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Governing Urban Climate Resilience (UCR): Systems, Agents, and Institutions in Shanghai, China

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Abstract: Climate change and urbanization intersect with escalating danger. Urban areas significantly contribute to climate change, which, in turn, poses severe threats to urban settings. The frequency and intensity of extreme events, like flooding and heat, are rising, with the need to enhance urban climate resilience (UCR) becoming more immediate. Scholarship tends to underrepresent general climate resilience in favor of specific hazards. This research seeks to contribute to the literature by exploring the case of Shanghai, China, discovering the mechanisms and characteristics of UCR governance, and examining how these outcomes are formed from a comparative gesture. The findings indicate that in Shanghai, 36.8% and 26.8% of climate resilience governance strategies are reflected in regional management and infrastructure construction led by the Water Affairs Bureau and the Meteorological Bureau. Furthermore, 30.6% of the strategies relate to the Water Affairs Bureau, showcasing a robust and integrated flood response. Meanwhile, 15.7% involve the Meteorological Bureau, boosting responses to high temperatures with better monitoring and early warning for increased flexibility and efficiency. Distinct governance processes for floods and extreme heat mirror these hazards' inherent characteristics and societal perceptions. With strong government willingness and support, Shanghai has rapidly enhanced its flood resilience capabilities within a brief timeframe. Conversely, addressing the emerging risk of extreme heat is still in the early stages of evaluation, due to the lack of a clear disaster-bearing system and identified responsible agents. This research suggests that the future of climate resilience governance in Shanghai may emphasize identifying the characteristics of critical climate-related risks, expanding social autonomy through grassroots self-governance, procuring economic backing from the central government, and applying the tool of urban spatial planning.

Keywords: climate change; resilience; urban governance; planning; policy

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1. Introduction

As global temperatures rise, climate change has become a most persistent, significant, and dynamic challenge for humanity [1]. The adverse impacts of climate change become increasingly apparent with the accumulation of greenhouse gas emissions. The IPCC Sixth Assessment Report (AR6) underscores the severity of these changes, revealing that human-induced climate change is driving widespread and rapid alterations in the atmosphere, ocean, cryosphere, and biosphere, thereby influencing weather and climate extremes worldwide [2]. Despite their global implications, the immediate and pronounced effects of climate change are often experienced at a local scale, particularly in cities [3]. The effects of urbanization and climate change are converging in dangerous ways. Urban areas are major contributors to climate change, accounting for over 70 percent of greenhouse gas emissions from global final energy use [4]. Meanwhile, urbanization puts the 4.2 billion inhabitants at risk through a combination of urban heat island (UHI) effects, air pollution [5], and climate-related hazards, such as floods, cyclones, storms, drought, and extreme heat and cold events [6,7]. However, this crisis has galvanized diverse stakeholders to collaborate on enhancing adaptation strategies, positioning cities as vital arenas for innovating and testing solutions to climate-related challenges [8,9]. This duality of cities as both centers of vulnerability and innovation underscores a critical narrative in the discourse on climate change [6,10–12].

Urban climate risks as complex systems challenges arise from the intricate interactions between social and ecological systems [13]. According to Holling (1978) [14], complex systems demand resilient governance, enabling policies and governance mechanisms to cope with unforeseen conditions. Academia's interest in the governance of urban climate resilience (UCR), including its necessity [9,15,16] and barriers [8,17–19], is rapidly evolving. Research targets specific hazards like floods in Asian cities [20–22] and extreme heat in North American urban areas [23,24]. Yet, a comprehensive grasp of UCR planning, policy dynamics, and characteristics remains limited, particularly in multi-hazard scenarios [25]. There is a need for cities, especially coastal cities, to foster general climate resilience rather than to focus solely on one specific resilience aspect because a particular resilience to risks could diminish the capacity of another [26]. The research employs a comparative lens to examine the mechanisms of urban governance tools in their response to different hazard scenarios, aiming to assess the generalization of UCR.

For these reasons, we selected Shanghai, a coastal megacity in East Asia, as our case study. China's coastal regions, housing over 78 million people, are mainly concentrated in the megacities of Shanghai, Guangzhou, Tianjin, and Shenzhen, accounting for 86.5% of the coastal Chinese population [27,28]. Shanghai, facing heightened climate risks with a decade-long temperature increase of 0.415 °C, has witnessed more frequent and severe extreme weather events [29]. For instance, in July 2022, Shanghai endured over 50 consecutive days of extreme heat, reaching a record high of 40.9 °C [30]. Additionally, in July 2021, the Typhoon "*In-fa*" made landfall, marking the rainiest typhoon in Shanghai's history [31]. Similar climate change trends are occurring in other Chinese coastal cities.

Since 2013, China's central government has initiated climate change responses, encompassing national strategic planning, the establishment of climate monitoring and early-warning systems, and the development of both gray and green infrastructure, alongside designating pilot cities for adaptation efforts. Shanghai has progressively implemented these initiatives, aiming to develop a distinctive climate resilience model for megacities. However, existing research on UCR governance predominantly focuses on European [32,33] and North American [23,34] contexts, with scant attention to cities in the Global South, not matching a disparity with the geographical distribution of climate hazard vulnerability. Shanghai's unique political framework positions its approach to climate resilience governance as a valuable addition to the global urban resilience discourse.

Intending to contribute to the literature, and framed through the lens of resilience governance, this research investigates the dynamic relationship between the threat of climate-related risks, especially extreme weather events, and the process of planning and policy formulation and their implementation at the local level. With Shanghai, China, as a case study, this research designed the analysis of planning and policy documents and the narratives of key actors to examine how cities organize their responses based on the general resilience of disaster risk reduction (DRR) and climate change adaptation (CCA) in response to specific hazard types. This research may offer insights into the facilitators and barriers within local UCR governance processes, potentially guiding urban decision-makers in addressing similar types of climate threats. The following questions were conducted in this research:

- Where do climate shocks and pressures manifest in urban systems?
- Who is involved in coping with climate resilience planning and policy?
- In what way are the urban resilience elements organized in the context of climate resilience?

The remainder of this paper is structured into eight sections. The initial section delineates the theoretical framework underpinning this research. Subsequently, the second section provides an overview of the foundational background and outlines the methodology employed in the case study. The third section categorizes the principal types of climate risks under consideration. The subsequent three sections explore the dynamics and characteristics of climate resilience governance in Shanghai, examining the roles of systems, agents, and institutions in detail. Ultimately, the paper concludes by examining the implications of the findings and suggesting avenues for further research.

2. Theoretical Bias and Analysis Dimensions

2.1. Components and Principles of UCR

Since Holling (1973) [35] introduced the concept of resilience to systems ecology, resilience has been defined as the ecosystem's capacity to sustain functions despite disturbance. Resilience, evolving conceptually through engineering, ecological, and evolutionary prototypes [26,36,37], is embraced across natural, physical, and social realms, with interpretations varying by context [38]. Climate resilience goes beyond risk reduction and aims to improve "a system's performance in the face of multiple hazards rather than preventing or reducing asset loss from a specific event [39]". In the context of urbanization, resilience is shaped by the complex and dynamic interactions among various interdependent urban subsystems, including the economy, human populations, social and ecological networks, biophysical features, regulatory frameworks, cultural norms, governance structures, and physical infrastructures. These interactions occur across multiple temporal and spatial dimensions and involve social, ecological, technological, economic, and spatial dimensions [40,41].

