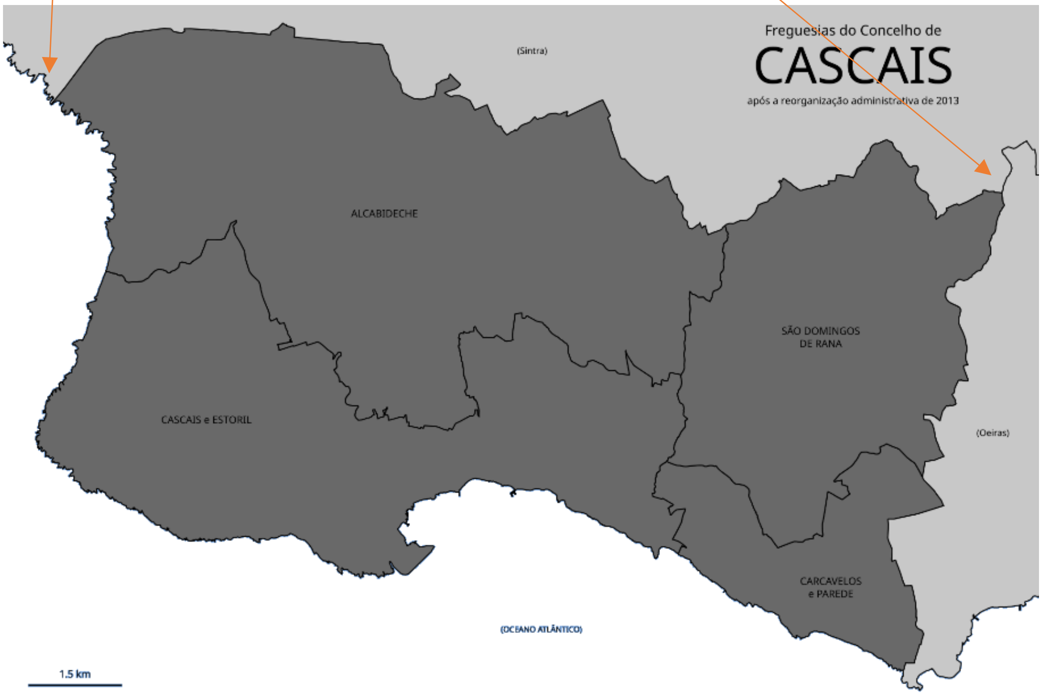


Figure 3-2: Municipality of Cascais.

Source:Plano Municipal de Ação Climática de Cascais (CMC, 2025)

Therefore, Cascais presents a unique and instructive case because it moves beyond theoretical planning. It demonstrates the tangible integration of nature-based solutions, community engagement, and targeted technological monitoring into a coherent urban resilience strategy. Analyzing its development, governance model, and implementation progress provides critical, transferable insights into the mechanisms through which coastal cities can effectively.

3.2 Climate Risks in Cascais

The municipality of Cascais faces a complex array of climate threats that demand immediate, science-based responses. Based on the 2010 strategic climate assessment for Cascais, the municipality faces a profound transformation of its local climate by the end of the 21st century, characterized by significantly higher temperatures and altered precipitation patterns. The projections indicate that annual average temperatures could rise dramatically by 3.4 to 6.5 degrees Celsius, creating a fundamentally hotter environment than the current climate baseline. Summer temperatures are expected to experience the most severe increases, with average daily temperatures rising between 5 and 10 degrees Celsius. In contrast, winter months will experience more moderate but still substantial warming of 2 to 4 degrees Celsius. This warming pattern will make extreme heat events increasingly common, with heatwaves becoming more frequent, longer in duration, and extending beyond traditional summer months into spring and autumn seasons (Câmara Municipal de Cascais, 2010b).

Figure 3-3: Surface air temperature anomalies for Cascais.
Calculated relative to the 1971-2005 period and projected every 5 years until 2096, show annual averages (black), summer (red), and winter (blue) trends in °C. Source: (Cascais Ambiente, 2021)

The municipality will simultaneously face significant hydrological changes as precipitation patterns shift substantially. Annual rainfall accumulation is projected to decrease from approximately 630 millimeters to between 420-580 millimeters, representing a considerable reduction in water availability. The summer period from June to September will become particularly arid, with the frequency of completely dry summers expected to double or triple compared to current patterns. While heavy precipitation events may occur less frequently, climate models suggest these rainfall events could become more intense when they do occur, potentially leading to periods of heavy downpour followed by extended dry spells (Câmara Municipal de Cascais, 2010b).

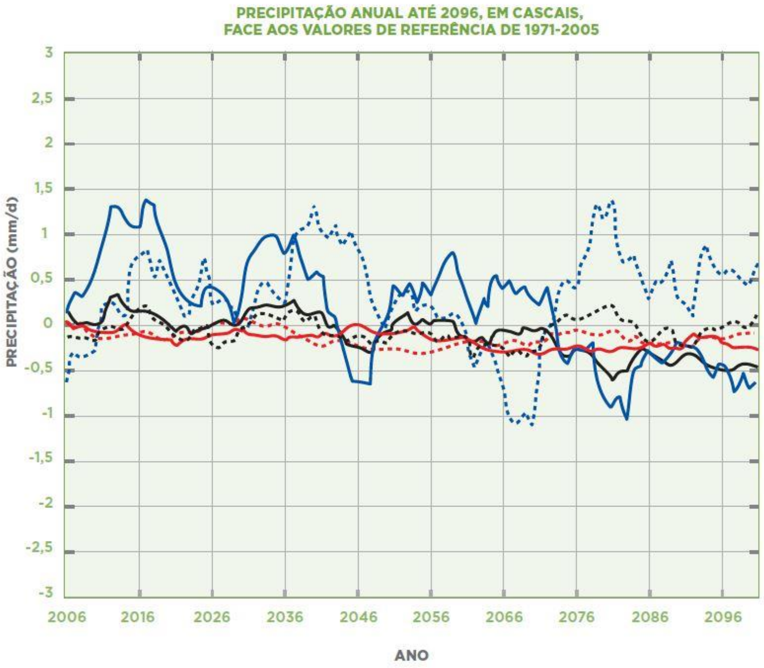


Figure 3-4: Precipitation in Cascais. Black lines show annual average precipitation anomalies, the red and blue lines represent summer and winter periods respectively, and all values calculated every five years until 2096 relative to the 1971–2005 baseline are measured in mm/day. Source: (Cascais Ambiente, 2021)

These climate transformations will fundamentally alter daily life and environmental conditions in Cascais. The combination of elevated temperatures and specific humidity conditions will lead to a substantial increase in "tropical nights" where temperatures remain above 25 degrees Celsius, preventing natural cooling and recovery from daytime heat. While winter months will become milder with reduced frost days, the overall climate will shift toward being "uncomfortably hot and dry in the summer" according to the assessment.

The report notes that the Atlantic coastal strip and mountain slopes may experience slightly less severe temperature extremes, but the entire municipality will undergo significant climate change impacts that will affect ecosystems, water resources, and human comfort throughout the year (Câmara Municipal de Cascais, 2010b).

The coastal geography of Cascais makes it particularly susceptible to sea level rise (SLR), with projections based on Rahmstorf (2007) indicating a potential increase of 0.5 to 1.4 meters by 2100 This environmental shift is projected to trigger extensive beach erosion, threatening 47% to 84% of the municipality's sandy areas .The economically vital Carcavelos Beach is among the most vulnerable, with models predicting losses of up to 64% of its area (Câmara Municipal de Cascais, 2010c).

Coastal infrastructure faces severe additional risks from cliff erosion. Geological studies calculate an average retreat rate of approximately 0.01 meters per year for the urbanized cliff sections. While slow, this process is persistent and episodic, with a maximum observed local retreat of 7 meters in some areas since 1942. This erosion, compounded by SLR and intensified storm surges, endangers critical infrastructure built near the cliff edges. The report specifically highlights that the dense urban network extending to the top of the cliffs between Cascais and Carcavelos creates significant risk scenarios, as buildings, roads, and railways are within zones susceptible to collapse and inundation (Câmara Municipal de Cascais, 2010c).

