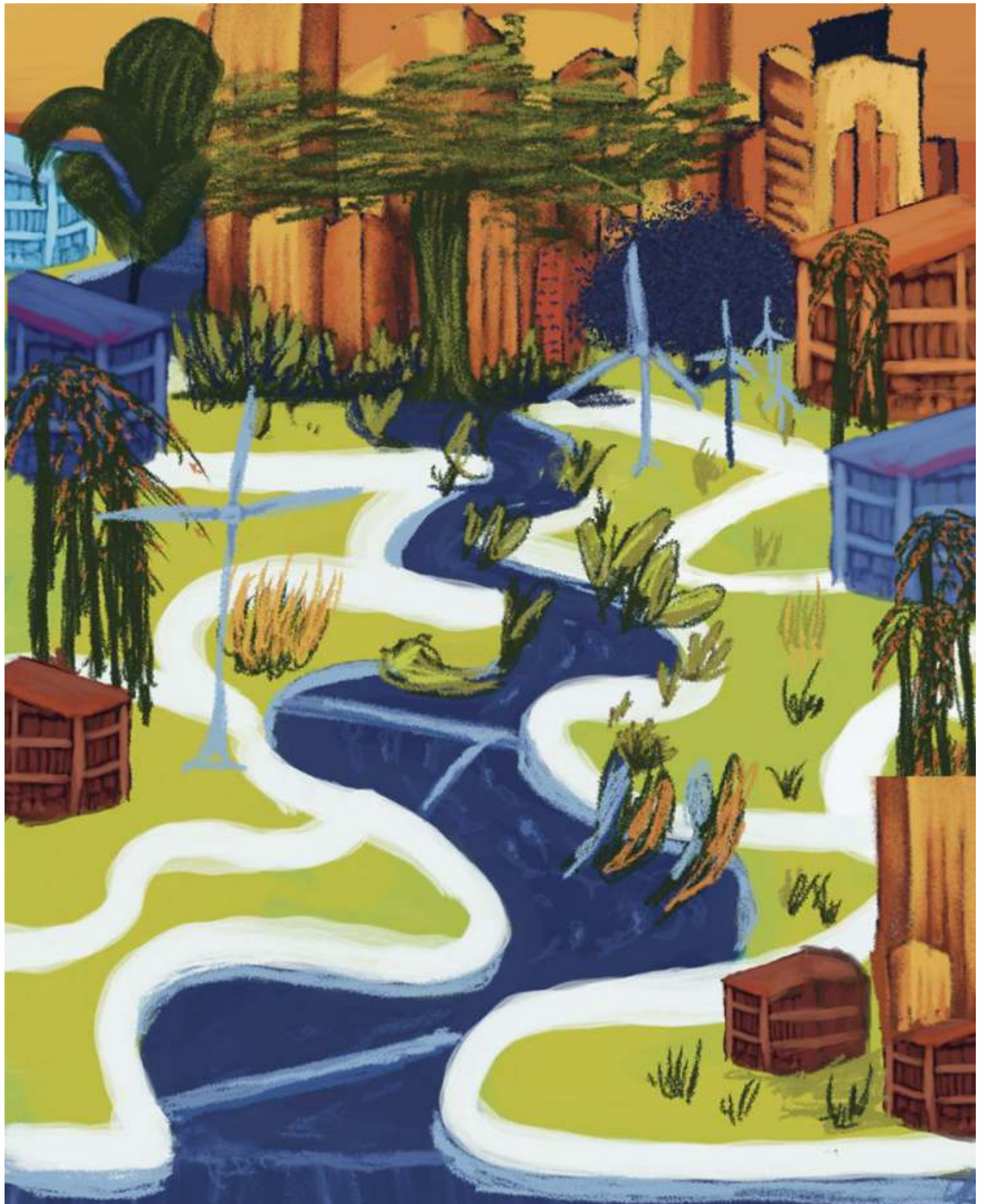




RESILIENT BLUE-GREEN CITIES



**SIMA
CLIM**

The cover of this report was created by Wira Tini

Wira Tini, a visual artist, presents in her work the perspectives of the Kokama people, of whom she is a descendant, and of northern Brazilian culture, connecting traditional knowledge with contemporary approaches. Her production highlights different conceptions and tensions with common sense. In her works, Tini mobilizes ancestral knowledge, environmental issues, and urban experience, broadening the cultural horizon of the public. Born in Manaus (AM), she has participated in several urban art exhibitions and festivals in various cities in Brazil, as well as collaborating with brands and organizations. She is the creator of Graffiti Queens, one of the first urban art festivals exclusively for women, and Graffiti Queens Magazine, which highlights relevant names in national and international urban art.



**SIMA
CLIM**

RESILIENT BLUE-GREEN CITIES

2025



Synthesis Report:

Resilient Blue-Green Cities

Coordinating Lead Author:

Maria Fernanda Lemos (PUC-Rio)

Lead Authors:

Bruna Fatiche Pavani (IIS)
Carlos Maurício Fonseca Guerra (MMA)
Carola Hein (TU Delft)
Cecília Polacow Herzog (SocialSeeds)
Chris Zevenbergen (IHE Delft)
Cláudio Carrera Maretti (ICLEI)
Hannah Arcuschin Machado (INSPER)
Inamara Santos Melo (MMA)
Koen Olthuis (Waterstudio)
Letícia Sabino (Instituto Caminhabilidade)
Luiza Bezerra Ribeiro (Rede Clima)
Maria Christina Barbosa de Araújo (UFPE)
Maria de Jesus de Britto Leite (UFPE)
Maurício Lamano Ferreira (USP)
Natália Cristina de Oliveira (USP)
Mila Avellar Montezuma Carneiro da Cunha (Rede Clima)
Osvaldo Moura Rezende (UFRJ)
Paula Freire Santoro (USP)
Paulo Renato Mesquita Pellegrino (USP)
Raiza Gomes Fraga (CGEE)
Raquel Azevedo da Cruz (PUC-Rio)
Roberto Montezuma Carneiro da Cunha (UFPE)
Taneha Bacchin (TU Delft)
Virgínia de Carvalho Leal (UFPE)

Review Authors:

Moacyr Cunha de Araujo Filho (UFPE)
Ronaldo Adriano Christofolletti (UNIFESP)



EXECUTIVE SUMMARY

INTRODUCTION	5
01. URBAN SYSTEMS	9
02. NATURE-BASED SOLUTIONS FOR CLIMATE-RESILIENT CITIES	78
03. PUBLIC POLICY: GOVERNANCE, FINANCING AND IMPLEMENTATION OF THE RESILIENT GREEN-BLUE CITY	97
04. CONCLUSION	126
REFERENCES	137

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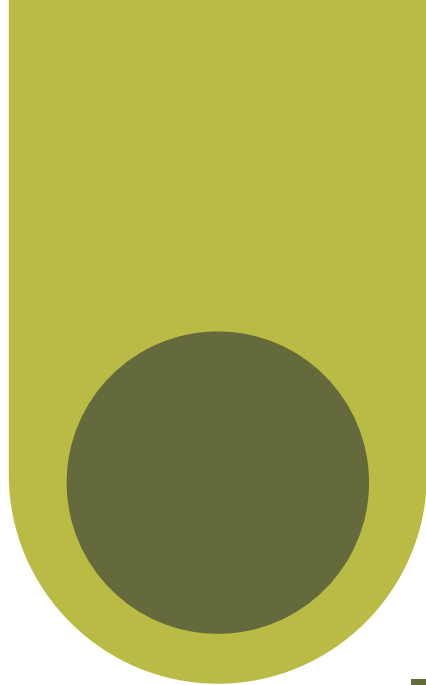
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INTRODUCTION



INTRODUCTION

Addressing the climate emergency requires: (a) coordinated action (between actors, sectors, scales and, above all, between actions and expected results, in terms of time and territory, avoiding unwanted and unplanned competition, negative side effects on the system and maximizing results); (b) long-term and flexible planning (as an effective means of coordinating actions and dealing with the level of uncertainty imposed by climate change); and (c) inclusive governance (aiming at climate justice and control of damage resulting from "maladaptation"), multiscale (given that the challenges of adapting urban systems — in transportation, sanitation, water supply, human flows, economy, to name a few examples — and natural systems — ecological, green-blue systems — go beyond administrative, political, and territorial boundaries in general) and intersectoral (considering the inseparability of the multiple systems that make up cities); in addition to (d) cooperation between the scientific community, governments, businesses, non-governmental institutions, and society in general, with all its diversity and multiple forms of knowledge. It also requires ensuring the integrity of ecological systems and promoting a “transformative adaptation” (a key concept for achieving resilience, as will be discussed in this report) of human systems (including urban systems) in order to achieve a pattern of “climate-resilient development.” (also a key concept) capable of overcoming the current prevailing state of reproduction of socio-climate vulnerabilities and risks imposed on these systems, mainly through the maintenance and even expansion of socioeconomic inequality and its impact on them.

Aware of the enormous challenge that this context represents for building socio-climate resilience in cities, and with a view to supporting governments, but also private initiatives in climate action, this report summarizing scientific and technological knowledge brings together and evaluates up-to-date knowledge on key issues in various sectors of urban management and planning for the construction of resilient blue-green cities in the context of climate change. The support that this report aims to provide is based on the understanding that scientific and technological knowledge — which must be balanced and combined with popular, traditional, and hyper-diverse knowledge in practice — is the basis for responsible decision-making, aiming at a transformative, consistent, robust, and fair adaptation of cities in the context of the climate emergency.



To enhance its objectives, this report, in addition to focusing on key urban planning sectors, also includes a look at the themes prioritized by the Brazilian national government in the Resilient Green Cities Program (PCVR), understanding that such alignment enhances the contribution of the scientific community and this report to the practical action of the Brazilian government, facilitating the appropriation and application of this knowledge.

The report is therefore structured in three main parts. The first section (1. Urban Systems Resilient to Climate Change) begins by presenting what science has shown to be a prerequisite for achieving a state of resilience and justice in cities, which is the prioritization of transformative forms of adaptation directly addressing socioeconomic and climate inequality, which imprint characteristics on urban systems that amplify and maintain the reproduction of socio-climate vulnerabilities and risks in cities (1.1. Socio-climate Vulnerability, Inequality, and Transformative Adaptation).

Next, still in the first section, we address urban systems in some of the most critical areas for territorial management and planning (Natural areas; Land use and occupation; Mobility and transportation; Infrastructure and sanitation; Social housing and informality; Health and human well-being), initially presenting a general diagnosis of socio-climatic risks and challenges and opportunities for adaptation (1.2. Understanding Urban Systems in Climate Change) and then the solutions that have been applied and discussed to address the main challenges in adaptation processes, using a similarly sectoral approach (1.3. Planning and Design of Resilient Urban Systems).

The second section (2. Nature-based Solutions for Climate-resilient Cities) specifically delves into adaptive approaches in nature-based solutions (NbS), in line with the interest of this approach for building urban resilience through the (necessary and urgent) reintegration of human (urban) and natural systems.

The third section (3. Public Policy: Governance, Financing, and Implementation of the Resilient Blue-green City) directly addresses the cross-cutting themes of the PCVR that focus on strategies for governance, financing, and implementation of actions for urban resilience, given the conditioning role that robust and inclusive governance, as well as effective financing and implementation, have for the success of the major goal of transforming Brazilian cities into



broadly resilient and fair territories in the face of the climate emergency.

The report concludes with a brief summary that once again highlights the main points of the report for each theme, summarizes the main challenges for consolidating resilient urban systems, the promising solutions that are being adopted, and the knowledge gaps that need to be addressed in future research. We therefore hope that the report will effectively contribute to providing security and encouragement for decision-making and transformative action in Brazilian cities towards resilience and climate justice.

1

URBAN SYSTEMS



URBAN
SYSTEMS

1. URBAN SYSTEMS

1.1. Socio-climatic Vulnerability, Inequality and Transformative Adaptation

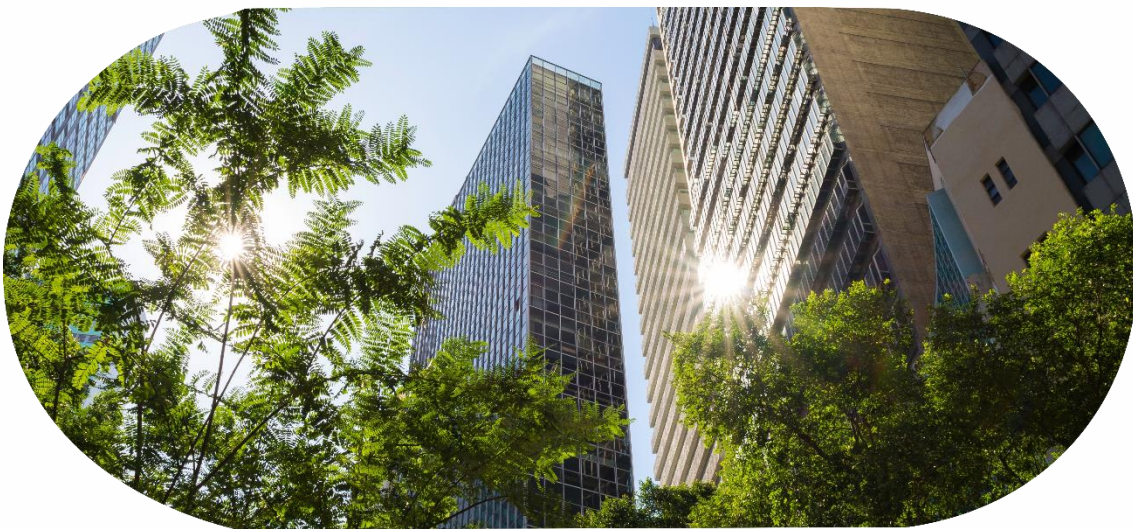
The global phenomenon of climate change entails a set of threats to ecological and human systems (cities, for example), such as prolonged droughts, storms, rising sea levels, among others (IPCC, 2022) which, in interaction with these systems, can cause negative impacts, losses and damage (Boyd et al., 2021), depending on their conditions of vulnerability and resilience (Raju et al., 2022; IPCC, 2018). Disasters, therefore, do not happen because of the climatic event, but because of the interaction between a climatic event and the system's vulnerability conditions. The vulnerability of the system is therefore the determining factor (Rau et al., 2022).

The biggest challenge this poses for building resilient cities is that the critical vector of socio-climatic vulnerability in cities is socio-economic inequality (Schipper, 2020) and the set of reflexes it imposes on the territory, such as poverty, informality, socio-territorial fragmentation, marginalization of social groups in decision-making arenas, poor distribution of urban resources and services, and the set of injustices and risks that characterize most cities in Brazil and around the world, especially large and megacities, defining an unsustainable and non-resilient urbanization pattern (Lemos, 2022). This pattern is predominantly reproduced in the large and megacities of the global south, but also in a large number of medium-sized cities. In Brazil, approximately 30% of the population is living in cities with more than 500,000 inhabitants (Brasil, 2024), thus falling under the influence of this unsustainable pattern.

Interrupting the reproduction of this urbanization pattern is a condition for urban resilience. The relationship between inequality, the predominant urbanization pattern in the global south and socio-climatic vulnerability is particularly relevant in the Brazilian context, since the country is currently the sixth most unequal in the world - based on the GINI coefficient (WPR, 2025).

If socio-climatic vulnerability is driven by inequality, building a city that is resilient, in a strong and lasting way, depends on the results of the adaptive measures adopted to address inequality. For this reason, several researchers in the field of climate adaptation have been

discussing the importance of prioritizing transformative adaptation (Fedele et al., 2019) – which, according to the IPCC (2022, p. 2899) is "adaptation that changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts" – over incremental adaptation, which maintains the system's attributes (IPCC, 2022). This does not mean, however, that incremental actions, in some cases, are not necessary and even desirable (Fedele et al., 2019). In the same vein, science has been warning of the negative consequences (most of which are unintended consequences) of what is understood as maladaptation (Schipper, 2020; IPCC, 2022), which is very present among the forms of adaptation in various regions of the world today (O'Neil et al., 2022; IPCC, 2023) and which, according to the IPCC (2022), are "actions that may lead to increased risk of adverse climate-related outcomes (...), increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future".



The understanding of transformative adaptation as a priority, aimed at reducing inequality and expanding climate justice (Malcolm et al., 2021), prioritizing the most vulnerable groups (Pelling, 2019), associated with the need to avoid maladaptation (Fedele et al., 2019; Schipper, 2020), trigger an important alert for decision-making processes and the formulation of policies, programs, plans and projects for resilience, because, considering the arguments presented here, no action, not even planting a tree, will necessarily be positive for resilience in the long term (Anguelovski, 2020). Only with predictive studies of the effects of each action on inequality, on a case-by-case basis – since vulnerability is always local-specific – can the chances of a truly transformative adaptation be increased, avoiding the



reproduction or transfer of vulnerability and the amplification of the risks we are aiming to reduce (Amorim-Maia, 2022).

Transformative forms of adaptation are also indispensable for promoting climate justice, since the impacts of climate events in interaction with human systems are felt disproportionately by the poorest and marginalized populations, given their increased vulnerability (IPCC, 2018; Pelling et al., 2019; Malcolm et al., 2021; IPCC, 2023). The very unequal and unfair distribution of exposure – for example, when populations without access to housing informally occupy river floodplains –, vulnerability – increased – for example, by precarious housing conditions, lack of resources for adaptation, lack of access to decision-making arenas, to name just a few components of sensitivity and adaptive capacity that define the high vulnerability of the urban poor – and the unequal distribution of risks – as a result of the threat to what is exposed and its vulnerability – leads to differentiated impacts both on a global scale (global south and north) and on a local scale (rich and poor); formal and informal areas; centers and peripheries, among others) (Malcolm et al., 2021).

What's more, global warming is progressing all the time and, with each additional degree, the challenges for resilience are greater, either because of the exponential increase in risks (IPCC, 2018) or because many of the adaptation options are no longer available, limiting the adaptation paths that initially existed. This is because, in a long-term process, external interferences (economic, technological, climatic disasters, among others) can eliminate certain adaptation options that still exist when the path is mapped out, preventing their implementation at the planned time and requiring a change of route (Schipper, 2022). Flexibility thus becomes a fundamental attribute of the planning system, so that deviations and course corrections are possible over time.

Thus, whenever adaptation is postponed, it is more difficult to ensure that there is enough time to implement fully preventive and transformative adaptation processes (IPCC, 2022). This increases the likelihood of an endless cycle of incremental interventions whose results quickly become obsolete, requiring new investments, as well as increasing the chance of maladaptation, making the most vulnerable increasingly vulnerable and, with it, the whole system more vulnerable – since the city is a system, it is fully affected by the dysfunctionality or



collapse of any of its parts (territories or subsystems: land use; mobility and transportation; green areas; infrastructure, etc.).

Adaptation is delayed, among many reasons, because basic needs are often imposed, draining government resources in less wealthy countries (Cavazos et al., 2024). Of course, these shortages, which are also coordinated with the context of inequality and the pattern of urbanization, especially in terms of housing, sanitation and transport, health and education, are also factors that increase vulnerability, which in fact gives them enormous relevance. Deficiencies in housing, sanitation and transportation have a direct effect on the sensitivity component of vulnerability, while health and education have a direct effect on the "adaptive capacity" component of vulnerability. However, there is no opposition between investment in these priorities and investment in adaptation. If interventions in these areas are made using adaptive parameters, especially with regard to infrastructure and construction interventions, adaptation can go hand in hand, at least reducing the backlog, or at least preventing the non-resilient urbanization model from being perpetuated. This requires reviewing and updating plans, laws and building regulations, combined with the application of available urban planning instruments.

Finally, transformative adaptation also depends to a large extent on the capacity for integrated, multi-scale, multi-sectoral and, above all, inclusive governance that is attentive to the intersectional challenges of cymatic justice (Amorim-Maia et al., 2022; Cavazos, 2024), giving vulnerable groups a voice in decision-making (Schipper, 2020) and effectively integrating and supporting community-based adaptation initiatives (Perkins, 2019). Otherwise, the privileges of groups are perpetuated by adopting actions that maintain the reproduction of the unequal development and urbanization model that leaves the excluded increasingly excluded. This places enormous importance on the development of inclusive climate governance structures and mechanisms for the effective participation of all in decision-making processes.

1.2. Understanding Urban Systems in Climate Change

1.2.1. Natural Areas

Natural areas are considered to be spaces free of buildings where there is a predominance of vegetation or bodies of water, and are respectively called green and blue areas. Preferably, they are home to native biodiversity (such as plant, animal, fungal and bacterial species that carry out important ecosystem processes), both in aquatic and terrestrial ecosystems. They can be protected areas, depending on whether they are legally or legitimately recognized as spaces created and managed for nature conservation, or conserved areas, created for other purposes, but which have natural ecosystems in a state compatible with this classification. Although they are often considered in isolation, natural areas are enhanced in interconnected systems, promoting gene flow (i.e. the ability of species to move within the urban green area), complementarities and integrated management between the different fragments. Natural areas have their ecological aptitudes highlighted when there is good participatory governance, especially considering criteria of guaranteeing rights, justice and equity (ICLEI, 2022; Maretti et al., 2022; 2023).

In the process of urbanization, many cities end up not prioritizing avoiding the occupation of areas with the potential to integrate the system of blue-green spaces (Almeida & Nunes, 2018; Guirao et al., 2021; Marengo et al., 2024). Once occupied, it becomes a huge challenge to convert these areas into natural areas. According to Corrêa (1995), spaces free of buildings, with varying degrees of conservation and vegetation density, represent one of the few territorial alternatives still available in cities, but which, because they have not been built on for legal, economic, cultural or accessibility reasons, often become the target of disputes between various interests - such as those of the neighborhood, the real estate market, road infrastructure or other sectors that dispute control of urban land use. In addition, the governments responsible, as a decisive actor in mediating these divergent interests, do not always advocate in favor of collective interests (Portney & Berry, 2016).

In Brazilian cities, which are developing on a foundation of socioeconomic and territorial inequality, the poorest and most vulnerable populations are often forced to occupy risk areas, such as

river floodplains and hillsides, often at risk of flooding and landslides, respectively (ICLEI, 2022; Maretti et al., 2022).

The impact of the absence, scarcity or ecological degradation of a robust system of blue-green areas integrated into the urban system has perverse consequences not only on the city's environmental quality, but on the quality of life of the population in general, as well as on their physical and mental health and well-being (Guimarães et al., 2021; Maretti, 2022).

Legal revisions have systematically reduced restrictions on this unsustainable model of occupation in Brazil (changes to the Forest Code and later to the Native Vegetation Law itself) (Brasil, 1965; 2012a; 2021a; Agência Senado, 2021; Antunes, 2022; Dino, 2022; Fasolo, 2022). Likewise, a predominant urban planning pattern in Brazilian cities is negligent in relation to the need to protect freshwater ecosystems in the occupied watersheds, which are of interest for the cities' own water supply (Carvalho & Silva, 2018; Carvalho et al., 2020; Donato, 2020). A comparative study between the metropolises of São Paulo and Mexico City shows that urban expansion has caused profound and irreversible changes in the natural systems of these basins, with the suppression of native vegetation, soil sealing and intense occupation of floodplains, compromising not only the hydrological balance, but also the capacity to supply and regulate urban water flows (Lima et al., 2023).



In the context of anthropogenic climate change, with an increase in the frequency and intensity of extreme events and the associated risks (IPCC, 2021), the presence of natural areas in cities and the integration



between urban and blue-green systems are strategic in tackling these risks, for several reasons: (1) natural areas allow water to infiltrate into the soil, and highly impermeable urban areas are more prone to flooding in heavy rain events (water runs off very quickly to the lowest points, where it accumulates) (Saraswat et al., 2016); (2) conversely, channelization, rectification or other water conditioning techniques, added to the removal of vegetation along watercourses, transfer the problems of greater and faster accumulation of water downstream, while at the same time enabling the occupation of floodplain areas, further increasing the risk to property and populations located in these areas that are subject to flooding (Vieira & Bustamante, 2021); (3) the occupation of hillsides, which are often technically unsuitable for the conditions of the terrain and type of soil, generates instabilities that increase the likelihood of landslides, while the original conditions of these hillsides, which are normally vegetated, keep them more stable (Vieira & Bustamante, 2021); (4) urban "heat islands" are caused by excessive radiation from materials used in high building densities (cement or concrete, asphalt or similar), while vegetation in urban areas, whether roadside trees or vegetation in squares, parks and preserved areas, provide shade and radiate little heat, helping to reduce the temperature of their immediate surroundings (Oliveira & Andrade, 2007); (5) green areas in the city help to improve air quality (by filtering and renewing the air), reducing the accumulation of pollutants (Edeigba et al., 2024); (6) failure to fully protect water bodies and watersheds can lead to a reduction in the availability of water to supply cities, as well as uncontrolled water flows in the urban territory and, as a result, a series of risks to the economy, safety, health and the built environment (Lima et al., 2023).

Faced with the challenges posed by climate change and accelerated urban growth, the preservation and strategic integration of natural areas into urban and peri-urban systems are emerging as essential components for the adaptation of cities. Ecosystem-based adaptation (EbA) plays a central role in integrating the protection, sustainable management and restoration of ecosystems to reduce climate vulnerabilities, while promoting benefits such as biodiversity conservation and mitigation of climate impacts (IPCC, 2022). Blue-green infrastructure, when strategically planned, contributes to ecological connectivity, reduces urban heat island effects and improves water quality and quantity, minimizing flood risks and water stress (Hegetschweiler et al., 2017; Lima et al., 2023). However, the prioritization of nature-based solutions (NbS) in urban planning still

faces institutional, economic and social barriers, resulting in the fragmented application of these strategies (Maretti et al., 2022; 2023). In addition, the implementation of these solutions often occurs unevenly, favouring more privileged neighbourhoods and contributing to gentrification processes, which reinforces socio-spatial inequalities and limits the universalization of the environmental and social benefits provided by these interventions (Maretti, 2024a). Thus, the effectiveness of blue-green infrastructure, the EbA and the NbS depends on participatory and equitable governance, which guarantees the democratization of access to these spaces and the construction of more resilient and inclusive cities. Examples of this include management for green infrastructure planning, such as municipal urban afforestation plans.

Urban Afforestation



Urban forests, made up of the urban afforestation of roads, squares and parks, are urban facilities that both suffer the effects of climate change and adapt cities to extreme events, i.e., either excessive rainfall or severe heat waves (Paquette et al., 2021; Esperon-Rodriguez et al., 2022). According to some climate forecasts, cities located in the southeastern region of South America, i.e., mainly the southern region of Brazil, will experience more frequent rainfall extremes in the coming decades, interspersed with possible heat waves during periods of drought. Other urban parts of the country will experience greater recurrence of ecological droughts, such as cities in the northeast, central-west and north of Brazil (IPCC, 2021).



In scenarios with a higher volume of rain or more concentrated rainfall (Alves et al., 2021), the important role of vegetation as an essential mediator in water control stands out (Hobbie & Grimm, 2020; Rahman et al., 2023). In this sense, Permanent Preservation Areas (PPAs) and other protected areas play a key role in adapting cities. It should be noted that the occupation of urban land over the last century has partially taken into account the environmental standards for the creation of PPAs, as provided for in the Forest Code (Brasil, 1965) in large and megacities in Brazil. As a result, this gap in planning has led to cities becoming more sensitive to episodes of heavy rainfall, which undoubtedly makes the poorest vulnerable, i.e., the population that uses areas of low real estate value such as the banks of rivers and streams for housing (Santos et al., 2021b; Azevedo et al., 2024). Urban tree planting on the banks of water bodies in urban areas lacks proper management and conservation infrastructure, such as the creation of linear parks (Millington et al., 2018).

In addition to the chaotic flooding scenario, extreme rainfall events are accompanied by strong gusts of wind that cause a series of damages to trees, mainly with branches and entire trees falling, posing a risk to humans and public and private infrastructures (Locosseli et al., 2021). Inadequate planting and lack of management are determining factors in this merciless scenario. Many city halls operate their environmental departments (or similar) with a lack of human resources for the existing demand, in addition to often not having specialized or trained professionals to manage such conflicts. Allied to this, ineffective and even non-existent monitoring in many urban areas puts municipal public administrations in check and leaves the problem orphaned of a solution (Jim, 2017; Ferreira et al., 2023a; 2023b). The lack of technology and innovative products in Brazilian cities limits efforts to properly implement urban afforestation (Santos et al., 2021a).

Qualified natural environments in urban centers, i.e., environmentally structured and/or planned squares and parks, are excellent facilities for the population to enjoy in terms of health promotion. According to data from the Brazilian federal government, 27.9% of the Brazilian population suffers from high blood pressure (Brasil, 2023a). The Ministry of Health recommends through the "Guide to Physical Activity for the Brazilian Population" (Brasil, 2021b) that the population should exercise outdoors in order to reduce the incidence of this chronic disease. However, several medium and large cities in Brazil have inequalities in the urban fabric that offer the wealthier population



structured and qualified green environments, while for the poorer population, when there is urban greenery nearby, it is usually limited to peri-urban forest massifs with no infrastructure for visitation and/or conditions for health promotion per se. This highlights a major gap in urban forestry planning, which neglects public health aspects in the spatialization of urban greenery in cities (Ferreira et al., 2023a).

Climate extremes marked by strong heat waves are also factors that threaten public health across the country. In the last decade, numerous scientific studies have reported the association of high human mortality rates with the severe effects of average air temperature in urban centers (Son et al., 2016; Geirinhas et al., 2020; Moraes, et al., 2022; Silveira et al., 2023; Corrêa, 2025). In this sense, academics have shown how urban afforestation can significantly contribute to reversing this situation, since both the shading of urban trees and evapotranspiration can mitigate the effects of urban heat islands (Drake et al., 2018; Qiu et al., 2017; Silva et al., 2018; Wang et al., 2019; Yu et al., 2025).

As well as mitigating the effects of temperature, urban afforestation can also mitigate the effects of particulate air pollution from the automotive fleet. Like the distribution of urban trees in the urban fabric, the mapping of particulate pollution also follows a similar trend in relation to social inequalities in most Brazilian cities. The socio-economically vulnerable population generally lives in places with high levels of particulate air pollution. In the port region of Santos, for example, people in situations of social vulnerability can breathe 3000 $\mu\text{g m}^{-3}$ of cadmium due to heavy fleet traffic, while in noble and green neighborhoods of the elites, this pollutant does not reach a concentration of 150 $\mu\text{g m}^{-3}$ (Theophilo et al., 2021; Ferreira, 2024). The irregular occupation of urban land combined with a lack of attention and infrastructure has led countless cities to face a sensitive scenario of fossil fuel-based urban mobility and high levels of air pollution, which have not been rigorously planned with the elements of nature (e.g., urban afforestation) (Ferreira et al., 2012; Martins et al., 2021; Ramon et al., 2022).