In practice, UCR combines the approaches of CCA and DRR to prepare and plan for, resist, absorb, recover from, adapt to, and transform climate disasters [42]. Integrating CCA and DRR has become a theoretical [43,44] and practical [45] pathway to improving UCR. This paper follows the conceptual understanding of UCR by defining its scope within governance as a collection of CCA and DRR. Then, we applied the sixteen climate resilience characteristics outlined by Meerow and Stults (2016) to align them with the processes of UCR [46] (Figure 1). The principles associated with the resistance phase include robustness, environmental considerations, transparency, and efficiency. In the absorption phase, resilience principles are reflected through redundancy, diversity, flexibility, and predictability. During the recovery phase, principles such as decentralization, feedback, and adaptability play a crucial role. Lastly, in the transformation (or adaptation) phase, the principles emphasized are integration, inclusivity, equity, an iterative process, and forward-thinking.

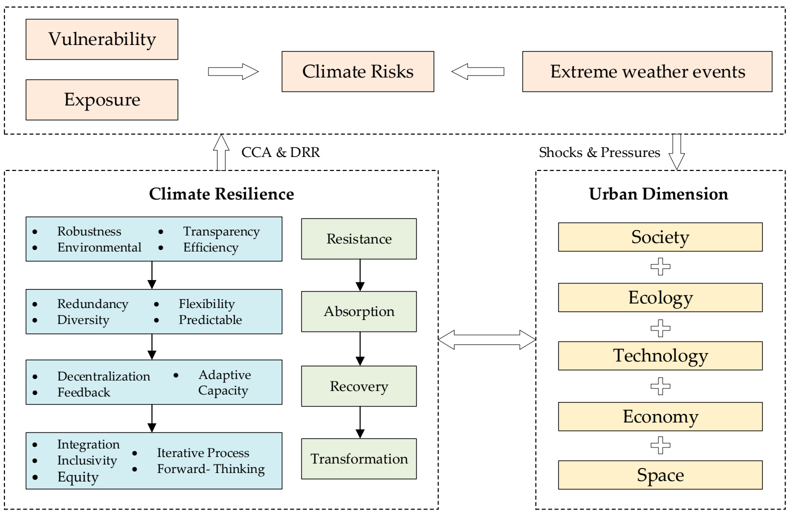

Figure 1. Conceptual framework for urban climate resilience (UCR). Some principles are relevant to multiple stages of the process. However, we have assigned them to a specific stage according to their primary contribution.

2.2. Framework for UCR Governance

In both theory and practice, UCR frameworks serve diverse objectives and are broadly categorized into two types [47]: one evaluates local government performance within global climate governance networks (e.g., network governance framework [48] and Urban Climate Change Governance Survey [49]); the other identifies critical barriers and challenges to the development and institutionalization of urban governance systems, (e.g., urban governance for adaptation [50]). Tyler and Moench (2012), upon reviewing UCR concepts and theories based on the Rockefeller-Foundation-funded Asian Cities Climate Change Network foundation, introduced a governance assessment framework centered on systemic access, agents' decision-making, and institutional information flow and learning [51]. This framework facilitates the analysis of resilience traits and governance barriers, aiding local governments. Therefore, this study is localized and improved regarding the extensive climate resilience framework.

We then developed a theoretical framework tailored to Shanghai, China, for the qualitative assessment of multi-hard resilience, building on the research conducted by Tyler and Moench (2012) and Du et al. (2018) [13,51]. As a starting point, systems, agents, and institutions are the three generalizable elements exposed to climate risks (Figure 2).

Figure 2. A framework of governing urban climate risks (modified from [13,51]).

Systems are to be governed and encompass both physical and social components, which provide service supply-and-exchange networks. The physical system, comprising urban structures, infrastructure developments, and the natural environment, should maintain functionality and operation under extreme stress during disasters. The social systems, defined by intricate human interactions and relationships within a society, are vital in equipping cities to address climate hazards through cooperation, participatory support, and shared cultural values [52].

Agents, including government sectors, companies, and communities, are the actors who deliberate and make decisions. Within the Chinese policy framework, government departments, as influential entities, are predominantly engaged in the decision-making process, often assuming a dominant role [53]. Yet, there exists a notable disparity in organizational structures and power distribution among these departments. Investigating this aspect sheds light on the function of urban planning departments and the challenges to collaborative efforts in multi-interest planning scenarios.

Institutions are the formal or informal social practices that structure behavior and interactions. These institutional rules establish guiding principles and procedures for agents to adhere to, defining the degree of permissible actions (legitimate opportunities) they can undertake in climate governance instead of delineating the limits of alternative actions [54].

3. Study Area: Shanghai, China

Shanghai, located on the southern bank of the Yangtze River Estuary along the eastern coast of China (120°52′–122°12′ E, 30°40′–31°53′ N), is a global megacity [55] characterized by a high concentration of population, assets, and information, covering an area of 6340.5 km^2 (Figure 3). In 2022, Shanghai's population has increased to 24.76 million, with a per capita GDP of USD 27,000 [56]. At present, Shanghai's population growth rate is 2.28% [57], with the core areas of the city (including seven districts such as Xuhui District) being densely populated. In contrast, the nine outlying districts, such as Jiading District and Pudong New Area, display a lower population density, with figures varying from fewer than 1000 individuals to approximately 7500 individuals per square kilometer [58].