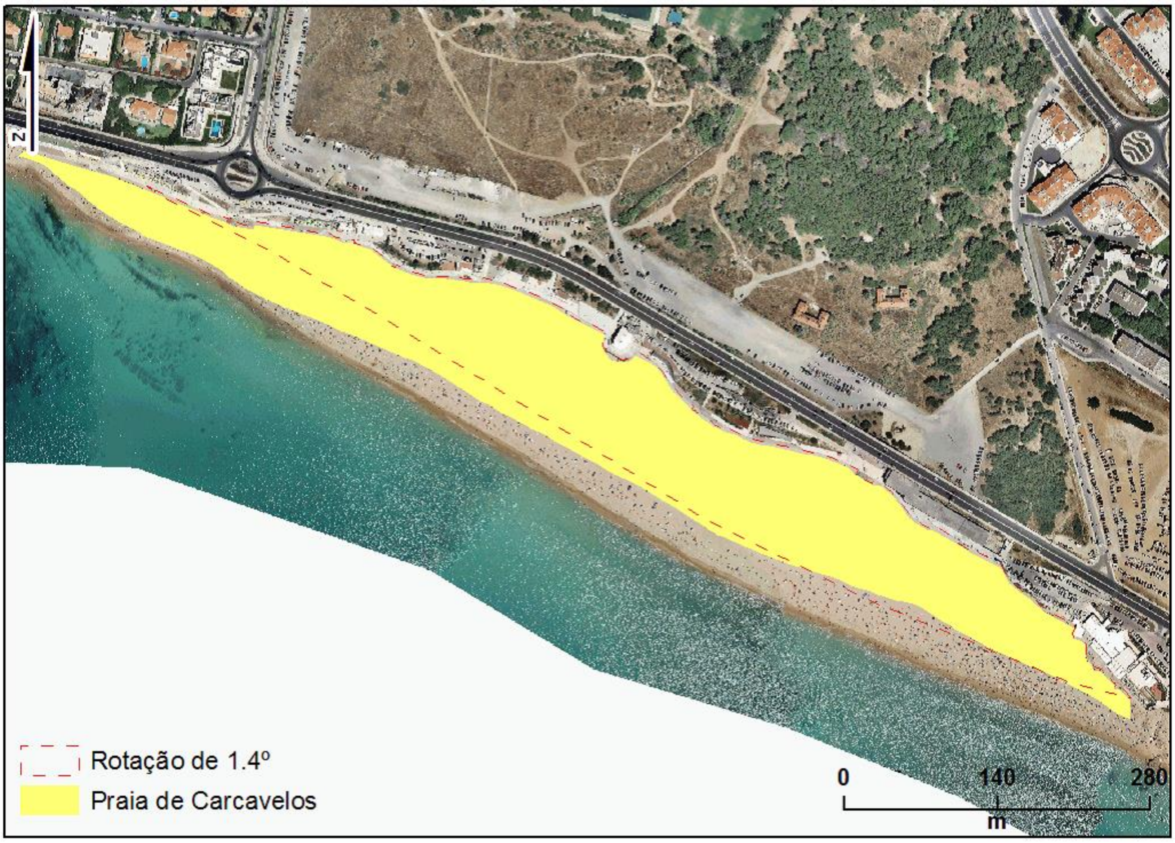


Figure 3-5 : Representation of the variation in the usable sandy area of Carcavelos Beach.
In response to a 10° clockwise rotation of the offshore wave direction (yellow – reference situation; dashed line – projected situation). Source: (Câmara Municipal de Cascais. 2010c).

Furthermore, the study projects a clockwise rotation in wave direction, which could reduce the usable area of key beaches like Guincho and Carcavelos by up to 18%. The combined impact of these factors sea level rise, wave rotation, and the municipality's inherently high coastline-to-surface-area ratio which presents a multi-faceted threat to Cascais's social, economic, and environmental stability Câmara Municipal de Cascais, 2010c).

While the municipality's coastal fringe is highly vulnerable to erosion and inundation, climate change also poses a severe and multi-faceted threat to Cascais's freshwater security. Projections indicate a drastic reduction in water availability, with modeling showing the potential for a 36-45% decrease in surface streamflow by mid-century (2020-2049) and a 60-72% decrease by the end of the century (2070-2099). This crisis extends to groundwater, the municipality's primary local source, with the recharge of the critical Pisões-Atrozela aquifer expected to decline by 20-55% over the same period. Compounding the problem of scarcity is a projected increase in the intensity of rainfall events, which elevates the risk of destructive flash floods in the region's steep, urbanized watersheds. Furthermore, reduced river flows will diminish the capacity to dilute pollutants, exacerbating existing water quality issues, while rising temperatures may promote algal blooms in reservoirs. This confluence of risks, diminishing quantity, worsening quality, and increasing flood volatility threatens the sustainability of public water supply, agricultural activities, and the health of aquatic ecosystems, demanding urgent and integrated adaptation strategies (Câmara Municipal de Cascais, 2010d).

This acute water crisis is intrinsically linked to and exacerbates the threats facing the municipality's natural ecosystems. Cascais's rich biodiversity faces a severe and multifaceted climate risk, primarily driven by increasing aridity and sea-level rise. Terrestrial ecosystems are highly vulnerable, with projections indicating potential local extinctions of endemic flora and specialist fauna—such as amphibians and reptiles—as rising temperatures and water stress exceed their survival thresholds. Crucially, this climate risk acts as a threat multiplier, exacerbating existing pressures like habitat fragmentation and wildfires. Marine systems are equally at risk; sea-level rise threatens to submerge critical intertidal habitats, while ocean acidification jeopardizes the survival of foundational species. Although warming may increase local fish species diversity, it threatens to destabilize key commercial fisheries. This systemic vulnerability underscores that protecting and restoring ecological connectivity and habitat resilience is a paramount adaptation strategy for the municipality, essential for safeguarding ecosystem services upon which Cascais depends (Câmara Municipal de Cascais, 2010e).

In addition, this systemic ecological vulnerability is compounded by a parallel and grave climate health risk facing Cascais's human population. The municipality's public health is directly threatened by a rising burden of heat-related mortality, with a local study quantifying a 4.7% increase in the risk of death for every degree Celsius above a 30°C threshold—a threshold projected to be exceeded with far greater frequency. Furthermore, climate change acts as a potent threat multiplier for urban health, exacerbating current air pollution levels and lengthening the seasonal window for the transmission of vector-borne diseases (Câmara Municipal de Cascais, 2010f).

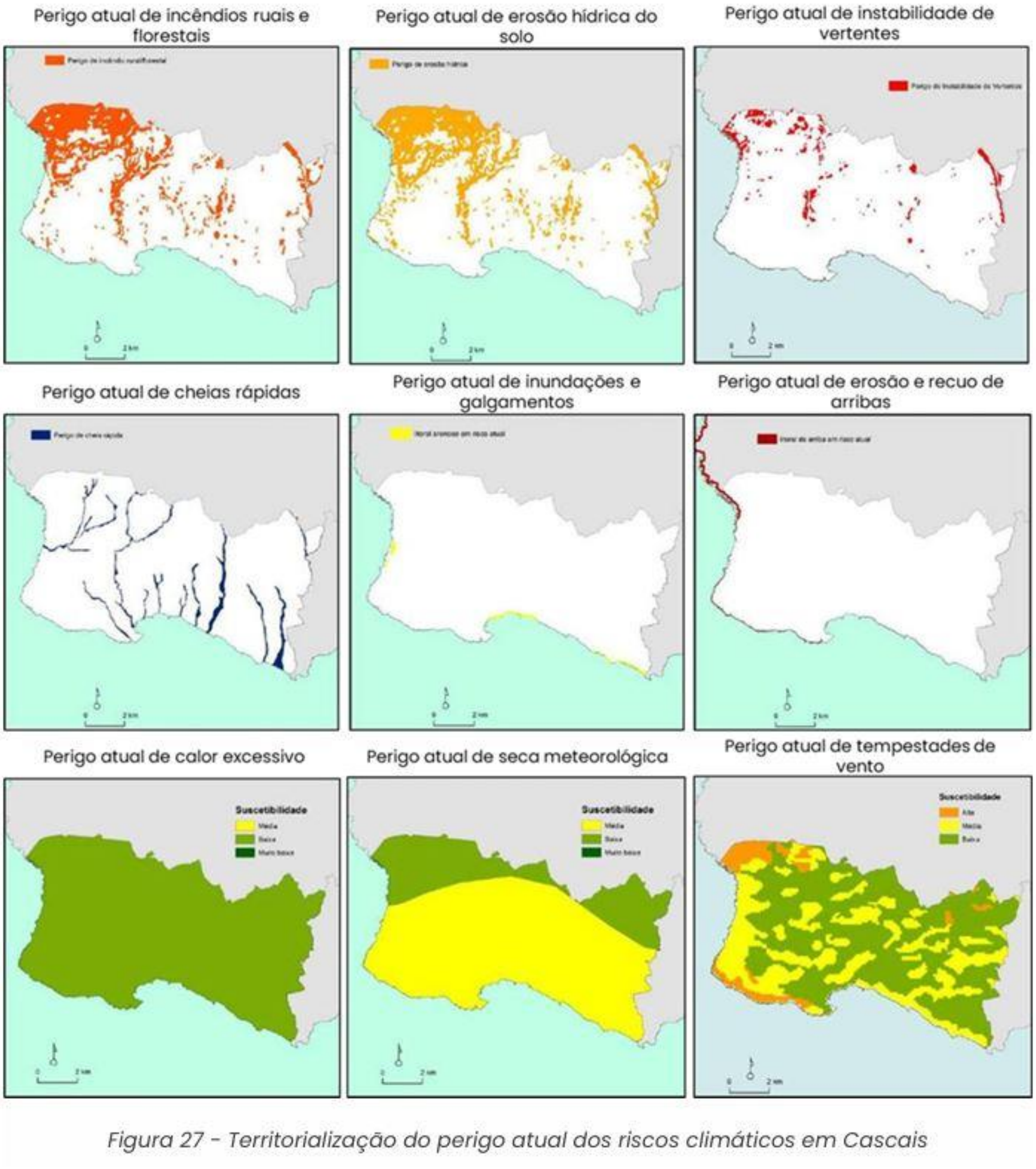


Figure 3-6 : Spatial distribution of current climate hazard risks in Cascais.