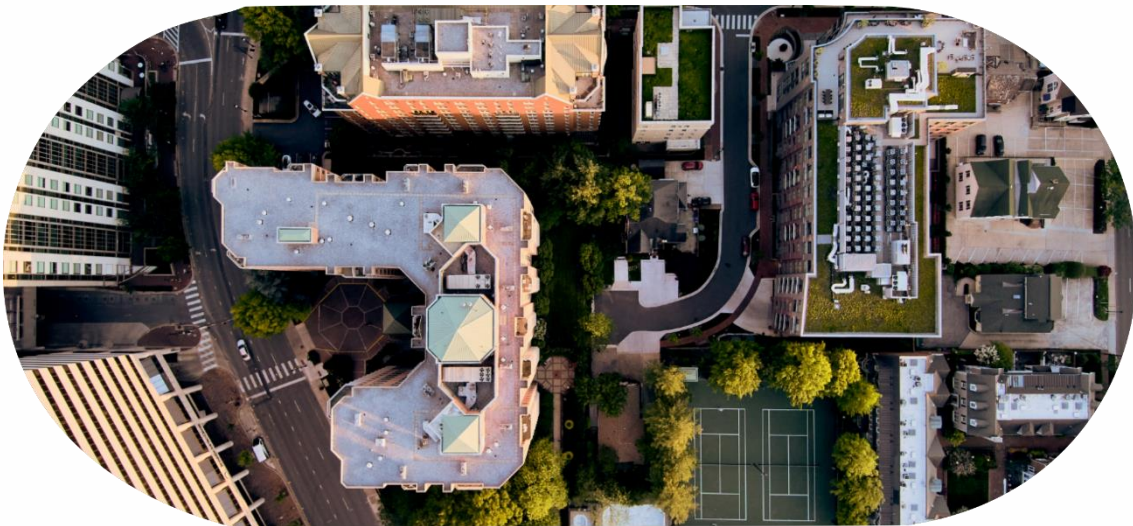
Thus, it is understood that, combined with other urban factors, the lack of qualified green environments and properly planned urban afforestation have led most Brazilian cities to experience a context of contemporary risk due to climate change, which requires a rapid response capacity to extreme climate events (Ferreira, 2024). Although

there are tools from the federal government to manage, expand and qualify urban greenery in Brazilian cities, municipal urban forestry teams need to get to grips with these instruments for comprehensive management involving urban forests (Ferreira et al., 2023b). The Urban Environmental Registry (CAU) is a tool of the Ministry of the Environment and Climate Change (MMA) that aims to improve management and increase the quantity and quality of green areas in cities, thus improving the quality of life for people and the environment in Brazilian cities. However, more incisive instruments, actions and policies at the federal, state and municipal levels need to integrate problems and solutions, with a view to public welfare.

1.2.2. Land Use and Occupation

The way in which territory is used and occupied largely influences the ability of a place or social group to achieve resilience to the effects of climate change, adopting both mitigation and adaptation measures (Ahern, 2011).

The occupation of Colonial Brazil already explained our polarized urbanization, concentrated in cities that received industrial economic development, while the occupation of rural territory took place with agro-export monocultures (Oliveira, 1982).



In rural areas, the export-oriented economy has imposed a pattern of occupation characterized by large deforested areas and soil contamination, with constant expansion of agricultural areas for the production of commodities such as soy, coffee, sugarcane and corn.



Recent data indicates that, between 1985 and 2021, the greatest expansion of urbanized areas occurred over areas of agricultural use, with the loss of natural formations to cities in the different biomes – 28% in the Cerrado, 23% in the Atlantic Forest, 22% in the Amazon, 19% in the Caatinga and 7% in the Pampa (MAPBIOMAS, 2022a). On the other hand, the territories of indigenous populations, quilombolas, riverside communities, among other community ways of life, are seen as territories that resist this dynamic of occupation (Pombo & Jacobi, 2024).

Urbanization is concentrated. Urban areas in Brazil concentrate around 87% of the Brazilian population (IBGE, 2024), mostly in large cities and metropolises, even though these urbanized areas correspond to only 0.44% of the Brazilian territory (IBGE, 2024), mostly large cities and metropolises. Furthermore, approximately 55% of the Brazilian population is concentrated within the first 150 km from the sea (IBGE, 2022), which increases the relationship between cities and estuarine and coastal environments. Furthermore, Brazilian urbanization can also be extensive (Monte-Mór, 1994), i.e., urbanization beyond the consolidated nuclei of cities, which escapes the "urban" or "rural" dichotomy. This occurs, for example, on the Amazon biome, read as an urbanized forest (Côrtes et al., 2020), or in different forms of dispersed (Bernardini, 2018), incomplete and precarious urbanization (Santoro, 2014) on the edges or connecting cities (Reis, 2006), produced informally or formally. Thus, urban boundaries are often expanded – between 1985 and 2021 urban areas grew by 3.2% per year, tripling the urbanized area in these 38 years (MAPBIOMAS, 2022a; 2022b) -- in processes of producing dispersed and incomplete urban territories, which consume natural resources (Reis, 2006; Santoro, 2014).

This pattern of urban occupation and expansion, even if localized, profoundly compromises cities' ability to respond to the effects of climate change. The loss of green areas, the neglect of the city's relationship with blue areas, the fragmentation of ecosystems and soil sealing not only reduce the adaptive capacity of territories, but also intensify the impacts of extreme events such as floods, droughts and heat waves (IPCC, 2022). Thus, the way in which land is occupied becomes a strategic factor for building more resilient cities, capable of integrating mitigation and adaptation actions in an articulated manner in the face of emerging climate challenges.



Brazilian cities are mostly sparsely populated (low building density) and can contain vast areas with few residents (low population density). The country has grown at a slower pace - from 2010 to 2022, the annual growth rate of the country's population was 0.52%, the lowest in the history of censuses (IBGE, 2022) - large cities have lost population while medium-sized cities (with more than 100,000 inhabitants) have gained (idem), but cities continue to grow in urban expansion, although in a few concentrated areas of some cities there has been verticalization with densification (Mendonça et al, 2024). Land use and urban planning proposals generally reinforce this model, which encourages horizontal expansion of the urbanized area. This model, which is supported by road construction, shapes nature by deforesting, sealing the soil, straightening and channeling rivers to make room for paved roads. Soil sealing modifies the hydrological cycle in urban areas, increasing their vulnerability to flooding (EU, 2012; Bezerra, 2015; Jaramillo & Nazemi, 2018).

Within urban limits, the process of unsustainable occupation that prevails in Brazil has allowed the city to advance over valley bottoms and rivers, landfills and removal of coastal vegetation, that today house public roads (Travassos, 2011; Bastos Moroz & Thieken, 2024) - remembering that the option for motorized mobility, by car or bus, in the country, has been the majority (Vasconcellos, 2014), as will be commented on in section 1.2.3. Mobility and Transport, which points to transportation as being responsible for the highest percentage of Greenhouse Gases (GHG) emissions in large cities - or in areas that offer different forms of risk, prone to flooding and landslides (Zioni et al., 2021). In addition, environmental sanitation in Brazil faces challenges such as the scarcity of drinking water, the absence of a sewage collection network and precarious and insufficient urban drainage (Instituto Água e Saneamento, 2025), all three systems being based on "gray infrastructure", as well as the generation of waste in quantity and without adequate disposal. The energy matrix and consumption is also uneven, with higher consumption by families with higher incomes (Leite et al., 2023).

In the intra-urban space, numerous forms of socio-economic, gender and racial inequalities are also evident, as well as processes of marginalization and exclusion of some groups, which contributes to socio-climatic vulnerability (Castellanos et al, 2022; Belmont, 2023). On the one hand, territories formally produced for white elites and the middle classes are the locus of financialized real estate interest, which

is also stimulated by federal policies for the construction of new units for purchase and sale, in the home ownership/private property model, in programs aimed at economic growth and job creation. Contradictorily, the housing produced is unaffordable for a large part of the population that makes up Brazil's huge housing deficit (with no resources or financing capacity). Metropolises such as São Paulo have produced as many as 75,000 new housing units a year (Secovi, 2023), which has helped to increase the value of urban land, while, contradictorily, the housing deficit has continued to grow, mainly due to the excessive burden of families with rent, the fastest-growing component in calculating the deficit and which accounts for 52% of it in the country (Fundação João Pinheiro, 2022). The Brazilian housing deficit has both a quantitative and a qualitative component. The precariousness of housing (qualitative component), mainly concentrated in areas of informal occupation, is a significant socio-climatic vulnerability factor (Adelekan et al. 2022; Castellanos et al., 2022), as will be discussed in more detail in section 1.2.5. Social Housing and Informality.



Formal urban development often takes place via gated, private, exclusionary vertical or horizontal condominiums, where few people live in vast built-up areas (Leonelli & Campos, 2018) and nature is a priced landscape (Ferrara & Pereira, 2023). Its architecture is structured in concrete, consuming a lot of natural and mineral resources, in systems that are not always suited to the local climate - with high energy consumption through the use of active systems to ensure comfort, such as air conditioning and artificial lighting.



Although international examples indicate that in many cities in the Global North, the stationary energy sector (buildings and industries) is the main contributor to GHG emissions (C40 Cities, 2018), the Brazilian reality is different. In the country's large cities, transportation is generally the largest source of urban GHG emissions, accounting for between 35% and 66% of the total, followed by the stationary energy sector, which accounts for 14% to 35% of emissions (PCRJ, 2019; PMSP, 2021; PMF, 2022; PMBH, 2023).

In Rio de Janeiro, transportation and stationary energy proportionally share responsibility for emissions, each with around 35%, while the other sectors account for 30% (PCRJ, 2019). In São Paulo, transportation accounts for 55% of emissions, stationary energy for 35% and waste for 10% (PMSP, 2021). In Belo Horizonte and Fortaleza, the transportation sector is even more dominant, with 66% and 59% of emissions, respectively (PMF, 2022; PMBH, 2023). This configuration shows that Brazilian strategies for mitigating urban GHG emissions need to pay attention to low-emission urban mobility policies and energy efficiency in buildings.

The civil construction sector generates a large amount of waste from demolitions and the construction process itself, which has a major impact on the environment due to its volume and the fact that it is not always disposed of and treated in an environmentally appropriate way.

At the other extreme, we find vast popular territories that concentrate populations in conditions of vulnerability, due to a number of combined factors, who are generally the first or most impacted by the effects of climate change (Adelekan et al., 2022; Castellanos et al., 2022). These are families who are constantly threatened with losing their homes, either because they can't pay the rent or installments for the property, or because they don't have security of tenure, living informally in an area and could be removed or relocated in absentia (Ungaretti et al., 2024), or because some disaster, on a very rainy day, could destroy their precariously built homes. In general, vulnerable populations are particularly subject to different forms of social oppression and marginalization - blacks, indigenous people and immigrants, as well as women, the elderly and people with broken social ties - and are particularly threatened with displacement due to processes of vulnerability and discrimination (Lacerda et al., 2022). These communities are systematically subjected to situations of environmental degradation and injustice in a racialized context, which



is called environmental racism (Belmont, 2023). In addition, these populations are also often on the margins of decision-making arenas, including with regard to the adaptation strategies that will be adopted with an impact on their lives, as discussed in section 1.1. Inequality and Socio-climatic Vulnerability.

Climate change impacts urban systems in many ways and losses and damage will be greater or lesser depending on the combination of the climatic event and the conditions of sensitivity and adaptive capacity of those exposed to it (IPCC, 2022). One of the threats in this context is the intensification of heat waves, which tend to largely affect urban areas, which already produce their own heat islands, and disproportionately affect groups that are already more sensitive, such as the elderly, children and homeless people (Adelekan et al., 2022; IPCC, 2022). Studies indicate that the number of individuals exposed to heat waves has increased significantly in recent decades and that the effects of heat combined with chronic diseases led to more than 48,000 deaths between 2000 and 2018, with higher mortality rates among people who are female, elderly, black, brown or with lower levels of education (Monteiro dos Santos et al., 2024). In addition to the heat, changes in rainfall patterns will also have an impact on cities.

In addition to heat, changes in precipitation patterns will also impact cities. In recent decades, Brazilian cities have faced an alarming increase in the frequency and intensity of rain-related climate disasters, with large-scale economic, social, and environmental impacts. The number of extreme rain-related events has more than tripled since the 1990s, jumping from 2,335 occurrences to 7,539 between 2020 and 2023 alone (Aliança Brasileira pela Cultura Oceânica, 2025). In the same period, the number of people affected has already doubled compared to the previous decade, with 2.4 million residents affected by the disaster in Rio Grande do Sul in 2024. Economic losses have also risen rapidly, reaching US\$ 132 billion in this decade alone — 123 times higher than in the 1990s. The impacts are not limited to material damage: almost 92 million Brazilians have been affected by these events since 1991, with more than 8.7 million displaced or homeless and 4,247 deaths recorded, representing 86% of all fatalities caused by climate disasters in the country (Aliança Brasileira pela Cultura Oceânica, 2025).

In Brazil, disordered urbanization and the predominance of grey infrastructure, such as the canalization of rivers and the construction



of pools, which reduces the integration between water and the urban landscape, have proven to be limited solutions for dealing with urban flooding, especially when combined with a process of land use change that reduces green open systems (Gomes & Veról, 2024). Although detention basins installed in urban areas (commonly known as pools) are designed to temporarily store rainfall runoff and reduce the peak of floods, their monofunctional implementation, without integration with green structures or social use of space, limits their potential to contribute to urban resilience (Tucci, 2008; Mendes & Santos, 2022). The channelization of watercourses, on the other hand, by accelerating runoff and eliminating natural flood areas, transfers the flood downstream, increasing the risk of flooding in the lower regions. The use of channelization techniques should be adopted as a last resort in remediation situations and not as a standard planning solution (Travassos, 2011; Moniz & Sant'Ana, 2024), or combined with nature-based solutions, such as hybrid solutions (green-blue-gray).

Historically, the urbanization process in Brazil has involved practices such as canalizing rivers, draining coastal lagoons and filling in wetlands to create developable land, drastically reducing water spaces in cities and compromising essential ecological functions (Tucci, 2008; Travassos, 2011; Moniz & Sant'Ana, 2024). This logic of urbanization disassociated from the dynamics of water and ecosystems has resulted in the fragmentation of natural systems and an increase in the environmental fragility of cities in the face of extreme weather events.

In coastal cities, land use and occupation have been characterized by intense urbanization that often disregards the ecological particularities and natural dynamics of the coastline. This urban advance has led to the removal of important ecosystems such as dunes, sandbanks, and mangroves, which act as buffer zones against extreme events and are replaced by pavement or housing. The replacement of these environments with urbanized areas close to the tide line has aggravated coastal erosion processes, increased the impact of storm surges, and intensified the salinization of aquifers (Alliança Brasileira pela Cultura Oceânica, 2025). With sea level rise and urban densification on wetter soils, additional risks arise, such as differential settlement and compromise of urban infrastructure. Furthermore, the predominant response to these risks has been coastal hardening through gray infrastructure solutions—such as low walls, sea walls, and breakwaters—which, although they offer localized



protection, tend to disrupt ecological flows, aggravate erosion in adjacent areas, and reduce biodiversity, even facilitating the proliferation of invasive species (Pardal et al., 2024). On the coast of São Paulo, a recent study mapped 244 km of coastline occupied by artificial structures such as walls, breakwaters, and piers (Pardal et al., 2024). In addition, more than 400 km of urbanized areas are located on low-lying land near beaches and mangroves, increasing the vulnerability of cities to storm surges and flooding. These impacts highlight the urgent need for more integrated coastal planning that recognizes the limits and ecosystem services of coastal zones. Today, this trajectory is reflected in the interruption of ecosystem services, the fragility of urban infrastructures and the increase in climate risks, especially for the most vulnerable populations.

Urban water management has been directly impacted by the expansion of impermeable surfaces, which reduce infiltration and alter the natural flows of the hydrological cycle, as discussed in section 1.2.4. Infrastructure and Sanitation. These changes contribute to an increase in the frequency of flooding, an increase in diffuse pollution and heat islands (Jacobi et al., 2020; Muñoz & Duarte, 2025). Observations in various cities indicate that urban planning parameters, such as permeability rates, encouraging the use of green roofs and infrastructure that favors aquifer recharge, have the potential to mitigate these impacts by directly influencing the planning and occupation of land (Coffman, 2002; Muñoz & Duarte, 2025). The implementation of such measures in urban contexts has been associated with improvements in water management and adaptation to climate change scenarios, with examples of application in cities facing similar challenges (Wong & Brown, 2008; Saraswat et al., 2016; Muñoz & Duarte, 2025).

Research shows that there is a gap in the existence of concrete plans and targets, as well as sources of funding, aimed at mitigating and adapting to climate change (Muñoz & Duarte, 2025). Climate adaptation plans are uncommon in cities around the world, including in Brazil, where their presence is less frequent compared to countries in the global north (Muñoz & Duarte, 2025). On some regional scales, such as in the European Union, there are examples that seek to integrate mitigation and adaptation (Muñoz & Duarte, 2025). However, many climate plans focus predominantly on reducing greenhouse gas emissions, often neglecting comprehensive adaptation approaches. In addition, a significant proportion of initiatives tend to prioritize green



agendas, such as increasing vegetation cover and creating urban cooling spaces, without fully integrating the relationships between the conserved natural environment and the urban fabric (Souza, 2024), furthermore, the importance of blue areas in this scenario is neglected, even considering that we live on a planet where more than 70% of the surface is covered by water.

It should also be noted that guidelines, plans and actions related to climate change can often be antagonistic. For example, the best mobility infrastructures for climate change, such as public transport corridors, tend to be located in high-income areas, where the use of individual transport is predominant. As a result, center-periphery commuting remains a challenge, reinforcing unsustainable models of urban occupation and mobility (Rolnik, 2003; Rolnik & Klintowitz, 2011).

Although Brazil has made progress in drawing up municipal master plans following the approval of the City Statute (Federal Law No. 10.257/2001 - BRASIL, 2001), only 53.1% of municipalities, or around 2,960 cities, have such plans (IBGE, 2021). It is noteworthy that many of these instruments lack specific approaches to climate mitigation and adaptation planning or present disconnected strategies in relation to climate plans (Muñoz & Duarte, 2025).

Contingency and disaster reduction policies and plans, which act on the impacts and not the causes, or reconstruction plans, implemented after the occurrence of events or accidents, which deal with losses and damage, also have a higher incidence than adaptation policies, plans and actions (Soares & Bonduki, 2024), which are preventive in nature and act on reducing vulnerability and building resilience, and this predominance reinforces a reactive dynamic. These disasters, which are not just the result of a climatic event or other natural phenomenon, but are the result of the interaction between these events and the vulnerability of the systems affected, and are therefore predictable, tend to affect popular and vulnerable territories more severely, highlighting the inequalities in climate risk management (IPCC, 2022).

1.2.3. Mobility and Transport

In Brazil, as in many cities in Latin America, the approach to the urban mobility and transportation system to cope with the effects of climate change is predominantly focused on mitigation actions to the detriment of adaptation actions, which are necessary to transform

cities into environments that are resilient to the effects of climate change (Di Giulio et al., 2018; Valderrama et al., 2019; Goes et al., 2020; Castellanos et al., 2022). A fair and efficient mobility and transportation system can help to reduce socio-territorial inequalities that are at the root of socio-climatic vulnerabilities (Carvalho & Brito, 2016). The predominance of mitigation actions is due to many reasons, including the fact that, in Brazil, the historical choice of road transport and motorized urban mobility has made this activity the main source of GHG emissions in cities, coming predominantly from individual motorized transport - cars and motorcycles (Franco, 2024). In some large Brazilian cities, transportation is responsible for 35 to 65% of GHG emissions - for example, 66% in Belo Horizonte (PMBH, 2023), 59% in Fortaleza (PMF, 2021), 55% in São Paulo (PMSP, 2021), 35% in Rio de Janeiro (PCRJ, 2019). This is because motorized transport mostly depends on burning fossil fuels that emit greenhouse gases and other pollutants. Data shows that 27% of the world's CO₂ emissions come from the transportation sector, which is led by cars that account for 45% of the volume emitted (UN Habitat, 2022).

Mobility policies that encourage individual motorized vehicles include low-cost or no-pay parking spaces, rules that require commercial establishments and residential buildings to have parking spaces, even when they are close to medium- and high-capacity public transport networks, and production tax incentives (Ferreira et al., 2020). In addition, urban planning has focused on motorized vehicles, creating large urban highways, sprawl and the suppression of natural areas. In addition, this urban model generates soil sealing in the city.



The progressive sealing of the soil in urban centers contributes to the negative impacts of climate change in cities, resulting in an increase in the temperature of urban centers and the formation of heat islands



(Zeman, 2012). When the sun's rays touch the surface, they heat the air in the atmosphere (Torres, 2011). Motorized vehicles and their supporting infrastructure generate heat islands. Data shows that the extreme presence of asphalt, which retains heat for hours, can increase the local temperature by up to 5°C (Departamento de Ciências Florestais da ESALQ, USP, 2012).

In addition to pollution and GHG emissions, this model of transportation based on the private automobile has contributed to the sprawl of cities, which has structured the formation of distant peripheral occupations or gated residential communities that require increasingly longer commutes, in addition to stimulating congestion in more central areas (Rolnik & Klintowitz, 2011), increasing heat islands and highlighting socio-territorial and gender inequalities.

In addition, the consumption of fossil fuels is proving to be unsustainable in the long term and reducing dependence on mineral-based fuels in urban mobility is one of the most important mitigation agendas for cities. According to Simob (ANTP, 2018), around 11.3 million TEP (tons of oil equivalent) are consumed annually in people's journeys, and cars consume 60% of the total and account for only 25% of journeys.

Contrary to these alarming figures, in Brazilian cities, the main way of getting around is on foot (39% of journeys), followed by 28% of journeys using public transport (ANTP, 2018). Women walk more than men (Harkot et al., 2018). This has been found in studies on Origin Destination surveys in various cities in Brazil, such as São Paulo, Curitiba and Salvador. In São Paulo, 50% of the journeys made by women from families earning less than R\$1,244.00 per month are made on foot and 28% by bus (PMSP, 2016).

In Salvador, 56% of all journeys made on foot in the city are made by women (PMS, 2017). In Curitiba, 1/3 of women's trips are made on foot, while only 1/5 of men's trips are made on foot (Curitiba, 2017; Sampapé, 2022). Women are also the main users of public transport, but these more sustainable journeys, on foot and by bus, are made in a precarious situation. While men predominantly use individual motorized vehicles, cars and motorcycles. This reinforces that the road model favors men over women, and that people who move actively, who do not contribute to emissions and worsening of the climate crisis, are the ones who suffer the most from the consequences, since walking is



hampered by extreme heat and extreme rainfall while cities do not implement adaptation and mitigation solutions.

The lack of adequate sidewalks, insufficient street lighting and the lack of integration with essential services (such as education, health and employment) compromise not only daily mobility, but also safety during extreme weather events such as floods and landslides. The implementation of well-planned and accessible escape routes on foot, but also by public transport, is fundamental to mitigating the risks associated with these natural disasters (CEMADEN, 2023). Community participation in defining these routes has been shown to be effective in preparing for and responding to disasters, as observed in case studies in Brazilian municipalities (CEMADEN, 2023).

In addition, the lack of preventive government measures increases the consequences of extreme weather events. Identifying areas prone to flooding and indicating escape routes are essential actions which, when neglected, leave populations more exposed to the impacts of climate change (Côrtes, 2024).

In recent decades, app-based mobility (through platforms that connect passengers with drivers of individual private vehicles) has brought new ways of getting around, stimulating motorcycle travel (Abílio et al., 2021) for people and for deliveries. The option for app-based transportation services in individual vehicles has grown in cities, receiving users who previously used public or active transportation, more sustainable options that were mostly used by women, and motorcycle trips have also grown as public transportation has not reached the spread of cities. Motorcycles have become an option for the poorest who live on the edges of cities, since the cost of fuel is a third of the bus fare (Vasconcellos, 2016), and bought over the long term with low down payments they are convenient for daily commuting and for generating employment and income, but they represent a high social cost in deaths and traffic accidents, as well as being polluting.

Public transport systems by bus, especially in metropolitan areas, often present challenges in terms of regularity, efficiency and equity (Vasconcellos, 2014). They frequently fail to meet demand, have poor services - few lines, no timetables and overcrowding. This decline ends up encouraging individual motorized modes as a solution for sprawling cities. Buses are also major consumers of fossil fuels, and electrification of the fleet is still taking place in only a few cities.



Active modes – by bicycle or on foot – face enormous challenges. Commuting on foot suffers from a lack of structure and violence – road, public and gender-based. The use of bicycles for everyday commuting is still low and predominantly male. Although they are considered priority modes in federal mobility policies, the priority of sharing roads is not felt by users, with many road accidents, making Brazil the third country in the world with the most traffic deaths (WHO, 2018).

Frequent and intense extreme weather events have a significant impact on urban mobility systems. These events include flooding at train and subway stations, rail and road closures, and obstruction of sidewalks and bike paths due to flooding, falling trees or electrical wiring. Studies have sought to predict more accurately the occurrence of climatic phenomena that affect mobility in large cities, as well as building comparative parameters to assess the vulnerability of urban mobility systems in different municipalities (ITDP, 2018; Machado et al., 2023).

As part of this effort, an index was developed that simplifies the degree of susceptibility of urban mobility systems to extreme weather events (ITDP, 2018). This index has the potential to guide the definition of regional priorities in public policies, action plans and funding for mitigation and adaptation measures. For example, the studies showed that the ten municipalities with the highest vulnerability indices are located in metropolitan regions, where a significant portion of the Brazilian population is concentrated. This scenario reinforces the need to give priority attention to these areas when developing integrated climate adaptation strategies (Machado et al., 2023).

Mobility planning, although essential for the organization of cities, is not present in all cities. The City Statute (Federal Law 10.257/01) requires cities with more than 500,000 inhabitants to have an urban transport plan integrated into the master plan. In recent decades, Brazil has produced a National Urban Mobility Policy (Law 12.587/12), which required municipalities with more than 20,000 inhabitants to draw up mobility plans – 56% of capital cities have or are revising their Mobility Plans (UCB, 2019) – but many municipalities have yet to do so. Furthermore, most of them do not indicate clear paths and targets for prioritizing active and public transport, guidelines of the National Mobility Policy (UCB, 2019).



This is also evident in the urban model that does not allow people to be close to basic needs. In the survey "15-minute cities - walking in Brazilian cities", carried out in 2021 by the Walkability Institute in partnership with MindMiners, only 13.3% of respondents said they had an educational institution within a 15-minute walk of their homes. In addition, only 19.8% said they had medical and health services nearby. Public spaces, such as parks, squares and beaches - essential for physical and mental health - are close to only 30% of people - with a significant drop considering class (Instituto Caminhabilidade, 2024a).

On a macro urban scale, the inefficiency, lack of integration and poor distribution of public and mass transport is a determining factor in the marginalization, fragmentation and social vulnerability of a significant part of the population living in urban peripheries, forced to commute many hours each day to access their workplaces in central and wealthy areas of cities (Carvalho & Brito, 2016).

Therefore, in the transport and mobility sector, urban resilience and effective climate adaptation are conditional on public policies capable of integrating safe and accessible mobility strategies, integrated with land use and occupation solutions, ensuring that all communities, especially the most vulnerable, have access to nearby basic services, workplaces, efficient escape routes, and adequate walkability infrastructure (which can be greatly benefited by the integration between human circulation spaces and the green-blue system in the city), public transport in a position to offer clear advantages over individual transport, according to the characteristics of each place, in a network distributed fairly throughout the city, helping to overcome inequalities and territorial fragmentation, expanding integration between places and communities.

2.2.4. Infrastructure and Sanitation

Brazil's water management system faces significant challenges due to rapid urbanization, climate change and environmental degradation (ANA, 2022). The country's hydrological cycle is becoming increasingly unbalanced, leading to frequent and intense climatic events such as floods and droughts (ANA, 2024). These extremes contribute to desertification (De Moraes, 2023), and rising sea levels are threatening Brazilian coastal cities such as Recife (Da Fonseca Netto et al., 2022; De Souza et al., 2024), Santos (Marengo et al., 2022b) and Belém (Henriques et al., 2024). A predominantly "over-engineered" approach,

heavily reliant on gray infrastructure, often fails to provide sustainable solutions, resulting in fragmented urban water management (Fletcher et al., 2015).

The sanitation deficit in Brazil is still significant, despite the legal requirement that access to sanitation services must be comprehensive and universal, comprising drinking water treatment and distribution systems, sewage collection and treatment, rainwater management and urban drainage and solid waste management, in accordance with Law 11.445/2007 (Brasil, 2007). According to the Panorama of Basic Sanitation in Brazil (MDR, 2021), sanitation is the "set of measures carried out with the aim of preserving environmental conditions, in order to improve the population's quality of life and facilitate economic activity".



Water security is a major concern in the context of the climate emergency (Quandt et al., 2022; Amapro-Salcedo et al., 2025). Although Brazil has around 12% of the world's available fresh water (Farjalla et al., 2021; Carvalho & Tulder, 2022), between 16.1% and 15.1% of the population is still not served by a drinking water supply network (IBGE, 2024; SNIS, 2023), which is equivalent to around 32 million people without access to safe water. In the water supply system, there is an estimated loss of 38.9%, between clandestine connections, leaks, thefts and lack of or incorrect measurement of consumption, generating a loss of 8 billion reais per year (Ávila et al., 2023).

In the last two decades, there has been a significant increase of 80% in water withdrawals, considering all sources, and future projections indicate that there will be an additional increase of 30% by the year



2030, in order to meet population growth and other demands of economic activities, to meet the future demand for water resources, essential for food and energy production (Gesualdo et al., 2021). Studies indicate an upward trend in prolonged periods of consecutive days without precipitation, as well as a greater frequency and intensity of dry spells and droughts in the Northeast region, showing the region's growing vulnerability to climate variations (Marengo et al., 2009; Jenkins & Warren, 2015; Marengo et al., 2017). For the Southeast region, climate projections indicate a possible increase in average temperature, accompanied by a reduction in total precipitation, at the same time that intense, short-duration precipitation events may become more frequent (Chou et al., 2014; Viola et al., 2015). Southeastern states such as São Paulo, Rio de Janeiro and Espírito Santo are already showing an upward trend in the occurrence of extreme daily rainfall events (Zilli et al., 2017). These climate changes, with impacts on regional hydrological regimes, will affect communities already vulnerable to extreme events today, intensifying conflicts and socio-economic problems (Marengo et al., 2017; Jong et al., 2018).