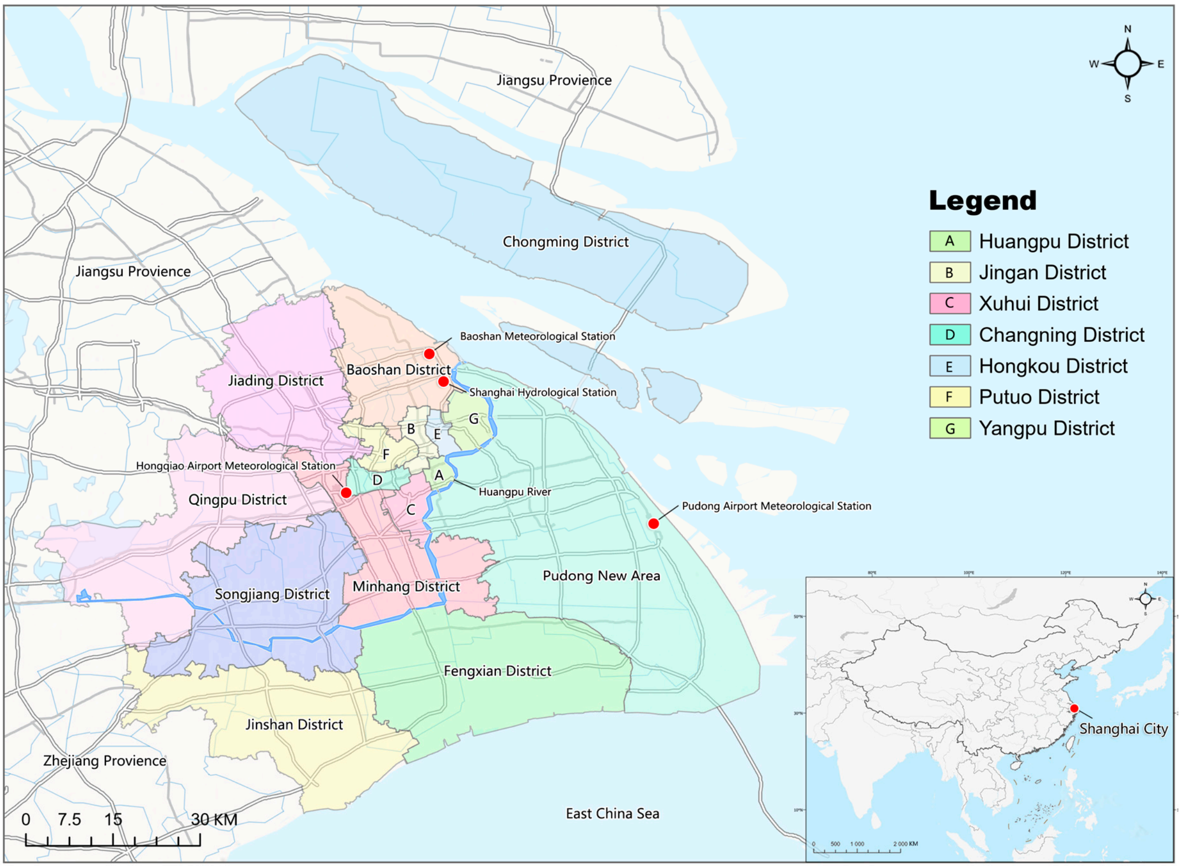

Figure 3. Distribution of administrative divisions and meteorological and hydrological stations in Shanghai, China.

Shanghai experiences a typical subtropical monsoon climate, with four distinct seasons and simultaneous rain and heat. Due to its position in the Western Pacific typhoon belt, tropical cyclones frequently pass through each summer (June, July, August, September), bringing high winds, storm surges, and heavy rainfall, making Shanghai humid and hot in summer. In recent years, global warming has markedly influenced climatic conditions in Shanghai, resulting in rapid increases in temperature, precipitation, and sea level [16]. The rates of temperature and precipitation increase in Shanghai have significantly exceeded national and global averages for the same period (Table 1) [16]. Shanghai is situated on an impact plain with a flat topography and an average elevation of about 4 m above sea level. This geographical setting, compounded by the escalating threat of rising sea levels, renders Shanghai increasingly susceptible to maritime hazards [59].

Table 1. Mean values and trends of meteorological elements/climate risk in Shanghai [60] ("↑" means rise, "↓" implies fall).

Meteorological Elements/Climate Risk		1993–2022 (30-Year) Average	Trend (/10 Years)
average temperature (°C)		17.4	↑0.415
annual precipitation (mm)		1308.3	↑157.8
sea level height (mm)		135.5	↑13.749
hurricane	days (d)	3.0	↑0.932
	maximum single-day average wind speed (knots)	27.4	↑0.012
storm	days (d)	3.7	↑0.237
	maximum single-day precipitation (mm)	101.6	↑16.274
extreme heat	days (d)	19.0	↑7.244
	maximum temperature extremes (°C)	37.7	↑0.568
extreme cold	days (d)	26.4	↓3.317
	minimum temperature extremes (°C)	−4.8	↓0.099

With respect to planning and policy, the "Shanghai 2035" plan, unveiled in 2017, aims to transform Shanghai into "a city of green and resilience". This strategic vision prioritizes mitigating the impacts of climate change, including sea level rise, extreme weather events, and the urban heat island effect. Furthermore, under the guidance and encouragement of the central government, Shanghai has distinguished itself as one of the select cities in China to independently formulate and execute a comprehensive action program for climate change adaptation.

4. Materials and Methods

4.1. Document Selection: Planning and Policy

We designed consistent data collection strategies. First, we defined the meaning of "planning" and "policy". In the Chinese urban context, the concepts of planning and policy reflect distinct aspects. Planning allocates spatial rights [61], whereas policy refers to other non-spatial governmental approaches, including legislation, regulations, and procedures. Second, we searched the planning and policy documents from open-access datasets. Using the Baidu search engine, we conducted a fuzzy document search with the keywords "Shanghai climate planning" and "Shanghai climate policy". Third, we selected the documents guided by two primary criteria: (1) relevance to DRR or CCA and (2) spatial strategies for planning.

Eventually, we acquired 12 planning documents (Table A1) and 13 policy documents (Table A2), forming the foundational basis for textual analysis [62]. Three types of plans are involved: (1) comprehensive plans, which are also named master or general plans; (2) specialized plans, which target specific types of local climate hazards; and (3) construction plans, which directly link to on-site implementation. Two categories of policies are counted: (1) guiding policies, which lack legally binding power and provide direction and advice to agents; and (2) legal policies, which constitute enforceable local laws.

4.2. Mixed Methods: Textual Analysis and Semi-Structured Interviews

Two coders independently reviewed the policy and planning documents, categorizing system elements into nine groups (economy, society, and ecology) following the classification of Brown et al. (2012) [63]. Regarding agent elements, the focus was on government sectors, which were classified into 12 departments aligning with the diverse functions of the Shanghai municipal government. Using these classifications, coders categorized measures in documents and added annotations using NVivo 12. Inter-coder reliability was assessed with Krippendorff's Alpha, yielding a satisfactory value of 0.65. Establishing a dataset, we compiled Shanghai's climate resilience systems and agents, addressing coding notes and discrepancies through coder discussions.

Based on the insights gained from textual analysis, we developed preliminary hypotheses regarding the interplay between systems and agents. Subsequently, we constructed a series of semi-structured interviews and questionnaires to delve deeper into the institutions' underlying mechanisms. We contacted eight interviewees to share their first-hand experience, involving four government officials, two urban planners from planning and design institutes, and two other critical stakeholders (Table 2). Their fields cover meteorological technology, environmental protection, urban spatial planning, emergency disaster prevention, and water conservancy engineering. A broad professional perspective mitigates bias arising from the subjective interpretations of a single respondent. The officers employed by municipal governments play a pivotal role in drafting, formulating, and implementing policies and funding. Working for local planning and design institutes—a form of public institution—urban planners contribute to the long-term urban and community planning processes. Other stakeholders are also involved with scientific institutions dedicated to researching climate impact and developing strategies.

Table 2. Interviewees by critical functions.