Adapted from: Câmara Municipal de Cascais, 2025.

The comprehensive climate risk assessment for Cascais positions the municipality as a frontline community confronting severe and immediate environmental threats. The convergence of acute water scarcity, coastal erosion, escalating heat stress, and ecosystem degradation reveals a systemic challenge that transcends traditional sectoral boundaries. These interconnected risks threaten the very pillars of Cascais's economy, particularly its tourism and real estate sectors, public health, and unique natural heritage (Ambiente Cascais, 2025). Conventional, siloed approaches to urban management are evidently insufficient to address the scale and complexity of this threat. The severity of these projections necessitates a paradigm shift from reactive mitigation to proactive, intelligent, and integrated adaptation. This imperative leads directly to an examination of how Cascais builds upon its strategic initiative as a smart city, deploying technology and data-driven strategies to build systemic resilience and safeguard its future.

3.3 Cascais strategies and technologies for climate risk mitigation and adaptation

The Municipality of Cascais has established itself as a leader in urban climate governance through an integrated framework that simultaneously addresses mitigation and adaptation. This effort is orchestrated under the overarching Municipal Climate Action Plan (PMAC2), which aligns local policy with Portugal's Climate Framework Law (Law No. 98/2021). Its objective is to implement policies for both mitigation and adaptation, targeting a reduction of greenhouse gas emissions by at least 55% by 2030 (Câmara Municipal de Cascais, 2025)

PMAC2 incorporates three fundamental dimensions: mitigating emissions, adapting territories to climate impacts, and combating energy poverty. This plan integrates and updates Cascais's previous pioneering strategies, including the Plano Estratégico de Cascais face às Alterações Climáticas (PECAC), which provided the initial century-long impact analysis using models from the Hadley Centre and IPCC scenarios, and the Plano de Ação para a Adaptação às Alterações Climáticas de Cascais 2030 (PA3C2) (Câmara Municipal de Cascais, 2010h; EMAC - Cascais Ambiente, 2018). The following sections will explore Cascais's specific strategies for climate risk mitigation and adaptation in greater detail.

3.3.1 Integrated Climate Mitigation Strategy in Cascais

The municipality of Cascais has developed a sophisticated and multi-layered climate mitigation strategy that effectively integrates long-term, evidence-based foresight with concrete operational planning. This strategy, evolving from the foundational *Plano Estratégico de Cascais face às Alterações Climáticas* (PECAC) to the actionable *Plano Cascais pelo Clima – Mitigação,* demonstrates a smart city approach where data modelling directly informs the deployment of specific technologies, infrastructural changes, and financial policies.

The strategic foundation was laid with the PECAC, which utilized detailed Energy-Emissions scenarios extending to 2070, built upon established IPCC SRES frameworks, to identify the most effective pathways for decarbonization (Câmara Municipal de Cascais, 2010g). This modeling was crucial as it moved the policy beyond assumptions, providing a scientific basis for prioritizing interventions. The analysis revealed that underlying socio-economic trends would be insufficient to meet the municipality's climate commitments, necessitating deliberate intervention (Câmara Municipal de Cascais, 2010g). It pragmatically ruled out certain technologies, such as large-scale wind and wave power, due to local constraints, instead identifying solar energy, bioenergy from waste, and systemic changes in mobility as the highest-impact areas (Câmara Municipal de Cascais, 2010g). This early work established the core philosophy that the most powerful mitigation measures are those that drive technological and infrastructural transformation rather than relying solely on behavioral change.

This strategic foresight was directly operationalized into the detailed measures of the 2023 plan. The mitigation strategy is executed through several key technological and policy domains:

- **Energy Transition**: Informed by the PECAC's identification of solar potential, the 2023 plan sets specific, quantifiable targets. The "Cascais Solar" initiative evolved into a comprehensive program to install 20 MW of solar PV on residential properties and an additional 11 MW on municipal buildings (Câmara Municipal de Cascais, 2023). This is supported by municipal subsidy programs designed to leverage private investment, a policy mechanism aimed at accelerating adoption beyond public assets alone.

- **Sustainable Mobility**: The PECAC's critical finding that reducing the *need* for mobility is more effective than promoting modal shift on an inefficient system is actioned through concrete policies (Câmara Municipal de Cascais, 2010g). The 2023 plan details the expansion of the cycling network by 100 km and the creation of carbon-free zones in historic areas to redesign urban space (Câmara Municipal de Cascais, 2023).

Furthermore, the early involvement in the national Mobi-e program materialized into a robust network of 600 electric vehicle charging points (500 semi-fast, 100 fast) to enable the technological transition of the private fleet (Câmara Municipal de Cascais, 2023). The most significant policy implementation is the provision of free public transport on the municipal bus network (MobiCascais), a tangible measure that removes financial barriers and directly incentivizes the use of collective mobility residents, workers, and students in the municipality via Viver Cascais Card In 2024, more than 135,000 journeys on the MobiCascais lines were validated with the Viver Cascais Card which helped the environment, as fewer cars circulating reduces CO2 emissions into the atmosphere (Ambiente Cascais, n.d.-a).

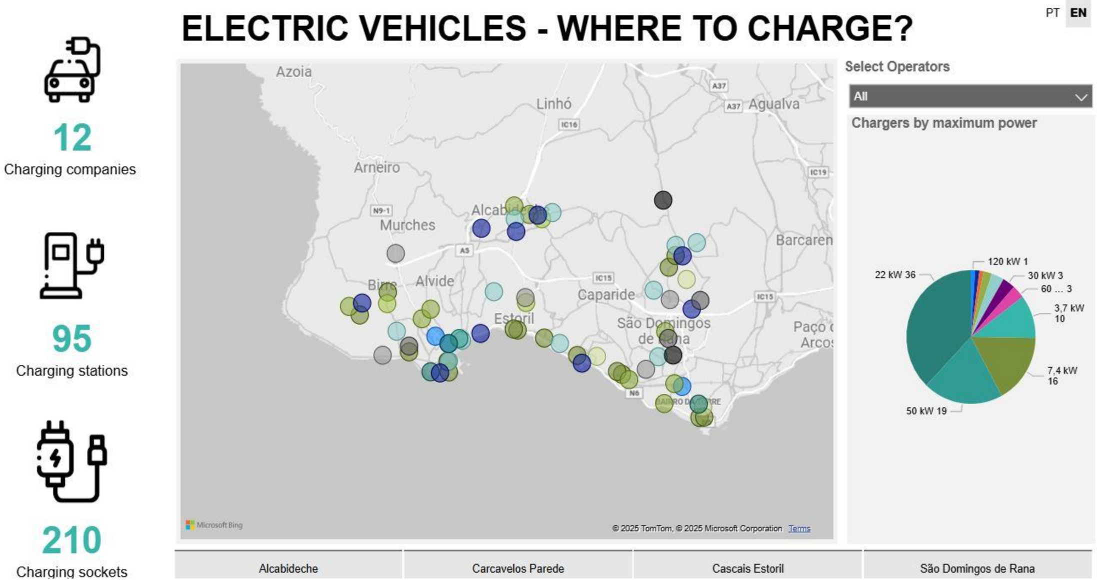


Figure 3-7: Electric vehicle charging infrastructure in the Cascais area.
The image shows there are 12 charging companies operating 95 stations with 210 sockets, and a detailed breakdown of charger power levels. Source: (Ambiente Cascais, n.d.-a).

In addition, flagship mitigation project is the integration of hydrogen-powered buses into the MobiCascais fleet. The M43 line, connecting Cascais Station to Guincho, is fully serviced by buses powered by hydrogen fuel cells, resulting in zero tailpipe GHG emissions (Ambiente Cascais, n.d.-a). Notably, this initiative is part of a circular economy model, as the future hydrogen supply is planned to be produced from landfill waste, thereby mitigating emissions from the waste sector while decarbonizing public transport.

- **Building Efficiency**: The strategy extends beyond energy generation to deep consumption reduction. The plan includes programs to support the private retrofitting of 10,000 homes with improved insulation and efficient windows, as well as the installation of 10,000 heat pumps (Câmara Municipal de Cascais, 2023). For its own operations, the municipality is investing €18.1 million, including a full conversion of public lighting to LED technology with sensors and the installation of smart energy management systems in municipal buildings (Câmara Municipal de Cascais, 2023).

- **Waste Management**: The PECAC's focus on bioenergy is realized through policies targeting waste. The 2023 plan includes measures to implement Pay-As-You-Throw (PAYT) systems and improve the separate collection of organic waste, strategies designed to reduce landfill volume and capture energy potential from waste streams (Câmara Municipal de Cascais, 2023).