The conditions of the domestic sewage collection and treatment system are even worse, with an indicator of 64.7% of households connected to a sewage collection network (IBGE, 2024), which is different from the information presented in the National Sanitation Information System (SNIS), which indicates sewage network coverage for 56% of the population (SNIS, 2023), or around 112 million people served. Of this collected sewage, 81.6% is actually treated, which means a sewage treatment rate in relation to the total generated in Brazil of 52.2% (SNIS, 2023). Thus, it can be concluded that the sewage generated by around 106 million people depends on inadequate or rudimentary individual solutions for final disposal, i.e., it is released directly into nature, without any treatment (Brasil, 2019).

All the sewage collected is transported by rainwater drainage networks, adapted to operate as a mixed network (Fadel & Dornelles, 2015; Oliveira et al., 2024), both artificial and natural. In Brazil, 37.2% of municipalities reported having combined or mixed rainwater drainage and sewage systems (SNIS, 2023). The result of this is the high level of degradation of Brazilian rivers, with 83,450 km of their water network with significant restrictions on use, such as abstraction for supply (ANA, 2019). Furthermore, in situations of flooding, when the volume of water precipitated exceeds the capacity of the drainage network, the result is that the excess water that flows over the streets ends up



accessing the sanitary sewage collection networks, resulting in a highly contaminated effluent (Sowby & Jones, 2022; Gogien et al., 2023; Oliveira et al., 2024). This combination amplifies the impacts on the city at the time of the disaster, with risks to the safety and health of the population as a direct and indirect effect, with an increase in the number of patients treated for illnesses that appear after flooding events (Tucci, 2001; Zoppou, 2001; Jemberie, 2023).

The proliferation of pathogens as a result of flooding increases the risk of infectious diseases, which can be aggravated by the displacement and agglomeration of those affected, difficulties in hygiene and food, as well as access to health services (Gallego et al., 2025). In this condition, the risk of spreading vector-borne diseases such as dengue and malaria is also increased (Yenew et al., 2025). In addition to the impact on the population's health, the additional volumes coming from the contribution of rainwater to the sanitary sewage collection and treatment system can impact the pollutant removal efficiency of sewage treatment plants (STPs), resulting in increased costs in sewage management (Sola et al., 2020).

In addition to this situation of degradation, it should be noted that there are still complex social challenges in Brazil, such as the large number of people living in slums, which total around 16.5 million people or 8.1% of the entire Brazilian population (IBGE, 2024). Thus, an important challenge for the universalization of sanitation services in Brazil consists of intensifying coverage for populations located in peri-urban areas, favelas and other informal settlements, which have a high density of housing, as well as rural areas, where the population to be served is very dispersed. The provision of water and sanitation services in these vulnerable areas is complex, depending on the combination of formal and informal infrastructure that can meet the particular requirements of this territory (Narzetti & Marques, 2021).

Considering the current framework of sanitation services, in order to achieve the established improvement targets, it will be necessary to break with the current model and expand the capacity to develop projects that include design, public procurement, construction and management and execution of contracts to accelerate the volume and flow of investments needed for universal access to water supply and sanitation (Dias et al., 2018; Narzetti & Marques, 2021). In addition, adaptive parameters should be incorporated into these new infrastructures, transforming the huge problem of the deficit and



inadequacy of these basic services into a great opportunity for transformative adaptation, cooperating to also achieve the Global Adaptation Target at COP28, which included "climate resilient sanitation" as one of its thematic objectives, offering an opportunity to increase joint efforts in the adaptation of sanitation services (Ahmed et al., 2025).

Finally, building urban resilience still faces the challenge of managing solid waste in a sustainable and resilient way. In Brazil, the composition of waste is diverse, but with a high proportion of organic and plastic waste. Disposal is a problem; collection is predominantly carried out by municipalities, but coverage is uneven, especially in rural areas and disadvantaged communities, with many municipalities still resorting to dumps, which are inadequate and cause environmental and social impacts (BNDES, 2024b).

Among the main challenges of urban waste management are the lack of infrastructure and resources in municipalities, the low environmental awareness of the population, or, for conscious people, the difficulty in changing behavior; the informality of recycling by waste pickers and the lack of effective implementation of legislation. In addition, a lot of waste, especially plastic items, obtained from fossil fuels and consumed on a large scale, does not have the capacity to biodegrade; it only fragments, producing huge quantities of microplastics that are already present in practically all natural environments, generating severe environmental impacts, as well as harm to animals and the human population (Ziani et al. 2023).

According to data released by the Brazilian Waste and Environment Association (ABREMA, 2024), 81 million tons of solid urban waste were generated in the country in 2023. These figures reflect population growth, urbanization and consumption patterns (Nascimento et al., 2015).

Over the last few decades (1990-2021), compared to other sectors, the waste sector has increased methane emissions the most in Brazil, accounting for 16% of the total. Despite this, the importance of this sector within climate action is still not adequately recognized (SEEG, 2022).

Waste management in Brazil shows marked inequalities between different regions. These disparities are related to economic, social and



environmental factors. More developed regions, such as the Southeast, have better waste collection and treatment infrastructures. On the other hand, in the North and Northeast, many municipalities face difficulties in collection and proper disposal. In Brazil, it is estimated that 61% of the MSW collected in 2022 was sent to landfills, corresponding to 43.8 million tons of waste.

In terms of impacts, more vulnerable regions are often more affected by soil and water contamination, which affects public health and people's quality of life. Poverty and lack of resources in some regions make it difficult to implement effective solutions, perpetuating a cycle of neglect and pollution.

These aspects show the complexity of solid waste management in the country and the need for an integrated and collaborative approach to address the challenges and promote sustainability (Brasil, 2022b).

There are few review papers investigating the impacts of climate change on sanitation services, focusing on changes in precipitation patterns and the consequent increase in flood risks for cities (Hyde-Smith et al., 2022). Lima et al. (2018) found patterns indicating a positive increase in annual rainfall totals in the Metropolitan Region of São Paulo, but point out that there are already current challenges to guaranteeing the demand for drinking water supply in the region, requiring investments in increasing storage capacity by building more reservoirs and dams, collecting rainwater in new and old buildings in cities and using recycled/reused water for landscape irrigation or recharging underground aquifers.

Climate change entails a significant increase in the current challenges to guarantee a reliable and quality service for the entire population, notably the increased risk to sanitation systems, as a result of both extreme events and gradual changes in the hydrological cycle, with corresponding changes in water resources (WHO, 2019; USAID, 2015):

- More intense or prolonged rainfall: Increased rainfall in an event can create more frequent and intense flooding, with the potential to disrupt sludge management services when roads and access to containment and/or treatment plants are blocked, and can result in sewage overflows, exceeding the treatment capacity of wastewater treatment plants. Possible increased



degradation and failure of sewer pipes, leading to a higher replacement rate and higher maintenance costs.

- More variable or reduced rainfall: Longer dry periods can lead to a decline in water supply, preventing the functioning of water-dependent sanitation systems such as toilets and clogs due to low sewage flows, with lower minimum flows. Long-term declines in surface water availability can decrease the viability of sewage to water and reduce the ability of surface water sources to dilute and attenuate pollutants contained in wastewater effluent. High variation in rainfall can cause soil movement in soils with a high clay content, resulting in damage to sewer pipes laid in these locations. Drier conditions can also have a beneficial effect of attenuating the flow of pathogens into water sources.
- More frequent or intense storms and cyclones: Storms can damage or destroy sewage pipes, power sources, treatment plants, individual and collective latrine structures, etc., potentially resulting in increased open defecation and disruptions to pumping and treatment facilities.
- Rising sea levels: Rising sea levels and consequent salinization can expose coastal wastewater treatment plants and other sanitation infrastructure to flooding and corrosive saltwater. Sewage systems located close to sea level may be subject to increased tidal gradients, increased groundwater infiltration and system overloading. This can result in reduced discharge capacity and increased risk of overflows during events of high precipitation and concomitant high tides.
- More variable and rising temperatures: Higher water temperatures can be more conducive to algal blooms, exacerbating the effects of sanitation pollution in freshwaters. Higher temperatures can also have the beneficial effect of increasing the efficiency of biological processes in wastewater treatment.

One adverse impact of climate change refers to the potential cascading effect caused by the failure of drainage systems, leading to flooding events, especially when these events affect critical infrastructure, including the sanitation system itself (Hilly et al., 2018; Romero-Lankao & Norton, 2018; De Bruijn et al., 2019; Almeida et al., 2020; Fekete, 2020). A major flood can also affect the energy sector, which consequently affects urban water systems, causing failures that can threaten water treatment capacity, as well as causing electromechanical, pumping and control systems to fail (Romero-



Lankao & Norton 2018; Almeida et al., 2020). The same can happen when communication systems are interrupted, when the operation of gates and pumps can be compromised (De Bruijn et al., 2019).

Sanitation infrastructures in Brazil already face significant challenges to universalization, which are exacerbated by climate change, with studies indicating that extreme events, such as more severe floods and droughts, intensify the vulnerability of the sanitation system, requiring urgent investments in adaptation and resilience (IPCC, 2021; ANA, 2020).

2.2.5. Social Housing and Informality

Informality and precarious housing are among the biggest challenges for adapting cities (Satterthwaite et al., 2020; UN-HABITAT, 2018). Informality in urban settlements stems mainly from inadequate regulations and lack of enforcement, especially when standards are designed for higher-income economies, without considering that a large part of the population still lives in poverty (Brown et al., 2014). In addition, it is associated with low income and environmental risks, not as a cause, but as a reflection of inequality and poverty (Brown et al., 2014).

Vulnerability to climate change and its effects is accentuated by the intertwining of inequality, poverty and informality, factors that shape cities (Romero-Lankao et al., 2014; Rasch, 2017; Leal Filho et al., 2019) and can hinder adaptation (Castellanos et al., 2022). In the process of urbanization of Brazilian cities, lower-income populations were expelled to peripheral and isolated areas, with poor infrastructure and high risk of disasters, such as river floodplains and hillsides, generally without real estate value because they consist of *non aedificandi* areas (Di Giulio et al., 2019; Saito et al., 2019; Du & Greiving Yap, 2022; Bastos Moroz & Thieken, 2024; Brasil, 2024a). Because they are outside formal laws and regulations on property, land use and building standards, the state often avoids working with informal settlements and, as a result, these settlements lack essential infrastructure for risk reduction – such as slope containment and sanitation – as well as fundamental social services for resilience (Revi et al., 2014; Satterthwaite et al., 2020). The socio-environmental and territorial vulnerability of these settlements is further exacerbated in the face of extreme weather events, as their residents have few resources to cope with and recover from the impacts generated by these crises (Castellanos et al., 2022).

In Brazil, there are 12,348 favelas and urban communities, where 16.5 million people live (IBGE, 2024), and it is estimated that more than 8.2 million people live in risk areas subject to floods, torrents and mass movements (IBGE, 2018). These are priority areas for strengthening community resilience to climate change, through property formalization programmes, housing improvements, disaster risk containment works and the provision of public services (Satterthwaite et al., 2020).



Brazil's housing deficit, estimated at 6.2 million homes - which represents 8.3% of the total number of occupied private homes in the country (FJP, 2023) - is yet another challenge aggravated by climate change. In 2023, Brazil was the country in the Americas with the highest number of internal human displacements, totaling 745,000 people affected by disasters (IDMC, 2024). This problem is manifested both by the removal of residents from disaster risk areas and by the forced displacement of vulnerable people affected by climatic events in search of better living conditions (Brasil, 2024a).

Displacement induced by natural disasters and climate change represents a profound rupture in the social fabric, disproportionately affecting black and low-income populations who are already exposed to multiple pre-existing vulnerabilities (Cunha, 2012; Muggah, 2015). This process implies uprooting from territories of belonging, compromising emotional ties, support networks and cultural identities (Espinoza Soto et al., 2022). Forced migration due to disasters not only disrupts social systems, but also reinforces structural inequalities and power relations, since response and recovery depend on the resilience



and coping capacity of these communities, which are often limited by socioeconomic and institutional factors (Islam & Khan, 2018; Espinoza Soto et al., 2022). Thus, displacement becomes part of a cycle of exclusion, precariousness and marginalization, with long-term implications for the social and economic integration of affected populations (Xavier Arena et al., 2024), often transferring, or reproducing, vulnerability from one place or community to another.

In the context of housing policies, the relocation of families to places far from their support networks and access to opportunities reinforces the condition of vulnerability (Marques & Rodrigues, 2013). Massive housing production programs increase the material conditions of the lower-income population, but their poor location results in a burden for families who spend more on commuting and have less access to support networks (Libertun de Duren, 2018). Housing policies do not usually address the needs that perpetuate poverty, vulnerability and marginalization (Garcia, 2017; Wainer & Vale, 2021).

In view of the effect of transferring vulnerability, the Minha Casa, Minha Vida (MCMV) program was reformulated in 2023 with the aim of offering "better location for housing developments, ensuring proximity to commerce, public facilities and access to public transport" (Brasil, 2023b). The MCMV produced 6 million housing units between 2009 and 2019, through public and private subsidies worth R\$223 billion (Brasil, 2020a) through the following lines of financing: Subsidized Housing Production, Financed Acquisition, MCMV Cities and Pro-Housing (Brasil, 2023c). The program caters for families with a monthly income of up to R\$8,000.00 in urban areas and, among other criteria, gives priority to families who have lost their homes due to disasters or who live in high-risk areas.

Another relevant housing program to address the issue of resilience and access to opportunities is the Union Property Democratization Program (Imóvel da Gente). This initiative aims to use Union property to implement housing and land regularization policies (Federal Decree No. 11.929, of February 26th, 2024; Brasil, 2024b). Through this program, housing movements can indicate that buildings owned by the union, located in urban centers, be transformed into housing. By taking advantage of the use of idle properties in places already provided with infrastructure, this program aligns itself with the principles of the social and environmental function of property, a concept initially established by the City Statute (Brasil, 2001) whose scope is

broadening in the face of climate change (Evers & RossBach, 2023; Machado et al., 2023).



Strengthening urban resilience to climate change, especially in vulnerable communities, is a complex challenge. Traditional top-down approaches, with linear design, implementation and monitoring processes, are insufficient. Instead, collaborative efforts that involve civil society organizations, policymakers and academics in co-creating more inclusive perspectives on urban risks and resilience priorities can lead to more effective decision-making (Bárcena & Bahadur, 2023). However, for these co-production initiatives to have a significant impact, it is essential to consider the power dynamics that influence urbanization and climate risk.

For co-creation and bottom-up processes to be effective, it is necessary to establish governance mechanisms that promote the active participation of affected communities in the formulation and implementation of adaptation solutions (Schipper et al., 2022; Jacobi, 2023). Groups living in informal areas are often marginalized and excluded from decision-making arenas, limiting their ability to influence policies that directly impact their lives (Castellanos et al., 2022). Incorporating Community-Based Solutions approaches can strengthen this inclusion by valuing local knowledge and increasing territorial resilience (Reid et al., 2009). In this way, the participation of communities in the construction of adaptation strategies not only improves the legitimacy and effectiveness of public policies, but also contributes to reducing historical inequalities (Jacobi, 2023).



Informality and precarious housing are central challenges for urban adaptation to climate change, requiring approaches that consider the complexity of socioeconomic and spatial inequalities (IPCC, 2022). Land regularization, improving infrastructure and incorporating nature-based solutions are strategies to strengthen the resilience of vulnerable communities (Castellanos et al., 2022). However, the effectiveness of these initiatives depends on the articulation between housing policies, urban planning and social inclusion, in order to avoid the reproduction of patterns of segregation and vulnerability.

2.2.6. Human Health and Well-being

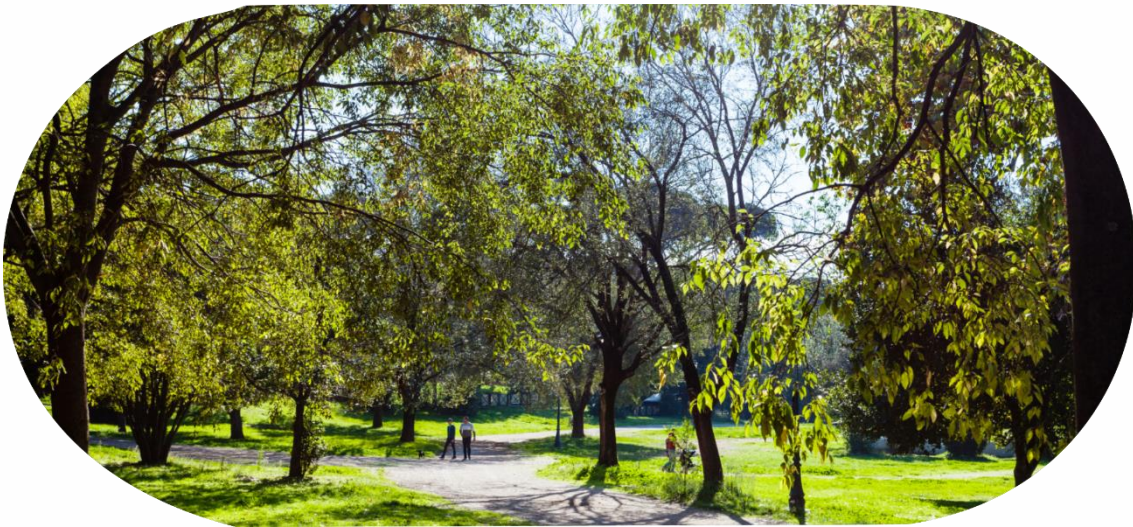
Urban quality of life encompasses not only the fundamental elements for human well-being, such as physical and mental health, safety, education, work and income, but is also closely linked to socio-environmental aspects (Enssle & Kabisch, 2020; Berdejo-Espinola et al., 2024).

A wide range of material and immaterial indicators have been discussed to portray the "good quality of life", with biodiversity playing a crucial role. Basically, four pathways connect biodiversity to human health and well-being, either beneficially or negatively (Marselle et al., 2021): through harm reduction (provision of medicines, reduction of exposure to air and noise pollution); through restoration (of attention, stress reduction); through its constructive capacity (promotion of physical activities, transcendent experiences); and through harm caused (wildlife hazards, zoonoses, allergens).

Among the material dimensions, the main aspects include food, water and energy security, housing, income and health. In the intangible dimension, notable elements are equity, strong social relationships, a sense of cultural identity, personal and physical safety, freedom of choice and action, and access to education (IPBES, 2019). In this context, biodiversity is directly related to these indicators and becomes a key element in urban planning processes (Vörösmarty et al., 2010; Glamann et al., 2017; Bressane et al., 2024). However, the rapid urbanization of Brazilian cities has resulted in a current scenario of biotic homogenization (Moro et al., 2015), along with the uneven distribution of high-quality green spaces within the urban fabric. This dynamic often favors a greater quantity and quality of urban vegetation in areas with higher average per capita income (Arantes et al., 2021; Sun

et al., 2022; Bressane et al., 2024), having a direct impact on the socio-territorial and climatic justice of urban systems.

Globally, while many individuals visit protected areas to connect with nature and experience biodiversity more intimately (Balmford et al., 2015), less affluent and usually vulnerable populations in most medium and large Brazilian cities remain distant from natural areas within municipal territories. This has led to a phenomenon described as the "extinction of experience", i.e., a reduction in contact with nature, resulting not only from changing lifestyle habits, but also from the lack or poor distribution of natural spaces throughout the urban system, especially healthy, biodiverse spaces accessible to all (Soga & Gaston, 2016; Jiang & O'Neill, 2017).



Among the spaces for experiencing nature in cities, urban parks stand out. They serve as essential refuges where city dwellers can find tranquillity and peace with nature, while at the same time being able to promote multiple psychological benefits, favoring this fundamental aspect of human health (Liu et al., 2023). Studies show that, in addition to direct contact with vegetation, the sound of various bird species in urban areas contributes to stress reduction (Taylor et al., 2020; Uebel et al., 2021; Zehra & Sharma, 2023; Korpilo et al., 2024), highlighting the importance of maintaining high standards of biodiversity in urban green spaces, since not only vegetation but also fauna in urban areas can positively impact the health of the population. Urban afforestation also plays an important role, due to its ability to integrate robustly into the urban fabric, creating corridors for birdlife and shading public roads. By making urban spaces greener and more livable, nature is brought closer to the city in a broad way, as demonstrated in the case



of Medellín, which has created a project of ecological bird corridors in the city (Alcaldía de Medellín, 2015).

In addition, evidence from various parts of the world shows that greater tree diversity is associated with a lower incidence of physical and mental health problems (Rook, 2013; Kuo, 2015; Aerts et al., 2018; Giacinto et al., 2021), and that increased exposure to green areas can lead to a reduction in various health risks (Oliveira et al., 2022). Similar patterns have been described for blue areas. Blue areas—such as beaches, mangroves, estuaries, coastal lagoons, and urban areas with bodies of water—play a central role in promoting human well-being, especially in urban contexts marked by socio-environmental inequalities and the increasing impacts of climate change. Scientific evidence shows that contact with natural aquatic environments is associated with improved physical and mental health, reduced stress, and strengthened social bonds, and is especially beneficial for children, the elderly, and vulnerable populations (Fleming et al., 2019; Leavell et al., 2019; Georgiou et al., 2021). In coastal cities, where large population contingents live in areas at risk and with less access to green and blue infrastructure, these zones offer natural buffering against extreme events, as well as spaces for leisure, contemplation, and physical activities. However, the unequal distribution of these areas highlights challenges of climate justice and access to well-being. Promoting their conservation, recovery, and equitable management is not only an environmental measure but also an essential public health and urban resilience strategy, aligned with the principles of One Health and the guidelines of the Decade of Ocean Science (Masterson-Algar et al., 2022).

Another point of note concerns environmental and climatic aspects and urbanization itself, which can also contribute to mitigating the impacts of vector-borne diseases (Carvalho et al., 2020). Dengue, malaria and Zika have become a growing concern in a scenario where uncontrolled urbanization creates environments conducive to the proliferation of vectors (e.g., *Aedes aegypti* mosquitoes) (Lin et al., 2024). In this scenario, the increase in non-forested areas seems to be related to the increase in cases of some of these diseases (Joyce et al., 2021).

Thus, the preservation of urban areas and contact with nature, in addition to all the benefits for the urban microclimate, drainage and numerous contributions to reducing risks associated with climate



change, is also capable of reducing the vulnerability of the population by contributing to their physical and psychological health.

Another important point concerns urban morphology, which can favor or reduce lighting, ventilation and insolation capacity. Also, depending on the local climate, it can create environments that favor, for example, the spread of respiratory diseases, or even the expansion of urban heat islands with direct consequences on the health of the population, among other impacts (Huang et al., 2019; Ma, 2021).

Climate change poses a range of effects on human health, including increased incidence of respiratory illnesses, long term mental health issues (Ebi et al., 2021), increased risks of infectious and vector-borne diseases, and non-communicable diseases (NCDs) (Hunter et al., 2024).

Changes in precipitation patterns and the more frequent occurrence of droughts, allied to higher temperatures, are ideal conditions to promote the growth of pathogens of vector-borne diseases (Zavaleta-Monestel et al., 2025). Extreme temperature events may also trigger heat-related illnesses (such as heat exhaustion, heat syncope, and heat stroke), depending on individual susceptibility (Ebi et al., 2021).

Common NCDs (e.g., type 2 diabetes and obesity) and climate change have in common important global vectors: increased urbanization, increased use of transportation, and production and ingestion of ultra-processed foods (AL-Shihabi et al., 2023). Type 2 diabetes (the most frequent disease type) originates from an internal inflammatory environment that impairs insulin responsiveness, and high temperatures also affect the activity of this hormone, thus constituting an important pathway contributing to an increase in diabetes incidence (Natur et al., 2022).

Cardiovascular diseases (CVDs) are also connected to environmental factors. A wide range of pollutants, but especially particulate matter, cause oxidative stress and systemic inflammation, leading to a substantial increase in CVDs (Sagheer et al., 2024).

Chronic diseases such as cardiovascular, cerebrovascular, and respiratory conditions, cancers, and diabetes pose significant public health challenges, as they are associated with reduced quality of life, functional limitations, and increased mortality risk (Costa Filho et al.,



2018). The cost of treating NCDs represents a threat to healthcare systems worldwide (Greenberg & Pi-Sunyer, 2019). Moreover, these diseases entail significant social and economic burdens, as they often manifest during the productive phase of individuals' lives.

Due to the possibility of rising temperatures on the planet, protected areas on the outskirts of cities should be increasingly sought after, as they offer environments with milder temperatures. However, rapid changes in land use, such as deforestation near urban perimeters, put these potential refuges at risk (Krutilla et al., 1995; Daunt et al., 2019), especially in regions where environmental public policies remain a low priority (Di Giulio et al., 2019; Ferreira et al., 2023), requiring special attention to this issue.

2.3. Planning and Designing Resilient Urban Systems

2.3.1. Natural Areas

Urban natural areas, including green and blue spaces, are crucial for mitigating the impacts of climate change and promoting urban resilience. However, the integration of these spaces into urban planning and design faces significant barriers, such as fragmentation, inequality in distribution, limited indicators and a decline in the use of formal planning instruments (ICLEI, 2022; Maretti et al., 2022, 2023). These challenges require systemic and integrated approaches that value the complexity and multifunctionality of urban and peri-urban natural areas.

Although indicators such as green areas per inhabitant are widely used, they are insufficient to represent the functionality and accessibility of natural spaces. models such as the "3-30-300 rule" (Konijnendijk, 2023) and the "ANGSt model" (Handley et al., 2003) offer practical guidelines, but do not always present robust scientific validation. Considering the combination of complexities, urban processes and clusters of urban natural areas, it is essential to adopt broader criteria that include ecological connectivity, governance, accessibility and proximity, among others, including in peri-urban areas, where pressure from urban sprawl is intense (Mackres et al., 2023; Deng et al., 2024).

Inequality in the distribution of urban natural areas is another critical challenge, exacerbating socio-economic inequalities and the impacts of the climate emergency. Studies indicate that cities in developing

countries have lower coverage of natural areas and greater internal inequality in their distribution (Arantes et al., 2021; Silva et al., 2023; Quirino, 2024). Connectivity between green and blue areas through ecological corridors and linear parks can reduce these inequalities, as well as improving resilience and the quality of urban life (Guirao et al., 2021; ICLEI, 2022).

Peri-urban planning, acting preventively, is particularly relevant for integrating natural areas into the urban fabric, promoting the transition between rural and urban areas in a functional and sustainable way. However, peri-urban areas are often neglected in master plans and formal governance systems (Maretti et al., 2022). This neglect limits their ability to function as buffer zones that mitigate the impacts of climate change, such as flooding and heat islands, and restricts local communities' access to essential ecosystem services (Cavalheiro et al., 1999; Maretti et al., 2023).

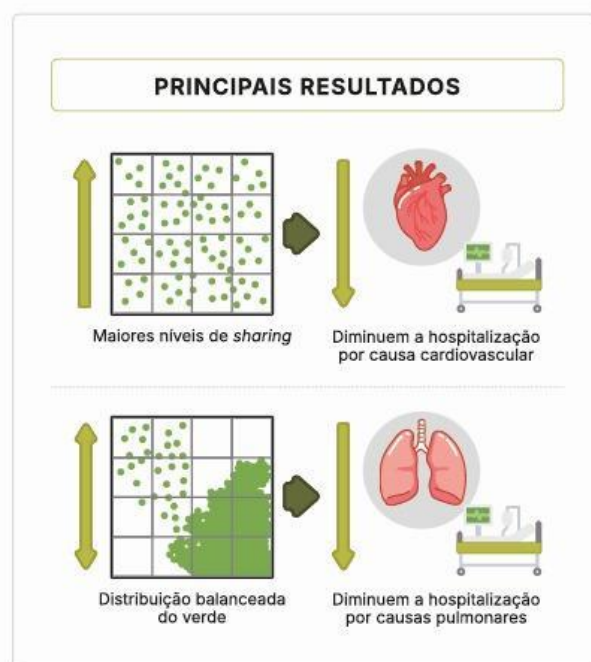


Figure 1. The importance of the distribution of urban green and blue areas (from Cirino, 2023, based on Cirino et al, 2022).

In the context of territorial planning, there is growing recognition of the role of river basins as strategic planning units. According to Maretti (2024) and Nieuwenhuijsen (2024), this approach makes it possible to integrate water resource management with socio-cultural and territorial dimensions, considering the complete water cycle, from its origin to infiltration, retention and reuse. Guirao et al. (2021) highlight the importance of identifying areas of high environmental value or with potential for regeneration, with a view to preserving riparian forests



(riparian and gallery forests), flood zones and other natural areas that promote a balance between urban development and conservation.

The literature suggests that structural and non-structural measures are complementary in the management of green and blue areas. For example, green infrastructure networks, park networks and natural drainage systems can be associated with zoning policies and master plans that prioritize watershed conservation (Maretti et al., 2022; ICLEI, 2022).

The historical and cultural integration of natural areas into urban planning is also a central point. The evolution of the concepts of green and blue areas reflects the growing awareness of their multifunctionality and ecological, social and cultural value (Stanley et al., 2012; Sakata, 2018). For example, historical models of urban parks, such as those proposed by Cranz & Boland (2004), highlight the importance of sustainable spaces that reconcile leisure, culture and ecological conservation. These values need to be incorporated into contemporary planning systems, with attention to the diversity of socio-economic and cultural contexts (Nucci & Cavalheiro, 1998; Maretti et al., 2023).

To overcome the challenges of fragmented governance and management, it is essential to develop Systems of Protected and Conserved Natural Green and Blue Areas (SANVAPCs), which combine multi-scalar planning, intersectoral coordination and community participation. These systems need to include clear guidelines for governance, financing, classification and management of the areas, with a focus on their integration into the urban fabric (ICLEI, 2022; Maretti et al., 2022; 2023). In addition, the adoption of international and national standards for protected and conserved areas, such as those proposed by the Convention on Biological Diversity (CBD, 2018, 2022) and the IUCN (Dudley, 2008) and the National System of Conservation Units (Brasil, 2000), can strengthen their effectiveness and sustainability (Maretti, 2021).



Figure 2. Concept of progressivity in local systems of protected and conserved areas (Maretti, 2021a; 2023; 2024a).

Finally, the relationships between urban and peri-urban natural areas, health and well-being reinforce the need for greater integration and planning. Studies indicate a positive relationship between access to green and blue spaces and urban quality of life, including mental health benefits, stress reduction and promotion of physical activity (Maas et al., 2006; WHO Europe, 2021; Nieuwenhuijsen, 2024). This evidence highlights the importance of planned systems that prioritize not only environmental conservation, but also the positive interaction of society with these spaces (Gascon et al., 2016; Beute et al., 2023).

