HEATWAVES: DEVELOPING A DIAGNOSTIC FRAMEWORK FOR EVALUATING HEAT RESILIENCE STRATEGIES

By

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Vienna, 03 June 2025

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Abstract

Heatwaves are the leading cause of climate-related deaths globally, a threat expected to intensify with continued planetary warming. While governments at various levels are implementing strategies to build resilience to heat, the literature defining best-practice is still emerging. This paper addresses this critical gap by developing and applying a novel diagnostic framework to evaluate the comprehensiveness – and therefore the likely effectiveness – of heat resilience strategies.

The framework's development draws on resilience literature and lessons from mature policy areas to identify core dimensions of resilience and key pathways of heat risk. These identified elements – absorptive, adaptive, and transformative capacities for resilience, and exposure, sensitivity, and management capacity pathways for risk – were synthesised into an evaluative matrix. Its utility was tested by applying the framework to existing heat strategies, mapping their components to measure comprehensiveness, identify strengths, and diagnose gaps.

Applying the framework generates a 'heat map,' visualising a strategy's intervention focus across resilience dimensions and vulnerability pathways. This process highlights areas of strong strategic coverage and areas of potential neglect. Ultimately, this research provides a structured diagnostic tool for policymakers to refine and enhance strategy effectiveness, fostering the development and diffusion of robust best-practice approaches to heat resilience.

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There is significant overlap between these groups.

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GLOSSARY

Shock	Refers to a sudden, disruptive event that impacts the functioning of a system.
Heat	In the context of environmental health and public policy, heat often refers to ambient thermal conditions.
Extreme heat	Refers to weather conditions characterized by unusually high temperatures, and often high humidity, that exceed the historical averages for a given location and time of year.
Heat Stress	Refers to the overall physiological burden on the body that results from exposure to excessive heat.
Heat shocks / heatwaves	Are generally defined as a prolonged period of excessively hot weather, which may be accompanied by high humidity, relative to the usual climate patterns of a specific region.
Resilience	Refers to the capacity of a system to withstand, recover from, and adapt to shocks while maintaining the ability to provide its core functions i.e., to provide services for human use.
Heat resilience strategy	Refers to a planned set of actions, policies, and measures designed to reduce the negative impacts of extreme heat and heatwaves on a population, infrastructure, and ecosystems
Wellbeing	In a public policy context, it encompasses various dimensions including physical health, mental and psychological health,

	social relationships, economic security, personal safety, and the quality of the living environment.
Risk	Refers to the potential for adverse consequences arising from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human system to the hazard.
Thermoregulation	Refers to the physiological process by which an organism maintains its core internal body temperature within a narrow, optimal range, despite variations in environmental temperature and metabolic heat production.
Urban Heat Island (UHI) effect	Refers to the phenomenon where urban or metropolitan areas are significantly warmer than their surrounding rural areas

INTRODUCTION

Extreme heat is the leading cause of climate-related deaths globally, negatively impacting almost every human activity on every continent. It directly causes high-fatality conditions like heatstroke and exacerbates chronic illnesses like cardiovascular disease and mental health issues. It reduces labour productivity and increases anti-social behaviour, all of which increases the pressure on healthcare and other social services. Finally, it compounds the risks posed by other slow and fast-moving disasters like air pollution, water scarcity, wild-fires, and pandemics. Between 2000 and 2019, the World Health Organisation estimates that heat stress is responsible for nearly half a million excess deaths annually (WHO 2024).

Heat is the most significant and direct cause of harm to humans from a changing climate. The Intergovernmental Panel on Climate Change (IPCC) predicts that it is a near certainty that global average temperatures will continue to rise, and that even with substantial climate action, the frequency, intensity, and duration of future heatwaves will increase (IPCC 2022). This will have significant consequences for human geography, affecting where and how people will live in the future.

In the face of this clear and growing threat, governments at various levels – city, regional, national – are developing and implementing strategies for building resilience to heat waves. For jurisdictions that have historically lacked exposure to extreme heat, like France and Russia, there is a lack of institutional experience with developing and operationalising heat resilience strategies. And in jurisdictions that have institutions with a tradition of extreme heat exposure, like India and Pakistan, the expected scale of future heat risk is increasingly recognised as something qualitatively different from this experience.