Categories	Number	Interviewees	Field
Government officers	4	S1: Expert, the Meteorological Bureau	Meteorological Technology
		S2: Officer, the Ecology and Environment Bureau	Environmental Protection
		S3: Senior Officer, the Planning and Natural Resources Bureau	Urban Construction and Management
		S4: Officer, the Emergency Management Bureau	Disaster Preparedness
Urban planners	2	S5: Planner, the Municipal Design Institute	Water Conservancy Engineering
		S6: Senior Planner, the urban planning and design company	Urban Spatial Plan
Other stakeholders	2	S7: Urban Planning Professor, a local university	Academic Research
		S8: Expert, the Urban and Transportation Development Institute	Resilience-related Study

We used Snowball Sampling to select interviewees and asked nine questions during the interviews (see the Appendix B, Table A3, for a list of questions covered in the semi-structured interviews relating to the study). These questions covered topics such as identifying climate risks in Shanghai, various management strategies, the impact on social groups, opportunities and challenges in addressing climate change, and their experiences and insights. Informed by the initial textual analysis, we developed a coding framework in NVivo and iteratively refined it using interview insights. Subsequently, drawing upon the urban climate resilience strategies identified within the planning and policy documents, we requested the interviewees to discern the characteristics requisite for achieving these strategies, from both system and agent perspectives. This process enabled the integration of previously overlooked aspects, such as strategic initiatives (e.g., autonomous actions by neighborhood committees) and challenges (e.g., extreme heat as a climate risk).

5. Results

The results first delineate the climate shocks and pressures prevalent in Shanghai, then explore the categories and characteristics of systems and agents, and finally emphasize institutions' role in linking them.

5.1. Climate Shocks and Pressures

Shanghai has developed strategies over recent decades to mitigate coastal and inland flooding [64]. Nevertheless, the city has observed a marked increase in the frequency and severity of climate-related disasters, surpassing historical patterns [65]. Our synthesis of textual analysis (Table 3) and interview data indicates that the primary risks confronting Shanghai are precipitation and temperature issues, notably flooding and extreme heat.

Table 3. Categories of climate shocks and pressures in planning and policy (warmer colors indicate a higher proportion of the same type of plan or policy).

Climate Disasters			Planning				Policy		
Time	**Causes**	**Codes**	**Comprehensive Plan (*n* = 2)**	**Specialized Plan (*n* = 7)**	**Construction Plan (*n* = 3)**	**14th Five-Year Plan [1] (*n* = 6)**	**Implementation/ Action Plan (*n* = 5)**	**Emergency Plan (*n* = 1)**	**Government Directive (*n* = 1)**
Acute	Meteorology	Typhoon	1	1	0	2	4	0	1
		Rainstorm	1	3	3	1	1	1	1
		Storm surge	0	1	0	3	4	1	0
		Strong wind	0	0	0	1	1	0	1
		Thunder	0	0	0	1	0	0	1
		Hail	0	0	0	0	0	0	1
	Temperature	Extreme Heat	1	0	0	1	1	0	1
		Extreme Cold	1	0	0	1	1	0	1
		Heavy fog	0	0	0	1	1	0	1
		Drought	0	0	0	1	0	1	0
Chronic	Hydrology	Flooding	2	7	3	4	5	1	1
		Sea-level rise	1	0	0	0	1	0	0
		Subsidence	2	0	0	0	0	0	0

[1] One of the most significant development policies set forth by the Chinese government covers the years 2021 to 2025.

5.1.1. Flooding

The analysis of planning and policy texts and the insights from interviewees substantiate the recognition of flooding as a significant climate risk in Shanghai. Flooding demonstrates a higher degree of consistency across both policy and planning. The complexity of flooding stems from various factors: high-density construction and sprawling urbanization, coupled with the centralization of infrastructure, exacerbate the flooding risk.

Multiple factors, including typhoons, storm surges, and astronomical tides, contribute to coastal flooding in Shanghai. Despite the rise in sea level rate in Shanghai, which was 13.74 mm/decade [66]—lower than national and global rates during the same period [2]—the city's vulnerability to coastal flooding remains high. The absence of natural barriers against storm surges, compounded by extreme weather phenomena like subsidence, tidal effects, and strong winds, leads to increasingly frequent and damaging coastal floods. Interviewees (S5, S8) noted that "even with coastal dyke flood protections designed for a 1-in-200-year event, extreme scenarios can still cause significant breaches, pressuring coastal infrastructure critically".

The likelihood of inland flooding, identified as Shanghai's most frequent natural disaster (Liu et al. 2016) [67], is about twice as much as coastal flooding. The inland floods, mainly triggered by extreme rainfall, are intensified by severe cold and warm convection during the Mei-yu season and typhoons during summer and autumn. Global warming heightened this convection and has increased the frequency of rainstorms, with an average of 0.24 days/decade and a rise in peak daily rainfall, up by 16.28 mm/decade [68]. S2 said, "Shanghai's low-lying terrain coupled with lower drainage standards in the lower reaches of the Huangpu River is highly susceptible to sheet-type waterlogging of roads, and even river flooding and field flooding".

5.1.2. Extreme Heat

In recent years, record-breaking extreme heat events in Shanghai have resulted in prolonged heat-induced droughts [69–71]. However, the plan only addresses the impacts of extreme heat in the comprehensive plan components. Whereas interviewees (S1, S7, S8) expressed concerns about the future trends of extreme heat, especially in citizen health and lifeline infrastructure, "the frequency of extreme heat events have surged by 8.5 times over the past three decades, indicating a remarkably steep progression".

Regarding population health, extreme heat and urban air pollution have been tightly linked to increased incidences of illness and mortality, particularly cardiovascular and respiratory diseases [72]. S4 noted a 20% increase in emergency hospital admissions during the 2022 summer, predominantly among seniors [73].

Concerning lifeline infrastructure security, the extreme heat dramatically increased electricity demand, thereby straining the power grid [74]. The extended heat in 2022 diminished the inflow from the Yangtze River's upper reaches. This situation, compounded by saltwater intrusion, precipitated a crisis in Shanghai's main water supply reservoir [75]. The possible scarcity of water resources led to public worries and resulted in incidents of panic buying and hoarding of bottled water (S8).

5.2. Elements of Governance

We conduct our governance components analysis using a phased approach. Initially, we described the composition and resilience characteristics of systems and agents. Subsequently, we evaluated the mechanism of institutions. Findings indicate that the regional government system and the Water Affairs Bureau (WAB) are central to the governance process. Shanghai has more robustly addressed flooding than extreme heat.

5.2.1. Systems: Critical Functions Keep Running

In planning and policy, the urban systems are divided into the following domains: regional government, infrastructure, ecological environment, emergency response, community cooperation, urban architecture, health and wellness, energy, and transportation (Figure 4). The regional government concentrates on managing urban water supply and drainage systems, incorporating meteorological monitoring, disseminating early warnings, and mobilizing rescue operations as part of this comprehensive approach. The infrastructure emphasizes water control, encompassing flood defense, resource utilization, diversion, and regulation. As for the ecosystem approaches, there has been a rejuvenation of Blue-Green Infrastructure (BGI), leveraging NbS and offering advantages to the city along a "No-Regrets" strategy. Meanwhile, emergency response and community cooperation demonstrate flexible social capital organization.

Strategies for governing flood risks are notably more extensive than those dedicated to extreme heat. Flooding involves 161 strategies, compared to a mere 48 for extreme heat. Furthermore, flooding strategies encompass urban architecture and transportation systems. In contrast, only limited strategies tackle extreme heat. Most measures addressing urban heat are supplementary to, or derivatives of, comprehensive DRR actions. These include enhancing the level of water infrastructures and bolstering real-time weather monitoring and communication.