An integrated perspective that considers the watershed as a planning unit expands the possibilities of connecting natural areas to the urban fabric in a functional and resilient way. This approach allows the ecological and social dynamics of watersheds to be understood and incorporated, promoting not only the conservation of riparian forests, flood zones and ecological corridors, but also the efficient management of the water cycle at multiple scales. By aligning territorial planning with the natural and socio-economic characteristics of river basins, it becomes possible to create systems that maximize water retention and infiltration, reduce climate risks and increase ecological and social benefits. In this way, green and blue areas stop being isolated elements and become structuring factors in tackling climate change and promoting more sustainable and

equitable cities (Guirao et al., 2021; Maretti et al., 2023; Nieuwenhuijsen, 2024).

Urban Afforestation

Natural areas are essential for a good quality of life in cities. Among its various types, afforestation is a component with multiple functions in the urban landscape. Its use as NbS goes beyond the scenic aspects of streets and avenues, but is directly part of the socio-economic context, especially with regard to public health. Studies have shown that the (re)qualification of afforestation and urban green areas for health promotion practices can reduce spending by the Unified Health System (SUS) on the treatment of Chronic Non-Communicable Diseases (Bielemann et al., 2015) - which represented more than 3.45 billion reais in 2018 (Nilson et al., 2020).

In addition, large variations in average air temperature caused by strong heat waves make older people or newborns vulnerable (Kim et al., 2024; Oh et al., 2024; Schapiro et al., 2024), and the islands of coolness promoted by densely wooded squares and parks can reduce the temperature range and generate benefits for public health in general, generating savings for public coffers.

Thus, there are a number of gains in the association between urban greenery and public health in municipal urban afforestation plans, which often focus on the technical aspects of tree inventory and the management of conflicts with urban equipment (Wolf et al., 2020). To this end, coordination between the state and federal spheres should provide direction and goals to be discussed and implemented at the local level. This interdisciplinary aspect of urban afforestation is an important tool for promoting health and saving public revenue.

Actions such as drawing up and implementing a National Urban Afforestation Plan can go beyond social aspects and provide guidelines and targets for emerging economic issues. This is the case of pointing out networks and means of financing for SbN in cities that are notoriously marked by highly complex problems, but which can have simple and efficient solutions based on urban afforestation. Such actions could potentially reduce some asymmetries in the urban context that may exist within states and between regions of the country (Zhang et al., 2024).



In some parts of Brazil, future ecological drought scenarios, marked by long droughts and reduced levels of rainfall (IPCC, 2021; Marengo et al., 2022a), will require a high level of response from public administrations. One way of tackling this scenario could be through urban afforestation that integrates terrestrial and aquatic ecosystems, creating, for example, important corridors for birdlife and other small species in cities. Protected areas such as urban PPAs and linear parks are elements of the urban landscape provided for in the forestry code (Brasil, 2012a) that should be discussed with city planners and other actors involved in land use planning. To make this debate more effective and broad public understanding of the issue, campaigns and programs should include urban afforestation as an elementary NbS for adapting urban areas to the droughts expected in some parts of the country (Frantzeskaki et al., 2016).

Furthermore, by planning the urban landscape with afforestation as a SbN, the ecological communities that exist in cities can benefit from increased floristic diversity and a wider range of ecological niches for urban fauna to use. This precept of increasing biological diversity is in line with the Brazilian proposals signed in international conventions and treaties, i.e. the Kunming–Montreal Global Biodiversity Framework (GBF), placing the country at the forefront of conservation strategies (Joly, 2022).

2.3.2. Land Use and Occupation

Reducing the risks associated with climate change in cities involves acting on the causes of global warming with mitigation actions, reducing the vulnerability and exposure of urban systems with adaptation actions, and also dealing with the possible losses and damage resulting from residual risks through disaster management (IPCC, 2022).

At the heart of mitigation and adaptation is a radical transformation of the production of urban territory. The city model, the structuring of space, and the forms of production and reproduction of the urban system, which are in many ways unsustainable (Lemos, 2022), need to be understood and reoriented towards Climate Resilient Development (CRD), through what science has classified as transformative adaptation (Adelekan et al., 2022; Schipper et al., 2022), as presented in section 1.1. Inequality and Socio-climatic Vulnerability. This is not a simple task or one with short-term results that can be summed up on



just one scale - it must be multi-scalar, thought out from the building to the city, region and country -; or on just one urban agenda - compact, sustainable cities, using nature-based, intelligent solutions, among others -; or on just one sectoral approach (government body, policy, program) (land use and occupation, environment, mobility, sanitation, housing, to name but a few). This defines the challenge of adopting systemic, long-term, multilevel, intersectoral, integrated and inclusive planning and governance strategies (Castellanos et al, 2022), which avoid perverse side effects that amplify social, climatic and territorial injustices, resulting in maladaptation (Schipper, 2020).

Cities have the opportunity to implement climate justice or climate-resilient development strategies (IPCC, 2022), which consider urban development needs based on mitigation and adaptation strategies to the effects of climate change.

Evidence indicates that mitigation and adaptation to the effects of climate change require significant transformations in territorial planning strategies (Castellanos et al., 2022). Studies highlight the importance of multi-scalar analyses to understand climate impacts in different contexts, such as biomes, urban areas and vulnerable territories (IPCC, 2022; Maretti et al., 2023).

On a regional scale, it can be seen that the economic development model shapes land use, often associated with intensive exploitation of natural resources. Analyzing the effects of climate change on biomes and the sustainable management of resources is fundamental to guiding regional policies (Maretti et al., 2023).

In the urban sphere, studies suggest that the success of resilience planning is conditioned by the correct assessment of the urban system's vulnerabilities to foreseeable extreme or progressive climatic events, which increase the possibility of loss and damage in situations such as floods, landslides, heat waves, among others (IPCC, 2022). In addition, knowledge of population projections and potential flows of climate refugees from severely affected urban areas (Castles, 2002) will also condition the success of planning resilient systems. These analyses make it possible to outline strategies that combine environmental preservation with urban resilience (Machado et al., 2023).

The literature indicates that effective plans and policies are those that integrate climate actions into multiple agendas, overcoming sectoral fragmentation. The cross-cutting nature of the climate issue, combined with robust scientific evidence, can increase the impact of public policies and create the basis for long-term political decisions (ICLEI, 2022; Ferreira et al., 2024).

Currently, in the proposals for plans and policies found, the green and blue agenda remains relevant -- providing for the expansion of vegetation, urban elements with water, cooling sites, wind corridors, to reduce thermal stress, with guidelines for wooded urban parks, green corridors, green roofs (Duarte et al., 2015), maintenance of mangroves and reefs in coastal zones. The preservation and recovery of green areas, in addition to reducing pollution and mitigating the effects of climate, helps to protect ecosystems and the natural water cycle, as discussed in section 3. Nature-based Solutions for Climate-resilient Cities.



The so-called climate refuges or urban oases have been highlighted as incremental measures to tackle heat islands in cities. These spaces are integrated into urban facilities such as parks, bus terminals and other public places, offering areas of thermal comfort during extreme heat events (Sousa et al., 2022). In Paris, "cool shelters" have been implemented - public areas that are air-conditioned or shaded by vegetation, with access to drinking water, where bottles of water are distributed to the population (Muñoz & Duarte, 2025).

In New York City, where heat is considered one of the greatest climate threats, measures have been adopted such as maximizing access to



cool indoor environments, cooling buildings and afforesting the city (with a target of 30% tree canopy coverage in the urban area) (City of New York, 2023). In addition, complementary strategies to territorial planning and design are being discussed, such as flexible working hours for workers exposed to heat, to minimize health impacts (Sousa et al., 2022).

The integration of gray and green infrastructure (hybrid infrastructure) has been identified as an important strategy to increase the resilience of urban water management and sanitation in urban systems and reduce the risks associated with climate change threats, particularly in heavy rainfall events (Dawson et al, 2018; Andersson et al., 2022; Castellanos et al. 2022). Research shows that population densification, combined with the preservation of natural areas with conservation potential, is essential for maintaining the hydrological cycle and ecosystem services, which are fundamental for urban resilience (ICLEI, 2022; Maretti et al., 2023). Revising urban models that have historically been based on horizontal territorial expansion, in order to adopt more efficient modes of territorial occupation, environmentally, climatically and also economically, can contribute to more sustainable urban systems, while at the same time protecting critical areas for climate regulation and biodiversity (Machado et al., 2023).

In the housing sector, there is a growing consensus on the need to decarbonize housing programs and adopt more sustainable practices, such as prioritizing the renovation, reuse and repurposing of buildings, as opposed to intensive demolition and reconstruction processes. In addition, the energy transition is often highlighted as a central point, involving the production of clean energy and equitable access to this energy, with affordable prices for the entire population (Gilmore et al., 2023; Leite et al., 2023). Also in this sector, the challenge of adapting informal settlements has gained more prominence in the global debate, and is central to the resilience of Brazilian cities, since, according to the latest IBGE Census of 2022, 16,390,815 people live in slums and informal settlements (over 8% of the population) and interventions in these areas often address disaster risk reduction triggered by climatic events, but do not invest in means of transformative adaptation, allowing the reproduction of vulnerability (See & Wilmsen, 2020; Castellanos et al., 2022).

Within the strategies for building urban resilience, water (access to drinking water and water for domestic and economic activities, but



also urban water management) is another critical issue for mitigating and adapting to climate change. The modification of the urban hydrological cycle, due to disorderly urban expansion and soil sealing, increases the exposure and vulnerability of the urban system and therefore increases the risks related to climate events. Respecting natural areas and restoring degraded ecosystems are measures that strengthen the capacity for infiltration, retention and water regulation, reducing urban vulnerabilities (Sousa et al., 2022; Bertoleti et al., 2025).

These approaches suggest that urban policies and planning should incorporate the protection, recovery or proper management of natural areas as an essential component of the process of densification and sustainable development of cities, ensuring the maintenance of ecosystem services and climate resilience.

Different agendas and models have been proposed to address climate challenges in cities. Historical agendas, such as sustainability, remain relevant, as long as their appropriation by the market in practices such as *greenwashing* is avoided (ICLEI, 2022). Current models include nature-based solutions (NbS), which aim to manage aquatic and terrestrial ecosystems in a sustainable and adaptive way (UNEA, 2022), helping to reduce the negative impacts of heavy rainfall, water scarcity and rising average temperatures on urban systems. Among the numerous strategies for applying NbS in cities, sponge cities (Chikhi et al., 2023), for example, use strategies such as drainage, retention and absorption of rainwater, combining natural and designed systems to reduce the impact of floods and improve water management (Duarte et al., 2015).

Nature-based solutions (NbS) have been recognized as effective strategies to increase urban resilience in the face of climate change (Souza et al., 2022), promoting the restoration, conservation and sustainable management of ecosystems. These solutions strengthen biodiversity, improve ecosystem services and contribute to adaptation and mitigation of climate impacts. In the case of densely urbanized areas, hybrid solutions can be planned and designed to optimize spaces. In other words, combining traditional infrastructures such as pools and dykes with SbN in order to maximize the environmental, social and economic benefits. They are considered cost-effective, multifunctional alternatives capable of generating direct benefits for the urban population, such as increasing water



security, regulating the microclimate and improving environmental quality (Novotny et al., 2010; EC, 2015; IUCN, 2016).

In addition to the approaches already mentioned, some cities have invested in adapting and preserving existing infrastructure. In New York, stormwater drainage strategies have been implemented to reduce flooding and overflows, as well as measures to filter sediment and protect the water supply during extreme events (City of New York, 2023). Studies on local food security have led to the creation of targets to reduce emissions related to the food chain and promote sustainable agricultural practices in the region (Goytua, 2024a, b, c).

Waste management has also gained attention, with efforts to create circular economies that integrate the recycling and reuse of materials, from organic to inputs such as asphalt. These initiatives reflect the importance of integrated, multi-scalar solutions for urban resilience in the face of climate change (ICLEI, 2022; Goytia, 2024a, b, c).

Studies suggest that urban climate strategies that move beyond reactive actions, adopting a preventive and transformative stance, have greater potential to deal with the challenges posed by climate change (IPCC, 2022). The management of the urban environment, in this context, needs to address not only mitigation measures, but also adaptive actions aimed at the specificities of cities (Ferreira & Duarte, 2019).

Climate adaptation is analyzed as a practice that must consider local factors, including physical, hydrological, cultural, historical and political aspects. These analyses highlight the importance of understanding social inequalities and the different degrees of vulnerability among populations such as the elderly, children, racialized communities and homeless people. Several studies point to the need to incorporate principles of climate justice, including the prioritization of groups most exposed to the impacts of climate change (Chu et al., 2016; Shi et al., 2016; Reckien et al., 2017; Chu et al., 2018; IPCC, 2022), however, there is much debate about the effectiveness of commonly used processes of inclusion and participation in decision-making arenas (Yazar et al., 2025).

The literature also explores strategies aimed at the resilience of vulnerable territories, involving the identification and characterization of areas and populations at risk (Castellanos et al., 2022). These



approaches emphasize the importance of considering transdisciplinary dimensions related to the threats posed by climate change and the housing crisis, highlighting the disproportionate impacts on popular territories. The impacts on this marginalized, segregated, vulnerable population are often enormous. And interventions in the field of housing improvements and slum urbanization usually focus on reducing geotechnical risk and not always on reducing vulnerability (Castellanos et al., 2022), remembering that the human aspect is part of adaptive capacity, as presented in section 1.2.5. Social Housing and Informality. As such, they are generally incremental actions that do not promote effective transformation and, therefore, resilience (Satterthwaite et al., 2020; IPCC, 2022; Taylor et al., 2025).

Research into disaster management policies and plans analyzes short-, medium- and long-term scenarios, often involving local communities and evaluating measures aimed at resilience. These analyses investigate ways of protecting life, reducing material damage and strengthening the capacity of communities in the face of disasters, whether natural or technological (Nogueira et al., 2014). This debate also focuses on the understanding that disaster areas in general are popular territories whose multiple vulnerabilities require an understanding of the interdisciplinary dimensions of this risk management, and the need to integrate them into urban and climate planning readings (UN Habitat, 2018).

In the direction of "climate urbanism" (Arruda Filho & Jacobi, 2024), some cities have revised their Land Use and Occupation Regulations (LUOS) as part of a climate change resilience plan, with the aim of guiding the adoption of specific measures to prepare and protect the population and to guide the process of construction, reproduction and renovation of urban systems. By identifying the communities that would potentially be affected, it becomes possible to establish a flood resilience zoning, which can include, among many measures, the installation of a flood park front with structures that collect and hinder the advance of water (Munhoz & Duarte, 2025). Niteroi, in Rio de Janeiro, has implemented an Orla Park, which has a mechanism to filter the water (wetlands) that reaches the lagoon while helping to improve drainage in the area (Vellozo et al., 2022). In some cases, such as New York, urban projects approved through zoning revisions are even motivated to finance the interventions provided for in the climate change resilience plan (Herreros-Cantis et al., 2020).



Other studies seek to establish relationships between flood risk, property values and investments in adaptation, revealing that flood-prone properties face significant price depreciation, but investments aimed at flood protection can transform this picture (Goytia, 2024a, b, c). By mitigating flood risk, they not only protect property values, but also stimulate urban revitalization, increase density and foster economic activity. They offer a tangible way to finance further resilience measures by creating a synergy between investments in adaptation, land use regulations and population dynamics (Goytia, 2024a, b). Within this key analysis are some cases studied by Goytia, which vary slightly. The case of Ho Chi Minh City in Vietnam (Goytia, 2024b) highlights the importance of the private sector, particularly micro-enterprises and small and medium-sized enterprises, in contributing to cost-shared adaptation initiatives. The Copenhagen case explores the interaction between risk factors and the dynamics of the mortgage and insurance markets, discussing the potential for systemic risk in the event of a major flood, the measures lenders are taking to mitigate their exposure to flood risk, and the strategies employed by public and private entities to manage climate-induced flood risks, with an emphasis on the city's proactive approach to urban resilience (Goytia, 2024c).

In addition to investment, the financing of transformations is debated in different ways, as in section 3.5 of this publication. Here, we have seen strategies for financing transformations through urban regeneration, as in the cases presented by Goytia (2024a, b, c), which appear through studies that affirm that the strategy of combating inequality must be at the heart of this financing agenda. For example, documents combating environmental racism have proposed taxing the super-rich to finance the fight against hunger, poverty and tackling the effects of climate change (Confluência das Favelas, 2024).

Experiences of urban policies and plans have articulated forms of democratic management and permanent financing of adaptive measures in the very short term. New York City (USA), for example, has proposed targets and has monitored their effectiveness with frequent public reports (New York City, 2023).

At the neighborhood scale, the literature suggests that the volumetry of buildings and tree masses, among other elements of urban morphology, can be studied and monitored and their impacts on the

environment measured, resulting in options for the management of built space in different Local Climate Zones (LCZ) (Raven et al., 2018; Ferreira et al., 2024).

On the scale of buildings, the context suggests the need to choose models, materials and construction systems for an architecture that has "thermal resilience", whose construction process is guided by optimized choices of materials that have less impact on the environment, that last for the long term and produce self-sufficient buildings (Raven et al., 2018). They call for re-evaluations on how to adapt existing buildings to the climate future, in retrofit models for low-income families, urbanization of subdivisions and slums. Or the use of renewable energies – such as photovoltaic solar panels and solar heating systems, which harness the sun's energy to generate electricity and heat water, reducing dependence on conventional energy sources – or buildings in which clean energy generation is greater than energy consumption, in "zero energy" projects (Ferreira et al., 2024; Ley et al., 2024).



2.3.3. Mobility and Transport

Mobility and urban transport is a critical sector for climate adaptation, with direct impacts on the resilience and sustainability of cities (Ford et al., 2018; Mehrotra et al., 2018; Quinn et al., 2018; Castellanos et al., 2022). Although it is strategic for urban adaptation, most of the investments in this sector reported in the scientific literature on coping with the climate emergency, particularly in Latin America, are in mitigation to the detriment of adaptation (Di Giulio et al., 2018; Valderrama et al., 2019; Goes et al., 2020; Castellanos et al., 2022).



Increasing the supply and quality of public transport is essential to encourage the migration from individual to collective modes, making the latter an advantageous option. Although some are still polluting, collective modes transport more people with less environmental impact, are capable of bringing greater integration and fairness to large urban conurbations that are already consolidated (large cities and metropolitan regions), and the use of renewable energies in transport can reduce the pollution and GHG emissions caused by this activity. This, however, requires significant improvements to the bus fleet, including affordable fares, greater supply to meet demand and cover the territory fairly and equitably, safety measures and accessibility, especially for vulnerable populations such as women and people on low incomes. The transition to rail and high-capacity modes, such as trains and metros, offers a leap in efficiency, as they transport a large number of passengers with fewer journeys. The Zero Fare policy, which proposes the use of public transport without charging the end user, already implemented in 106 cities, is a viable alternative for increasing accessibility (Santini, 2024). Reducing individual modes, whether motorized or electric, is a crucial strategy for tackling excessive consumption of urban space, soil sealing and congestion, paving the way for the implementation of green agendas in cities. Investing in efficient, comprehensive and inclusive public transport is a prerequisite for reducing the use of private cars and thus freeing up space, currently dedicated to cars, for pedestrians and natural spaces, with numerous environmental gains, for human health and for tackling climate change (Roca-Barceló, 2024). Planning a sustainable and climate-resilient mobility and transportation system, however, requires coordination with land use and occupation planning.

The search for walkable cities is also central to climate adaptation. Proximity and accessibility to essential services and local-scale commerce and services reduce the need for motorized travel. The concept of the 15-minute city, popularized in Paris and building on the principles of neighborhood units from the early 20th century (Farr, 2007), exemplifies how urban reorganization can transform mobility patterns. This strategy aims to ensure that daily needs can be met on foot or by bicycle, promoting active and sustainable mobility (Moreno et al., 2021b).



Some of the solutions implemented in Paris to implement the 15-minute city concept are: changing street design and removing motorized traffic from strategic streets. The project began in the streets around schools and on major avenues in the central part of the city. Initially, the motorized flow was blocked by means of tactical urbanism (Moreira, 2019) and then with works to change the design and create new parks and green areas linked to active travel corridors.

In recent years, several linear park initiatives have been implemented in Brazil, such as the Rachel de Queiroz Park in Fortaleza, which demonstrate the potential to integrate active mobility and green areas, while improving urban drainage and reducing climate vulnerability (Instituto Caminhabilidade, 2024b). Another highlight is Via Parque in Caruaru, which has transformed 8 km of the railway line that crosses the city into a linear park and active travel corridor that connects 16 neighborhoods and different urban contexts, promoting the integration of people, generating diverse dynamics of occupation and appropriation of space by the population (Instituto Caminhabilidade, 2024b).

Active mobility, such as walking and cycling, faces significant challenges, including a lack of adequate infrastructure and high rates of public, road and gender violence. Investing in improving sidewalks, bike lanes and connected public spaces is key to fostering this sustainable modality. In Fortaleza, for example, recent renovations have replaced asphalt with interlocking pavements, which are permeable, heat up less and increase road safety as they reduce speeds (Bezerra, 2015; Oliveira, 2020). In addition, measures such as the creation of bicycle racks and the promotion of education for road



sharing can contribute to safer and more inclusive mobility (Lemos et al., 2017).

In the short term, car-free streets can act as urban oases for people, as they become cooler, offering shade from more intense tree planting, and replacing their asphalt paving with more permeable pavements, which contribute less to urban heat islands. In the medium and long term, it is possible to reverse the urbanization model that favours infrastructure for private cars, taking up space that could be occupied by green infrastructure. A 2015 study carried out in Beijing, China, estimated that car engines were responsible for a 1°C increase in air temperature in the summer, which led to an extra consumption of 14.44 GWh in connected air conditioners (Li et. al, 2025).

The integration of mobility policies and urban planning aimed at resilience and risk reduction, especially related to heat extremes, can therefore benefit from the inclusion of green areas and nature-based solutions in mobility projects, such as green corridors and green roofs, which can reduce heat islands and improve urban environmental quality in general. Studies show that urban afforestation can significantly counteract the warming effects of motorized transport, highlighting the importance of urban afforestation in mobility and transport system planning to tackle the climate emergency (UN Habitat, 2022).

In Latin America, cities such as Bogotá and Buenos Aires have been developing urban plans aimed at linking mobility and land use, with the aim of reducing the need for daily commuting. In Bogotá, for example, the Territorial Planning Plan (POT) established 33 Local Planning Units (UPL), designed to promote urban development based on the 15 to 30 minute city concept (Bogotá, 2023). These units have been distributed equitably among the city's territories, respecting their social, cultural and economic dynamics, and seeking to ensure population and territorial balance. The proposal aims to redistribute opportunities and essential services on a local scale, in order to plan, organize and manage urban needs closer to citizens.

Climate challenges also demand a review of land use to encourage population and functional densification along medium- and high-capacity public transport routes. The concept of Transportation-Oriented Development (TOD) proposes the integration of public transportation and land uses, promoting housing density and



environmental efficiency in urban areas (Santini, 2024). The concept of "Complete Streets" emerges as a strategy for transforming urban space to promote safe and accessible mobility for all people, regardless of the mode of transport used. Complete streets align infrastructure, land use and public policies to ensure a more equitable, healthy and sustainable urban environment (Santos et al., 2021c; Santos et al., 2021d). However, it is crucial that this density is accompanied by adequate infrastructure for active and collective travel, ensuring a just and accessible transition for all social groups.

Travel Demand Management (TDM) proposes the combination of economic, regulatory, physical and operational instruments with the aim of creating conditions and incentives that lead to changes in people's behavior in relation to urban mobility (Soriano et al., 2020). These strategies favor more sustainable commuting choices (active and collective transport), while at the same time contributing to cities that are more resilient to extreme climate effects (FGV Cities, 2021).

The most common GDV actions include: reducing the use of individual motorized transport; promoting active modes (walking and cycling); encouraging the use of public transport; changing travel times and destinations to avoid overloading systems; and eliminating unnecessary journeys. The redistribution of road space, for example, by reducing the area dedicated to cars and expanding infrastructure for active modes and public transport, is a measure that can simultaneously meet mitigation and adaptation objectives.

The Avoid-Shift-Improve approach offers an integrated methodological framework for these strategies (FGV Cities, 2021). The "Reduce" axis seeks to minimize the need for motorized travel by promoting mixed land uses and shortening distances. The "Change" axis encourages the replacement of less sustainable modes of transport with cleaner and more inclusive alternatives. The "Improve" axis focuses on increasing the energy efficiency of the fleet and systems, reducing residual emissions.

The adaptation of the mobility and transport system must give priority to those groups and territories made vulnerable by the predominant urbanization model, based on the private car, whose socio-territorial injustices have been exacerbated by extreme climate events, especially for some groups such as women, the poor and peripheral populations. By 2050, around 160 million women worldwide could be



pushed into poverty as a direct result of climate change (UN Women, 2024). Approximately 70% of the world's 1.3 billion people living in poverty are women. They are also the heads of household in 40% of the poorest households in urban areas. In addition, because they take on caregiving roles, in extreme weather events women are overwhelmed with caring for other people. In this sense, the participation of women and the inclusion of a gender perspective and "care mobility" in adaptation plans for the mobility and transport system is essential. Having women and children participate in the discussion of city planning is a prerequisite for achieving more sustainable and inclusive cities, both as a matter of equal rights and from the point of view of the need to improve safety in public spaces and sustainable mobility, since they are the ones who move the most on foot and by public transport (Sabino et al., 2021).

Another issue that deserves attention in the planning of mobility and transportation systems aimed at urban resilience is the role of this system in contingency and disaster reduction plans. In 2024 São Paulo suffered from the worst air quality in the world for several consecutive days, according to the Swiss website IQAir, and studies show that private vehicles make an important contribution to this problem. In figures, vehicles account for 72.6% of greenhouse gas emissions, although they only transport 30% of people (IEMA, 2017). In countries such as France, Spain, Mexico and Colombia, the pollution levels reached in São Paulo would already be considered an emergency situation, forcing contingency measures such as restricting cars in the center and free public transport.

Finally, in order to reduce the vulnerability of mobility and transport systems and increase urban resilience, it is essential that mobility plans are drawn up and monitored in an integrated manner with other sectoral policies, including housing, the environment and sanitation. These examples highlight the importance of multisectoral, evidence-based strategies to tackle the challenges of mobility and climate adaptation.

2.3.4. Infrastructure and Sanitation

Projections that point to a progressive growth in demand for water in Brazil, as discussed in section 1.2.4, highlight the need for effective water resource management strategies to guarantee sustainability and water security in the face of growing demographic and environmental



pressures. Brazilian policies, plans and programs, at all levels of management, face the challenge of preparing the country for this growing demand, aggravated by climate change and its effects, particularly long periods of drought, with a direct impact on the availability of water in the national territory. The National Water Security Plan - PNSH (ANA, 2019), does not incorporate climate scenarios and models in its definition of objectives and development of strategies, which is a significant limitation in the design of this plan. To effectively face the challenges posed by climate change, it is crucial that the plan explicitly includes adaptive strategies to climate impacts, such as nature-based solutions and insurance mechanisms, to ensure resilient and sustainable water management (Gesualdo et al, 2021; UNEP, 2021).

Cities' sanitation infrastructure is key to dealing with the potential impacts of the climate crisis, as it is responsible for organizing surplus surface runoff from rainfall (drainage and rainwater management systems), distributing drinking water and protecting natural water systems (water supply and wastewater collection and treatment systems). Although the PNSH presents targets for reducing the negative impacts of water scarcity and flooding events using infrastructure improvements, by the year 2035, the implementation of non-structural measures is crucial to further reduce the environmental and socio-economic impacts resulting from these adverse events (Kundzewicz et al., 2002; Simonovic, 2002; Horn & Elagib, 2018; Watanabe et al., 2018). Non-structural measures, such as risk management policies, public education and awareness programs, land use regulations and urban planning, are essential to complement structural solutions, promoting an integrated and sustainable approach to mitigating the impacts of extreme hydrological events (Andjelkovic, 2001; Kovář et al, 2014; Coutinho et al. 2020).

Currently, there is a significant gap in the integration of Brazilian legal frameworks governing water resources (Law 9.433/1997, Brasil, 1997), basic sanitation (Law 11.445/2007, Brasil, 2007; Law 14.026/2020, Brasil, 2020b), climate change (Law 12.187/2009, Brasil, 2009) and civil defense (Law 12.602/2012, Brasil, 2012b), compromising the effectiveness of public policies and hindering the implementation of comprehensive strategies to tackle complex challenges.187/2009, Brasil, 2009) and civil defense (Law 12.608/2012, Brasil, 2012b), compromising the effectiveness of public policies and hindering the implementation of comprehensive strategies to tackle complex and



interconnected challenges. To promote efficient and sustainable management, it is essential that these legal frameworks are harmonized, enabling coordinated and synergistic actions that enhance resilience and adaptability in the face of climate change and other associated risks (Mikhael et al, 2021; Lazzati et al., 2024).

According to the National Basic Sanitation Plan - PNSB (Brasil, 2013), investments of R\$122 billion and R\$182 billion have been estimated for water supply and sewage systems, respectively, which are necessary to meet the national targets for universalization of basic sanitation services by 2033 and also the Sustainable Development Goals. Urban areas will demand 95% of these investments (Gesualdo et al, 2021).

According to the National Solid Waste Policy, the management of MSW must respect the following order of priority: non-generation, reduction, reuse, recycling, treatment of solid waste and environmentally appropriate final disposal of waste, thus prioritizing practices that are less harmful to the environment and that contribute to the establishment of a more circular economy (ABREMA, 2024).

The National Solid Waste Plan - PLANARES (Brasil, 2022b) emphasizes that tackling environmental challenges requires a focus on action planning and the drafting and application of relevant legislation. Among the strategies mentioned by PLANARES are:

- Investment in infrastructure for selective collection in households.
- Stimulating the circular economy.
- Training recycling cooperatives.
- Expansion of spaces for composting, with the involvement of the population.
- Implementing reverse logistics.
- Effective application of legislation.
- Development of biodegradable products.
- Adherence to Zero Waste programs.

However, all these proposals will be more effective if they are aligned in parallel with a broad campaign to raise awareness and educate the population about the environment, so that the objectives of solving the problem can be achieved.

One initiative that has emerged as promising in this regard is the Instituto Lixo Zero Brasil - ILZB (s.d.), a program founded in 2010,

whose main goal is to guide people to change their lifestyles and develop sustainable practices, where all discarded materials are used as resources for other uses.