Building resilience to contemporary and future heat shocks is therefore a comparatively new issue for policymakers to grapple with, and as such, they have yet to consolidate around what 'best practice' looks like. This is true across the range of issues in the field, including which interventions work best in which contexts, what processes to use for formulating strategies, or even which metrics should be used for evaluating the effectiveness of existing strategies. Given both the immediacy and scale of the risks posed, there is a need to rapidly develop and diffuse best-practice approaches.

This research takes a step toward consolidation and aims to develop a novel framework for evaluating the comprehensiveness, and therefore the likely effectiveness, of different strategies for building resilience to heat shocks. This framework is not intended to be a prescriptive engine for recommending specific interventions or processes in a given context. Instead, it draws on theory and the best-practise resilience strategies in more mature fields to identify the characteristics good resilience strategies have and maps these across the different pathways heat can affect human activities. This provides policymakers with a diagnostic framework that can be applied to their own resilience strategies to identify areas that could be reformed or developed further.

This thesis contains five sections. Section I is a brief literature review that outlines the evolution of resilience as a term of art to construct a working definition for this paper. Section II outlines the methodology I follow and sets out the research questions that will guide the development of the evaluative framework. Section III is a mapping exercise in which I answer these research questions and synthesise the results to produce the evaluative framework. In Section IV, I apply this framework to two existing heat resilience strategies from different jurisdictions, analyse where they do and do not align, and discuss the implications. Section V concludes with a discussion of the paper's key findings and the implications for policy, and identifies avenues for future research.

LITERATURE REVIEW: DEFINING RESILIENCE

This literature review provides a concise overview of how resilience evolved from a term in the natural sciences to its current usage in contemporary public policy discourses. The purpose of this is to develop a working definition for resilience that will frame the rest of the paper.

As a term of art, 'resilience' is a highly contested and one '…in danger of becoming a vacuous buzzword from overuse and ambiguity' (Rose 2007). Originally, used in the natural sciences to 'describe the capacity of a material or system to return to equilibrium after displacement' (Norris et al. 2008), it has proliferated across academia and is used in disciplines as diverse as computer science, immunology, human development, communications, and psychology (Longstaff 2009).

From physics and mathematics, resilience is then appropriated by ecologists. C.S. Holling develops the concept of 'ecosystem resilience' to describe the amount of disturbance a system can absorb before its fundamental relationship and structure change before shifting to a new stable equilibrium (Holling 1973). Unlike previous understandings of resilience, this new concept emphasises adaptiveness, variability, and unpredictability. It acknowledges that a resilient system can contain unstable components and does not necessarily have to return to its pre-shock status-quo. This focus on multiple equilibria shifts the analytical focus away from individuals and places it squarely on systems.

From here, it leaks into the social sciences, first into psychology – referring to human development – and then into public health discourses – looking at community and social resilience – and then economic resilience. This latter usage is relevant, as it deals with post-disaster conditions and responses. It focuses on how different economic units (firms, households, etc) cope and adapt after a shock (Rose 2004). Rose distinguishes between ‘inherent resilience’ – ordinary coping abilities – and ‘adaptive resilience’ – maintaining function through ingenuity or extra effort.

Reid and Botterill (2013) trace the evolution of resilience from academia into contemporary public policy discourses. They reflect that the competing academic definitions, combined with varying definitions used by governments, firms, and the public, is problematic for public policy as a discipline and as a practise (Reid and Botterill 2013). Different understandings imply vastly different policy goals and outcomes: focusing on system stability versus individual wellbeing, returning to the status-quo versus adapting to new states, or emphasising post-hoc recovery versus proactive preparedness.

Given the many definitions available, I use a composite definition that draws on both the historical usage and current usage in mainstream public policy discourses (Folke et al. 2010). I define resilience as: the capacity of a system to withstand, recover from, and adapt to shocks while maintaining the ability to provide its core functions i.e., to provide services for human use.