Policy-based strategies account for 61.2%, while planning-based strategies comprise 38.8%. Regional management, infrastructure, community cooperation, urban architecture, health and wellness, urban energy, and transportation systems are related to policy. Conversely, in ecological environment systems, strategies are more spatially oriented and implemented through planning, for instance, by constructing urban waterfront green corridors and advancing 3D greening projects.

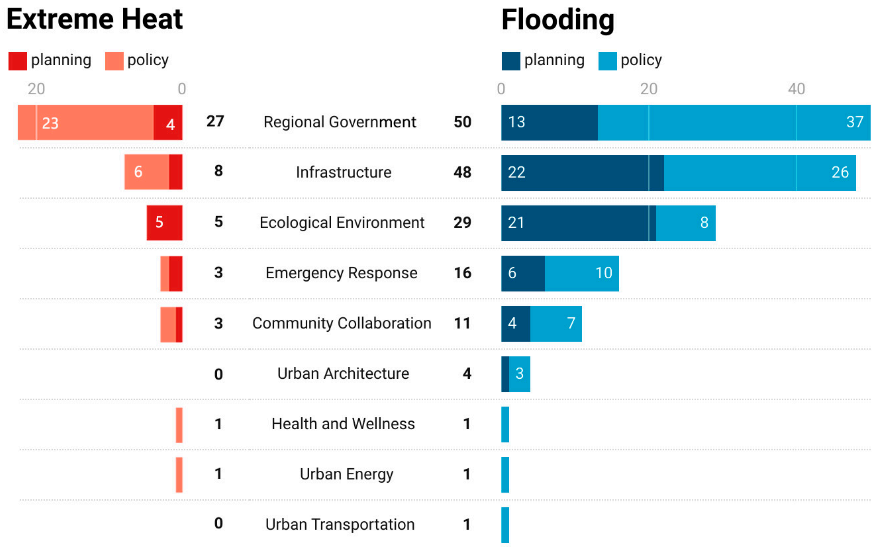

Figure 4. The frequency of system components in flooding and extreme heat.

As for the resilience characteristics within systems, we identified robustness and integration as essential. These indicate that the systems can withstand external shocks and quickly return to their previous state while facilitating coordinated actions across various subsystems. For flooding, robustness predominates, accompanied by integration, adaptability, and predictability. In contrast, for extreme heat, the systems are characterized by a balanced mix of integration, robustness, and predictability (Figure 5).

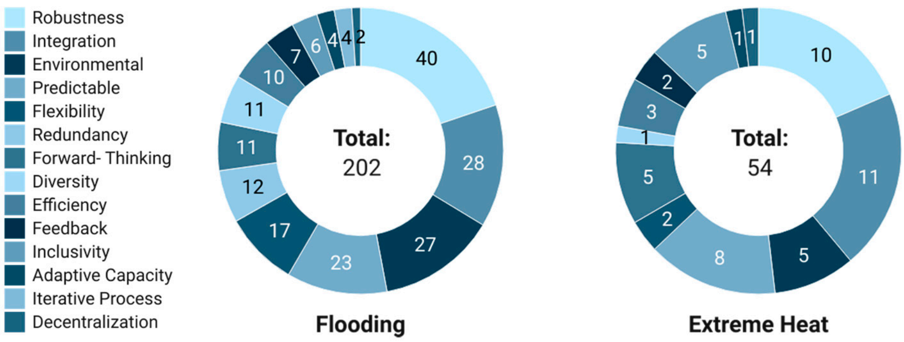

Figure 5. Resilience characteristics in urban systems.

5.2.2. Agents: Leading Sectors Organize Actions

As for agents, departments such as the WAB, the Housing and Urban–Rural Construction and Management Committee (HURCMC), and the Meteorological Bureau (MB) hold a central position, followed by the Ecology and Environment Bureau (EEB), the Emergency Management Bureau (EMB), the Planning and Natural Resources Bureau (PNRB), and the Economy and Information Commission (EIC). Neighborhood committees in each community represent the lowest level of government and the starting point of grassroots autonomy. Additionally, the Landscaping and City Appearance Administrative Bureau (LCAAB), the Transportation Commission (TC), the Health Commission (HC), and the Development and Reform Commission (DRC) also contribute to the governance process (Figure 6). The WAB is primarily responsible for urban water-related issues, such as flood control and water supply during drought. The HURCMC collaborates with the WAB to advance Sponge City and promote the Zero Carbon Buildings (ZCB). The MB monitors weather dynamics, tracks long-term climate trends, issues timely early warning alerts, and evaluates potential climate-related disasters.

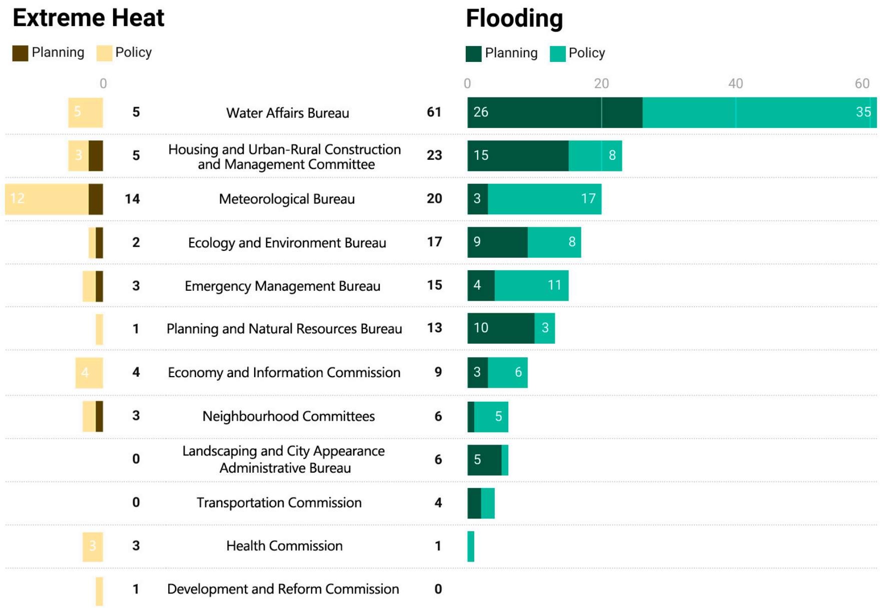

Figure 6. The frequency of agent components in flooding and extreme heat.

The agents focus differently on concerns about two climate risks, showing a higher priority for addressing flooding in strategy than extreme heat. The WAB is the lead agency for flooding issues control, supported by the HURCMC in planning design and the MB in weather information. However, the MB contributes significantly in extreme heat, with the other agents primarily addressing spin-off issues, such as water supply shortages from drought. For flooding, most government departments focus on policy-driven governance; only the HURCMC, EEB, PNRB, and LCAAB adopt planning approaches more.