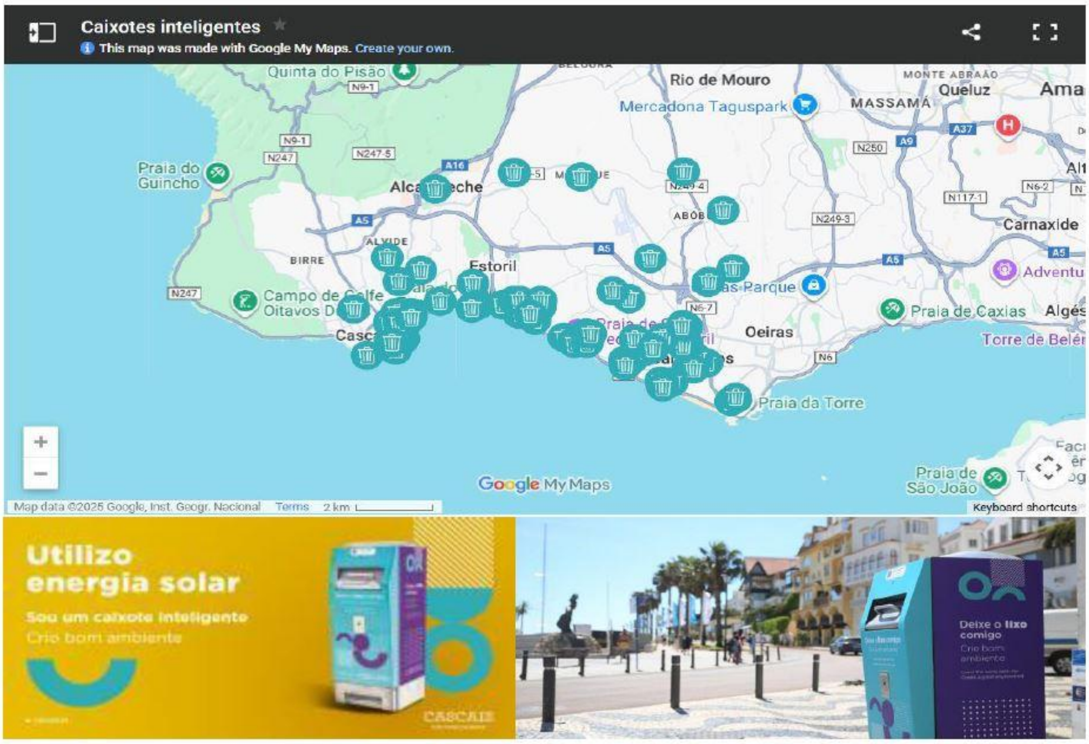


Figure 3-8: Caixotes Inteligentes (smart Bins).

The location of each in across the Cascais municipality. Source: (Ambiente Cascais, n.d.-)

A significant mitigation effort is the modernization of urban waste collection through the deployment of smart trash cans (caixotes inteligentes). This network of over 140 solar-powered units features compaction technology and fill-level sensors, which optimize collection routes by reducing frequency by approximately eight times (Ambiente Cascais, n.d.-b).

- **Urban Greening:** The iTree - Street Trees in Cascais project is a foundational element of the municipality's data-driven strategy for climate risk mitigation and urban resilience. This initiative, developed through a cooperation agreement with the Higher Institute of Agronomy, utilizes a specialized software tool from the USDA Forest Service to scientifically quantify the ecosystem services provided by the urban forest (Ambiente Cascais, n.d.-c).

  This project directly supports climate mitigation by accurately measuring the carbon storage and sequestration capabilities of Cascais's street trees, translating their biological function into tangible data on greenhouse gas reduction. Furthermore, it is a critical tool for climate adaptation. The iTree analysis enables the municipality to understand how its urban forest mitigates the urban heat island effect through shading and evapotranspiration, a crucial defense against rising temperatures and heatwaves.

Figure 3-9: Infographic from the iTree - Street Trees in Cascais project.
The picture highlighting the top five tree species in Cascais ranked by their ecosystem services: pollutant removal, avoided rainwater runoff, and gross carbon sequestration. Data visualization includes species names (e.g., Cedro-do-Buçaco, Choupo-tremedor) and their annual environmental contributions.
Source: (Ambiente Cascais, n.d.-c).

It also evaluates the role of trees in managing climate-related flood risks by quantifying their capacity to intercept rainwater, delay runoff, and reduce peak flow during heavy precipitation events (Ambiente Cascais, n.d.-c).

In conclusion, Cascais exemplifies how a municipality can effectively translate ambitious climate goals into tangible action through a structured, multi-faceted approach. By building upon the foundational *Plano Estratégico de Cascais face às Alterações Climáticas* (PECAC), the 2023 *Plano Cascais pelo Clima – Mitigação* operationalizes a clear vision with targeted measures across energy, mobility, built environment, waste management, and urban greening. Key initiatives such as the deployment of solar infrastructure, the expansion of free public transportation and electric vehicle networks, building retrofits, smart waste systems, and data-driven urban forestry demonstrate a commitment to systemic change. This integration of strategic foresight with practical, technology-enabled solutions positions Cascais as a pioneering example of local climate leadership, showcasing how municipalities can drive meaningful decarbonization while enhancing urban resilience and quality of life.

3.3.2 Adaptation Strategy in Cascais

The municipality of Cascais, Portugal, presents a compelling case study of a smart city whose intelligence is manifested not solely through digital technology but through a sophisticated, holistic, and participatory governance framework for climate risk adaptation. Moving beyond the common techno-centric smart city model, Cascais exemplifies how strategic planning, deep stakeholder engagement, and a commitment to nature-based solutions can build profound urban resilience. Its journey from initial strategic assessment to concrete, funded action offers a replicable blueprint for integrated climate adaptation.

The foundational step in Cascais's approach was a comprehensive scientific assessment of vulnerabilities. The pioneering *Plano Estratégico de Cascais face às Alterações Climáticas* (PECAC), developed in 2010 in collaboration with the University of Lisbon's Climate Change Impacts, Adaptation, and Modelling (CCIAM) group, provided the critical evidence base (Câmara Municipal de Cascais, 2010h). This study was among the first at the municipal level in Portugal to project localized climate impacts, forecasting a temperature increase of 1.7°C to 3.2°C by the end of the century, a significant decrease in annual precipitation, and a heightened risk of coastal flooding and wildfires (Câmara Municipal de Cascais, 2010h). The

PECAC’s innovative methodology involved a multi-criteria workshop with local experts and stakeholders to identify and prioritize adaptation options, emphasizing measures with high importance, urgency, and ‘no-regret’ co-benefits, such as improving water efficiency and rehabilitating riverine ecosystems (Câmara Municipal de Cascais, 2010h).

Building upon this strategic foundation, Cascais transitioned decisively from planning to implementation with the *Plano de Ação para a Adaptação às Alterações Climáticas de Cascais 2030* (PA^{3}C^2) (EMAC - Cascais Ambiente, 2018). This action plan is distinguished by its participatory co-creation process, developed through an "investigation-ação participativa" (participatory action-research) methodology involving over 150 stakeholders from municipal departments, civil protection, public health, and local communities (EMAC - Cascais Ambiente, 2018). This process ensured that the plan was not a top-down directive, but a shared vision, embedding ownership and enhancing the feasibility of its 13 measures and 80 specific actions, which are outlined in Table below.

Measure Number & Name	***Type***	***Key Actions***	***Addresses***
1. Communication Campaigns	Non-Structural	Climate week, online platform, documentaries, and school programs.	All vulnerabilities (Raise awareness)
2. Separate Sewer & Storm water	Grey/Non-Struct	Inspection plans, CCTV surveys, and fixing improper connections.	Flooding, water pollution
3. Sustainable School Program	Non-Structural	Environmental education, school gardens, and climate exhibitions.	Education & awareness
4. Alternative Water Supply	Grey	New pipelines, reservoirs, and remodeling water treatment plants.	Water scarcity, droughts
5. Green Corridors & River Restoration	Green	Renaturalizing rivers (e.g., Ribeira das Vinhas), creating ecological corridors.	Biodiversity loss, heat
6. Eliminate Water Pollutio	Grey/Green	Remodeling sewer networks, inspecting properties, and cleaning septic tanks.	Water pollution
7. Renaturalize Sintra-Cascais Park	Green	Reforestation with native species, genetic bank, dune restoration, and volunteer programs.	Biodiversity, fires
8. Forest Fire Defense Plans	Green/Non-Struct	Managing forest fuels, controlling invasive species, and creating firebreaks.	Wildfire risk
9. Coastal Protection Plan	Grey/Non-Struct	Risk zone mapping, cliff stabilization, and warning systems for coastal hazards.	Sea-level rise, erosion
10. Heatwave Contingency Plan	Non-Structural	Implementing health protocols, beach sensors for heat index, and public alerts.	Heatwaves

11. Disease Vector Surveillance	Non-Structural	Monitoring and controlling mosquitoes and other disease vectors.	Spread of diseases
12. New Urban Parks & Infi tration Zones	Green	Creating naturalized parks that absorb rainwater and using treated wastewater for irrigation.	Flooding, heat, drought
13. Bioclimatic Planning Legislation	Non-Structural	Incentives for green architecture, urban planning rules to limit large impervious surfaces.	All vulnerabilities

Table 3-1: Synthesis of the 13 priority adaptation measures from the Cascais Municipal Climate Adaptation Action Plan (PA^{3}C^2).
Grouped by thematic area and categorized by 3 types of intervention, which are 1: Green Measures (Ecosystem-based Adaptation), 2: Grey Measures (Hard/Engineered Infrastructure), and 3: Non-Structural or Soft Measures. Adapted from: (EMAC - Cascais Ambiente, 2018).