This definition 1) focuses on systems as the referent object, reflecting that it is used to develop a framework for evaluating system-level strategies for meeting human needs, 2) is relevant over a range of temporalities, reflecting the scope of existing resilience strategies, and 3) focuses on the functions the system serves, reflecting that these can occur at different equilibria.

Research Design

This chapter describes the research design and methods I use to build and apply a diagnostic framework for evaluating heat resilience. I employ a mixed-methods, sequential approach, answering three main research questions (RQs) over two phases.

Phase I: Framework Development

This phase focuses on creating the framework itself. To do this, I have formulated two research questions:

1. What core dimensions and mechanisms recur in resilience-building strategies across policy areas?

2. Through which pathways – exposure, sensitivity, and management capacity – do extreme heat events create risk for human populations?

The aim of RQ1 is to establish a taxonomy / formula to serve as an outline for our diagnostic tool. By generating a generic blueprint of what a 'best-practice' resilience-enhancing strategy looks like, I also identify what aspects a heat resilience strategy needs to have to be effective.

The aim of RQ2 is to identify how human populations are at risk to heat shocks. Understanding the types of vectors through which heat affects people and the systems they rely on also identifies which areas a heat resilience strategy should focus on to be effective.

Putting the answers to these RQs together then forms our framework. Expressed in a table format: the dimensions and mechanisms identified in RQ1 become the headings of the table's columns, and the pathways identified in RQ2 are the headings of the table's rows.

To answer RQ1, I will undertake a systematic review of the relevant literature on resilience. This involves drawing deeply from the comprehensive theoretical and methodological insights of resilience as a science and reviewing existing resilience strategies in more mature fields to search for commonalities in framing and approaches.

Answering RQ2 will involve a similar exercise but with respect to understanding risk. It will draw on theoretical models for understanding risk – as a function of exposure, sensitivity, and management – and examine existing resilience frameworks in other policy areas for validation.

Phase II: Framework Application

This phase focuses on applying and testing our diagnostic framework. I have selected two existing heat resilience strategies as cases. These cases are deliberately drawn to ensure a diversity of geographic and governance contexts. This is to minimise the diagnostic tool's blind spots and increase its multi-jurisdictional usefulness. A key limitation in my case selection is that due to language constraints, these strategies must either be either from English speaking jurisdictions or have English translations of both the strategy and related documents.

To do this, I have formulated a third research question:

3. How do the proposed policy interventions and mechanisms in a given strategy correspond to each combination of resilience dimension and heat vulnerability pathway?

To answer RQ3, I examine each case, breaking the strategy down into its components (specific interventions, implementation guidelines, evaluation study, etc) and coding them against our framework. Visualising our diagnostic tool as a table, I use each strategy's components to populate the cells. This generates a kind of heat map, indicating which combination of dimensions and pathways a given strategy focuses on and which it neglects.

This exercise also produces a third output: components that are not captured by the framework. These components are discussed in their relevant case study analysis section and reasons for their inclusion and rejection are given there.

Table 1 below contains a summary of the research design, explaining the rationale and expected output for each research question.

Table 1: summary table explaining each research question's rationale and output

Research question	What we are doing	Why we are doing it	What is the output
RQ1	Identifying generic resilience dimensions / mechanisms.	This provides the categories against which we can judge a strategy's comprehensiveness and therefore likely effectiveness.	A typology of resilience dimensions and mechanisms that can be used as evaluation criteria i.e., "a complete strategy covers x, y, z."
RQ2	Mapping heat-vulnerability pathways.	This reveals how people are vulnerable to heat and therefore what vulnerability points heat resilience strategy should address.	A causal model of heat vulnerability (exposure, sensitivity, adaptive capacity) that can be used as the diagnostic 'pathways' checklist.
RQ3	Cataloguing policy instruments / levers.	Mapping policy levers across our resilience typology and vulnerability pathways creates a 'heat-map' allowing us to determine where a strategy is strong and where it has gaps.	A matrix linking resilience dimension and vulnerability pathway to different classes of policy instruments.