Similarly, the agents dealing with extreme heat primarily rely on policy. Notably, the agents of extreme heat exclude the involvement of the LCAAB and the TC. Nevertheless, it includes the DRC, an agent not engaged in flooding, implying that extreme heat strategies align with carbon mitigation.

Integration and efficiency stand out as the principal characteristics of the agents. The agents will likely enhance operational efficiency, both within the government and externally, through a cross-sectoral approach and the integration of various action plans. Additional prominent characteristics of the agents include forward-thinking, flexibility, transparency, and diversity. In their approaches, the agents emphasize integration as a critical response characteristic for flooding and focus on efficiency when dealing with extreme heat (Figure 7).

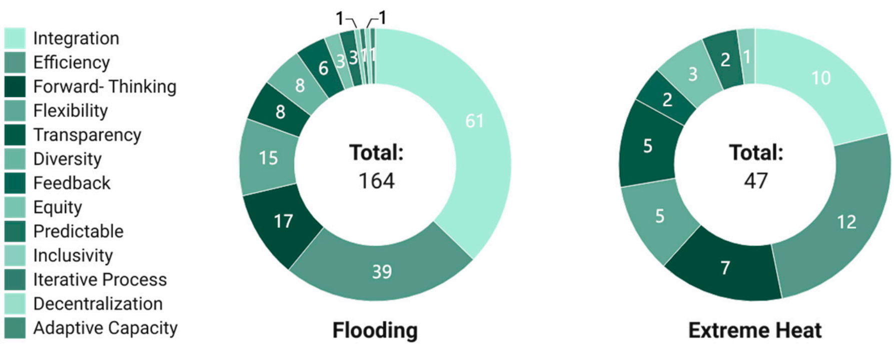

Figure 7. Resilience characteristics in governing agents.

5.2.3. Institutions: Distinctions between Risks

Institutions function as coordination tools, bridging the integration of systems and agents. Flooding and extreme heat share a specific mechanism: the government integrates administrative levels to address extreme weather, enhances operational efficiency, ensures infrastructural safety through regional coordination, and thus minimizes urban damage while swiftly restoring city functions post-disaster. The above approach is demonstrated through the consistent and comprehensive integration strategies of extreme weather warnings and emergency response across the planning and policy documents. Despite that, there is a marked divergence in institutional approaches between flooding and extreme heat (Figure 8).

As a conventional risk, flooding is almost addressed by systematic institutional tools. Key among these are the development of flood control and drainage infrastructure, the revolution of Sponge Cities, and the restoration of river and lake systems. These three approaches represent a long-term commitment to implementing flood-related plans and policies. The Flood Control and Drainage Infrastructure Project (FCDIP) aligns the city's embankment standards with the consensus on climate change trends, utilizing digital monitoring and simulations to identify gaps and water-prone areas. Sponge City's efforts aim to mitigate the disruption of the hydrological cycle caused by new town construction, employing nationally standardized guidance for this purpose. The WAB leads both tools, enhancing the infrastructure's robustness, redundancy, and environmental performance. Meanwhile, river and lake system restoration, an extension of the Sponge City principles, is spearheaded by the EEB, leveraging the ecological function of the ecosystem.

Other thematic strategies primarily concentrate on policy aspects, including lifeline projects, emergency response team building, and regional protection scheduling. In particular, the policy appeals to flood risk assessment and mapping. Conversely, the planning fails to publish a publicly accessible flood-prone map.

While extreme heat represents an emerging risk, the droughts induced by heat accumulation have been a historical disaster. Shanghai performs lifeline maintenance actions for extreme heat in both planning and policy. The WAB is instrumental in securing the water supply system, while the EIC oversees the regulation of the power system, especially during peak demand periods. These approaches demonstrate enhanced system flexibility, bolstering the agents' efficiency. Other aspects of the planning dimension, including urban breezeway design, three-dimensional (3D) greening, and solar roof initiatives, are experimental and pilot in nature. The general governance process for extreme heat has not yet successfully integrated these measures.

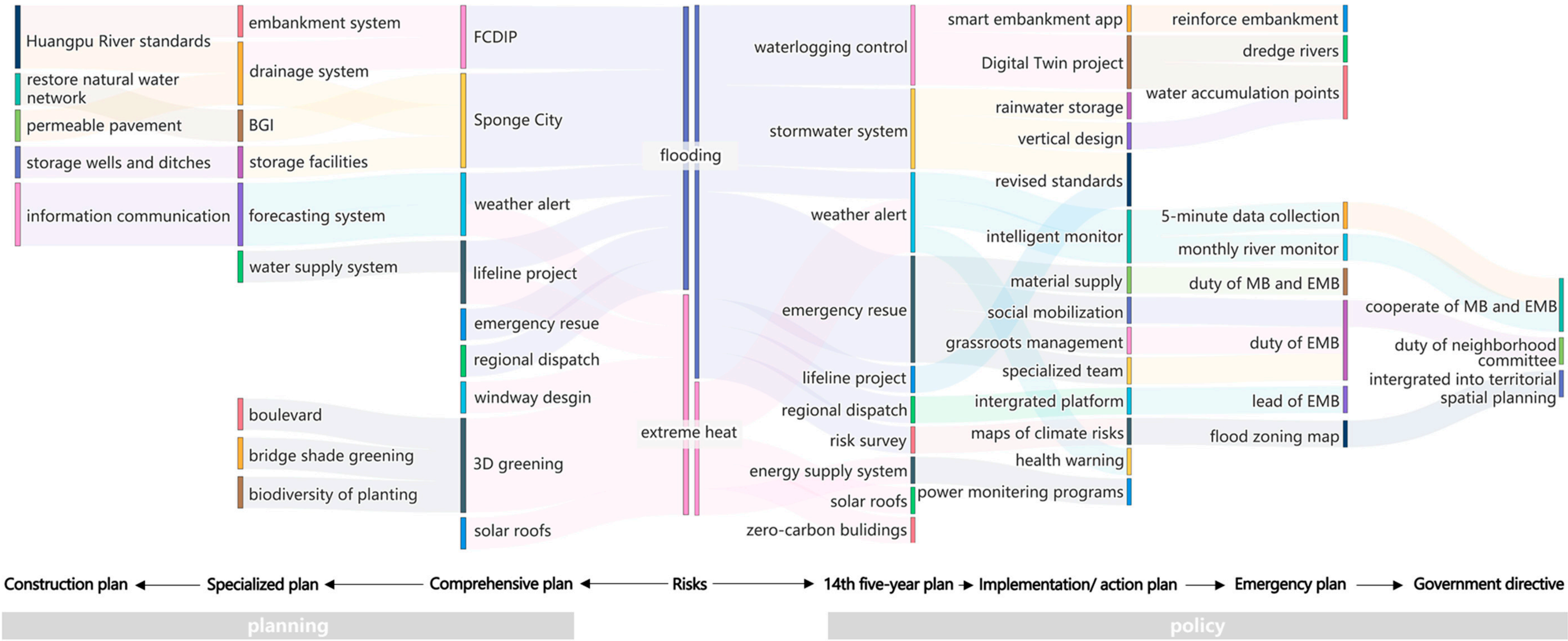

Figure 8. Strategy Transmission in Shanghai's Climate Resilience Governance.