The substance of the PA^{3}C^2 reveals a smart adaptation strategy that prioritizes green infrastructure and ecological resilience over purely technological or grey solutions. The plan is predominantly composed of green (53%) and non-structural (40%) measures, with only 7% classified as grey infrastructure interventions (EMAC - Cascais Ambiente, 2018). This ecosystem-based approach is evident in core measures such as the renaturalization of rivers (e.g., Ribeira das Vinhas) to mitigate flooding and improve biodiversity, the creation of green corridors to connect habitats and provide cooling, and the large-scale implementation of forest management plans to reduce wildfire fuel loads (EMAC - Cascais Ambiente, 2018). These actions directly address the high-priority vulnerabilities identified in the 2010 PECAC workshop and leverage natural systems to provide cost-effective, multi-functional benefits.

The initiatives of the Cascais municipality for the climate risk adaptation are more disused as below:

- **Water management**: Cascais demonstrates smart urbanism through its integrated management of critical resources, particularly water. Recognizing water scarcity as a paramount risk, the PA^{3}C^2 mandates a multi-faceted strategy. This includes hard infrastructure projects like a third water pipeline and reservoir remodeling to diversify supply, alongside soft measures like a rigorous water loss management program and the promotion of alternative water sources, such as using treated wastewater for irrigation (EMAC - Cascais Ambiente, 2018).

  Cascais's water management strategy is a proactive and data-driven pillar of its climate adaptation framework, directly targeting the acute risk of drought by transitioning the municipality from a linear consumption model to a circular, efficiency-focused system. Guided by the diagnostic Matriz da Água de Cascais, which quantifies vulnerabilities and flows, the strategy implements targeted demand reduction through public water-saving kits and promotes a crucial shift to alternative sources like treated wastewater and rainwater for non-potable uses such as irrigation; furthermore, it replaces water-intensive lawns with climate-resilient dryland meadows. This integrated approach that combining consumption efficiency, diversification of supply, and ecosystem-based adaptation systematically reduces the territory’s reliance on scarce potable water and enhances its resilience to increasing water scarcity (Câmara Municipal de Cascais, 2019).

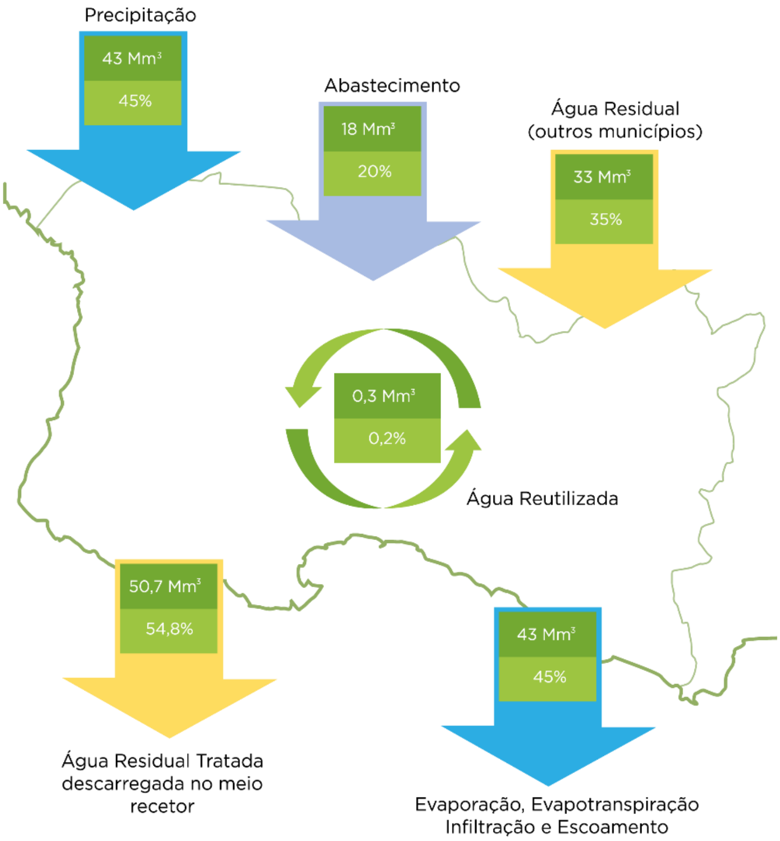


Figure 3-10: Analysis of Cascais's water resources in 2017. Adapted from (Câmara Municipal de Cascais, 2019).

The diagram from Águas de Cascais depicts the region's water balance, showing a near-perfect equilibrium between in-flows and outflows. A total of 94 Mm3 (million cubic meters) of water enters the system from three main external sources, while 93.7 Mm3 exits through two primary outflow points. A small but significant detail is the 0.3 Mm3 internal loop, which highlights a localized water recycling or reuse process within the region.

- **Public participation:** A critical element of Cascais's smart adaptation is its focus on social resilience and inclusive governance. The first measure of the PA^{3}C^2 is dedicated to communication and sensitization campaigns, acknowledging the 2014 survey finding that while 70% of residents viewed climate change as a threat, only 34% believed it was a political priority (EMAC - Cascais Ambiente, 2018). A cornerstone of this sensitization effort is the Cascais Environmental Education and Awareness Program (PESA). Launched in the 2012/13 academic year, PESA operationalizes the Escola Sustentável (Sustainable School) vision by integrating climate adaptation and environmental sustainability directly into the educational curriculum, fostering a culture of resilience from a young age (Ambiente Cascais, n.d.-d).

The program provides a multidisciplinary offering of activities for schools on themes such as climate change, circular economy, biodiversity, and water conservation, serving as a fundamental tool to prepare young people for participatory and conscious citizenship in line with the Sustainable Development Goals (Ambiente Cascais, n.d.-d). The governance model itself is designed for inclusivity, establishing a Climate Action Commission with technical working groups and a Local Council for Sustainable Development to ensure continuous dialogue between technicians, citizens, and the private sector (EMAC - Cascais Ambiente, 2018).

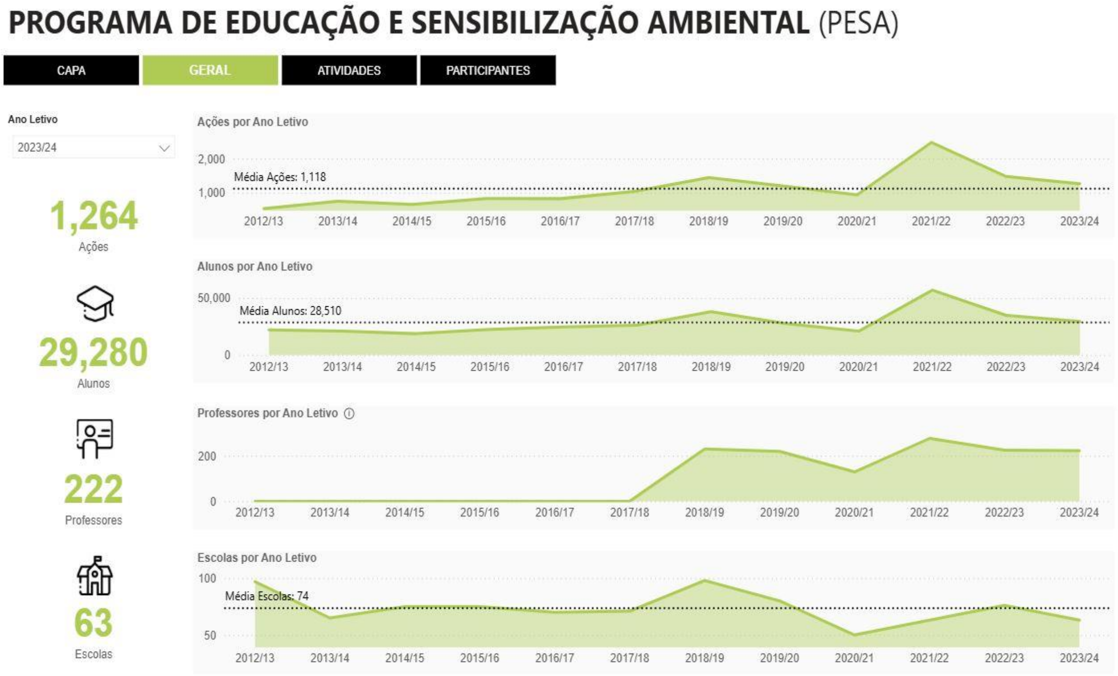


Figure 3-11: Cascais Environmental Education and Awareness Program (PESA) a summary of 2023/2024 of participants report.
Source: (Ambiente Cascais, n.d.-d)

- **Financed Implementation, Monitoring, and Transparency:** the intelligence of Cascais's approach is confirmed by its commitment to transparency, monitoring, and financed implementation. The PA³C² is not an aspirational document; it includes a detailed investment plan totaling over €11.6 million until 2030, with specific annual budgets allocated to each action (EMAC - Cascais Ambiente, 2018). A robust framework of 49 quantitative indicators is established to monitor progress, measuring outcomes from the technical (e.g., km of remodeled sewer network) to the ecological (e.g., survival rate of planted trees) and the social (e.g., number of participants in awareness campaigns) (EMAC - Cascais Ambiente, 2018).