FRAMEWORK CONSTRUCTION

This section is split into three parts. Part I answers RQ1. It conducts a systematic review of the resilience literature to identify the key dimensions and mechanisms good resilience strategies address and validates these with comparisons to resilience strategies in more mature policy areas. Part II is focused on RQ2. It examines risk frameworks and details how exposure, sensitivity, and management capacity determine the pathways through which human populations can be vulnerable to heat. Part III synthesises these findings to produce our diagnostic tool and expresses it as in a table format.

Part I: Core Dimensions of Resilience

Resilience as theory

In the literature review, I defined resilience as the capacity of a system to withstand, recover from, and adapt to shocks while maintaining the ability to provide its core functions. Building resilience is therefore not just about returning to a pre-shock state, but involves learning, adaptation, and sometimes, fundamental transformation. Using this definition, a system's level of resilience can be thought of as being a function of three sub-capacities: absorptive, adaptive, and transformative capacity.

Absorptive capacity refers to the ability of a system to absorb the impact of a shock while maintaining essential functions using existing resources and response mechanisms. Also referred to in the literature as 'robustness' or 'precursor resilience', it is about buffering shocks and withstanding immediate pressure in order to mitigate damage and hasten the return to the pre-shock status quo (Boin and van Eeten 2013). Key elements include preparedness, the robustness of critical systems, and the availability of reactive response mechanisms. Absorptive capacity is most useful for managing temporary shocks, shielding the system from disruption and mitigating the need for the system to engage in costly adaptation or even costlier transformation measures.

Adaptive capacity refers to the ability of a system to adjust its characteristics and behaviours to better cope with existing or expected future shocks (Smit and Wandel 2006). It involves learning from past experiences, anticipating future risks, and making incremental adjustments to the system to minimise the impact of the shock either before or as it happens. Adaptive capacity is most useful for addressing shocks that are expected to be frequent or permanent. In these cases, maintaining robustness becomes increasingly costly over time, and adapting the system to reduce its exposure is necessary for both mitigating the damage of the shock and minimising the cost of maintaining sufficient levels of absorptive capacity (Adger and Vincent 2005).

Transformative capacity refers to the ability of a system to fundamentally reform in the face of new or existing significant and persistent / permanent shocks (Davoudi, Brooks, and Mehmood 2013). Transformative capacity differs from adaptive capacity, in that it represents a system's ability to qualitatively change itself and alter its trajectory. Beyond absorption and incremental adaptation, a system may be confronted with a shock, or the prospect of one, that requires it to invest in new technologies or infrastructure that create new path-dependencies, or conversely, to strategically retrench and retreat from high-risk areas. These decisions alter the system's trajectory and even how it manifests physically (Folke et al. 2010).

As alluded to their definitions, each capacity is more or less relevant at different times, relative to a shock.

During a shock, absorptive capacity is the most important – emergency management and disaster response mechanisms are active and are usually the political priority. Adaptive changes may occur during this time, but the focus is on limiting immediate harm. Investment decisions during a shock are usually focused on reallocating contingency resources and scaling up existing investments in robustness measures.

Post-shock, absorptive mechanisms refocus from damage mitigation to status-quo restoration. This is also a transition period, as learning processes begin and communities make decisions around how to build back (Albright and Crow 2021). The scope of these decisions depends on the choices the community made prior to the shock about how much to invest in their adaptive capacity and what kinds of absorptive capacity to build. These choices create path dependencies and affect the return on investment for further investment in resilience.

Between shocks is when adaptive and transformative capacities are most relevant. Communities make decisions about how much their systems need to change based on their understanding of the risks that they face. The quality of these decisions is directly related to the level of adaptive and transformative capacity they possess: their ability to predict the frequency and severity of future shocks, the effectiveness of their learning processes and decision-making institutions, and their ability to reallocate resource and change incentives to operationalise these predictions and lessons learned.

It is important to note that these capacities are not mutually exclusive, and that specific interventions intended to develop one type of capacity may also produce benefits for another. Likewise, some interventions that are designed to build a certain capacity may undermine another.

Resilience in practise

Examining more mature policy domains provides useful lessons for how these capacities are built and operationalised in practise. This part continues the discussion on the dimensions of resilience and their temporal relevance and examines them in the context of flooding and flood control.