6. Discussion

Our analysis indicates that Shanghai increasingly acknowledges the profound impacts of climate-induced disasters, notably flooding and extreme heat. Accordingly, the city integrates DRR and CCA into planning and policy. In the governance of urban climate resilience, the social dimension's subsystems play a pivotal role, encompassing regional governance, emergency response mechanisms, and community cooperation. These are closely followed by the ecological dimension's subsystems, which include ecosystems and urban energy infrastructures. Conversely, the economic, technological, and spatial dimensions are interwoven with the social and ecological dimensions, serving as instrumental means to enhance resilience governance.

Nevertheless, significant opportunities for advancement remain, particularly in addressing the increasing severity and frequency of extreme heat, engaging a broader range of actors in decision-making, and improving consistent strategies across multilevel plans and policies. Urban planning plays a secondary and limited role, as seen in the level of consistency and engagement of plans. Firstly, the construction plan infrequently translates the strategies outlined in the comprehensive plan. Secondly, departments associated with planning, specifically the PNRB and the HURCMC, do not play a dominant position in the governance process. Our discussion focuses on the priorities of climate risk response, the distribution of agent power, and the potential capacity of urban planning to explain the reasons for the abovementioned results.

6.1. Flooding and Extreme Heat: Identify Processes and Characteristics of Different Risk Types

The climate resilience governance in Shanghai exhibits distinct processes and characteristics in response to two types of climate risks: flooding and extreme heat. Divergent social perceptions of flooding and extreme heat directly influence this outcome. Flooding, a meteorological disaster with a lengthy history and considerable destructiveness, has been emphasized in Shanghai's planning and policy systems across various types and levels. In contrast, extreme heat is a dangerous weather condition not recognized as a meteorological disaster by people (S1, S4). In Shanghai, China, which has historically been a predominantly agrarian society, drought, a compound disaster triggered by extreme heat, is more familiar [76]. As a result, governance of extreme heat is less systematic than flooding and focuses on coping with drought's effects, i.e., securing urban water supplies.

We posit that the essential factor in enhancing resilience to flooding lies in the ascent and depth of Sponge City. This initiative embodies a "dual-track approach", integrating dedicated and mainstreamed processes [77]. (1) The first phase is the "dedication" phase: In 2014–2015, the central government introduced the technical guidelines for constructing sponge cities nationally [78] and advocated for the absorption and on-site utilization of "70% of rainfall", establishing a practical methodology and setting long-term goals for Sponge City [79]. In 2016, supported by the central financial subsidies, Shanghai joined the second batch of Sponge City construction pilots. Subsequently, Shanghai published and implemented a series of specific construction plans related to Sponge City. (2) The second phase is the "mainstreaming" phase: Local governmental agents have further integrated the Sponge City principle, with strategies persisting in Shanghai's comprehensive plan and guiding and legal policies. Sponge City revolution has stage-by-stage bounced Shanghai's resilience to flooding forward. Despite this, during specific flood events, Shanghai tends to focus on critical functions maintenance and a bounce-back after the flood.

Governance for extreme heat primarily aligns with the broader goals of the city. Despite particular concern from government officials (S1, S3, S4) and professionals (S6, S7, S8), the undervaluation of extreme heat results in existing strategies primarily as by-products of other objectives (e.g., carbon neutrality). An inadequate understanding of extreme heat hampers resilience governance compared to flood governance, undermining general climate resilience.

Nonetheless, we contend that synergistic governance across climate risks indicates that responses to one type of risk, including BGI, digital rapid response, and regional resource linkages, can enhance resilience against various risks. Strategies enhancing general climate resilience must be identified and prioritized for implementation.

6.2. Systems and Agents: Clarify Departmental Responsibilities and Empower Self-Governance

In bureaucratic governance systems, identifying leading sectors enhances climate resilience for specific types of risks. Our research indicates that the WBA is the primary authority for urban flood prevention, overseeing responsibilities for wet territories. The HURCMC has power over the spatial design of drainpipes, green spaces, and other elements related to flood affairs in dry territories, playing a supportive and coordinating role. While some argue that path dependency, rooted in outdated planning and policy, may pose intersectoral barriers for agents to effectively collaborate [80,81], the WBA prioritized flood resilience with the support of a dedicated financial grant from the central government, which has resulted in a significant increase in the city's level of flood resilience.

On the other hand, the MB significantly impacts the governance of extreme heat with meteorological observation and warning capabilities. The primary emphasis of these strategies is keeping citizens informed of weather dynamics changes, demonstrating the systems' efficiency. However, governance reliant on the timely dissemination of meteorological information remains basic, failing to catalyze a governance transformation and inadequately addressing future climate change risks. Therefore, introducing authoritative entities to spearhead extreme heat risk governance is essential.

From the perspective of time series, planning and policy measures led by government departments primarily concentrate on the disaster preparation phase while ignoring the onset and recovery phases [82]. However, neighborhood committees present a unique position. Neighborhood committees are at the end of the hierarchical system of government but also act as a bridge connecting the bureaucracy with the residents [83]. The establishment of "a community grid management system in Shanghai during the COVID-19 pandemic" (S5) could offer a fundamental effect on urban climate governance [84,85]. Neighborhood committees have been primarily assigned to the frontline response to emergencies and possess the potential to enhance inclusiveness, decentralization, and adaptive capacity for agents [38].

In fact, before China's 1978 reform and opening-up, China's urbanization was relatively low, with both rural and urban societies dominated by "local geography" and an "organizational mode of association" social structure [86]. In the governance of society, rituals constrain people's beliefs while traditions guide people's behaviors. This underscores the necessity of fostering a moral climate in grassroots self-governance, emphasizing principles such as "cooperation and mutual assistance", "care for the vulnerable", and "collective responsibility".

6.3. Planning and Policy: Discover Opportunities for Urban Planning

The administrative agents related to urban planning have limited involvement in climate resilience governance. This level of engagement is unexpected, given the interdisciplinary nature of urban planning and the authority it holds over land use. In urban flooding governance, the WAB has consistently held a dominant position, even after introducing Sponge City, where the HURCMC was also supportive. The state institutional reform in 2018 resulted in the restructuring of planning powers [87]. Shanghai transferred land use planning powers from the HURCMC to the newly established PNRB. The HURCMC retained authority solely for the organization of construction plans. China's transition and restructuring in urban planning power distribution present both challenges and opportunities for planning to enhance its role in climate governance through institutional reorganization, in particular, for new types of climate risks [23,24].

Nonetheless, there is a policy push for increased engagement in planning, urging the incorporation of climate-related risks like flooding into territorial spatial plans and developing a flood-prone map in Shanghai. The significant "path dependency" and "sunk costs" associated with traditional flood management models persist in constraining the transformative potential of climate resilience efforts, consistent with observations from studies in Guangzhou [88] and Da Nang [13].