A critical element of this implementation is the innovative AdaptCascais Fund, a financial instrument designed to mobilize civil society by funding local adaptation projects proposed by communities, NGOs, and associations (Câmara Municipal de Cascais, n.d.-a). The fund exemplifies a shift from top-down planning to co-created action, having supported 16 projects across two editions, focusing on river rehabilitation, urban greening, the circular economy, and awareness campaigns. Its success is evident in its growth: the financial allocation increased from €24,000 in the 1st edition to €50,000 for the 3rd edition (2025), with per-project funding rising from €3,000 to €5,000, reflecting the high value placed on community-led initiatives in building municipal resilience(Ambiente Cascais, n.d.-e).

In conclusion, the implementation of the *Plano de Ação para a Adaptação às Alterações Climáticas de Cascais 2030 (PA3C2)* demonstrates a remarkable and sustained commitment to building urban resilience. The plan’s success is quantitatively evidenced by its consistently high implementation rates, progressing from 68% of actions implemented in 2022 to 75% in 2024 (Ambiente Cascais, 2024), a significant achievement that underscores the municipality’s operational effectiveness even amidst external challenges like the COVID-19 pandemic and increasingly frequent extreme climate events.

This high rate of execution is a direct result of the plan's foundational strengths: its basis in updated climate science and a participatory development process involving over 150 stakeholders (EMAC - Cascais Ambiente, 2018), its strategic focus on ecosystem-based measures, and its robust governance framework featuring clear financing and a comprehensive monitoring system. The establishment of the AdaptCascais Fund is a particularly notable innovation, as it exemplifies the model of civic co-production that mobilizes local knowledge and resources, thereby amplifying the plan's impact and fostering deep community engagement in resilience-building (Câmara Municipal de Cascais, n.d.-e).

Therefore, Cascais's PA3C2 transcends being a mere policy document; it represents an actionable, accountable, and adaptive governance model. Its structured yet flexible approach, combined with its proven ability to deliver concrete results, positions Cascais as a leading example of how municipalities can effectively translate climate adaptation strategies into tangible on-the-ground resilience.

Chapter 4

Discussion

This research aimed to investigate how smart city strategies contribute to climate resilience, using Cascais, Portugal, as the primary case study. The analysis reveals that Cascais exemplifies a highly effective, pragmatic model of urban climate governance, one that derives its intelligence not from futuristic technology alone, but from a powerful integration of scientific foresight, participatory governance, and a strategic prioritization of nature-based solutions. While its approach may lack the technological spectacle of larger global cities, it offers a highly replicable blueprint for how medium-sized municipalities can translate the smart city paradigm into tangible, on the ground resilience.

4.1. Strategic Foresight as the Foundation for Action

A central finding of this study is that the most critical "smart" technology a city can employ is not a sensor, but a scientifically robust risk assessment. Cascais's pioneering Plano Estratégico de Cascais face às Alterações Climáticas (PECAC) in 2010 provided the indispensable evidence base that transformed climate action from a political aspiration into an urgent, targeted priority (Câmara Municipal de Cascais, 2010b, 2010c, 2010d). By downscaling global IPCC models to project localized impacts, from a 60-72% decrease in surface streamflow to the potential loss of 84% of sandy beach areas, the PECAC generated the political will and technical clarity needed to justify significant public investment and long-term planning.

This aligns with the scholarly view of smart urbanism as a data-driven endeavor (Bibri & Krogstie, 2017), but crucially highlights that the most vital data is often long-term climatic projections. This foundational work allowed Cascais to identify and prioritize "no-regret" measures, ensuring that early actions would deliver co-benefits regardless of uncertain future climate pathways. This strategic foresight is the bedrock upon which all subsequent smart actions from the PA^{3}C^2 to the Municipal Climate Action Plan (PMAC2) have been built, demonstrating that a smart city is, first and foremost, an informed one (Câmara Municipal de Cascais, 2025).

4.2. The Participatory Governance Model: Beyond Top-Down Technocracy

A key divergence of the Cascais model from the stereotypical top-down, technocratic smart city is its profound commitment to participatory governance. The development of the Plano de Ação para a Adaptação às Alterações Climáticas de Cascais 2030 (PA^{3}C^2) through a participatory action-research methodology involving over 150 stakeholders exemplifies a shift from municipal government to multi-stakeholder *governance* (EMAC - Cascais Ambiente, 2018). This process embedded a shared ownership of the climate agenda across departments, civil society, and the private sector.

The most potent expression of this philosophy is the AdaptCascais Fund. This initiative extends far beyond consultation to actively finance and empower community-led resilience projects, effectively crowdsourcing innovation and fostering a deep sense of civic stewardship (Ambiente Cascais, n.d.-e). This directly addresses critiques by scholars like Hollands (2008, as cited in Albino et al., 2015) that smart cities can be exclusionary. Furthermore, the PESA educational program integrates climate adaptation into school curricula, building long-term social capacity and awareness from a young age (Ambiente Cascais, n.d.-d). This demonstrates that Cascais's participatory infrastructure is both structural (the Fund) and cultural (Education), ensuring that its smart resilience is socially embedded and sustainable.

4.3. The Primacy of Nature-Based Solutions over Technological Spectacle

In contrast to the heavily technological narratives often associated with smart cities, Cascais's strategy is distinguished by its deliberate prioritization of green and soft measures. The PA^{3}C^2 is composed of 53% green (ecosystem-based) and 40% non-structural measures, with only 7% grey (engineered) infrastructure (EMAC - Cascais Ambiente, 2018). This strategic choice recognizes that nature is the most multifunctional and cost-effective form of resilience infrastructure available. Initiatives like the renaturalization of the Ribeira das Vinhas simultaneously mitigate flood risk, enhance biodiversity, improve water quality, combat the urban heat island effect, and increase public amenity value.

This is not to say technology is absent. Instead, it is deployed pragmatically as an *enabler* to optimise these natural and social systems. The iTree project uses data analytics to quantify the carbon sequestration and stormwater retention benefits of the urban forest, providing an evidence-based rationale for further investment in green infrastructure (Ambiente Cascais, n.d.-c). Smart trash cans with fill-level sensors optimise collection routes, reducing GHG emissions from municipal vehicles (Ambiente Cascais, n.d.-b). This represents a mature understanding of technology as a tool to enhance efficiency and validate performance, rather than as an end in itself.

4.4. Comparative Context: Pragmatism over Scale

When benchmarked against global leaders, Cascais's approach is notable for its pragmatism and replicability. While Amsterdam's Schoonschip is a brilliant example of citizen-led technological innovation (Sorkhabi et al., 2023), and Singapore's Smart Water Grid is a feat of engineering at a national scale (Gupta et al., 2020), these models can be difficult to transplant to medium-sized cities with more constrained budgets.

Cascais's strategy is built on a portfolio of smaller, interconnected actions: a solar panel subsidy, a river restoration project, a community fund, and an educational program that collectively build systemic resilience. This modular approach is less reliant on massive capital investment and may be more adaptable and less risky for similar municipalities. It suggests that the path to a climate-smart future for many cities may lie not in a single technological leap, but in the diligent and integrated execution of a multitude of smarter, coordinated steps across governance, society, and ecology.

4.5. Limitations and Ongoing Challenges

Despite its strengths, the Cascais model continues to face ongoing challenges. First, while participation is structured, there is an opportunity to deepen digital engagement. Implementing digital platforms for participatory budgeting or real-time citizen reporting can broaden accessibility and engagement, thereby mitigating the risk of a digital divide and enhancing transparency.

Second, as noted in the mitigation analysis, while progress is evident, such as the hydrogen-powered M43 bus line and free public transport, Cascais's mitigation efforts lack the transformative urban redesign of a project like Barcelona's Superblocks (Mueller et al., 2020). Reducing car dependency requires not just alternative vehicles, but a fundamental rethinking of urban space to prioritize people over cars, an area where further ambition is needed.

Ultimately, the success of this model hinges on sustained political commitment and institutional alignment. The high implementation rate of the PA^{3}C^2 (75% in 2024) is impressive

(Ambiente Cascais, 2024), but maintaining this momentum across electoral cycles and ensuring seamless coordination across all municipal departments remains a perpetual challenge that requires enduring institutional resolve.

4.6. Conclusion: A Replicable Model of Intelligent Resilience

In conclusion, the case of Cascais demonstrates that a smart climate-resilient city is best understood as a learning, adaptive system. Its intelligence is derived from its ability to listen to science, engage its citizens, and leverage its natural capital. Technology plays a crucial but supporting role as an enabler of efficiency and monitoring.

Cascais may not be defined by the same scale of technological innovation as Amsterdam or Singapore, but it offers something perhaps more valuable: a proven, realistic, and holistic blueprint for action. Its journey from the strategic diagnosis of the PECAC to the implemented, participatory actions of the PA^{3}C^2 and the PMAC2 provides a robust model for other coastal cities worldwide. It proves that meaningful, smart climate action is achievable at the local level when it is built on the three pillars of science, participation, and nature, a model of resilience that is not only smart but also wise, equitable, and enduring.

Chapter 5

Conclusion

This thesis examined how smart city strategies and technologies contribute to climate change mitigation and adaptation, focusing on the municipality of Cascais and drawing lessons from international cases. The analysis demonstrated that smart city development, when grounded in digital technologies, advanced spatial planning, and data-driven governance, offers a strong framework for strengthening urban resilience in the face of escalating climate risks.