Flooding, whether from coastal storm surge, overflowing rivers, or excess rainfall, is a long-standing risk to human settlements. The most obvious form of absorptive capacity are physical defences like dams, levees, floodwalls, and surge barriers built to withstand specific flooding magnitudes (Hegger et al. 2016). It includes early warning systems and related infrastructure, allowing for timely evacuation and deployment of temporary flood management tools like sandbags and dike-digging (Hegger et al. 2016). Absorptive capacity is also built through financial mechanisms like insurance schemes and disaster relief funds that spread risk and help affected individuals, firms, and communities absorb flood-related losses (Botzen and Van Den Bergh 2008).

In this context, adaptive capacity is built through policies that acknowledge the dynamic nature of flood events and aim to limit exposure. An example of this is Bangladesh's 'living with floods' approach, where central and local authorities are empowered to restrict settlement in high-risk zones, mandate the use of water-resistant construction materials, and encourage the use of salt-resistant crops (Letsch, Dasgupta, and Robinson 2023).

Transformative capacity in the context of flood resilience looks like policymakers internalising new information about the expected development of future floods and making system-level changes to how they plan for them. An example of this is the paradigm shift in Dutch planning with the implementation of their 'Room for the River' programme. Confronted by the twin risks of rising sea levels and sinking landmass, Dutch policymakers predicted that their approach of increasing robustness by building ever taller dikes would eventually undermine wellbeing. Taller dikes mean more water is stored in rivers during flood events, which increases the amount of damage caused when the dikes are inevitably breached. Internalising this lesson, the Netherlands instituted a multi-decadal programme of investment and planning reform to reconfigure their built environment and governance structures to produce a qualitatively different approach to flood management (de Bruijn, de Bruijne, and ten Heuvelhof 2015).

Summaries of these resilience dimensions are captured in Table 2 below.

Table 2: summary table of resilience dimensions

Capacity	Definition	Relevant phase	Key attributes
Absorptive	Ability to absorb / withstand immediate impacts and return to status quo.	During shocks and in immediate aftermath.	*Mechanisms:* robust warning systems, buffering tools and protocols. *Planning horizon:* short-term (days / weeks). *Flexibility*: moderate, depends on pre-defined plans.
Adaptive	Ability to adjust, learning from experience and reducing exposure over time.	Between shocks and during recovery.	*Mechanisms:* learning processes, planning and regulatory levers *Planning horizon:* medium to long-term (years to decades) *Flexibility*: high, focuses on learning and iterative improvement
Transformative	The ability for a system to fundamentally change itself in the face of risk.	After and between shocks.	*Mechanisms:* strategic investment and planning functions *Planning horizon:* long-term (decades to generations).

			Flexibility: depends on ease of reallocation and institutional reform.

Part II: Heat Risk Pathways

Extreme heat events do not affect all individuals, communities, firms, or systems equally. Being exposed to heat risk is the result of a complex interplay of factors that determine the likelihood and severity of adverse impacts. This section examines the pathways through which extreme heat creates risk for human populations.

Conceptualising risk: exposure, sensitivity, and management capacity

To provide a coherent and robust conceptualisation of risk and vulnerability, I utilise the risk framework the IPCC developed in their 2014 *Fifth Assessment Report* and refined in the subsequent 2022 *Sixth Assessment Report*. In a climate context, the IPCC defines risk as arising from "dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human system to the hazard" (Garschagen et al. 2020). This definition of risk differs from its use in other contexts in that it is explicitly human-centric: for there to be risk, there needs to a human system that is both exposed and vulnerable to a hazard.

Expressed as a formula:

Risk = Hazard (e.g., heatwaves) x Exposure x Vulnerability

And:

Vulnerability = Sensitivity x Management Capacity

Hazards refers to physical events or trends that can cause harm if people and systems are exposed and vulnerable. Hazards can be acute, occurring suddenly and producing immediate harm. They can also be chronic, developing slowly and generating costs over an extended timeframe (Garschagen et al. 2020). Finally, acute and chronic hazards can be interrelated. In a heat context, heatwaves are acute hazards, and their frequency, intensity, and duration is driven in part by the chronic hazard of increasing ambient global temperatures (Dosio et al. 2018).