The ILZB is an autonomous, non-profit civil society organization that works to disseminate the Zero Waste concept in Brazil. ILZB represents the Zero Waste International Alliance (ZWIA) in Brazil, an international movement of organizations that use the Zero Waste concept and principles around the world.



These solutions, when integrated and implemented effectively, covering institutional, financing, management, technological matrix, participation and social control aspects, can contribute significantly to improving the management of sanitation services in Brazil, promoting sustainability and environmental protection, turning basic sanitation actions to the field of social rights and, in this way, part of a public policy supported by strong state action (Borja, 2014).

Structural and Non-structural Measures

Tackling the climate crisis in the infrastructure sector will require the adoption of structural and non-structural measures. Among the structural measures, the literature highlights the integration of gray infrastructure and green-blue infrastructure, known as hybrid solutions or infrastructures (green-blue-gray infrastructure), which have been shown to be effective in preventing flooding (Ahmed et al., 2019; Drosou et al., 2019; Drosou et al., 2019; Romero-Duque et al., 2020), sanitation, water scarcity, landslide prevention and coastal protection (Leal Filho et al., 2018; McPhearson et al., 2018; Castellanos



et al., 2022). The literature also points out that distributing these infrastructures throughout the basin instead of installing reservoirs, combined with Low Impact Development (LID) measures, can be more sustainable and even more efficient than traditional solutions (Miguez et al., 2015; Da Silva et al., 2018).

Water reservoir measures play a crucial role in flood control (Alencar et al., 2014; Vergutz et al., 2019), in reducing scarcity and improving water quality (Alencar et al., 2014) and in energy generation (Zhang & Shang, 2023; Rocha et al., 2024), taking into account possible increases in GHG generation (Ubierna et al., 2021). Reservoirs help regulate the flow of water, storing excess during heavy rains and releasing it gradually during periods of drought, ensuring a continuous supply of water. They also contribute to the production of hydroelectric power, providing a reliable source of energy. In addition, reservoirs support aquifer recharge and improve water quality by trapping sediments and pollutants (Mohammadzadeh-Habili & Khalili, 2020). The use of reservoir structures can help recover part of the natural flood buffering capacity of river basins, lost during the process of land occupation (Fonseca et al., 2006).

Non-structural measures to reduce flood risks include land mapping. Mapping the Susceptibility of the Physical Environment to Flooding is a crucial tool for flood risk management, which allows for the preliminary identification of flood-prone areas, providing important inputs for urban planning and the implementation of risk mitigation measures, using multi-criteria methods (Kazakis et al., 2015; Akay, 2021; Miranda et al., 2023), statistical (Tehrany et al., 2014; Amaliah & Syabandi, 2023) or machine learning algorithms (Tehrany et al., 2013; 2015; 2019).

Flood susceptibility mapping helps prioritize areas that need specific interventions, improving the efficiency of flood management strategies and reducing the impacts of these events on communities and infrastructure (Miranda, 2023). Recently, Miguez et al. (2024) proposed a conceptual framework capable of properly integrating the dynamics of rainwater into the system of open spaces in a functional way, establishing an Area of Hydrological Interest (AIH) to structure urban expansion in an integrated manner and respecting the natural processes of the watershed. The initial step consists of defining the HIA, made up mainly of open spaces that can be used to support urban drainage functions and organize land use in the process of urban



expansion. This delimitation provides the basis for interpreting the watershed into three functional arcs, covering in particular the upstream, intermediate and downstream areas of the watershed. This can guide the planning of a set of flood mitigation interventions, with a focus on the use of Green-Blue Infrastructure. Finally, the success of these measures depends on the mapping of risk areas (Sayers et al., 2013; Grigg, 2023).

2.3.5. Social Housing and Informality

Slum upgrading, housing improvements and land regularization initiatives, associated with infrastructure provision, can play an important role in the process of adapting to climate change (Teferi & Newman, 2018; Núñez Collado & Wang, 2020; Satterthwaite et al., 2020; Lemos, 2022), while at the same time reducing the risk of disasters (Castellanos et al., 2022). Recent experiences in Brazil illustrate the role of these social housing initiatives in reducing disaster risks associated with climatic events, such as the Periferia Viva Program. The main objective of this program is to improve the quality of life of residents of precarious settlements, through integrated actions that cover "socioeconomic, housing, environmental, land, urban infrastructure, disaster risk prevention and access to public services and facilities" (Brasil, 2023e, p. 8). One of the program's requirements is that interventions prioritize the reduction of risks associated with climate change, such as "landslides, slope failures, debris flows and other mass movements" (Brasil, 2023e, p. 30). The programme establishes that measures related to infrastructure provision should be integrated with other urbanization works, prioritizing bioengineering solutions, green infrastructures and other nature-based solutions, favouring community ownership of the structure implemented (Brasil, 2023e).

Social housing and slum upgrading projects need to take into account the increased frequency and intensity of extreme weather events (Libertun de Duren et al., 2021). Interventions should include, in the design, construction and maintenance phases, the additional pressures on infrastructure caused by both climate change and intensified population densification following the implementation of improvements. In addition, the combination of these interventions with non-physical measures, such as strategies to increase the presence of the state in these informal and marginalized territories, through social programs that contribute to reducing the influence of



organized crime and promoting improvements in the lives of the population in general, are fundamental for the outcome of adaptation to be transformative in the long term and not just incremental (Libertunde Duren et al., 2021). Adaptation actions, beyond concentrating efforts solely on disaster risk reduction works, increase resilience to climate change by strengthening the capacity to respond to its impacts. The climate crisis is a systemic challenge, requiring coordinated responses between different sectors and levels of government, and multifaceted, stemming from various social, economic and environmental agendas.

Considering the climate challenges that informal areas and slums most commonly face in view of climate change, among them the risks associated with heat waves and drought, recent literature points to the promising strategy of adopting green infrastructure and nature-based solutions in slum urbanization projects and social housing provision in general, which, in addition to the localized benefits of inserting green structures, contributes to increasing the total green coverage of municipalities (Moreno et al., 2021a; Wolff et al., 2023).

By allowing residents to remain in their communities, slum upgrading is considered a good solution for maintaining social cohesion, considering, of course, the safety of these areas after the intervention. In contrast, relocating families to areas far from their community can disrupt support networks and change lifestyles and cultural habits, causing irreparable damage and increasing injustices, even if the physical-structural and geotechnical risks are remedied in the new settlement (Núñez Collado & Wang, 2020; Viana, 2021; Araújo et al., 2024a). As a result, the vulnerability of the relocated group can often be transferred or even intensified in the new location, constituting what is known as maladaptation (Schipper, 2020; See & Wilmsen, 2020).

Adaptation actions, particularly involving vulnerable and marginalized populations, such as in informal settlements and slums, can benefit from community-based processes, led by the community or with robust participation and inclusion strategies, strengthening the adaptive capacity of the community involved (Martins & Rocha, 2019; Viana, 2021; Du et al. 2022). Community approaches to adaptation, such as housing cooperatives, self-managed housing and truly participatory processes, are transformative urban practices. This agenda must integrate sustainable development, the fight against



poverty, disaster risk management and adaptation and mitigation strategies to tackle climate change (Muntó, 2018; UN Habitat, 2018; Núñez Collado & Wang, 2020; Satterthwaite et al., 2020; Valadares & Cunha, 2018; Viana, 2021).

Another promising action front in the field of social housing adaptation is the transformation of idle properties in urban centers into social housing, which is the subject of the Program for the Democratization of Federal Properties (Imóvel da Gente), described in section 1.2.5. Social Housing and Informality. In this sense, social movements have played a fundamental role in occupying empty or underused properties in central areas. However, there are legal, urban planning and financial challenges, as the regulation and effective implementation of policies to enforce the social function of property and the city are less than necessary (Cavalcanti et al., 2022; Moretti et al., 2024). One example is compulsory installment, building and use (PEUC), linked to successive sanctions for non-compliance with obligations (progressive IPTU over time and expropriation with public debt securities).

Housing improvements, interventions aimed at ensuring adequate living conditions, promote "habitat health" by considering building, sanitary, environmental and landscape aspects (Satterthwaite et al., 2020). When associated with technical assistance for social housing (ATHIS), these actions play a fundamental role in the climate adaptation of cities, especially in informal settlements (Cavalcanti & Alvim, 2020; Balbim et al., 2024). Improvements in housing, such as adapting infrastructure, increasing thermal comfort and implementing efficient drainage systems, make spaces more resilient to extreme events such as heat waves and floods (Cavalcanti et al., 2019). In addition to reducing socio-environmental vulnerabilities, the strategic implementation of these policies can contribute to environmental justice, addressing historical inequalities and promoting socio-economic inclusion.

In addition to initiatives aimed at slum upgrading and housing improvements, the implementation of contingency plans and the structuring of early warning systems are key strategies for reducing the impact of extreme weather events in informal settlements. Strengthening local governance and community participation in the formulation of these plans are essential to ensure their effectiveness (Keating et al., 2017; Werthmann et al., 2024). Warning systems that

involve social participation increase residents' ability to respond, reducing human and material losses (Adams et al., 2022).

Faced with the challenges posed by climate change, the adaptation of informal settlements and precarious housing requires integrated approaches that combine resilient infrastructure and community participation. Interventions must consider not only the mitigation of environmental impacts, but also social aspects, such as maintaining support networks and community cohesion, avoiding displacement processes that could result in maladaptation and the widening of socio-territorial inequalities (See & Wilmsen, 2020). In addition, strategies such as using idle properties for social housing and incorporating green infrastructure have the potential to reduce vulnerabilities and strengthen urban resilience (Moreno et al., 2021a; Cavalcanti et al., 2022; Wolff et al., 2023; Moretti et al., 2024).

2.3.6. Human Health and Well-being

Public health is an issue that transcends specific government departments at different levels, but is closely tied to socio-environmental matters. In this sense, planning healthy cities must necessarily integrate environmental agendas to promote health and well-being (Oliveira et al., 2023).



Well-planned urban environments are able to control the degree of lighting, ventilation, insolation and safety, both in buildings and in public spaces, adapting the environment to present and future local climatic conditions, thus having a high potential to promote health and quality of life, thereby reducing cases of diseases (WHO, 2025) that disproportionately affect the most vulnerable populations (Doiron et al., 2024).



Most large cities in South America are highly vulnerable due to a combination of factors such as socio territorial inequalities and poor access to infrastructure, housing and healthcare, as well as their exposure to atmospheric pollution (Castellanos et al., 2022). Preventive diagnosis for chronic diseases plays a fundamental role in guiding spatial planning of investments in health and environmental sectors. The identification of vulnerable populations and regional risk patterns allows a more efficient resource allocation to areas with higher incidence of conditions such as infectious, vector-borne or chronic illnesses (Brissette et al., 2019). The integration of environmental data with preventive health diagnostics further strengthens decision-making processes, especially when considering how environmental exposures influence the onset and progression of the diseases (Fletcher-Lartey & Caprarelli, 2016). For instance, air pollution, lack of green spaces, and urban heat islands have been linked to increased incidence of non-communicable diseases, making environmental planning a key component in preventive strategies (Wang & Tassinary, 2024).

Promoting healthy environments, implementing green spaces designed to improve health near residents' homes, and planning other preventive measures – such as high-quality public spaces for physical activity – can reduce public expenditures while providing citizens with healthier and fulfilling lives (Oliveira et al., 2022; 2023).

Nilson et al. (2020) demonstrated that, in Brazil, more than R\$ 3.45 billion were invested in NCDs treatment in 2018. Out of this amount, 59% was allocated to the treatment of systemic arterial hypertension, 30% to diabetes, and 11% to obesity, primarily among individuals aged 30 to 69 years. A portion of this expenditure could have been avoided with environmental planning considering health-related aspects, as evidence points out that strategical green spaces can prevent NCDs (Astell-Burt et al., 2021; De la Fuente et al., 2021; Yang et al., 2023). This could also avoid loss of productivity (as most people in the referred age group are active workforce) and social costs to families and governments (Asbeque et al., 2023).

Incorporating not only biodiversity but also ecosystem processes and services into urban planning can be a viable strategy for health promotion, since besides preventing diseases, the exposure to green spaces can promote wellbeing, relaxation and quality of life (Oliveira et



al, 2022). In this sense, adaptation strategies in urban centers have the potential to function as health promotion interventions.

Bielemann et al. (2015) demonstrated that approximately 15% of investments in Brazil's Unified Health System (SUS) are attributable to sedentarism. These findings raise the hypothesis that requalifying urban green spaces for physical activity can be an economically and socially advantageous strategy in the short and medium terms, as such investments can address the primary needs of the population, particularly those who lack access to privatized leisure. These topics align with federal public policy recommendations, such as the National Health Promotion Policy (Brasil, 2010a) and the National Environmental Policy (Brasil, 1981), among others.

In addition, strategic environmental planning of urban green spaces can assist territorial planning by designating areas of geological risk for biodiversity conservation (Kim et al., 2021), thereby preventing the disorganized use and occupation of high-risk areas prone to natural disasters. An integrated approach combining urban planning, public health, and environmental considerations can foster the development and implementation of public policies. An example is the Municipal Atlantic Forest Plan (Plano Municipal da Mata Atlântica, PMMA), the primary instrument of the Atlantic Forest Law (Law 11.428/06 - Brasil, 2006). This plan aims to foster a municipal cartography focused on land tenure and the identification of priority areas for the conservation of the biome. Such a political instrument can guide specific locations for enriching urban green spaces, democratizing health-promoting areas for the entire population.

Moreover, Urban Forestry Plans may consider including health-related indicators linked to urban greenery. For instance, the poor quality of sidewalks damaged by tree roots accounts for a significant portion of orthopedic hospital admissions, especially among the elderly. Data from the World Health Organization's global report on fall prevention in older adults indicate that more than 50% of hospital admissions for individuals over 65 years old result from falls in public spaces (WHO, 2010; 2021), often caused by unresolved conflicts between trees and sidewalks.

The development of adaptation strategies is a key issue. Services such as climate-health surveillance, observatories and forecasting climate-related disasters, as well as identifying locations where vulnerable



populations are exposed to climate hazards and associated health risks is crucial (Castellanos et al., 2022). Adaptations concerning human health require strengthening the public health system, building a resilient infrastructure, epidemiologic surveillance and the integration with environmental policies (Castellanos et al., 2022).

Environmental planning, requalifying urban green spaces, reducing greenhouse gases emissions and fostering environmental public policies are beneficial to counteract both climate change effects and public health outcomes (Tong et al., 2021). Furthermore, nature-based solutions to mitigate air pollution, urban heat islands and vector nursing spots are essential to provide a healthier scenario for sustainable cities (Santanna et al., 2025). This includes promoting treescape and recovering water bodies, besides providing a strong environmental and social governance system. Therefore, it is recommended that health and environmental policies are strongly integrated to make cities increasingly healthier for everyone.

2

NATURE-BASED SOLUTIONS FOR CLIMATE-RESILIENT CITIES



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2. NATURE-BASED SOLUTIONS FOR CLIMATE-RESILIENT CITIES

2.1. Conserving and Restoring Nature to Adapt Cities

Nature plays a crucial role in urban processes and the quality of life of the human population. Numerous ecosystem services are provided by natural areas (green and blue) in urban and peri-urban environments, especially those with greater biological diversity (McDonald et al., 2013). For millennia, we have had connections with nature, but today we need a more stable perspective of this contact, since the urban way of life has exhausted the main points of harmony in the "human vs. nature" relationship, leading to a scenario of rapid landscape transformations and changing climate patterns (Folke et al., 2021).



The climate crisis and intense human densification in Brazil's medium-sized and large cities demand solutions that, while serving as instruments for adaptation (or coping with climate change), conserve and foster ecological processes and flows that are essential to life in urban and peri-urban areas. In this sense, a fundamental concept has emerged that has been widely debated and accepted by the scientific community, called "Nature-Based Solutions". Nature-based solutions can be defined as actions that protect, recover and regenerate local ecosystems in order to face social, economic and environmental challenges in an effective and adaptive way, providing human well-being, ecosystem services, resilience and benefiting biodiversity (Sowińska-Swierkosz & Garcia, 2022; UNEP, 2022).

This concept aligns with the needs of urban environments and incorporates previous concepts, promoting a better consideration of



the role of nature in cities. SbN plays an essential role in conserving biodiversity in critical areas of urban landscapes and guarantee natural processes and flows, contributing to temperature regulation and stormwater management, among other essential benefits for improving quality of life. These interventions also help to adapt cities to climate impacts such as floods and heatwaves, strengthening urban resilience (Bush & Doyon, 2019).

Urban ecological infrastructure (UEI), another related concept, is made up of green (terrestrial vegetation), blue (aquatic systems), turquoise (wetlands) and brown (non-vegetated areas) areas, forming an essential system for buffering the impacts of climate extremes. The conservation of these ecological areas, combined with gray infrastructure (conventional engineering), allows cities to better withstand climate impacts and their potential consequences on the urban environment (Depietri & McPhearson, 2017; McPhearson et al., 2018). This combination of green and gray infrastructure therefore represents different ways of considering the importance of nature in cities. However, the risk of gentrification and prioritizing the most socially vulnerable areas must be considered, as these are the ones that suffer the most from climate impacts (Tozer et al., 2023).

In some Latin American locations, for example, there is a growing movement to retain rainwater to meet local needs, valuing the conservation of water resources and providing resilience against periods of drought (McPhillips et al., 2023). It is therefore essential to consider the importance of taking advantage of natural areas in the urbanization process, optimizing their ecosystem services and avoiding the occupation of environmentally strategic sites, thus more effectively promoting nature conservation in cities. However, in many situations, these natural areas have had their integrity and ecological functions reduced, making it necessary to restore them. In more extreme situations, although common, when not even degraded natural areas remain in sufficient volume, it becomes necessary to requalify bodies of water and their banks, hillsides and other spaces of greater interest for the ecosystem balance of urban and peri-urban environments.

In this regard, for example, the Brazilian federal government, through the Ministry of the Environment and Climate Change (MMA), launched the Green and Resilient Cities Program (PCVR, Brasil, 2024a) in 2024. This program includes in its scope the proposal to act on urban systems with processes that involve the conservation, recovery and



renaturation of cities through NbS, which can and should be associated with social equity, decentralization and adaptability (adaptive management) in its implementation, with intense engagement of society (from its planning to its maintenance). The programme is geared towards fulfilling a set of necessary and desirable functions for (re)humanizing cities and promoting conditions to minimize disasters and increase urban resilience (Choo & Yoon, 2024).

2.1.1. Conserving Nature in Cities

The types of open, green and blue, protected and conserved areas have particular definitions and characteristics. Open spaces are unbuilt, public, permeable and natural areas, i.e., with local vegetation. They are spaces for cities to 'breathe' in the midst of the built environment, with its buildings and roads, as well as being important for civic or community functionality, when collective activities are allowed. Green areas are types of spaces free of buildings where the fundamental compositional element is vegetation, preferably native. Any type can be considered, such as (vegetated) squares, rain gardens, pocket parks, etc. But sometimes they are only considered from a minimum area - for example, not considering avenue flowerbeds (Lima et al, 2018). Green areas are important for water infiltration, climate stability and improving air quality (Ferreira et al., 2024). Blue areas are types of open spaces, where the fundamental element is bodies of water. These spaces can be streams, rivers, lakes, lagoons or other types found in specific biomes, such as streams in the Amazon.

Urban parks (and similar) are a type of green area and can include blue, urban areas that are relatively larger in size or have more expressive vegetation content. They can include fragments of natural, native ecosystems. Urban parks are primarily intended for leisure, recreation or physical activity, but they can also have important cultural activities. Urban parks have their own specific management, often by environmental secretariats or departments or similar - unlike more generic green areas, such as flowerbeds, squares, etc., which are usually the responsibility of municipal construction or infrastructure departments (São Paulo, 2016).



Another relevant typology is linear parks and ecological corridors, which consist of urban parks or elongated areas, thus promoting connections between urban gene pools (Medeiros, 2016).

Therefore, the role of maintaining urban green patches as places to accommodate biodiversity stands out. These places are potential types of parks or other protected areas for the management of connected natural areas in cities. Such protected areas can be located in valleys and have legal restrictions on construction within their boundaries, taking into account, for example, the possibility of river flooding. In this way, the ecological connection between different green areas can make it possible to maintain biodiversity for longer periods of time, while at the same time offering leisure spaces with cycle paths and trails.

This way of understanding the distribution and connection of natural areas in the urban environment may still be the only alternative for bringing green areas to poorer neighborhoods (Cavalheiro et al., 1999; Cranz & Boland, 2004; Maretti, 2022; 2023; Maretti et al., 2022, 2023).

Protected areas, in the most internationally accepted concepts, are areas with nature conservation objectives, sometimes explicitly demanded, created, delimited and with specific management, made possible by legislation or social legitimacy (Dudley, 2008). In Brazil, the most direct correspondence are conservation units (UCs; Brasil, 2000), defined in accordance with Article 225 of the 1988 Brazilian Constitution (Brasil, 1988). Thus, international terminology differs from Brazilian terminology, since the protected areas officially defined in Brazil, according to the National Strategic Plan for Protected Areas (Brasil, 2006), go beyond the UCs. Conserved areas, in the usual international concepts, have been progressively incorporated into spatial conservation strategies. Since the end of the 20th century,



greater diversity has been progressively considered in protected areas, including indigenous and community conservation areas (Maretti & Simões, 2020). Starting with the Global Strategic Plan approved in 2010, the Convention on Biological Diversity (CBD) introduced the language "other effective spatial conservation mechanisms" (in interpreted translation) - known by the acronym "omecs" or by the (unofficial) adaptation by IUCN of "conserved areas" (CBD, 2010). The "omecs" were defined by the CBD in 2018 (CBD, 2018) as areas that actually conserve biodiversity. And reinforced in the current Kunming-Montreal Global Biodiversity Plan (CBD, 2022). These have been called conserved areas.

2.1.2. Reclaiming Nature in Cities

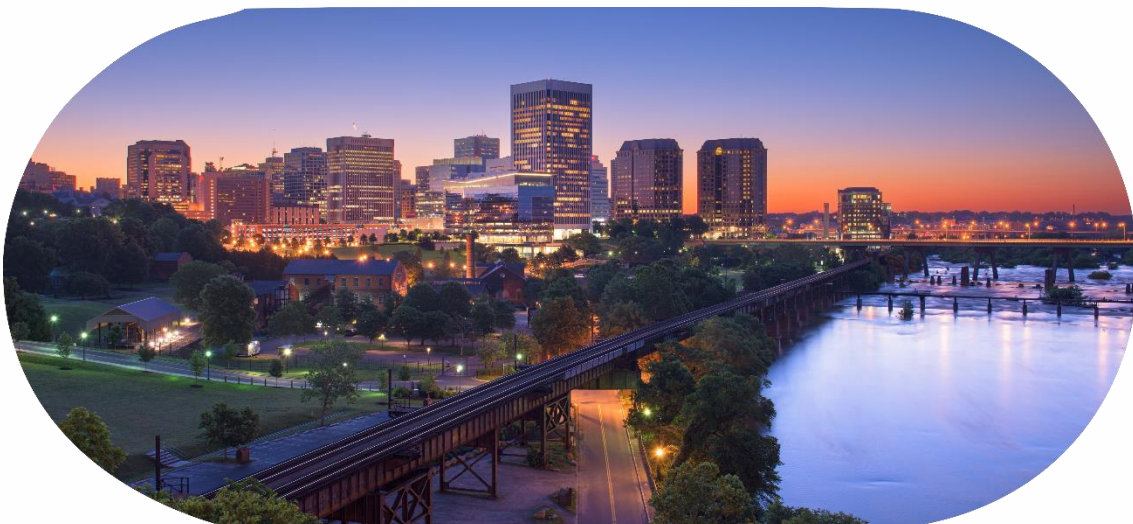
The recovery of natural ecosystems, such as rivers, streams and flood areas, is an important strategy for tackling and mitigating a set of environmental damages and imbalances that the urbanization process has caused by prioritizing building spaces for car flows while channeling water flows, which are strategic for the ecological and water balance of the urban environment. The lack of ecological planning for the occupation of urban areas and their expansion without integrating green infrastructure with widely used gray infrastructure has resulted in cities that are more vulnerable to extreme climatic events such as floods and droughts (Herzog, 2013), as well as enormous damage to the quality of life in urban centers, considering microclimate, biodiversity, leisure spaces and easing the stress associated with city life, among other factors that interfere with this quality.

Numerous projects to revitalize urban water bodies around the world have shown that the investment is much lower than the socio-environmental gains. The Cheong Gye stream project in Seoul (Korea) is an example of urban regeneration. The city revitalized the area of an extensive viaduct to re-establish the watercourse that ran under it, reintroducing native flora and fauna and promoting a hybrid engineering and ecological (grey and green) infrastructure. As well as reducing flooding, the project improved quality of life (air quality, leisure and contemplation spaces, a more pleasant landscape, among others) and stimulated the local economy, serving as a model for other cities in South Korea that are now prioritizing the regeneration of industrial landscapes (Pontes, 2024).

In several cities, including Portland and Seattle (USA), 'green streets' have been reclaimed and converted into rain garden systems, which have reduced surface runoff and mitigated diffuse contamination, promoting environmental conservation and the well-being of local ecosystems (Bush & Doyon, 2019). It is also noteworthy that the recovery of green infrastructure in very gray landscapes can reestablish multiple benefits aimed at increasing urban resilience. The introduction of vegetation with NbS interventions is essential for thermal comfort at different scales, since the shading potential and evapotranspiration capacity of trees contribute to thermal mitigation in cities.

At the city scale, studies have shown that protected areas contribute significantly to thermal mitigation while at the same time promoting other ecosystem services, such as maintaining biodiversity, standing out as important urban facilities to be restored whenever possible (Kumar et al., 2024). This indicates that the greater the number of parks and other types of protected areas in a city, the richer the biodiversity and the more effective the urban system's ability to withstand extreme weather events, especially heat waves (Isbell et al., 2015, Oliver et al., 2015; García-Palacios et al., 2018).

This trend towards environmental comfort has also been shown at the scale of the square or park, where positive associations have been observed between thermal mitigation promoted by urban flora and taxonomic and structural diversity (Francoeur et al., 2021; Marando et al., 2022). Some functional groups of trees have a greater capacity for evapotranspiration and therefore have greater potential to humidify the urban atmosphere (Wood & Dupras, 2021), leading to a milder local climate.





Especially for Brazilian cities, which are predominantly found in megadiverse biomes, increasing urban floristic diversity brings multiple benefits that are reflected not only in greater thermal comfort, but also fosters greater niche breadth for the biodiversity of animals that directly or indirectly inhabit urban green areas, making the ecological system of cities more resilient (Berthon et al., 2021; Lehmann, 2021).

It should be noted, however, that in large cities in equatorial and tropical regions, the thermal mitigation effect of vegetation is less significant than in large cities in other geographical regions, i.e., temperate climates (Deng et al., 2024). This further reinforces the need for Brazilian cities to recover green infrastructure as adaptation equipment in their respective planning. The recovery of green and blue areas in cities should be a priority on the municipal agenda, as it is an NbS instrument that makes urban areas more adapted to the extreme climatic episodes that may become more frequent in the coming decades (Geirinhas et al., 2021).

2.1.3. Adapting Cities Based on Nature

Urban expansion planned with ecological neighborhoods (eco-neighborhoods), which have NbS designed in a systemic way, are inspiring examples. In the city of Freiburg (Germany), the "Rieselfeld" and "Vauban" neighborhoods were designed with different types of NbS in a system, in order to maintain the ecological functioning of natural processes and flows, enabling rainwater management, heat island mitigation, areas for social integration, leisure and recreation (Herzog, 2013).

These processes of renaturalization of urban environments, of course, need to be understood critically according to the context in which they are inserted, particularly considering the socio-economic differences between cities in the countries of the global north and south. Therefore, examples from cities in the global north are evaluated to add to the process of finding local solutions that are suitable for Brazilian cities and aligned with the specific demands and priorities of the national urban context, in all its dimensions and scales: ecological, economic, demographic, cultural, institutional, infrastructural, etc.

Taking the above premise into account, we can see that countries in the global north have invested significantly in SbN projects. Since 2015,



the European Union has invested 665 million euros in 76 research and innovation projects, with a total of 1391 partners from 71 countries (EU, 2023). This has facilitated the promotion of new green infrastructures and the adaptation of urban environments to face the impacts of climate change. These investments have strengthened the scientific and practical knowledge base on NBS in several cities (EU, 2015). In the United States, SbN projects have expanded to include large scales, with the Federal Highway Administration promoting the integration of SbN on federal highways, creating more resilient and adaptable landscapes to extreme weather events (Buckingham & Torossian, 2021). The creation of multifunctional projects in degraded urbanized landscapes, such as multifunctional parks, rain gardens and regenerated spaces in "dump" and mining areas, is gaining popularity around the world, with the aim of offering new sustainable and multifunctional areas for urban communities. By fostering multifunctional urban landscapes, naturalization can reconcile human well-being, biodiversity maintenance and food security (Lavorel et al., 2022).

As a highlight, food production through urban gardens has a low carbon footprint and is a sustainable way of planning cities (Dimitri et al., 2016). It is estimated that more than 70% of global food production is consumed in cities, although between 15% and 20% is only produced in these places (UNEP, 2025). Scholars argue that, globally, the urban agriculture system not only guarantees part of food security, but is an excellent equipment for social mobility, since systems of cooperatives and civil society organizations can be structured in cities with wide socioeconomic inequality, thus favouring the socially vulnerable part of the population (Poulsen et al., 2015; Kanosvamhira, 2024).

From the perspective of introducing nature into cities as a means of social equity, training low-income young people and other vulnerable groups in urban agricultural practices can be an opportunity to combat unemployment and thereby lift families out of extreme poverty (Brauw & Suryanarayana, 2015; Sharaunga et al., 2016; Christiaensen et al., 2021). However, this issue needs to be further worked on in the scientific community and integrated into the agenda of stakeholder actions, since this interest in public policies is notorious in areas with high economic inequality (Maïga et al., 2020), making the issue extremely strategic for the country's development.

It is also worth noting that, in addition to acting as a social lever, urban agriculture offers numerous ecosystem services, in many cases



standing out for being an element of resistance and resilience to climatic extremes, thus offering a context of long-term sustainability (Qiu et al., 2024). However, it is necessary to properly plan these food production areas, avoiding proximity to sources of pollution (e.g. roadsides) and management with chemical products (Säumel et al., 2012; Antisari et al., 2015; Bretzel et al., 2016).