International initiatives such as the smart energy systems of Amsterdam, the integrated mobility strategies of Barcelona, and the green infrastructure and water management models of Singapore highlight the diverse range of technological and planning tools available for climate action. These cases illustrate the value of digital monitoring networks, predictive modelling, smart mobility, and integrated resource management. However, they also reveal persistent challenges for medium-sized municipalities, including financial constraints, high technological costs, and limited implementation capacity.

In this context, Cascais presents a strong and context-appropriate example of climate smart urbanism. Through strategic plans such as PECAC and PA^{3}C^{2}, as well as smart mobility systems, digital environmental monitoring, green infrastructure, and participatory mechanisms like the AdaptCascais Fund, the municipality has made notable progress in both mitigation and adaptation. Its implementation rate of 75 percent by 2024 reflects not only technical capability but also a strong institutional commitment to long-term climate governance.

The findings show that the approach in Cascais integrates three essential components: scientific climate risk assessment, participatory and collaborative governance, and strategic innovation. This combination reflects the core principles of smart city resilience, where technology, planning, and community engagement work together to support informed decision making and adaptive capacity. It also aligns Cascais with the Sustainable Development Goals by contributing to a more sustainable and resilient urban environment for its residents.

Based on the analysis, several lessons emerge for municipalities facing similar climate pressures. These include the importance of investing in scalable digital systems, embedding climate objectives into spatial planning, strengthening coordination across municipal departments, and maintaining participatory mechanisms that reinforce public trust and long term policy continuity.

In conclusion, this study affirms that smart city strategies can significantly enhance climate mitigation and adaptation when technology is integrated with planning and governance rather than treated as an isolated solution. Cascais demonstrates that medium-sized cities can adopt effective, transferable, and evidence-based approaches to climate resilience, providing valuable guidance for other coastal municipalities facing increasing climate risks.

Bibliographic References

1. Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama, Eds.). Cambridge University Press. Source:https://doi.org/10.1017/9781009325844
2. Mumford, L. (1961). *The city in history*. Harcourt, Brace & World.
3. Davis, M. (2006). *Planet of slums*. Verso.
4. Hodder, I. (2006). *The leopard's tale: Revealing the mysteries of Çatalhöyük*. Thames & Hudson.
5. Childe, V. G. (1950). The urban revolution. *The Town Planning Review, 21*(1), 3–17. https://doi.org/10.3828/tpr.21.1.k853061t614q42qh
6. UN-Habitat. (2020). *World cities report 2020: The value of sustainable urbanization*. United Nations Human Settlements Program. https://unhabitat.org/world-cities-report-2020-the-value-of-sustainable-urbanization
7. Van De Mieroop, M. (2016). *A history of the ancient Near East, ca. 3000–323 BC* (3rd ed.). Wiley-Blackwell.
8. Kostof, S. (1991). *The city shaped: Urban patterns and meanings through history*. Little, Brown and Company.
9. Engels, F. (2009). *The condition of the working class in England*. Penguin Classics. (Original work published 1845).
10. Fullilove, M. T. (2004). *Root shock: How tearing up city neighborhoods hurts America, and what we can do about it*. Ballantine Books
11. Jacobs, J. (1961). *The death and life of great American cities*. Random House.
12. National Academies of Sciences, Engineering, and Medicine. (2020). *Climate change: Evidence and causes: Update 2020*. The National Academies Press. https://doi.org/10.17226/25733
13. United Nations Human Settlements Program. (2022). *World cities report 2022: Envisaging the future of cities*. UN-Habitat. https://unhabitat.org/world-cities-report-2022
14. Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report. Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee & J. Romero (Eds.)]. IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647
15. United Nations Office for Disaster Risk Reduction (UNDRR). (2017). *Terminology on disaster risk reduction*. UNDRR.

16. Global Alliance for Buildings and Construction (Global ABC). (2021). *2021 Global Status Report for Buildings and Construction*. United Nations Environment Program.
17. Hallegatte, S., Rentschler, J., & Walsh, B. (2018). *Building Back Better: Achieving resilience through stronger, faster, and more inclusive post-disaster reconstruction*. World Bank Group.
18. k Angelidou, M., Psaltoglou, A., Komninos, N., Kakderi, C., Tsarchopoulos, P., & Panori, A. (2018). Enhancing sustainable urban development through smart city applications. *Journal of Science and Technology Policy Management*, *9*(2), 146–169. https://doi.org/10.1108/JSTPM-05-2017-0016
19. Bibri, S. E., & Krogstie, J. (2017). Smart sustainable cities of the future: An interdisciplinary literature review. *Sustainable Cities and Society*, *31*,183212. https://doi.org/10.1016/j.scs.2017.02.016
20. Samarakkody, A., Amaratunga, D., & Haigh, R. (2023). Technological innovations for enhancing disaster resilience in smart cities: A comprehensive urban scholar's analysis. *Sustainability*, *15*(15), 12036. https://doi.org/10.3390/su151512036
21. ITU. (2016*). Recommendation ITU-T Y.4900: Key performance indicators for smart sustainable cities*. International Telecommunication Union.
22. Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. Journal of Urban Technology, 22(1), 3-21. DOI:10.1080/10630732.2014.942092
23. Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanović, N., & Meijers, E. (2007). Smart cities: Ranking of European medium-sized cities. Centre of Regional Science, Vienna University of Technology.
24. Greenfield, A. (2017). *Radical technologies: The design of everyday life*. Verso Books.
25. Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for smarter cities. IBM Journal of Research and Development, 54(4), 1-16.DOI: https://doi.org/10.1147/JRD.2010.2048257
26. Hollands, R. G. (2008). Will the real smart city please stand up? City, 12(3), 303-320. DOI:10.1080/13604810802479126
27. Shwayri, S. T. (2013). A model Korean ubiquitous eco-city? The politics of making Songdo. Journal of Urban Technology, 20(1), 39-55. DOI:10.1080/10630732.2012.735409
28. United Nations. (2015). *transforming our world: The 2030 Agenda for Sustainable Development*. https://sdgs.un.org/2030agenda
29. UN-Habitat. (2022). *People-centered smart cities: A playbook for developing and implementing a smart city mission*. United Nations Human Settlements Program (UN-Habitat).
30. Allam, Z., & Newman, P. (2018). Redefining the smart city: Culture, metabolism and governance. *Smart Cities*, *1*(1), 4–25. https://doi.org/10.3390/smartcities1010002
31. Revi, A., Satterthwaite, D. E., Aragón-Durand, F., Corfee-Morlot, J., Kiunsi, R. B. R., Pelling, M., Roberts, D. C., & Solecki, W. (2014). Urban areas. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the*

Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 535–612). Cambridge University Press.

32. City-Zen Project (2019). *City-Zen Roadshow: Smart Solutions for Smart Cities - Amsterdam Deliverable*. This is a public deliverable report that details the outcomes. http://smart-cities-marketplace.ec.europa.eu/projects-and-sites/projects/city-zen/city-zen-site-amsterdam?lang=en
33. European Commission. (2020). *City-Zen: Final Report Summary*. CORDIS. Retrieved from https://cordis.europa.eu/project/id/608703/reporting
34. Sorkhabi, N. M., Begorre, A., & Tobin, S. (2023). *Schoonschip, A Sustainable Urban Housing Project in Amsterdam* [Unpublished manuscript]. ARCH 517, McGill University.
35. International Energy Agency. (2017). *Digitalization & Energy*. OECD. https://www.iea.org/reports/digitalisation-and-energy
36. Sorkhabi, N. M., Begorre, A., & Tobin, S. (2023). *Schoonschip: A Sustainable Urban Housing Project in Amsterdam*. ResearchGate. https://doi.org/10.13140/RG.2.2.12720.57606.1
37. Ajuntament de Barcelona. (2023). *Barcelona green infrastructure and biodiversity plan 2020*.
38. Rueda, S. (2018). Superblocks for the design of new cities and renovation of existing ones: Barcelona's case. In M. Nieuwenhuijsen & H. Khreis (Eds.), *Integrating human health into urban and transport planning* (pp. 135-153). Springer International Publishing. https://doi.org/10.1007/978-3-319-74983-9
39. Ajuntament de Barcelona. (n.d.). *Electric vehicle master plan*. Urban Planning, Ecological Transition, Urban Services and Housing. Retrieved from https://www.barcelona.cat/en/
40. Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso-González, M. J., & Narayan, J. (2017). Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges. *Urban Planning*, 2(2), 13–25. https://doi.org/10.17645/up.v2i2.931
41. Mueller, N., Rojas-Rueda, D., Khreis, H., Cirach, M., Andrés, D., Ballester, J., ... Nieuwenhuijsen, M. (2020). Changing the urban design of cities for health: The superblock model. *Environment International*, 134, 105132. https://doi.org/10.1016/j.envint.2019.105132
42. Rueda, S. (2018). Superblocks for the design of new cities and renovation of existing ones: Barcelona's case. In M. Nieuwenhuijsen & H. Khreis (Eds.), *Integrating human health into urban development and transport planning* (pp. 135–154). Springer.
43. Vardakas, J. S., Zenginis, I., Zorba, N., Echave, C., Morató, M., & Verikoukis, C. (2018). Electrical energy savings through efficient cooperation of urban buildings: The smart community case of 'Superblocks' in Barcelona. *IEEE Communications Magazine*, 56(11), 26–33. DOI: 10.1109/MCOM.2017.1700542
44. Wu, A. N., & Biljecki, F. (2022). Roofpedia: Automatic mapping of green and solar roofs for an open roofscape registry and evaluation of urban sustainability. *Landscape and Urban Planning, 214,* 104167. https://doi.org/10.1016/j.landurbplan.2021.104167