Exposure refers to the presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by a hazard (IPCC 2014b). In the context of heat, it means being physically present in places where heatwaves happen.

Sensitivity refers to the degree to which a system of species is affected, either adversely or beneficially, by a hazard. The effect can be direct (e.g., variable background temperatures affecting crop yields) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (IPCC 2014b). In a heat context, sensitivity means the predisposition of a person or system to be harmed by that exposure.

Management capacity refers to the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC 2014a). In a heat context, this refers to the existing resources and capabilities available to communities to manage heat shocks. As referenced in the earlier discussion of the dimensions of resilience, this refers to the existing ability of a system to manage shocks i.e., its baseline level of resilience. From an analytical perspective, the practical difference between management capacity and the sub-capacities of resilience described in the previous section is that the former refers to a system's pre-existing level of resilience, while the latter is used to articulate how a marginal policy or initiative affects the resilience of that system.

For the purposes of developing a diagnostic framework for evaluating policy, this paper focuses on the exposure and vulnerability (sensitivity and management capacity) components. This is because given the global nature of the hazard (climate change) and our unit of analysis (city and state-level), exposure and vulnerability are the only drivers of risk that are realistically amenable to local-level policy changes.

Summaries of these key risk pathways are captured in Table 3 below.

Table 3: summary table heat risk pathways

Capacity	Definition	Key attributes in a heat context
Exposure	The presence of people and their systems in settings that could be adversely affected by hazards.	Being physically present in places where heatwaves happen.
Sensitivity	The degree to which people (individual or collectively), or a system is affected, adversely or beneficially, by a hazard.	The predisposition of a person or system to be harmed by exposure to heat. Effects can be direct or indirect. A sub-component of vulnerability.
Management capacity	The ability of people, institutions, systems to adjust to damage, take advantage of opportunities, or respond to consequences.	The existing resources and capabilities available to manage heat shocks i.e., a systems pre-existing level of resilience. A sub-component of vulnerability.

Key pathways affecting heat risk

Now we have a conceptual understanding of the drivers of heat risk, this part expands on this by discussing some of the key pathways under each driver. Note, this is not intended to be a comprehensive analysis of every vector through which an individual, community, or system is affected by heat. Instead, the aim is to produce a typology of the most likely pathways through which heat affects people and systems.

Pathways affecting exposure

An important exposure pathway are geographic and environmental factors. Living in naturally hotter climates, arid regions, or areas prone to the Urban Heat Island (UHI) effect significantly increases exposure. These areas have some combination of a high level of heat-retaining surfaces, like asphalt and concrete, and a lack of heat dispersing surfaces, like plant cover or bodies of water (Deilami, Kamruzzaman, and Liu 2018).

Construction materials are generally important beyond the UHI, particularly for housing. Poorly designed or constructed buildings with inadequate insulation, ventilation, or lack of access to cooling tools, like air conditioning, leads to higher indoor temperatures and increases exposure (Zhou et al. 2020). Overcrowding can exacerbate these issues.

Occupational exposure is important driver of exposure. Outdoor workers, like construction and agricultural workers, and those working indoors without climate control, like some factory and kitchen workers, are more exposed than other workers. Relatedly, people with less ability to control their surroundings, like homeless populations or the disabled, are also more exposed.

Pathways affecting sensitivity

There are a range of physiological factors affecting how sensitive a population is to heat. Age is important, with the elderly and very young being the most vulnerable groups, owing to their reduced ability to thermoregulate and limited autonomy (Johnson, Wilson, and Luber 2009). Individuals with pre-existing health conditions and chronic illness like cardiovascular disease, kidney disease, diabetes, and mental health conditions likely also have impairments that either affect the body's ability for thermoregulation or are exacerbated by heat stress (Ebi et al. 2021). Some medications can also interfere with thermoregulation and fluid retention. Pregnant women are also more susceptible to heat stress, with potential risks to both maternal and foetal health (Ebi et al. 2021).