The renaturalization of urban environments through food production presents good opportunities both in places with high density and in places with an abundance of open spaces. In contexts of intense urban densification, encouraging the use of green roofs in food production is a good SbN, especially given the limitations of free green spaces, which guarantees the supply of food and other ecosystem services (Walters et al., 2018; Jacobs et al., 2023; Rolhauser et al., 2023). On the other hand, territories with an abundance of green patches in the urban fabric can be restored using agroecological techniques, which connect to the fundamental social, ecological and economic principles of urban agriculture, presenting themselves as an important NbS, guaranteeing greater food security while re-establishing ecological patterns and functions in urban areas (Villavicencio-Valdez et al., 2023).

Globally, the biodiversity found in cities is explained by a series of variables, be they climatological, social or land use (Nielsen et al., 2014; Turrini & Knop, 2015, Uchida et al., 2021). Tropical and subtropical regions have high levels of biological diversity, with some regions being considered biodiversity hotspots (Harvey et al., 2020). However, Cincota et al. (2000) showed at the beginning of this century that more than half of these hotspots had a population density above the world average, strongly threatening the existence of some species, especially in the Cerrado and Atlantic Forest biomes, which are home to metropolitan regions such as Brasília and São Paulo, respectively.

From the perspective of adapting urban areas and with the aim of conserving the genetic heritage found in Brazilian cities, urban afforestation has the potential to re-establish part of the wildlife, whether these individuals are only transient or permanent. The use of broad functional diversity in green areas strengthens ecological relationships and increases the system's resistance to anthropogenic pressures (Paquette et al., 2021).



In order to maintain high biodiversity in urban areas, following the pattern of peri-urban or natural areas outside the urban fabric, some metrics for floristic diversity have been well established and used in different parts of the world. Some authors have promoted a maximum taxonomic limit of 10% of any particular species, 20% of any genus or 30% of any botanical family for some parts of the planet (Santamour, 1990; Cumming et al., 2008), however, more realistic proposals with a global standard of biodiversity in cities have been adopted recently, bringing metrics with high potential to promote ecosystem services consistent with a current climate scenario (Browning et al., 2024; Vsuviano et al., 2025).

This is the case with the 3-30-300 rule, which recommends that every urban dweller should have at least three trees visible from their home (to improve the visual connection with nature), 30% vegetation cover in their neighborhood (to reduce heat islands and improve air quality) and a park or green area within 300 meters of their home (for easy access to recreational spaces and health promotion) (Konijnendijk, 2021). However, it should be noted that the environmental heterogeneity, as well as the socio-economic and cultural characteristics of each Brazilian region and city do not allow for a single rule for the country, and it is up to each territory to plan appropriately and sensibly for its reality.

This helps to increase the natural diversity found in tropical and subtropical systems and decreases the levels of biotic homogenization reported in urban areas (McKinney, 2006; Lokatis & Jeschke, 2022; Sidemo-Holm et al., 2022; Deng et al., 2024; Rivest & Kharouba, 2024).

The adaptation of cities using another important strategy, urban afforestation, requires special care, as not all taxonomic groups of trees have the aptitude to be planted in urban areas, either due to their

sensitivity to atmospheric pollutants or other factors such as high temperatures (Bulbovas et al., 2010; Barwise & Kumar, 2020). In addition, morphological characteristics should be selected when choosing the main species to be planted in urban areas, which includes species that have aerial roots, large and heavy fruits, flowers with excessive slippery substances on sidewalks, among other morphological attributes (Lüttge & Buckeridge, 2020). This becomes fundamental from the perspective of active mobility planning, where pedestrian walkability must always be safe, while also being protected from intense sunlight.

Conservation, recovery and adaptation strategies reinforce the fundamental role of Nature-Based Solutions in strengthening resilience, sustainability and quality of life for urban populations.

2.2. Biodiversity and Sustainable Urban Planning

2.2.1. Blue-green Approach: Integrating Conservation, Urban Afforestation and Green Infrastructure

The Green-Blue Systems design approach includes conservation, restoration and innovative urban planning to promote sustainable urban environments that are resilient to climate change and enhance quality of life. By combining green spaces (urban forests, parks, squares, green corridors, waterfronts and green roofs) with blue spaces (beaches, waterways, wetlands and drainage systems), cities can create a more harmonious interaction between human activity and natural ecosystems (Ahern, 2011).





With this, it is hoped that territorial planning will increasingly appropriate the approach involving blue-green infrastructure as a framework for managing ecosystems on multiple scales. In this context, Nature-Based Solutions gain special prominence, but it is important that NbS actions do not focus on specific socio-environmental problems, but expand to interconnected spatial relationships, expanding the supply of ecosystem services. This systemic and integrated approach between green and blue infrastructure more significantly addresses multi-scalar ecological networks and their multifunctional benefits, ranging from biodiversity corridors to climate regulation in urban-rural gradients (Langemeyer & Baró, 2021).

Globally, some cities stand out for their high capacity for integrated management between green and blue infrastructure. These are the cases of Melbourne (Australia) and Rotterdam (Netherlands) and Belo Horizonte (Brazil), which have implemented policies to integrate both infrastructures by creating interconnected systems, i.e., addressing heat mitigation, flood resilience and other sustainability challenges holistically (Rangel et al., 2021; Oliveira et al., 2022). However, it should be noted that promoting integrated policies and actions requires overcoming even greater challenges, such as governance barriers, lack of resources for audacious projects and lack of local knowledge about the dynamics and processes associated with the ecosystems in question (Davies & Laforzezza, 2019).

2.2.2. Regenerative and Restored Urban Spaces: Connecting Blue-green Infrastructure, Municipal Systems and Oases of Resilience

The conservation and restoration of ecosystems, especially through afforestation (planting trees in deforested areas) and the protection of natural habitats, are key elements in achieving greater resilience. In urban contexts, expanding green areas and increasing tree cover are essential for increasing biodiversity, reducing the urban heat island effect, improving air quality and providing shade and cooling. The restoration of urban green environments, focused especially on the revitalization of degraded landscapes such as derelict land and inactive industrial areas, can transform areas with a low supply of ecosystem services into multifunctional places, with integrated blue and green spaces that benefit both human well-being and biodiversity (He, 2019).



However, given this agenda, there is a need to migrate from a traditional restoration approach, i.e., one focused predominantly on rural or peri-urban areas, to urban environments that present numerous challenges, including intense fragmentation of forest fragments, a high occurrence of invasive species and severe urban heat island effects, which brings to light these problems and the need to create targeted and specialized approaches to local demands (e.g. removal/replacement of invasive species with native species). It should be noted that urban forest restoration is an emerging field within environmental science, requiring evidence-based practices to avoid costly trial-and-error methods and ensure long-term success (Bertoletti et al., 2025).

In addition, the redesign of open spaces - including streets, sidewalks, setbacks, squares and parks - is a pillar of Green-Blue Systems in urban areas. These interventions not only improve urban aesthetics, but also extend the ecological function of the city by increasing permeable surfaces for rainwater absorption, reducing flooding and runoff, creating more accessible and safer public spaces and acting as ecological springboards for biodiversity. Urban parks and squares become multifunctional areas, serving as urban oases that offer leisure spaces, improve physical and mental health and act as refuges during extreme weather events such as heatwaves (C40, 2020).

A comprehensive municipal system of protected and conserved areas - both public and private - is crucial for a sustainable urban fabric. However, special attention should be paid to the various Brazilian cities that experienced high population growth and rapid urban expansion in the 20th century, as these are territories that have historically presented the greatest challenges in restoring these natural spaces. With this in mind, it is understood that efforts should be directed towards restoring nature, especially in medium-sized and large cities, so that these urban areas not only become more resilient to extreme weather events, but also become inclusive elements that promote human well-being.

Effective management of these natural spaces ensures that ecosystems thrive, offering benefits such as biodiversity conservation, flood control, water filtration and promoting social equity by guaranteeing access to nature for all citizens (UNEP, 2023). Such management of natural areas in cities fosters the provision of ecosystem services through urban refuges or oases, which play a key role in the Green-Blue Systems approach. These urban oases are



designed under the "safe to fail" concept - that is, they can absorb and recover from stresses, such as intense rainfall or extreme heat, without significant damage (Delaney, 2018).

In addition to restoring green patches, other strategies can ensure high efficiency in the provision of ecosystem services, such as green roofs and walls, which are effective solutions for expanding and connecting green areas in densely populated urban regions. These systems help to manage rainwater, improve the energy efficiency of buildings and contribute to biodiversity by providing habitats for birds and pollinators (Williams, 2014).

The performance of green roofs and walls as NbS depends on the particularities of each project, which must be adapted to local conditions. Certainly, encouraging green roofs in densely populated areas is a highly recommended alternative. In a basin in the Aricanduva River basin in the city of São Paulo, a location with high demographics, green roofs required almost half as much vegetation cover to prevent the channel from overflowing when compared to other traditional permeable surfaces. In addition to increasing resilience in times of high rainfall, green roofs serve as efficient NbS, as they can add food production and other environmental benefits. This proposal to adopt green roofs in densely populated communities living on the poverty line could be an excellent way of making the transition to sustainability (Ferreira & Rocha, 2023). Cities with more financial resources and more concerned about the Sustainability and Climate Agendas can adopt the practice of green roofs on public buildings, i.e. schools and other buildings, serving as an example for the rest of society to follow.

2.2.3. Strategies for Resilient Cities: Multifunctionality and Functional Redundancy in the Preservation and Recovery of Urban Ecosystems

The "safe to fail" concept is incorporated into Green-Blue Systems to ensure that urban environments withstand and recover from extreme weather events. Green roofs, permeable sidewalks and rain gardens are examples of systems designed to deal with excess water during storms without collapsing. By planning redundancies, i.e., multiple systems performing the same function, cities ensure that if one system is overloaded, another takes over, maintaining functionality and minimizing damage (Ahern, 2011). This functional redundancy of projects should be directed at specific objectives, such as increasing flood control, or increasing gene flow and maintaining high biological diversity in cities, among others (Mestre et al., 2021). This means that



more than one strategy is used for the same purpose, depending on the conditions of the territory.

These redundancies can be planned from natural elements that seek to preserve, restore and create green and blue infrastructure, ensuring that valuable ecosystems remain efficient in providing essential services such as carbon sequestration and wildlife habitat. By integrating these principles into project planning and design, urban areas become more resilient, sustainable and liveable, improving water management, protecting biodiversity and promoting social well-being. The design principles of Green-Blue Systems seek to harmonize natural processes with human development, creating cities that are better prepared for the challenges of climate change and raising the quality of life for all residents, as well as urban competitiveness (Niemeijer, 2014).

2.3. Water and Sustainable Urban Planning

Effective water management and governance demand a systemic approach that considers the full hydrological cycle and designs for resilience across scales—from river basins to cities and urban blocks (WEF, 2025). Examples of successful large-scale implementation include the China's Sponge City Program and the Netherlands' Room for the River. The Sponge City demonstrates systematic urban water management transformation (Ma et al., 2020). In China, the Sponge City Initiative (SCI) represents a significant implementation of integrated blue-green-grey infrastructure, aiming to address urban flooding while promoting ecological sustainability. Wang et al. (2018) documented that successful integration requires careful consideration of local hydrological conditions, urban morphology, and existing infrastructure networks. The Netherlands' Room for the River project, in turn, showcases long-term adaptation planning (Rijkswaterstaat, 2023).



The integration of blue-green-grey infrastructure has emerged as a crucial strategy in urban water management, particularly through the Three-Point Approach (3PA) framework (Van De Ven et al., 2024). This framework addresses everyday urban water challenges, design standards, and extreme events through a comprehensive lens that combines traditional grey infrastructure with nature-based solutions (Randall et al., 2025).

This approach integrates the Three-Point Sponge Policy Approach (3PSPA), emphasizing sustainable urban water management to address day-to-day, exceedance, and extreme conditions, including floods and droughts. By adopting "Sponge" principles—Sponge-Country, Sponge-River Basins, Sponge-Cities, and Sponge-Blocks—urban environments can become adaptive systems that mitigate climate impacts while ensuring water availability and ecological health (Van De Ven et al., 2024).

Systemic nature-based solutions (NbS) offer opportunities to reframe how we plan and design water management systems, focusing on resilience, sustainability, and integration with natural ecosystems (Van De Ven et al., 2024).

The Three Point Sponge Policy Approach (3PSPA) is a combination of the 3PA framework with the sponge city concept, intended to create a hybrid optimized approach for urban and beyond urban waters. It emphasizes creating urban systems that absorb, retain, and release water efficiently, mimicking natural hydrological cycles. Incorporating sustainability into urban water management for addressing all three domains of day-to-day, exceedance events, and extreme floods or droughts events (Van De Ven et al., 2024). The Day-to-Day management includes the Integration of green infrastructure for daily urban water management, optimizing water resources while



protecting urban water quality. The Extreme Events management, in turn, focuses on designing strategies that accommodate extreme floods and droughts by creating systems that can absorb excess water during extreme weather events or store it for dry periods, thus maintaining urban resilience.

The Three Point Sponge Policy Approach Applied Across Multiple Scales

- **Sponge-Country:** National strategies that encourage landscape-wide NbS, focusing on reforestation, soil conservation, and watershed management to enhance water retention and reduce downstream flooding. This paradigm is supported by evidence suggesting that landscape restoration significantly enhances water retention and mitigates downstream flooding risks (Tellman et al., 2018; Currea et al., 2024). Research indicates that incorporating NbS into such broad strategies can lead to cost-effective solutions that enhance both infrastructure resilience and social well-being, particularly in the context of growing populations and climate variability (Seddon et al., 2020; Lalonde et al., 2024).
- **Sponge River-Basins:** At the watershed level, integrating green infrastructure like wetlands, riparian buffers, and floodplains helps manage both water quantity and quality, reducing flood risks and promoting biodiversity. Evidence shows that these natural features not only reduce flood risks but also bolster biodiversity (Miralles-Wilhelm, 2023; Zalaznik et al., 2023). Studies confirm that NbS can effectively manage stormwater, thus playing a vital role in flood mitigation while also providing significant ecological benefits, such as habitat provision and improved water quality (Tsegaye et al., 2020; Randhir & Klosterman, 2024).
- **Sponge Cities:** Urban areas that integrate water-sensitive designs, including permeable pavements, green roofs, rain gardens, and constructed wetlands. At the urban level, Sponge Cities incorporate water-sensitive designs, including permeable pavements and green roofs. The efficacy of these measures has been documented, demonstrating improved stormwater management and gradual water release that mitigates flooding and facilitates groundwater recharge (Teston et al., 2018; Liu et al., 2023). Decentralized water management systems within Sponge Cities are highlighted as essential for optimizing urban water systems. These systems allow for quick implementation



and adaptation to urban growth patterns, aligning infrastructure development closely with community needs (Younos, 2011; Medeiros et al., 2017).

- **Sponge-Blocks:** Finally, at the neighborhood scale, termed Sponge-Blocks, localized water management through micro-water-retention systems is prioritized. This approach reinforces the overall goal of decentralizing water management to alleviate pressure on centralized infrastructures (Yan et al., 2018; Leigh & Lee, 2019). Research illustrates how decentralized strategies foster resilience against water-related risks and enhance community engagement in resource management, ultimately resulting in a more sustainable urban water cycle (Schuetze & Santiago-Fandiño, 2014; Cole et al., 2022).

Price (2003) and Allen & Holling (2010) argue that sustainable NbS must balance robustness with adaptability. This dual capability enables systems to both withstand external pressures and evolve as needed, fundamental to long-term sustainability. Central to this vision is the integration of infrastructural ecologies, which harmonize green and gray infrastructures with aquatic ecosystems, fostering networks and flows that transcend traditional siloed designs. Historical institutionalism highlights the importance of addressing legacy path dependencies, learning from past missteps, and aligning long-term investments with sustainable water futures. Innovative technologies, such as floating and amphibious structures, further enhance adaptability to extreme conditions.

Beyond physical resource management, water bodies should be recognized as living entities, essential to biodiversity, cultural heritage, and human well-being. Blue areas—rivers, lakes, wetlands, and coasts—are vital for promoting climate resilience, enhancing quality of life, supporting biodiversity, and providing recreational opportunities. A collaborative governance framework that integrates diverse stakeholders across the water-land interface is crucial for fostering inclusive, resilient water systems. This systemic, multi-scale perspective ensures that nature-based solutions for water management are robust, equitable, and adaptable to the uncertainties of a changing climate.

3

PUBLIC POLICY: GOVERNANCE, FINANCING AND IMPLEMENTATION OF THE RESILIENT GREEN-BLUE CITY



**PUBLIC POLICY:
GOVERNANCE, FINANCING
AND IMPLEMENTATION OF
THE RESILIENT GREEN-BLUE CITY**

3. PUBLIC POLICY: GOVERNANCE, FINANCING AND IMPLEMENTATION OF THE RESILIENT GREEN-BLUE CITY

3.1. Governance: Multi-scale, Intersectoral and Inclusive

Effective governance is the basis for achieving urban resilience and sustainability and it is important to integrate diverse governance strategies to address the complex challenges that cities face (UN Habitat, 2022). Effective governance of climate adaptation in cities requires capacity and strategies for horizontal and vertical multi-stakeholder integration, as well as sectoral, multi-scalar integration and the ability to support long-term adaptation processes (Chu et al., 2017; Castellanos et al., 2022). The ability to formulate and operationalize public policies guided by integrated, multi-scalar environmental governance, capable of articulating regulatory, institutional and financial instruments, is also one of the keys to shaping resilient green cities (Sotto et al., 2019; Araújo et al., 2024b).

Multi-level Governance

Managing climate change requires multi-level governance cooperation, starting from the local to the global and from the public to the private (Viola & Franchini, 2022). Starting from the global involves, for example, including documents with global strategies for sustainable urban development in the design of policies, plans and actions. The inclusion of strategies to meet the UN's Sustainable Development Goals (SDGs) would be fundamental, whose integration with the objectives set for building a resilient city is necessary (Carvalho et al., 2024). At the intergovernmental level, the UN has declared the Decade of Ocean Science for Sustainable Development (2021-2030) and the Decade on Ecosystem Restoration (2021-2030) as essential agendas for achieving the Sustainable Development Goals. These agendas emphasize the importance of co-production processes, multilevel and multisectoral actions, nature-based solutions, and scientifically informed decisions in their design and development plans. The Decade of Ocean Science for Sustainable Development, popularly known as the Ocean Decade, is based on the highest concentration of humans in coastal areas and was designed around 10 challenges (Agostini et al., 2024; Arbic et al., 2024; Calewaert et al. 2024; Glithero et al., 2024; Hatje et al., 2024; Haugan et al., 2024; Miloslavich et al., 2024; Muller-Karger et al., 2024; Pinardi et al., 2024; Sabine et al., 2024) so that national and subnational governments,



including municipalities, can adapt their cities and actions with a view to sustainability and climate resilience.

Furthermore, the structuring of climate governance can take advantage of different policies and initiatives that aim to promote collaboration between the national, state and municipal levels. Different documents are aimed at this collaboration, such as the Metropolis Statute (Brasil, 2015), for example, which, although it lacks clear guidelines for inter-federative integration, aims to promote collaboration between the national, state and municipal levels (Zimmerman et al, 2023). Another would be the Brazilian Charter for Smart Cities, which aims to promote collaboration between different actors for sustainable urban development (Brasil, 2020c) and the National Plan for the Implementation of the Decade of Ocean Science for Sustainable Development (MCTI, 2021), which sets out priorities for action in each region of the country, developed in a participatory and multisectoral manner. Specific projects can also help by promoting intersectoral and interregional cooperation. Currently, for example, initiatives such as the CITinova II project - Promoting integrated metropolitan planning and investments in innovative urban technology in Brazil aim to develop actions to accelerate sustainable development in Brazilian metropolitan regions (Belém, Florianópolis and Teresina) with fewer greenhouse gas emissions and prioritizing biodiversity conservation (FUNBIO, 2023).

Participatory Governance

A high capacity to promote the engagement of the various actors impacted and to welcome community-based initiatives are also determinants of efficient governance of adaptation processes (Rosenzweig et al., 2017; Castellanos et al., 2022). These conditions for a robust climate governance capacity are in line with the understanding of governance as democratic, participatory, non-hierarchical, collaborative and participatory with coordination and integration between administrative and territorial scales - local, regional and national - (Matarazzo et al., 2021), as well as between various actors and sectors that make up the urban system - infrastructure, land use, mobility, environment and natural resources, among others (Empinotti et al., 2023). This participatory governance also requires monitoring and evaluation mechanisms and environmental performance indicators (Krisan, 2022), with transparent, accessible data, which generally involves institutional



integration and a digital transformation in public services, for example, with the General Data Protection Law (LGPD) (Brasil, 2018) regulating the collection and use of data (Filgueiras et al., 2025). It also requires institutional training and ongoing social engagement, building a culture of co-responsibility in the management of urban commons, and increasing the transparency and inclusive capacity of adaptation processes (Krisan, 2022). Social participation is a central element of fair and democratic governance, helping to reduce economic, social and territorial inequalities (Jacobi, 2023).

Governance and Disasters

Faced with the consequences of climate disasters, cities around the world are working to create new governance structures to better respond to disasters and minimize citizens' vulnerability to climate change, reacting to a history of poor governance that has often harmed urban communities (Viana, 2011). In these events, public management is called upon to implement policies capable of coordinating agents from different governmental and non-governmental spheres. For example, the city of Rio de Janeiro established the Operations Center (COR) in December 2010 in response to fatal landslides in the city. The center operates 24 hours a day, monitoring indicators such as rainfall, fire risks and temperature. COR's governance model is innovative, integrating 30 agencies (municipal, state and public services) to create multidisciplinary decision-making (Pinto & De Castro, 2022). The Center actively engages communities through training and proactively communicates with citizens: it provides alerts through news and social media channels and collects data from citizens through the city's mobile app (idem).

Preventive planning and not just public actions related to disasters require governance structures for this prevention, demanding the design of specific policy arrangements, the creation of institutions, plans, programs and actions that involve financial resources. Municipalities generally do not have the financial resources to make the necessary investments in infrastructure, which hinders the progress of adaptation processes (Coalition for Urban Transitions, 2021).

Governance to Eradicate Poverty / Tackle Inequalities

Generally, those most affected by the impacts of climate change and disasters are the most vulnerable, and in order to tackle socio-territorial vulnerabilities and inequalities, the quality of urban governance is seen as the most important factor in eradicating poverty and promoting prosperous cities (UN Habitat, 2022). When designing strategies for environmental sustainability, for example, the quality of governance involves linking them to ways of combating racism, gender inequality, extreme poverty, among other forms of discrimination and intersectional power differences. There are already coalitions with such objectives, such as the Brazilian Coalition of Inclusive and Sustainable Cities (UNESCO, 2024). In addition, the issue of migration and climate displacement requires inclusive governance, ensuring that public policies meet the needs of displaced people. An example in this direction is São Paulo's Municipal Policy Plan for Refugees and Migrants, an example of inclusive integration (Municipal Law 16.478, São Paulo, 2016).

Governance for NbS and Green Mobility

Certain issues require different collaborations to make up climate governance. The territorial implementation of blue-green solutions for the resilient city requires planning and regulation strategies that incorporate Nature-Based Solutions (NbS), blue-green infrastructure and ecosystem approaches, promoting environmental restoration, ecological connectivity, urban drainage control and climate resilience (Frantzeskaki & McPhearson, 2021). Research shows that designing governance aimed at implementing NbS requires participatory governance whose community engagement and local knowledge contribute to more effective and sustainable solutions (United Nations Environmental Programme, 2023). Governance aimed at green mobility solutions, on the other hand, calls for partnerships between government and industry, which are crucial for the development and implementation of green mobility solutions, and whose collaboration can leverage resources and expertise to accelerate the transition to sustainable transportation (WEF, 2024).



The Importance of Education and Communication in Strengthening Governance

Building cities that are more resilient to the climate crisis requires more than infrastructure: it requires behavioral change, adaptive capacity, and informed decision-making by citizens and public and private managers. This transformation is only possible with structured investment in climate education and communication strategies that connect science, culture, and public policy (Ruiz-Malién et al., 2022). Urban climate adaptation needs to be understood as a collective responsibility, and this requires that all sectors of society—health, mobility, housing, economy, governance—base their decisions on a new ecological and climate logic.

In this scenario, education is not only a tool for raising awareness, but a structuring axis for training generations capable of understanding the complexity of climate change and acting with social and environmental responsibility (Stenvenson et al., 2017; Trott et al., 2023). When incorporated into basic education, this training broadens the reach of science beyond academia, influencing diverse sectors and fostering political and social engagement. Communication, in turn, plays the role of keeping the issue alive in the public sphere, generating pressure for institutional and electoral commitments.

A relevant example for understanding the importance of education and communication in governance to address the climate crisis is the way in which ocean culture, and its implications for climate governance, has emerged as a strategic concept, recognized by the UN, within the Decade of Ocean Science for Sustainable Development (UNESCO-



IOC, 2017). Far from being restricted to marine conservation, ocean culture represents an integrated understanding of the relationship between the ocean, climate, territory, and human well-being (McRuer et al., 2025). It is an educational, communicational, and cultural approach that strengthens society's role in building nature-based solutions—especially in urban contexts—and contributes to the design of blue-green cities: territories where ecological infrastructure, coastal planning, and the enhancement of aquatic ecosystems are integrated into urban resilience.

Based on Challenge 10 of the Decade of Ocean Science for Sustainable Development — “changing humanity's relationship with the ocean” — ocean culture articulates four interdependent dimensions: education, communication, cultural connections, and knowledge systems (UNESCO-IOC, 2025a). This perspective broadens the impact of climate education by integrating scientific, traditional, and community knowledge, building bridges between the local and the global, between everyday urban life and the ocean cycles that shape the climate and water and food security of all regions, even those far from the coast.

Brazil is a global leader in this field. It was the first country to join UNESCO in committing to the Blue Curriculum, pledging to engage in a participatory process to incorporate ocean culture into public education policies at the national, state, and municipal levels (UNESCO-IOC 2022, UNESCO-IOC 2025b). Initiatives such as the Blue School Program, the Ocean Olympics, and the technical reports of the Brazilian Alliance for Ocean Culture join several other movements for education, popularization of science, and combating misinformation, demonstrating how the country has translated this concept into concrete, intersectoral, and territorialized actions. These actions strengthen the adaptive capacity of cities, promote climate justice, and position Brazil as a global leader in educational solutions for a sustainable climate future.

In a process of climate impacts that we discuss on a decadal scale, investing in education, which also takes years or even decades to generate transformation, is essential to changing the current situation (Stenvenson et al., 2017). While immediate actions remain essential, parallel broad investment in innovative, active, and contextually relevant education will facilitate and strengthen immediate actions



over the years and enable exponential growth once we have a society that is effectively engaged in the importance of blue-green cities.

3.2. Promoting the Participatory and Inclusive Development of Diagnoses, Plans, Projects and Interventions

The formulation of climate adaptation diagnoses, plans and projects demands more than technical solutions - it requires an approach that considers social and environmental justice in an integrated manner. According to Schlosberg (2012), adaptation policies should be guided by a perspective of climate justice based on the theory of capabilities, prioritizing not only the equitable distribution of resources, but also the recognition of vulnerabilities, the effective participation of affected communities and the expansion of conditions for individuals and groups to live dignified lives. This implies understanding adaptation as a question of justice, which must restore and strengthen human and ecological capacities in the face of climate impacts.

In this context, fostering a democratic culture is essential. The broad and qualified participation of different social actors in the construction of adaptive responses allows diagnoses and proposed actions to reflect the needs, knowledge and priorities of vulnerable populations (Schlosberg, 2012). Thus, adaptation policies not only address climate risks, but also contribute to reducing the structural inequalities that limit the resilience of communities (Schlosberg, 2012).

Inclusion and social participation are key elements in building diagnoses and plans for climate adaptation actions that recognize territorial specificities and structural inequalities. Broad and qualified participatory processes help to avoid forms of maladaptation - that is, strategies that, instead of mitigating vulnerabilities, end up exacerbating existing socio-environmental inequalities (Schipper, 2020). In informal areas, for example, actions focused only on reducing the risks of climate disasters, without structural transformations, often result in the reproduction of vulnerability (See & Wilmsen, 2020; Castellanos et al., 2022). Yazar et al. (2025) note that many cities still fail to meaningfully involve the most marginalized groups, adopting mechanisms of symbolic participation. To strengthen fair environmental governance, it is necessary to promote the decentralization of power and ensure the active presence of civil



society, with special attention to conflicts that reveal social, territorial and climatic inequalities (Jacobi, 2023).

Integrating scientific knowledge with local, traditional and indigenous knowledge contributes to more effective solutions, rooted in the territory and culturally appropriate. This implies valuing the everyday experience of populations living with climate risks, promoting processes of co-production of knowledge. Several studies have shown that involving communities in adaptation initiatives based on local knowledge can strengthen resilience and facilitate acceptance of the proposed measures (Reid et al., 2009; Orlove et al., 2023). This recognition contributes to fairer policies adapted to local socio-cultural realities.

Studies show that community-based adaptation actions - especially in vulnerable contexts such as slums and informal settlements - are more effective when they include or are led by the communities themselves (Martins & Rocha, 2019; Viana, 2021; Du Greiving & Yap, 2022). In Brazil, experiences monitored by CEMADEN (2023) show that including the community in risk management contributes significantly to preparing for and responding to extreme events. The governance of adaptation and risk reduction projects therefore requires a participatory approach that allows for the development of the adaptive capacity of populations in situations of greater fragility (Jacobi, 2023).

The effectiveness of climate adaptation policies depends on the continuous and articulated involvement of multiple actors - including government, civil society, the private sector, universities and community organizations. International literature points out that broad engagement and the strengthening of community-based initiatives are determining factors for the success of adaptation strategies (Anguelovski et al., 2014; Castellanos et al., 2022). Sustained political leadership, intersectoral integration and the institutionalization of actions require not only normative guidelines, but concrete structures for participation and collaboration between diverse actors, who share responsibility for formulating and implementing actions.



Transparency in decision-making processes and public *accountability* are key elements in ensuring the legitimacy, monitoring and course correction of adaptation policies. Studies indicate that adaptive governance is strengthened when there are clear channels of accountability and instruments that guarantee social control (OECD, 2024). Governments and institutions must make information on risks, decisions, resources and results accessible, ensuring that the population can monitor and evaluate the actions implemented. The absence of social control mechanisms can weaken public trust and compromise the effectiveness of climate policies, especially in contexts of high inequality.

There is now a consensus that the involvement of all stakeholders from the start of the planning process to the implementation and monitoring of solutions is essential if they are to be sustainable over time (Dushkova & Kuhlicke, 2023; Torres et al., 2023). To this end, co-creation is fundamental, in order to increase awareness and knowledge among society and the various players, seeking to reconcile the benefits, responsibilities and different (often conflicting) interests, with a focus on the needs of the local people. Co-creation allows the process to be transparent, inclusive - with a focus on benefits for the least favored sections of the population. There are methodologies for the co-creation process that can be adapted to local contexts in order to streamline participatory development from diagnosis and planning, to co-production, co-implementation and co-monitoring and evaluation (Dushkova & Kuhlicke, 2023).