45. Hodson, E., Vainio, T., Nader Sayún, M., Tomitsch, M., Jones, A., Jalonen, M., Börütecene, A., Hasan, M., Paraschivoiu, I., Wolff, A., Yavo-Ayalon, S., Yli-Kauhaluoma, S., & Young, G. (2023). Evaluating social impact of smart city technologies and services: Methods, challenges, future directions. *Multimodal Technologies and Interaction*, *7*(3), 33. https://doi.org/10.3390/mti7030033
46. Gupta, A. D., Pandey, P., Feijóo, A., Yaseen, Z. M., & Bokde, N. D. (2020). Smart water technology for efficient water resource management: A review. *Energies*, *13*(23), 6268. https://doi.org/10.3390/en13236268
47. Bulkeley, H., Broto, V. C., & Maassen, A. (2016). *Governing urban low-carbon transitions*. Routledge. https://doi.org/10.4324/9780203839249
48. Kitchin, R. (2014). The real-time city? Big data and smart urbanism. *GeoJournal*, *79*(1), 1-14. https://doi.org/10.1007/s10708-013-9516-8
49. Revi, A., Satterthwaite, D. E., Aragón-Durand, F., Corfee-Morlot, J., Kiunsi, R. B. R., Pelling, M., Roberts, D. C., & Solecki, W. (2014). Urban areas. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 535–612). Cambridge University Press.
50. Basher, R. (2006). Global early warning systems for natural hazards: systematic and people-centred. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 364*(1845), 2167–2182. https://doi.org/10.1098/rsta.2006.1819
51. Goodchild, M. F. (2007). Citizens as sensors: the world of volunteered geography. *GeoJournal, 69*(4), 211–221. https://doi.org/10.1007/s10708-007-9111-y
52. Khalid, M., Roxin, A., Cruz, C., & Ginhac, D. (2017, December 1). A review on applications of big data for disaster management. In *2017 13th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS)* (pp. 370–375). IEEE. DOI:10.1109/SITIS.2017.67
53. Perera, C., Zaslavsky, A., Christen, P., & Georgakopoulos, D. (2014). Sensing as a service model for smart cities supported by Internet of Things. *Transactions on Emerging Telecommunications Technologies*, *25*(1), 81-93. https://doi.org/10.1002/ett.2704
54. Chen, C., Han, Y., Galinski, A., Calle, C., Carney, J., Ye, X., & van Westen, C. (2024). *Integrating urban digital twins with cloud-based geospatial dashboards for coastal resilience planning: A case study in Florida*. DOI: https://doi.org/10.48550/arXiv.2403.18188
55. UNDRR. (2019). *Global assessment report on disaster risk reduction*. United Nations Office for Disaster Risk Reduction. https://www.undrr.org/gar
56. Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., ... & Rowe, B. (2007). Green roofs as urban ecosystems: Ecological structures, functions, and services. *Bioscience, 57*(10), 823-833. DOI: 10.1641/B571005

57. Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, 97(3), 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006
58. Pignatta, G., Lim, N., Mughal, M. O., & Acero, J. A. (2018). *Tools for Cooling Singapore: A guide of 24 simulation tools to assess urban heat island and outdoor thermal comfort*. Cooling Singapore. https://doi.org/10.3929/ethz-b-000428031
59. Dai, Y., Huang, Z., Khan, N., & Labbo, M. S. (2025). Smart water management: Governance innovation, technological integration, and policy pathways toward economic and ecological sustainability. *Water*, *17*(1), 1932. DOI:10.3390/w17131932
60. Moreno-Ibarra, M., & Torres-Ruiz, M. (2019). Civic participation in smart cities: The role of social media. In A. Visvizi & M. D. Lytras (Eds.), *Smart cities: Issues and challenges: Mapping political, social and economic risks and threats* (pp. 31–46). Elsevier. https://doi.org/10.1016/B978-0-12-816639-0.00003-X
61. Ministry of Sustainability and the Environment. (2021). *Singapore Green Plan 2030*. Singapore Government. https://www.greenplan.gov.sg/
62. Câmara Municipal de Cascais. (2010a). *Cascais and the 2030 agenda for sustainable development: Voluntary local review of progress toward the sustainable development goals in Cascais*. https://www.cascais.pt/sub-area/revisoes-locais-voluntarias-vlr-voluntary-local-reviews
63. Câmara Municipal de Cascais. (2025). *Plano municipal de ação climática de Cascais*. Ambiente Cascais. https://ambiente.cascais.pt/sites/default/files/anexos/pmac_cascais_final41.pdf
64. Câmara Municipal de Cascais (2010b). *Plano Estratégico de Cascais face às Alterações Climáticas: Estudos setoriais* - cenário climático [PDF]. Retrieved from: https://www.cascais.pt/sites/default/files/anexos/gerais/new/3_04_cenarios_climaticos.pdf
65. Câmara Municipal de Cascais (2010c). *Plano Estratégico de Cascais face às Alterações Climáticas: Estudos setoriais - Zonas costeiras* [PDF]. Retrieved from: https://www.cascais.pt/sites/default/files/anexos/gerais/new/10_11_estudos_sectoriais_zonas_costeiras.pdf
66. Câmara Municipal de Cascais (2010d) .*Plano Estratégico de Cascais face às Alterações Climáticas: Estudos setoriais - Recursos Hídricos* [PDF]. Retrieved from: https://www.cascais.pt/sites/default/files/anexos/gerais/new/7_08_estudos_sectoriais_recursos_hidricos.pdf
67. Câmara Municipal de Cascais (2010e). *Plano Estratégico de Cascais face às Alterações Climáticas: Sector Biodiversidade*[PDF]. Retrieved from: https://www.cascais.pt/sites/default/files/anexos/gerais/new/6_07_estudos_sectoriais_biodiversidade.pdf
68. Câmara Municipal de Cascais (2010f). *Plano Estratégico de Cascais face às Alterações Climáticas: Sector Saúde* [PDF]. Retrieved from: https://www.cascais.pt/sites/default/files/anexos/gerais/new/8_09_estudos_sectoriais_saude_humana.pdf

69. Câmara Municipal de Cascais (2010g). *Plano Estratégico de Cascais face às Alterações Climáticas: Estudos para o esforço de mitigação das alterações climáticas no concelho de Cascais [PDF]*. Retrieved from: https://www.cascais.pt/sites/default/files/anexos/gerais/new/12_13_estudos_sectoriaia_mitigacao.pdf
70. Câmara Municipal de Cascais (2010h). *Plano Estratégico de Cascais face às Alterações Climáticas:* Sectoral Adaptation Report[PDF]. Retrieved from: https://www.cascais.pt/sites/default/files/anexos/gerais/new/11_12_estudos_sectoriais_adaptacao.pdf
71. Câmara Municipal de Cascais. (2023). *Plano Cascais pelo Clima – Mitigação*. Retrieved from:https://ambiente.cascais.pt/pt/page/plano-cascais-pelo-clima
72. (Ambiente Cascais, n.d.-a). *Mobility initiatives and public transportation policies*. Retrieved from: https://data.cascais.pt/en/geral/mobilidade
73. (Ambiente Cascais, n.d.-b). *Smart Crates or Caixotes Inteligentes*. Retrieved from https://ambiente.cascais.pt/pt/projetos/caixotes-inteligentes
74. (Ambiente Cascais, n.d.-c). *iTree - Street trees in Cascais*. Retrieved from https://ambiente.cascais.pt/pt/projetos/itree-arvores-das-ruas-cascais
75. (Ambiente Cascais, n.d.-d). *Educação Ambiental - PESA*. Retrieved May 23, 2024, from https://ambiente.cascais.pt/pt/educacao-ambiental/escolas
76. (Ambiente Cascais, n.d.-e). *Fundo AdaptCascais*. Retrieved from: https://ambiente.cascais.pt/pt/page/fundo-adaptcascais
77. EMAC - Cascais Ambiente. (2018). *Plano de Ação para a Adaptação às Alterações Climáticas de Cascais 2030* (1st ed.). Câmara Municipal de Cascais. Retrieved from: https://ambiente.cascais.pt/pt/page/plano-acao-adaptacao
78. (Câmara Municipal de Cascais, 2019). *Matriz da Água de Cascais*. Retrieved from: https://www.cascais.pt/sub-area/matriz-da-agua-consulta-populacao
79. (Ambiente Cascais, 2024). *Relatório de Progresso do PA3C2 2024*. Retrieved from: https://ambiente.cascais.pt/pt/page/plano-acao-adaptacao

⟨2025⟩

Freshta Ahmadi

Smart Cities and Climate Risk Mitigation and Adaptation: Smart Technologies and Strategies for Resilient Urban Development.

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

NOVAFCSH
FACULDADE DE CIÊNCIAS SOCIAIS E HUMANAS
UNIVERSIDADE NOVA DE LISBOA