Our study also found that Shanghai's climate resilience planning system lacks an interlock between comprehensive, specialized, and construction plans. Objectives outlined in the comprehensive plan are progressively diluted or lost during the hierarchical transmission of the plans. The phenomenon is especially evident in managing extreme heat, as initiatives like the "spatial control of urban wind channels" proposed in the comprehensive plan have not been implemented in next-step plans and policies. A comparable situation arises when governing extreme heat in North American cities [23], where dedicated planning for such events is lacking. This indicates a necessity to integrate heat reduction strategies with the objectives of other planning domains.

Governance of UCR lacks cohesive spatial planning support across scales [89]. For extreme heat, urban planners can draw from the experience of flooding. Commencing with the comprehensive plan and delving into the creation of specialized plans, the emphasis should be on emphasizing the synergistic benefits of managing extreme heat in alignment with citizen health and zero-carbon goals and effectively promoting extreme heat governance.

6.4. Limitations

Our methodology faces significant limitations affecting the depth and breadth of our findings. The timing of our interviews in July and August 2023 offers a mere snapshot of governance mechanisms, potentially missing their long-term evolution. This limitation restricts our findings to a specific, transient context and diminishes their broader applicability. Furthermore, power dynamics between interviewers and interviewees may have impeded the gathering of in-depth narratives [90], thereby limiting the richness of our content. The lack of a wider range of participants, especially the inclusion of both technical experts and decision-making leaders from the same departments, has also reduced the diversity of perspectives and experiences in our analysis.

7. Conclusions

This study examines the current status and barriers to climate resilience governance within China's coastal megacities, focusing specifically on Shanghai's policies and planning for climate resilience. Our study shows that Shanghai actively integrates climate resilience into its current urban governance system. This case is particularly intriguing due to Shanghai's high climate vulnerability despite its abundant physical and social resources. Although a social consensus exists to enhance climate resilience, Shanghai lacks a specialized plan or policy to integrate DRR and CCA strategies—making general climate resilience governance a piecemeal rather than a dedicated or mainstream approach.

The case of Shanghai reveals marked disparities in the governance processes for climate risks, with hydrological disasters (exemplified by floods) and extreme temperature events (illustrated by extreme heat) being managed differently. The primary resilience systems involve regional management, constituting 36.8% of governance strategies, and infrastructure, accounting for 26.8% of these strategies. Key institutions in climate resilience governance include the Water Affairs Bureau and the Meteorological Bureau, with 30.6% of strategies for the former and 15.7% for the latter. The WAB aims to enhance robustness (19.2% of resilience characteristics) and integration (14.9% of resilience characteristics) in flood and drought management through regional and infrastructure systems. Simultaneously, the MB improves flexibility and efficiency, employing digital technology to address extreme heat.

This study posits that variations in resilience governance mechanisms and depth across climate risks primarily stem from the inherent characteristics of climate hazards and public perceptions. Historically, floods inflict observable damage, whereas heat disasters, traditionally less noticeable, are increasingly acknowledged due to climate change. Insights from flood management could inform broader climate resilience strategies, including those for high temperatures. Furthermore, it is observed that Shanghai's government-directed climate governance prioritizes preparatory actions. Effective management of disaster response and recovery phases may require engaging grassroots autonomy more extensively.

Another lesson to be learned is that the progression of Shanghai's climate planning, from a comprehensive approach to more specialized construction planning, indicates a potential reduction in strategic depth, likely attributable to the limited governance role of the planning department (with only 6.4% of governance strategies involving this department). Notably, policies advocate for integrating climate risk into national spatial planning, underscoring the need for enhanced planning department engagement in climate resilience governance. This is especially crucial for tackling emerging risks like extreme temperatures, where the share of strategies focused on managing extreme heat is merely 42.5% of those for flood management, indicating a governmental-driven push for planning to assume a more significant role in climate resilience governance.

In light of the intensifying impacts of global climate change, the imperative for building resilience to climate risks in urban areas is growing more urgent. A phased approach involving dedication followed by mainstreaming could be advantageous when designing governance processes for comparable cities. This approach entails delineating clear responsibilities of governments, allocating resources to leading agents, and augmenting the system's general climate resilience capacity.

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Appendix A

Table A1. The planning list relates to the climate resilience of Shanghai.

Plan Type	Plan Name	Year
comprehensive plan	Shanghai City Comprehensive Plan (2017–2035)	2018
	Yangtze River Delta Ecological Green Integrated Development Demonstration Zone Land and Space Comprehensive Plan (2021–2035)	2023
specialized plan	Shanghai Metropolitan Area Collaborative Space Planning (2035–2050)	2022
	Shanghai Comprehensive Disaster Prevention and Reduction Plan (2022–2035)	2022
	Shanghai Sponge City Special Planning (2016–2035)	2016
	Shanghai Flood Control and Waterlogging Planning (2020–2035)	2021
	Shanghai Urban Rainwater Drainage Planning (2020–2035)	2020
	Special planning for slow traffic space connection in the outer ring green belt and areas along the line	2022
	Special planning for dikes and ecological landscapes on both sides of the Huangpu River (middle and upper reaches)	2022
construction plan	Construction plan for areas along the Huangpu River (2018–2035)	2020
	Construction planning for areas along the Suzhou River (2018–2035)	2020
	Sponge City construction planning for different administrative districts in Shanghai	-

Table A2. The policy list contains climate resilience of Shanghai.

Policy Type	Policy Subtype	Policy Name	Year
guiding policy	14th five-year plan	Shanghai's "14th Five-Year Plan" for Water System Management	2021
		Shanghai's Marine "14th Five-Year Plan"	2021
		Shanghai Meteorological Service Guarantee "14th Five-Year Plan"	2021
		Shanghai Emergency Management "14th Five-Year Plan"	2021
		Shanghai's "14th Five-Year Plan" for the development of "Huangpu River" and "Suzhou River"	2021
		Shanghai's "14th Five-Year Plan" for ecological and environmental protection	2021
	implementation/action plan	Smart Water and Marine Three-Year Action Plan (2022–2024)	2022
		Shanghai's three-year action plan for ecological environment protection and construction from 2021 to 2023	2021
		Shanghai's "14th Five-Year Plan" Urban Drainage and Flood Prevention System Construction Action Plan	2022
		Shanghai Carbon Peak Implementation Plan	2022
		Shanghai Action Plan for Adapting to Climate Change (2023–2035)	2023
	emergency plan	Shanghai Water Affairs Bureau Flood and Drought Disaster Prevention Emergency Plan	2022
legal policy	government directive	Shanghai Meteorological Disaster Prevention Measures	2022

Appendix B

Table A3. Questions of the semi-structured interviews.

No.	Questions
1.	What do you think does Shanghai face the main types of climate risks? Any representative examples? Any representative examples?
2.	What is your role in managing climate risks?
3.	Which government agencies or other organizations are involved in the governance of climate risks?
4.	What climate disaster events in Shanghai have deeply impacted you in the past five years?
5.	Do you know which groups in Shanghai are adversely affected by climate disaster events?
6.	What is the current model or process for managing climate risks in Shanghai?
7.	In your opinion, what are the main barriers to enhancing climate resilience in Shanghai?
8.	Can you share your organization's experiences facing climate risks in Shanghai?
9.	Do you have any good suggestions for enhancing climate resilience in Shanghai?

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