3.3. Policy Implementation

Considering the targets for limiting temperature rise set out in the Paris Agreement, we are still a long way from reaching a satisfactory level in terms of implementing national climate policies in line with the commitments needed to achieve the more robust target of keeping global temperatures below 1.5°C (Rogelj et al., 2023). The risk status of the aforementioned climate action monitoring indicators is reinforced by research traditions with methodologies that seek to link global, national and local scales, integrating the climate lens (Fanning et al., 2022). Therefore, even in the face of a sense of urgency that demands pace and efficiency in climate action, the challenges of territorializing national policies at the local level go hand in hand with a historical process of shaping a complex agenda, all the way to the effective use of urban resilience instruments as an active contribution to achieving positive results in the global balance of emissions (Pauw et al, 2020; Fanning et al., 2022).

Like the other signatory countries of the aforementioned climate action commitments, Brazil is not yet a nation whose set of policies reflects an adequate treatment of the issue (Tracker, 2024; Talanoa Climate Policies, 2023; Nature, 2023). Our point of focus will be the distance that separates, in the current estimates, the emissions projection scenario based on current actions and policies from the commitments signed with the latest update of the Brazilian NDC (Nationally Determined Contribution) (Brasil, 2024c). And so, based on the effort to structure and implement national policies, we can see where we are and what is missing to align practice with the implementation of public policies.

The current structure of the Climate Action Policy in Brazil relies on the legal framework of the National Climate Change Policy (PNMC), established by Law No. 12.187/2009 (Brasil, 2009) and regulated by Decree No. 7.390/2010 (Brasil, 2010b), which details the mechanisms for its implementation (Motta et al., 2011). In addition to reinforcing the focus on mitigation and adaptation, these instruments assume the operationalization of the policy via sectoral plans (energy, industry and transport, agriculture and livestock and land use and forests), with attention to participatory processes and coordinated within the federal government by an inter-ministerial committee. The PNMC represents the country's landmark ratification of its commitments to the United Nations Framework Convention on Climate Change



(UNFCCC), but government plans (between intentions and results) and adjustments to the ambitions of the NDCs with each update make the non-linearity of these efforts evident and highlight a central challenge, which concerns the conditions for maintaining the continuity and consistency of actions and policies in the face of financial contingencies and the capacity to implement their targets (Pauw et al., 2020; Milhorange et al., 2022).

At the end of 2023, the process of participatory construction of the Climate Plan was launched, a review of Brazil's climate policy until 2035 and updating the goals, objectives and strategies set out in previous plans, advancing the stages of implementation of the national policy. Coordinated by the Interministerial Committee on Climate Change (CIM) and involving 22 ministries, the plan is based on two pillars: mitigation and adaptation. Parallel to this effort, it is worth highlighting the initiative of the Ministry of Finance, which in August 2024 announced the launch of the Ecological Transformation Plan (Brasil, 2024d). Composed of six structuring axes (sustainable finance; bioeconomy; energy transition; circular economy; adaptation to climate change and technological densification), the plan was designed to promote a just ecological transition, with a focus on sustainability, the generation of green jobs and greater productivity.

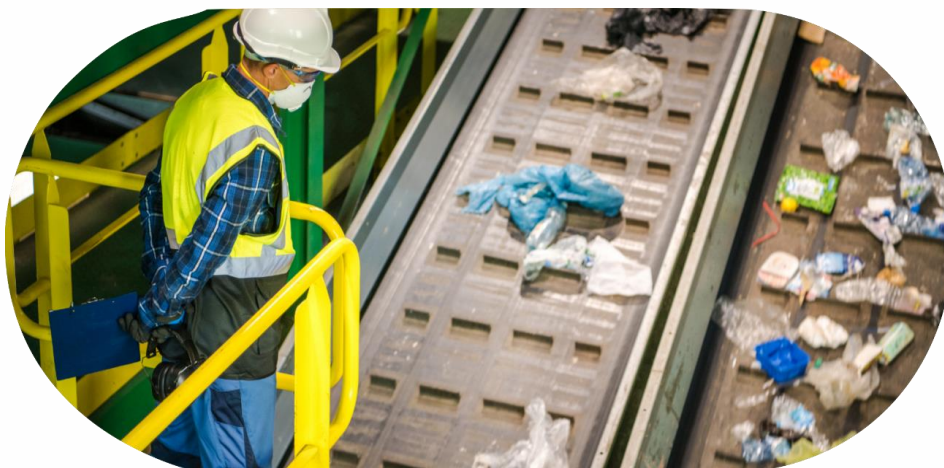
There is something new in this policy and where it comes from, which indicates a significant turning point for all institutional climate action, since the climate agenda is now part of the national development strategy (Hochsteler, 2021) and effectively represents a new breath for the agenda as a whole. The perception and tackling of the issue as a strategic opportunity introduces an important change, especially for developing nations such as Brazil, with relevant assets to leverage its ecological transition process and contribute to the goals of other nations, including developed ones (Althouse et al., 2020; Wang et al., 2024).

The repertoire of actions linked to the national climate agenda is complemented in the Brazilian context by the Transversal Environmental Agenda of the 2024-2027 Multi-Year Plan, an initiative of the Ministry of Planning and Budget (MPO) in partnership with the Ministry of the Environment (MMA) and the Inter-American Development Bank (IDB) (Brasil, 2024). Among the other five cross-cutting agendas, the environmental one has the greatest number of attributes: present in 50 of the 88 finalistic programs, with 113 specific



objectives, 372 deliverables and 150 institutional and normative measures, under the responsibility of 25 agencies. The agenda cuts across the strategic, tactical and managerial levels of the PPA and systematizes the federal government's commitments for the next four years in seven dimensions: 1) prevention and control of deforestation and firefighting; 2) conservation, protection and recovery of biodiversity, ecosystems and biomes; 3) management and conservation of water resources; 4) management and conservation of marine resources and the coastal zone; 5) bioeconomy; 6) environmental quality in urban and rural areas; and 7) tackling the climate emergency; among which we highlight the last two (Brasil, 2024e).

The cross-referencing of policies and plans highlighted so far provides a favorable institutional framework for the emergence of state, district and municipal climate plans. However, this is a reality in the making: of the 27 capitals, including the Federal District, 16 cities have yet to complete a plan. However, at the level of sub-national action, the Green and Resilient Cities Program (PCVR), established by Decree No. 12.041/2024 (Brasil, 2024a), is gaining relevance among other integrative public policies. Based on an integrated approach across the territory, with a focus on populations in metropolitan regions and municipalities with high social vulnerability, the program aims to increase the resilience and environmental quality of Brazilian cities. According to data from the AdaptaBrasil platform, 2801 of Brazil's 5570 municipalities are currently classified as having high or very high climate vulnerability (Brasil, 2024f). There is also the Adapta Cidades project, an initiative of the MMA, aligned with the adaptation axis of the Climate Plan and aimed at supporting the preparation of 260 municipal adaptation plans. The challenges of implementing and integrating climate action policies on a multiscale basis in the territories are therefore considerable, and these challenges are growing in importance as we try to narrow the gap between the sufficiency targets set out in the NDC and the actual contributions made by places (Veiga & Garcia, 2021). Brazil's accumulated experience with participatory governance processes, coupled with the recent centrality given to the climate agenda in national development strategies, represent relevant catalysts for effective gains and advances in the territorialization of the climate action agenda in cities (Maia et al., 2024).



A clear example of the challenge of integrating scales for effective policy implementation is the issue of solid waste. Although still poorly implemented at municipal level, the national framework has made progress. The National Solid Waste Policy, regulated by Decree No. 10.936, of January 12, 2022 (Brasil, 2022a), harmonizes and unifies legal provisions, in addition to ratifying determinations and concepts already brought in by the PNRS, with a view to the proper management of solid waste in the national territory and brings new features such as the creation of the National Reverse Logistics Program. An important instrument of the PNRS for systematizing data related to waste management in the country is the National Solid Waste Management Information System (SINIR), which must receive, analyze, classify, systematize, consolidate and disseminate qualitative and quantitative data and information on solid waste management (<https://sinir.gov.br>). This information should be published and made available in other official databases that can contribute to improving the management and environmentally appropriate management of solid waste (ICLEI, 2012).





The National Solid Waste Plan (Brasil, 2022b) is also an important instrument of the National Solid Waste Policy, outlining guidelines, strategies, actions and targets to improve solid waste management in the country. In addition to the closure of all rubbish dumps, it is planned to increase waste recovery to around 50% in 20 years. Thus, half of the waste generated should no longer be landfilled and will be reused through recycling, composting, biodigestion and energy recovery. Currently, only 2.2% of municipal solid waste is recycled (Sinir, 2024). In another important initiative, the Federal Government launched the National Circular Economy Strategy, which will promote the efficient use of natural resources and the redesign of production chains and products, encouraging the regeneration of nature.

Although each action front represents a challenging scope of action in its own right, the effective delivery of results, given the unprecedented complexity and uncertainty of the climate change scenarios we are now facing, will increasingly depend on the continuous integration of intersectional climate policies. The experience of the design and trans-scalar articulation that prepares the implementation of the PCVR in the Brazilian context therefore establishes a necessary level of reference for the entire ecosystem of public policies which, as a condition of success and systemic effect, must operate each plan, program or action as a system (Skagen & Boasson, 2024).

3.4. Public Policies and Climate Migration

Within the scope of resilient green cities, focusing on the phenomenon of human mobility, ensuring the correct management of so-called "climate migration", can become part of cities' effective adaptation strategy. This umbrella term includes migration, displacement and planned relocation (IOM, 2024). According to the UN Disaster Displacement Platform, displacement can be understood as the forced movement of people, while migration consists of the voluntary movement of individuals and, in turn, planned relocation corresponds to the planned process of resettling groups of people in new locations (UNOPS, 2024).

In addition, according to the literature, the term "climate migrant" refers to individuals or groups who move both internally and externally, on a temporary or permanent basis, due to the imminence or occurrence of an environmental adversity in their place of origin (Ramos, 2011). The voluntariness of this displacement depends on the



degree of vulnerability of the groups and is related to the need, desire and ability to actually migrate (Serraglio et al., 2019).

By understanding the historical flow of climate displacement in their territory, states can anticipate trends and prepare public policies to deal with their effects, but not all states have an accurate and detailed internal system for monitoring these displacements (IDMC, 2024). In Brazil, for example, data on displacement comes mostly from official state agencies linked to disasters. However, in order to understand all the dimensions of displacement, a system is needed to collect and share disaggregated data that breaks down age, gender and health status, and that information is collected before, during and after movements (UNDRR, 2019).

In Brazil, the National Civil Protection and Defense Policy, defined in Law No. 12.608/12, provides for the conceptualization of "homeless", "displaced" and "disaster", but not that of climate displaced person or migrant (Brasil, 2012b). From the point of view of environmental justice, it is necessary for states to adopt a climate justice perspective when formulating and implementing laws and plans to tackle climate change, which must always be based on human rights and particularly consider the situation of the most vulnerable people (IACHR, 2024).

In this sense, it is interesting to consider legal frameworks that provide for prevention, mitigation and adaptation programs to avoid forced climate displacement, as well as the adaptation and strengthening of institutions to carry out such programs (IACHR, 2024). In addition, it is necessary to establish mechanisms and strategies for monitoring situations of risk of displacement and to guarantee access to justice and effective reparation for the displaced (IACHR, 2024).

The historical and well-known migration of people from rural to urban areas poses a number of challenges for the migrant population and the receiving population (Granado, 2020). In this sense, it is important to ensure that climate migrants have access to basic services, since integration is a condition for the protection of human rights (Cavedon-Capdeville et al., 2023).

Also with regard to the local integration of migrants, social assistance services are particularly important. Although there is already a technical document from 2016 regulating the role of social assistance in assisting migrants (Brasil, 2016), it is important to emphasize the



importance of integrated action between the services of the Unified Social Assistance System (SUAS) and the National Civil Protection and Defense System (SINPDEC) to ensure that social assistance does not act in isolation in the territory and ensure social protection for the displaced (Brasil, 2023d).

As for the third term relating to climate migration, planned relocations, the analysis of Fiji's experience is interesting. Fiji's National Planned Relocation Plan (2018) is one of the only ones in the world that provides guidelines for all the actors involved in the process. In particular, the guidelines stress the importance of the involvement and ongoing participation of communities in the relocation process, especially in decision-making, site selection, the drafting and execution of the plan and follow-up after the relocation. The document also provides for the application of consistent procedures to ensure that the planned relocation is sustainable at all stages of its implementation (Fiji, 2018).

The example of Fiji highlights the importance of formulating fair and sustainable guidelines applicable to cases of planned relocation. Finally, as suggested guidelines for a planned relocation process, the following stand out: (i) valuing the knowledge and opinions of the affected communities; (ii) building long-term collaborative relationships between public authorities, the community and non-state bodies; and (iii) adopting financing models that meet long-term challenges and are multidimensional, seeking cooperation with national and international social organizations (Gini et al., 2024).

3.5. Expanding and Facilitating Access to Traditional and Innovative Financing Mechanisms

Climate change is imposing significant economic costs on Brazil, especially affecting urban populations. In order for cities to adapt to these impacts, it is essential to implement projects aimed at building and adapting resilient green cities. This implementation requires robust funding to foster systems capable of preparing for, coping with, responding to and recovering quickly from extreme events, in order to maintain and preserve their essential functions and structures (Berkeley et al., 2010; IPCC, 2022). Thus, projecting the resources needed for these initiatives is a challenge, since it is necessary to work with future events that are not so predictable (Lomba-Fernandez et al., 2019).

These initiatives require scalable, sustainable and accessible financing mechanisms, capable of guaranteeing the continuity of environmental and social benefits. The diversification of funding sources, including public and private resources and innovative mechanisms such as green bonds and development funds, is fundamental to the viability of these projects (BNDES, 2024a; Samuels & Maehara, 2024).

The Resilient Green Cities Program (PCVR) in Brazil exemplifies this approach, promoting climate adaptation and green infrastructure in vulnerable areas. Its lines of action include expanding access to traditional and innovative financing, especially for metropolitan regions and municipalities with high social and climate vulnerability (Brasil, 2024a).



International organizations have played a crucial role in providing financial and technical tools for the implementation of resilient urban projects. These partnerships increase access to resources and promote the exchange of knowledge between cities, strengthening local capacity to develop robust projects that are attractive to investors (C40 Cities Finance Facility, 2024).

3.5.1 Viability, Durability, Scalability and Financial Sustainability

Building CVRs requires robust and sustainable financing, capable of guaranteeing the viability, durability and scalability of projects and programs. The financial viability of these initiatives is intrinsically linked to the ability to mobilize long-term resources, diversify funding sources and integrate innovative mechanisms that promote economic, social and environmental returns. In the Brazilian context, where



climate challenges are intensifying and urbanization is accelerating, the creation of a public policy programme for CVR requires a multifaceted approach that combines traditional and innovative financing, multisectoral engagement and alignment with regulatory frameworks and global strategies (IPCC, 2022).

The viability of CVR projects depends on the ability to attract and guarantee continuous financial flows. This involves diversifying funding sources, including public, private, international and multilateral resources. Public-private partnerships (PPPs) and regional and international alliances are effective strategies for sharing risks and resources, strengthening the financial resilience of projects. In Brazil, the Climate Fund of the National Bank for Economic and Social Development (BNDES) is an example of a public mechanism that offers specific lines of credit for sustainable urban infrastructure, supporting low-carbon initiatives and climate adaptation (BNDES, 2024b). Similarly, the BNDES Azul Program provides financing for the decarbonization of naval fleets, restoration of coastal marine ecosystems, and a sustainable blue economy with opportunities for adaptation at different levels (BNDES News Agency, 2024). In addition, the integration of national and sub-national public policies with global strategies, such as the Sustainable Development Goals (SDGs) and the Paris Agreement, expands the potential for financial and technical support for CVR projects. The National Policy for Payment for Environmental Services (Brasil, 2021c) is a relevant regulatory framework, as it establishes a remuneration system for providers of environmental services, such as family farmers, traditional communities and indigenous peoples, encouraging the conservation of biodiversity and the provision of ecosystem services (Brasil, 2021c).

Although traditionally applied in rural areas, Payment for Environmental Services (PES) has been gaining prominence and application in urban contexts as a strategy for financing nature-based solutions and promoting resilient green cities. In the state of São Paulo, for example, Bill No. 416/2024 is being processed, which seeks to establish the State Policy for Payment for Urban Environmental Services - PEPSAU, in the state, integrated and articulated with the State Policy on Climate Change. Payment for Environmental Services programs that pay for spring recovery projects are also classic examples that impact or can impact the environment of green and resilient cities, and it is even desirable for municipal Master Plans to dialogue with PES programs and policies, like municipalities such as



Florianópolis (SC), Palmas (TO) and São José dos Campos (SP) that integrate PES into their urban planning schemes (Bontempi, 2024).

Financial sustainability is an essential pillar for maintaining CVR projects. Sustainable projects must generate tangible returns that cover their operating costs and allow for reinvestment. In the case of Nature-based Solutions (NbS), such as the restoration of ecosystems and the creation of green infrastructure, economic self-sufficiency can be achieved through mechanisms such as the trading of carbon credits, urban ecotourism and the sustainable use of natural resources (UNCDF, 2024). The use of tax incentives and subsidies is also an effective strategy for increasing the attractiveness of CVR projects. The Brazilian Greenhouse Gas Emissions Trading System (SBCE) is an example of a mechanism that can boost investments in emissions reduction by offering tax benefits to companies that achieve carbon intensity reduction targets (Brasil, 2024g).

The durability of CVR projects is directly related to social engagement and the active participation of local communities, especially vulnerable groups such as traditional communities and indigenous peoples. Including these actors in the planning and execution of projects increases the acceptance and longevity of the initiatives, as well as ensuring that the benefits are distributed equitably (Samuels & Maehara, 2024). Monitoring and evaluation tools, such as nature-based contribution quantification models (e.g., InVEST) and traceability technologies (e.g., blockchain), reinforce transparency and funder confidence, while enabling the accurate measurement of environmental and social impacts (MISHRA et al., 2023). Programs such as the Local Climate Adaptive Living (LoCAL) Facility of the United Nations Capital Development Fund (UNCDF) can promote community engagement and capacity building of local managers, facilitating access to climate finance and the implementation of adaptive projects (UNCDF, 2024).

Scalability is a critical factor for the expansion of CVR projects, especially in a country as large as Brazil. Successful projects must be designed with the potential to be replicated in different urban contexts, allowing them to gain scale and maximize positive impacts. The formation of inter-municipal consortia is an effective strategy for sharing resources and infrastructure, expanding the reach and viability of urban resilience initiatives (Global Infrastructure Hub, 2022). Training public and private managers to draw up competitive



proposals for international funding is also essential to expand the scale of projects. Initiatives such as the C40 Cities Finance Facility, which supports cities in raising funds for sustainable infrastructure, can serve as a model for Brazil, especially in small and medium-sized cities that face difficulties in accessing climate finance (C40 Cities Finance Facility, 2023).

The creation of a national CVR program in Brazil represents an opportunity to integrate traditional and innovative financing, align public policies with global goals and promote multi-sector participation. The main opportunities include strengthening regulatory frameworks, such as the Payment for Environmental Services Act and the Brazilian Emissions Trading System, which can provide legal certainty and attract investors. The expansion of tax incentives and subsidies for NBS and green infrastructure projects can attract private investment and guarantee the financial sustainability of the initiatives. Including local communities in the planning and execution of projects increases the durability and equity of the programs. Training public managers and exchanging experiences between cities through networks can boost the replication of resilient solutions. One such network is "Making Cities Resilient 2030" (MCR2030, 2024), a global initiative that aims to make cities more resilient by 2030. In addition, the issuance of *green bonds* and the creation of municipal climate funds are alternatives for increasing access to financial resources.

In summary, the viability, durability, scalability and financial sustainability of CVR projects in Brazil depend on an integrated approach that combines diversified funding, social engagement, technical capacity building and alignment with public policies and global strategies. The creation of a national CVR program, aligned with the SDGs and the Paris Agreement, can transform climate challenges into opportunities for sustainable and inclusive development.

3.5.2. Financing Mechanisms

The transition to greener, more resilient cities is essential to meet the challenges of climate change. To make this transformation possible, it is essential to have access to financing mechanisms that guarantee the implementation of sustainable projects, programs and actions. These mechanisms not only provide financial resources, but also promote innovation, multisectoral participation and the integration of public



policies, becoming pillars for building cities capable of adapting to and mitigating climate impacts (IPCC, 2022; UNCDF, 2024).

In the national context, mechanisms such as the National Climate Change Fund (Fundo Clima) and the National Environment Fund (Fundo Nacional de Meio Ambiente - FNMA) stand out, offering resources for green infrastructure, waste management and urban resilience projects. These funds, in addition to the traditional, incorporate innovative approaches, such as Payments for Environmental Services (PES) and the Fines Conversion Program, which encourage environmental conservation and the recovery of degraded areas (Brasil, 2020d; Brasil, 2021c; BNDES, 2024b). In addition, mechanisms such as parliamentary amendments and participatory budgeting allow local communities to directly influence the targeting of resources for priority initiatives, such as urban afforestation and climate adaptation (Brasil, 2024e; São Paulo, 2024). Private funds and public-private partnerships (PPPs) have also gained relevance, attracting investment for large-scale projects such as urban parks and renewable energy systems (Mishra et al., 2023b; C40, 2024).

Brazil also has a set of urban policy instruments that also offer significant potential for climate finance (Maleronka, 2025). Among the tax instruments are the Urban Property Tax (IPTU) and the improvement contribution, which make it possible to recover part of the appreciation generated by public investments. Non-tax instruments include urban development obligations in land parceling projects, the onerous grant of change of use, the onerous grant of the right to build, the transfer of the right to build, density bonuses and the consortium urban operation, all of which are provided for in the City Statute (Brasil, 2001; Rossbach, 2016) and have the potential to finance green infrastructure, social housing and interventions aimed at climate adaptation (Smolka, 2014; Maleronka, 2025). The literature highlights that, when applied systemically and adapted to local technical and political conditions, these instruments can strengthen the fiscal capacity of municipalities and enable structuring investments aimed at urban resilience and ecological transition (Aurélio Costa, 2023; Caldas, 2023; Nobre, 2023; Machado, 2025).

Still in the sub-national spheres, the Tax on the Circulation of Goods and Services (ICMS) also allows states to establish environmental or socio-environmental criteria that benefit those municipalities that demonstrate specific environmental actions, such as the recovery of



springs, the creation of municipal Conservation Units or even the closure of "dumps" and the correct disposal of solid waste through the creation of sanitary landfills (Moura, 2015).

At the international level, funds such as the Green Climate Fund (GCF) and the Climate Investment Funds (CIF) and the Global Environment Facility (GEF) stand out for financing large-scale climate adaptation and mitigation projects, with a focus on Nature-Based Solutions (NBS) and low-carbon technologies (GCF, 2024; CIF, 2024). Multilateral banks, such as the World Bank and the Inter-American Development Bank (IDB), are also key, offering resources for green infrastructure and sustainable mobility (Brasil, 2024h). In addition, initiatives such as the C40 Cities Finance Facility and the Global Climate Change Alliance Plus (GCCA+) provide technical and financial support for the implementation of resilient urban policies, connecting cities to global financiers (C40, 2024; GCCA+, 2024). These international mechanisms, most of which are emerging, complement national resources, expanding the reach and effectiveness of local initiatives (GEF, 2024; Adaptation Fund, 2024).

Below are the main national and international mechanisms for promoting and enabling financial resources for the construction and adaptation of resilient green cities.

National Mechanisms

1. National Climate Change Fund (Fundo Clima): Managed by the BNDES, it offers specific credit lines for resilient and sustainable urban development projects, including waste management, energy efficiency, green and blue infrastructure, and urban resilience (BNDES, 2024b).
2. National Environment Fund (FNMA): Offers non-reimbursable resources through calls for proposals for projects to reduce climate vulnerability in urban and rural areas, such as urban green areas, water security and urban agroecology (MMA, 2023).
3. Fund for the Defense of Diffuse Rights (FDD): Finances environmental protection initiatives, such as the recovery of degraded areas, with a focus on sustainable development and social inclusion (MJ, 2024).
4. Subnational funds: State and municipal funds, such as São Paulo's Special Fund for the Environment and Sustainable

- Development (FEMA), support local green infrastructure and environmental management projects (São Paulo, 2024).
5. Fines Conversion Program): This program allows environmental fines to be converted into investments for environmental recovery and conservation projects. It is a strategic tool for financing green infrastructure initiatives and nature-based solutions (NbS) in urban areas (Brasil, 2020d).
 6. Parliamentary amendments: Funds from parliamentary amendments can be directed towards green infrastructure projects, sustainable mobility and urban waste management, especially in small and medium-sized cities (Brasil, 2024e).
 7. Environmental Compensation: Mechanisms such as environmental compensation and voluntary programs, provided for in Law 12.651/2012, can finance environmental restoration and conservation projects (Brasil, 2012a).
 8. Payments for Environmental Services (PES): Remunerates providers of environmental services, such as the maintenance of urban green areas and the conservation of ecosystems (Brasil, 2021c).
 9. Participatory Budgeting: Participatory processes, such as Participe+ in São Paulo, allow the population to indicate priority proposals for public investment, such as climate adaptation plans and the implementation of rain gardens (São Paulo, 2024).
 10. Private Funds: Investments from private companies and foundations can be mobilized for CVR projects, especially those aligned with corporate sustainability goals, such as environmental, social and governance (ESG). These funds are important for complementing public resources and broadening the scope of initiatives (Mishra et al., 2023b).
 11. Voluntary Programs: Voluntary initiatives, such as donations from companies or philanthropic organizations, can be channeled into implementing CVR projects. These programs are flexible and can support local actions, such as urban afforestation and the creation of green areas (IPCC, 2022).
 12. *Blended finance*: Focused on attracting private investment to projects with a high social or environmental impact, using public or philanthropic resources as a catalyst for projects with less attractive financial risks or returns in the short term (OECD, 2018; BNDES, 2021).
 13. Public-Private Partnership (PPP): Long-term agreements between the public sector and the private sector for the execution of infrastructure projects or public services. Focused

- on the division of responsibilities and risks between the public and private sectors. Tax incentives and public guarantees reduce financial risks for investors, while prioritizing public interests such as affordable housing and climate resilience (World Bank, 2017).
14. Carbon credits: The generation of carbon credits through urban NbS can finance local climate mitigation and adaptation initiatives. For example, clean energy, sustainable mobility and ecological restoration projects help reduce greenhouse gas (GHG) emissions and improve air quality in cities. The creation of regional markets for carbon credits is a promising strategy (IPCC, 2022). In this regard, Law 15.042/2024 establishes the Brazilian Greenhouse Gas Emissions Trading System (SBCE) (Brasil, 2024g).
 15. Green and Sustainable Bonds: These financial instruments raise funds on the market for projects with a positive environmental impact, such as the revitalization of degraded areas. The issuance of green bonds has grown globally, offering opportunities to align financial returns with sustainable results. Technologies such as *blockchain* can be used to monitor results and increase investor confidence (Mishra et al., 2023a).
 16. Urban policy instruments as set out in the City Statute: Urban Property Tax (IPTU), improvement contribution, urban obligations in land parceling projects, onerous grant of change of use, onerous grant of the right to build, transfer of the right to build, density bonus and consortium urban operation (Brasil, 2001; Smolka, 2014; Rossbach, 2016; Maleronka, 2025).
 17. Tax instruments, such as the Tax on the Circulation of Goods and Services (ICMS): municipal transfers can be linked to socio-environmental criteria (Moura, 2015).

International Mechanisms

1. Multilateral Development Banks (MDBs): Institutions such as the World Bank, the Inter-American Development Bank (IDB) and the Development Bank of Latin America (CAF) finance green infrastructure projects, sustainable mobility and low-carbon technologies on a large scale (MPO, 2024).
2. Climate Investment Funds (CIF): Finances pilot projects in developing countries, with a focus on energy transitions, climate resilience and nature-based solutions (NBS). The Climate Smart Cities program is particularly relevant to CVR (CIF, 2024).

3. Green Climate Fund (GCF): Provides technical and financial support for projects with large-scale replication potential, such as urban ecological corridors and SbN-based stormwater management systems (GCF, 2024).
4. C40 Cities Finance Facility: Facilitates the implementation of pioneering CVR projects, offering technical and financial support to align proposals with global climate objectives (C40, 2024).
5. Global Environment Facility (GEF): Finances biodiversity conservation projects, the creation of green spaces and sustainable land use planning, with a focus on blue-green infrastructure and ecological corridors (GEF, 2024).
6. Adaptation Fund: Finances pilot and scale projects that use SbN to manage floods, urban heat islands and water management problems, especially in vulnerable cities (Adaptation Fund, 2024).
7. The Rockefeller Foundation Resilient Cities Initiative: Supports technical training, study, articulation, governance in resilient infrastructure projects, such as solutions to heat islands and floods (Rockefeller Foundation, 2024).
8. Climate Action Fund - UNFCCC: Supports projects aligned with the goals of the Paris Agreement, especially in urban mitigation and SbN, with a focus on biodiversity and urban planning (UNFCCC, 2024).
9. Cities Climate Finance Leadership Alliance (CCFLA): Facilitates access to finance for urban greening and low-carbon development, attracting private investment for green infrastructure (CCFLA, 2023).
10. Nature4Climate: This coalition is committed to accelerating investment in BNH in the fight against climate change for the benefit of people and biodiversity, in particular through advocacy, communication and networking (Nature4Climate, 2024).
11. The European Union's Global Climate Change Alliance Plus (GCCA+): Provides technical and financial assistance for capacity building and governance reform related to climate adaptation in urban areas, with a focus on resilient urban policies (GCCA+, 2024).

3.5.3. Increased Access to Financing

Increasing access to funding for projects, programs and actions aimed at building CVRs is a central challenge not only for the implementation of urban adaptation measures. The transition to more sustainable cities adapted to climate change requires robust and accessible financial resources, capable of enabling initiatives such as green infrastructure, nature-based solutions (NbS), low-carbon technologies and sustainable waste management. However, the complexity of funding mechanisms, a lack of technical capacity building and bureaucratic barriers often limit access to these resources, especially for groups such as traditional communities, indigenous peoples, small and medium-sized landowners and even small and medium-sized municipalities. To overcome these challenges, it is essential to adopt strategies that facilitate access to funding, combining traditional and innovative mechanisms, as well as promoting inclusive and decentralized governance models.

According to the CHAMP 2024 report (Samuels & Maehara, 2024), particularly for sub-national governments, there is a financing deficit for climate actions that limits investments and hinders access to resources, mainly due to fiscal restrictions, lack of structured projects or low credit capacity. In these cases, access to funding is one of the biggest obstacles. It is common for cities to have already identified what they need, but to be paralyzed by the lack of access to funding streams or calls for proposals, always presenting difficulties in terms of their ability to access resilience funding (MCR2030, 2024).

Strategies to facilitate access to financing are equally important to ensure that resources are made available in an equitable and efficient manner. Partnerships are one such strategy, combining the management capacity of the private sector with lower interest rates from the public sector, which reduces the costs and risks associated with projects (World Bank, 2017). Another approach is the creation of national climate finance funds, which centralize resources for climate adaptation and mitigation projects, ensuring greater transparency and efficiency in the allocation of resources (Samuels & Maehara, 2024). These strategies not only increase access to resources, but also promote the active participation of different actors in the governance and implementation of projects.

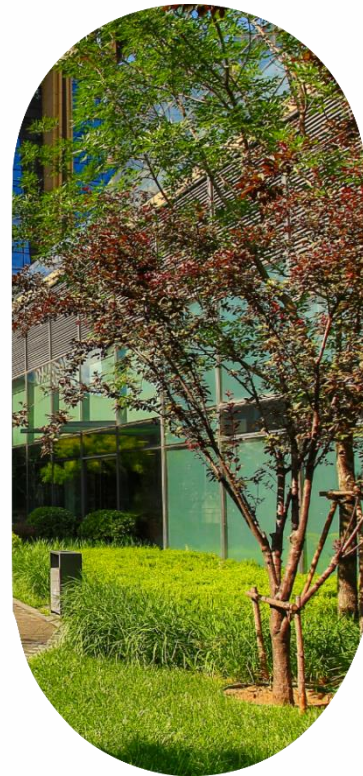


Equitable green financing mechanisms can improve resilience in all sections of society (Ojo, 2024b). In the specific case of traditional communities and indigenous peoples, expanding access to finance is crucial, given their importance in environmental conservation and the implementation of NbS. Strategies such as targeted subsidy programs, technical training and simplification of bureaucratic processes are necessary to ensure the active participation of these groups. Thus, these targeted programs can correct some social inequalities, ensuring that some more vulnerable groups also have access to improvements and results. In addition, tax incentives and training programs can strengthen the capacity of these communities to design and manage sustainable projects, ensuring that the environmental and social benefits are distributed equitably.

Small and medium-sized landowners also play a vital role in implementing SbN, such as restoring degraded areas and adopting regenerative agricultural practices in urban areas. In Brazil, the Growth Acceleration Program - New PAC and the Brazil Climate Investment Platform (BIP) are examples of initiatives that seek to integrate public and private investments to promote the ecological transition. The BIP, in particular, focuses on priority sectors such as the bioeconomy and regenerative agriculture, offering opportunities for small producers to access sustainable resources and technologies (Brasil, 2023e; BNDES, 2024c). These initiatives demonstrate how well-structured public policies can expand access to financing for historically marginalized groups, promoting climate and social resilience.

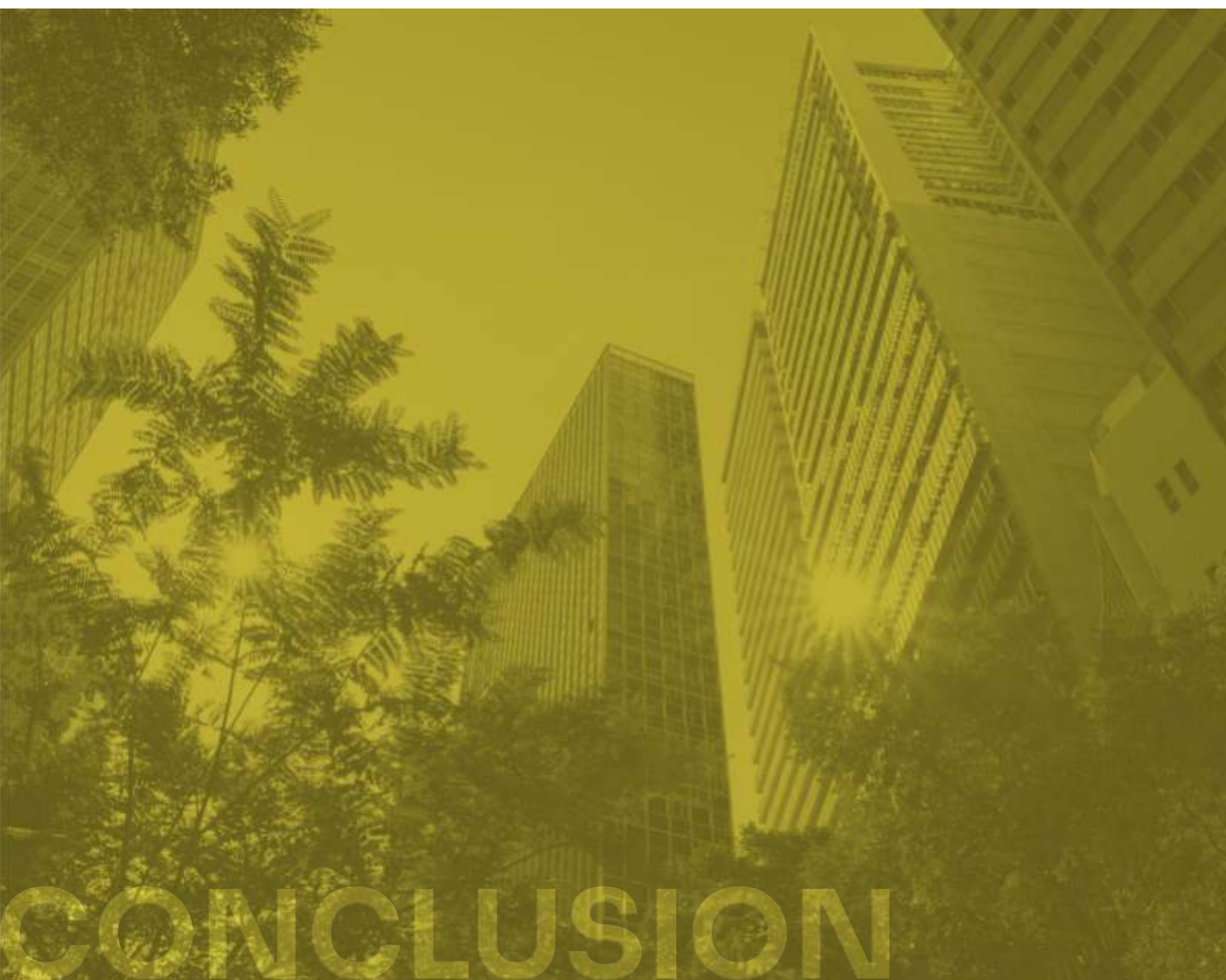
To ensure that access to funding is expanded in an equitable and efficient manner, actions such as local capacity building, the establishment of collaborative networks and the use of technology and innovation are recommended. Training programs for municipalities, local organizations and communities on project preparation and fundraising are essential, especially in small and medium-sized cities. The creation of regional consortia can increase the strength of proposals submitted to national and international funders, while digital platforms can connect projects to investors, ensuring transparency and traceability of results (Samuels & Maehara, 2024). In addition, strengthening public policies, such as incorporating BNN into municipal master plans, can create legal frameworks that guarantee access to financial resources and greater security for investors.

Increasing access to funding for building resilient green cities is essential for implementing effective public policies. Targeted strategies are key to ensuring the participation of diverse actors in the implementation of SbN and climate governance. By simplifying funding mechanisms and strengthening public policies, Brazilian cities can become global models of climate resilience, transforming environmental challenges into opportunities for sustainable development.



4

CONCLUSION



4. CONCLUSION

The assessment of scientific and technical knowledge on the construction of resilient blue-green cities in Brazil, carried out in this report, revealed a set of critical issues, obstacles to be overcome, priorities to be addressed, opportunities to accelerate and enhance adaptation, as well as some solutions that are proving promising for reducing socio-climate risks in general. It also revealed that research in Brazil still has some knowledge gaps that hinder and delay the process of transforming cities into more equitable and resilient systems.

As has been widely demonstrated, increasingly frequent disasters are not caused by climatic events, but by the interaction of these events with the vulnerability of what is exposed to them. Vulnerability therefore becomes an essential variable in determining the impacts that systems will suffer from climate change. Vulnerability also becomes an essential variable for understanding who will suffer most from losses and damages caused by the residual risk of ineffective mitigation and adaptation processes — and the data clearly show that it will be the poorest populations and marginalized and precarious areas of urban or rural territories.

In cities in the global south, although not exclusively, socioeconomic inequality and all its repercussions on the territory are one of the factors that most influence the vulnerability of people, institutions, and places. As such, adaptation processes that aim to create climate-resilient systems (urban or otherwise) are compelled to act objectively to reduce socioeconomic, territorial, and climate inequalities if they are to achieve a state of lasting and consistent resilience. In adaptation processes that also act to reduce inequalities, the system undergoes a change at the root of the problem, which causes and allows vulnerability to be transferred and reproduced indefinitely. Processes such as these are called transformative adaptation, which is proving to be a priority form of adaptation, especially in countries in the global south, capable of avoiding maladaptation processes, which have been observed to be predominant in Brazil and almost everywhere else in the world. In addition, science has shown that for adaptation processes to be truly transformative and avoid adverse, unplanned effects (maladaptation), especially regarding the expansion of socio-territorial and climate injustices and inequalities that lead to the reproduction and transfer of vulnerability (between groups and



places), there is a need for integrated, multiscale, multisectoral, and, above all, inclusive governance (with the adoption of effectively participatory and collaborative strategies), as well as long-term planning capacity and integration between human and ecological systems—between cities and natural areas.

The systemic integration of natural areas — green and blue — into urban and territorial planning is emerging as a promising strategy for strengthening climate resilience, expanding socio-environmental equity, and promoting quality of life in cities. However, this potential faces concrete obstacles in the disconnect between urban and environmental planning, reflected in fragmented policies, overlapping regulations, and unequal access to the benefits generated by these integrated natural spaces. The adoption of the watershed as a strategic planning unit offers an opportunity to articulate ecosystems, infrastructure, and land use in order to increase biodiversity, ecosystem services, and resilience to extreme weather events. In this scenario, Nature-based Solutions (NbS) stand out for their cross-cutting and multi-benefit approach, aligning conservation, climate adaptation, and territorial justice. Even so, their implementation is often limited by institutional, economic, and social barriers, as well as legal loopholes that allow environmental guidelines to be relativized in urban land use planning processes. Added to this is the lack of validated indicators that can comprehensively measure ecological functionality, the provision of ecosystem services, equity in access, and the multiple social and environmental benefits associated with natural areas. These challenges point to the need to integrate environmental and urban policies through legal and planning instruments that recognize natural areas as essential infrastructure for resilience. This implies strengthening the use of watersheds as a planning unit, expanding the application of SBN with territorial justice, and developing indicators capable of guiding evidence-based decisions.

Most cities are still developing without maintaining open or natural spaces and without promoting green and blue areas that are conserved or protected in already urbanized areas, with a negative impact on the quality of life in urban areas. The vast majority of technical and scientific publications have shown that these areas are fundamental for human well-being and, increasingly, for tackling the climate emergency. Therefore, resilient cities will require special attention to preserve or create significant natural areas (including green and blue



areas). Although it is possible to (re)convert urban spaces (with measures ranging from street tree planting or the implementation of flower beds on avenues to the conversion of underutilized open areas into urban parks, linear parks, and conservation units), it is necessary to prioritize preventive actions and the conservation of environmental quality throughout the urbanization process, as well as organizing their management into functional municipal systems of natural, green, and blue areas, safeguarding spaces with less urbanized characteristics (with less paving and construction, more permeable areas, more silence, less visual and noise pollution, etc.), while integrating them with the urban dynamic. In addition, the urbanization process in Brazil has created cities with an uneven distribution of green areas, resulting in biotic homogenization and restrictions on the availability of these areas, especially for lower-income populations, which represents a major challenge for promoting well-being in urban centers. The adoption of nature-based solutions and the strengthening of environmental planning policies integrated with other sectors stand out as opportunities, since the requalification and proper management of urban green spaces have the potential to reduce cases of arboviruses and social and economic costs associated with the treatment of chronic non-communicable diseases, in addition to promoting the mental health of the population. However, there is still a knowledge gap about the relationship between green areas and human health in cities, with clear indicators to measure the impact of these areas on the health of the population in the context of climate change.

The urbanization pattern that characterizes Brazilian cities, particularly large cities and megacities, is unsustainable and non-resilient. It is a sprawling model, disconnected from the logic of the ecological systems (green and blue) present in the territory, with large impermeable areas advancing over valley bottoms, floodplains, steep slopes, low-lying coastal areas, and a set of situations that increase the risk conditions for the system. These cities are fragmented, both socially and economically and, as a result, spatially, in reinforcing socio-territorial inequalities and the marginalization of a large part of the population. The housing deficit, both qualitative and quantitative, is evident in Brazilian cities, and informality, both in housing and in work, creates a very significant challenge for resilience. Similarly, deficiencies in sanitation, water supply, and urban drainage systems widen the gaps between rich and poor areas within cities, but also between cities. The road-based model is predominant, with huge public transport deficiencies — reinforcing territorial fragmentation



and marginalization of less affluent populations — and is therefore intensive in private car use and fossil fuel consumption. All these characteristics, common to medium-sized, large, and mega-cities in Brazil, reflect the country's enormous socioeconomic inequality and create a condition of vulnerability that increases socio-climate risks in general, but imposes a very unequal distribution of these same risks across urban areas and their populations. They impose a very high pattern of energy consumption and GHG emissions, causing heat islands and recurrent flooding. With the enormous concentration of people in cities and the concentration of cities in coastal areas, these systems are now at high risk, and disasters are being observed with greater frequency, with increasingly significant losses and damage.

Investments in urban adaptation are still low, especially when compared to investments in mitigation, and many of the actions correctly prioritize the housing, sanitation, and transportation sectors, but they do so within a non-resilient construction model, wasting the opportunity to carry out such works in a way that contributes to the resilience of the system (by applying adaptive parameters) and thus delaying adaptation. Brazilian cities have been prioritizing gray solutions, which reproduce a non-resilient pattern of urbanization and contradict the understanding that hybrid solutions — which combine conventional engineering techniques, known as “gray,” with green techniques—are more promising. Adaptation and mitigation plans, articulated and adequately coordinated with urban territorial planning (master plans and other instruments), are still very limited among Brazilian municipalities in the long term, and this hinders the adaptation process. Adaptive and transformative urban planning requires a real understanding of climate threats within climate change scenarios, as well as the vulnerabilities of systems, which are always location-specific. Thus, one of the relevant knowledge gaps for planning resilient cities is the ability to generate, access, and manipulate climate data, scenarios, and socio-climate vulnerability assessments at the local level.

Disaster contingency actions (policies, plans, and projects) predominate over long-term integrated planning, which would allow for preventive and transformative action. Instead, reactive actions and reconstruction are favored. As a result, greater losses and damage fall on already vulnerable populations, and the prospect of changing this situation is very limited, as is the prospect of migrating from an unsustainable development model to a climate-resilient development



model. The transformative adaptation of cities and the adoption of a climate-resilient development model for human systems also requires investment in human capital, in order to increase the adaptive capacity of individuals, groups, and institutions, but also integration between natural, rural, and urban systems, as well as integration between different territorial and administrative scales and, last but not least, integration between different sectors or subsystems (natural areas, land use and occupation, mobility, sanitation, housing, etc.) within the urban system.

With regard to urban mobility systems, active mobility, especially walkability, is central to climate change adaptation and mitigation in cities, considering that most urban travel is done on foot. Promoting urban environments that prioritize walking not only reduces dependence on motorized vehicles, but also enhances social, environmental, and public health gains. At the same time, it is essential to expand efficient and inclusive public transportation that offers viable and fair alternatives to individual motorized transportation. The concept of 15-minute cities, adopted in Paris and in Latin American experiences such as Bogotá and Buenos Aires, exemplifies how reorganizing urban space to facilitate walking can be a cross-cutting strategy, integrating transportation, land use, and environmental quality. For this transition to be fair and effective, it is essential to incorporate gender perspectives and meet the needs of vulnerable populations. Thus, active mobility and public transportation are fundamental axes for building resilient, sustainable, and inclusive cities in the face of current climate challenges.

In the basic sanitation sector, analysis of the information collected highlights the precarious nature of water supply, sewage, and urban drainage services in Brazil, and the intensification of these challenges in the face of climate change. One of the biggest obstacles is the lack of infrastructure in vulnerable areas, such as slums and informal settlements, where service provision is limited and unequal. On the other hand, a promising opportunity arises in the adoption of hybrid solutions — which integrate green-blue-gray infrastructure — capable of mitigating flooding and increasing the resilience of urban systems, providing ecosystem benefits to cities. To enable this opportunity to move forward, an important knowledge gap must be filled regarding the integration of legal frameworks governing water resources, sanitation, and climate adaptation, which limits coordinated action. The adaptation process of Brazilian cities would benefit from



systematic and more comprehensive investment in research on the effectiveness of nature-based solutions in different urban contexts, internalizing the various potential co-benefits that such measures can bring to the population and natural systems.

The housing sector, especially considering the enormous challenge of informality in Brazilian cities and the large deficit (quantitative and qualitative) that still exists in the country, is possibly one of the most critical sectors for transforming cities into systems that are resilient to climate change. Informality and poor housing conditions pose significant obstacles to adaptation, which can only be overcome by directly addressing social and spatial inequalities. Recurring housing projects, plans, and policies that address impacts related to climate change focus on reducing risks to the physical safety of homes and populations, mainly related to flooding and landslides, in an incremental rather than transformative manner. They also include contingency and recovery plans and measures. Among the solutions are the conversion of vacant properties into social housing, land regularization, housing improvement, and slum urbanization, always accompanied by the provision of sanitation infrastructure (water supply, sewage, storm water drainage, and solid waste collection). Recurrently, when these actions are focused on reducing geotechnical and flooding risks, population relocation is adopted as the preferred solution, which is, in most cases, an incremental measure that leads to adverse effects, including urban expansion and inequalities and the transfer of vulnerabilities and risks (maladaptation). It is not common for adaptation or risk reduction actions in the housing sector to be guided by local climate change data and scenarios, but rather by known climate patterns, limiting the longevity of the intervention and its ability to build resilience. Finally, the report highlights that the effectiveness of these adaptation actions generally depends on good coordination between sectors and the active participation of the population through inclusive participatory processes to prevent the repetition of patterns of segregation and maladaptation. Processes led by the communities themselves or with strong social participation help to strengthen their adaptive capacity — by raising public awareness of the climate emergency, risk perception, and knowledge of available solutions, collective organization capacity, and strengthening solidarity networks, trust, and capacity for cooperation with the government — in addition to promoting greater socio-territorial and climate equity and justice.



Brazilian cities are also challenged by migration processes that are occurring and intensifying due to climate change and its related impacts. The implementation of strategies to analyze climate displacement flows can enable governments to anticipate trends and, based on this, stay ahead of the problem by developing appropriate public policies to ensure resilient green cities, including displaced persons as part of the adaptive response of cities. In this regard, it is worth noting the consistent knowledge gap in the absence of an accurate displacement monitoring system that is fed before, during, and after movements, and the lack of disaggregated data that breaks down information such as age, sex, and health status. Another challenge is the development of national legal frameworks that consider the perspective of climate justice when addressing forced climate displacement, paying special attention to the most vulnerable groups. Finally, with a focus on the latter, there is an opportunity to study more in depth some successful examples, such as Fiji's Planned Relocation Plan, in order to apply consistent procedures to ensure that planned relocations in Brazil are sustainable at all stages of implementation.

This report also explored, with special attention, the potential of NbS for promoting climate-resilient urban systems, highlighting that their application has proven to be a promising option for addressing the challenges of the climate crisis, simultaneously promoting urban adaptation and biodiversity conservation, as well as well-being and quality of life for people. The creation, recovery, and conservation of green and blue areas, integrated with public policies and urban infrastructure, allows for the mitigation of climate extremes, improves quality of life, and strengthens socio-environmental resilience. Urban forests, for example, are emerging as promising NbS for tackling floods and heat islands, while promoting public health and socio-environmental equity. However, the lack of integrated planning, technical resources, and investments in proper management limits their potential, especially in peripheral areas, where the lack of green infrastructure exacerbates vulnerabilities. It is important that NbTs be implemented on a scale appropriate to the challenges they are intended to address. A promising opportunity lies in the implementation of interconnected green-blue systems, which can expand ecosystem services and reduce public costs for health and climate adaptation. However, there is still a gap in the systemic and equitable implementation of these solutions, especially in Brazilian cities, where there is inequality in access to urban green spaces and a



lack of integrated guidelines for multisector y management. The opportunity lies in consolidating national programs such as the PCVR and formulating applicable metrics such as the 3:30:300 rule, combining environmental justice, social participation, and ecological innovation. Some of the biggest challenges for the adoption of NbS are the effective training of all stakeholders—public and private—the lack of legal frameworks, and sources of financing. There is a knowledge gap in monitoring the efficiency and effectiveness of implemented NbS projects. Key indicators for adapting cities to more severe climate events, as well as the various ecosystem services that each project offers, should be considered. Future research also needs to investigate the limits and potential of NbS in densely urbanized tropical contexts, especially their effectiveness in reducing climate vulnerabilities in peripheral territories. There is also a knowledge gap regarding resilient tree species and effective urban restoration strategies, requiring research that combines ecology, urban planning, and inclusive public policies.

From a climate-resilient systems planning perspective, integrating urban and ecological systems and applying NbS, the report paid particular attention to the role of water in cities. Section 2.3. Water and Sustainable Urban Planning explores a regenerative urban planning approach that aims to integrate cities into the biomes in which they are located. An example of this methodological approach is Research by Design, as through the 3PSPa, which allows for the progressive co-development and continuous improvement of adaptive, transdisciplinary, participatory, and multiscale planning and a commitment to the creation of socio-environmental public policies based on a strategy of building biomimetic cities, redesigned from the matrix of their biomes.

The last section of the report explored technical and scientific knowledge on the following topics: climate governance; participation and inclusion in urban resilience actions; implementation of urban adaptation policies; the challenge of climate migration processes; and financing adaptation.

As already discussed in this conclusion, there is almost unanimous agreement that robust governance strategies and mechanisms, with horizontal and vertical integration of multiple actors, intersectoral, multiscale, and capable of supporting long-term processes and



articulating regulatory, institutional, and financial instruments, are critical to the success of adaptation.

Climate change imposes significant economic costs on Brazil, requiring above all that urban populations and their cities be prepared and adapted to these impacts. Thus, the creation of resilient blue-green cities requires the expansion and diversification of climate finance mechanisms, combining traditional, innovative, and mixed instruments, such as carbon credits, national and foreign multilateral funds, PSAs, and green bonds. The implementation of CVR structures requires robust financing that can guarantee the viability, durability, and scalability of these projects. It is essential to integrate national and subnational public policies with global strategies, such as the UN SDGs and the Paris Agreement.

The most significant challenge today is equitable and effective access to these resources, especially in a country as socially and environmentally unequal as Brazil. Small and medium-sized municipalities, traditional communities, indigenous peoples, and small rural or urban landowners suffer from limited access due to technical, fiscal, and bureaucratic barriers, preventing projects with positive socio-environmental impacts from being implemented.

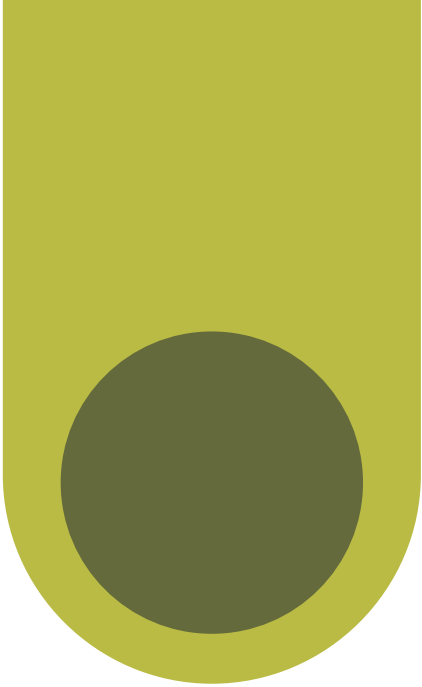
Alternatives or public policies that establish coordinated and decentralized national and subnational climate finance programs, investing in technical training, simplifying access procedures, encouraging intermunicipal or regional consortia, and developing digital platforms that can connect good projects with good investors are some of the most promising opportunities.

On the other hand, there are gaps in regulatory and institutional instruments that could interrelate existing instruments, such as the Master Plan and the Payment for Environmental Services Program, as well as the absence of mechanisms for multiscale measurement and assessment of the environmental, social, and economic impacts of financed projects, allowing for the monitoring, comparison, and adjustment of the performance of financed VRC initiatives, applying combined metrics (climate, equity, economy, health) and emerging technologies (such as geospatial models or blockchain) in order to provide greater transparency, traceability, and attractiveness of projects for public or private financiers.

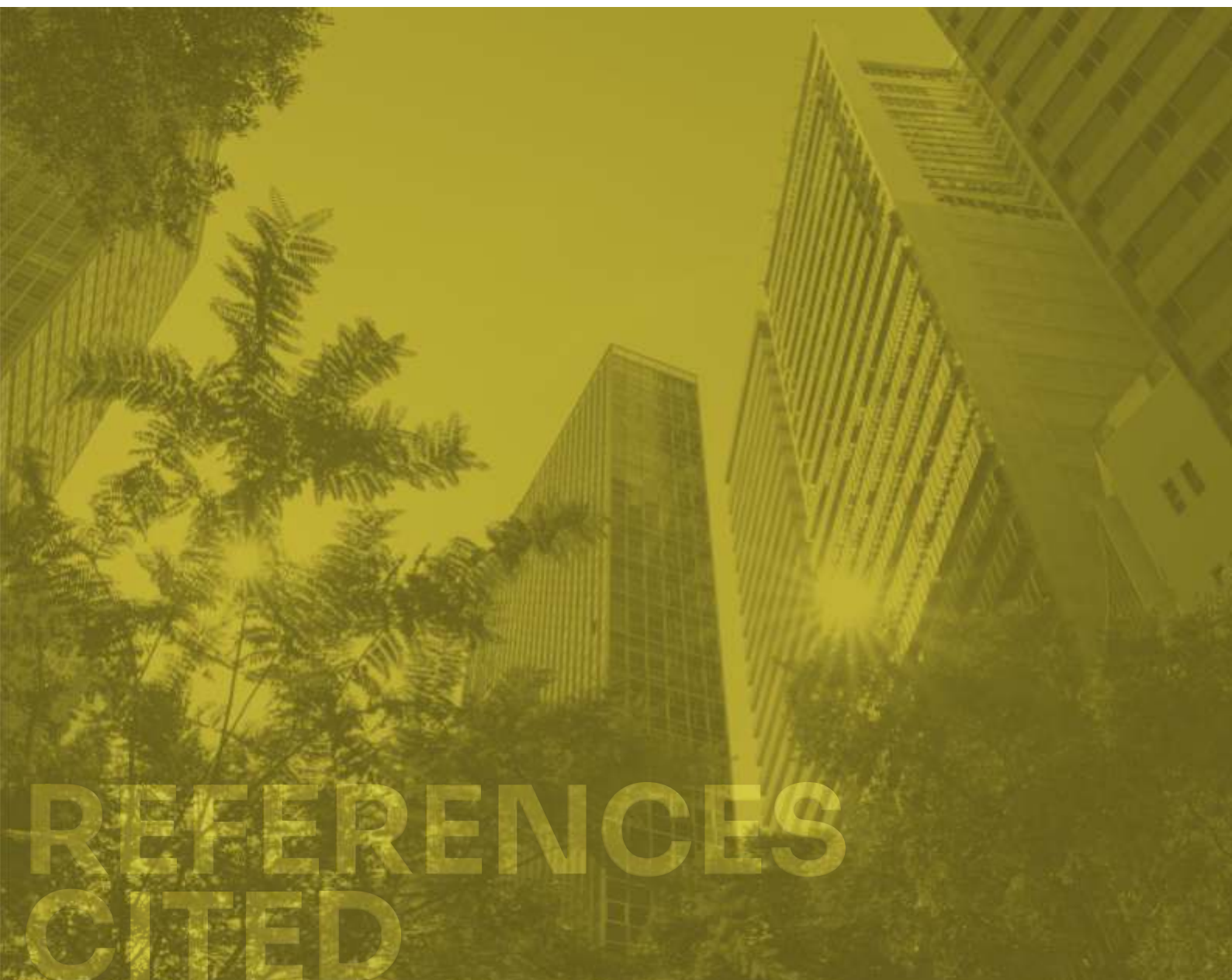


With regard to existing federal public policies that address climate challenges, the Resilient Green Cities Program and the Climate Plan offer an opportunity to integrate national policies with subnational efforts in different urban and rural contexts. Monitoring and evaluating the results of the two initiatives mentioned above is an opportunity for future research, considering the different methodologies for evaluating existing public policies and the potential contribution to the government for refining these approaches, which, in essence, aim to integrate federal government actions for cities, promoting increased urban resilience in Brazil.

This report highlighted the enormous challenge that climate change poses for science and public management in preparing cities for a resilient future, but it also pointed to a set of opportunities and solutions that are already being applied around the world and in Brazil to adapt urban and ecological systems, which are inextricably linked. There is still a great deal of work to be done to expand research and technological development that will enable knowledge-based decision-making, and a major effort is still needed to ensure transformative and truly inclusive adaptation processes in order to increase socio-territorial and climate equity and justice and the resilience of Brazilian cities.



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The complexity of the effects of global environmental and climate change, including their future projections, requires interdisciplinary and transdisciplinary approaches. These approaches are essential for understanding the interactions between social, biophysical, and ecological systems, characterizing the risks of impact, vulnerability, possibilities for mitigating their causes, and adaptation solutions. The Synthesis Center on Environmental and Climate Change (SIMACLIM) has as its main mission to integrate accumulated and ongoing research from various national and international research networks and groups, organizing information and assisting in Brazilian government planning to achieve goals established in agreements on climate change. SIMACLIM is funded by the Ministry of Science, Technology and Innovation (MCTI) through the National Fund for Scientific and Technological Development (FNDCT), FINEP Process 01.22.0584.00.

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