Socio-economic factors also play a role. Low-income households are more likely to inhabit low quality housing, occupy heat exposed jobs, and lack access to cooling tools like air conditioning (Johnson, Wilson, and Luber 2009). Social isolation also plays a role, with individuals living alone, particularly the elderly or disabled, being less likely to receive support during heatwaves (Naughton et al. 2002). Education also matters, with a lack of awareness of heat risks and protective measures also increasing sensitivity.

Pathways affecting management capacity

There are a range of factors that determine a society's ability to respond to heat shocks. at the individual level, this looks like access to personal cooling tools (e.g., air conditioning and fans), knowledge of heat safety practises (e.g., importance of hydration, activity modification, appropriate clothing), the ability to seek assistance when needed, and the financial resources to cope with heat-related expenses (Naughton et al. 2002). At the community level these are things like the availability and accessibility of public cooling infrastructures (e.g., green spaces and water bodies) and community support networks (e.g., support systems for vulnerable individuals).

At the national / systemic level, institutions like health system capacity and infrastructure reliability matter for a society's ability to manage heat stress events (Mason et al. 2022).

Governance systems play a significant role here, acting as multipliers by supporting decision-making and improving learning mechanisms.

Cross-cutting examples of vulnerable populations

Understanding the distinct yet interconnected vulnerability pathways are essential for designing targeted and effective heat resilience strategies. For the purposes of designing a diagnostic framework, they are essential for understanding who these strategies help and who they do not. See below for illustrative examples of how this interconnectedness play out:

- An elderly individual with a heart condition (high sensitivity) living along in a top-floor apartment without air conditioning in a dense urban area (high exposure) who is aware of available cooling centres but has mobility issues that prevents access (low management capacity) is at extreme risk during a heat wave.
- An individual in their 30s who lives with their spouse (low sensitivity) and works in an office (low exposure) in a city where they have good access to health care (high management capacity) faces low risk during a heat wave.
- A homeless individual with access to shelter (medium exposure) with mental health and substance abuse issues (high sensitivity) but has adequate access to healthcare facilitates faces a medium-high level of risk during a heat wave.

Part III: Synthesising an Evaluative Framework

The preceding sections have established the core dimensions of resilience (absorptive, adaptive, and transformative capacities) and the way pathways through which populations and systems can be at risk from heat (exposure, sensitivity, management capacity). This part synthesises these findings to construct a diagnostic framework for evaluating heat resilience strategies.

The resilience dimensions discussed in RQ1 provide the ‘how’ of building resilience i.e., the types of capacities that strategies should cultivate. The vulnerability pathways discussed in RQ2 describe the ‘what’ i.e., the specific aspects of heat risk that heat resilience strategies need to address. An effective heat resilience strategy should operate across multiple dimensions and address all risk pathways.

Table 4 below is the result of this synthesis. It is structured as a matrix, with the core resilience dimensions as columns and the heat risk pathways as rows. Each cell in the table represents an intersection where specific types of interventions can be mapped to and diagnostic questions can be formulated. By examining the distribution of these initiatives across the resilience dimensions and risk pathways, we can gain insights into the overall nature, strategic priorities, and potential gaps of a given heat resilience strategy.

Table 4: diagnostic framework for heat resilience strategies

Capacity / pathway	**Absorptive**	**Adaptive**	**Transformative**
Exposure	*How does the strategy reduce exposure to heat during heat events?* *E.g., cooling centres, water misting stations, work-stop orders, public shade provision.*	*How does the strategy reduce long-term or chronic heat exposure?* *E.g., urban greening, cool materials mandates, land-use planning to reduce UHI, minimum insulation standards*	*What system-level investments / disinvestments are made to alter future patterns of exposure?* *e.g., redesigning urban districts for passive cooling, restricting development in high UHI zones, population relocation*
Sensitivity	*How does the strategy reduce harm to sensitive groups during heat events?*	*How does the strategy reduce the underlying sensitivity of populations over time?*	*What systematic investments are being made to qualitatively reduce the population's sensitivity profile?*

	e.g., targeting warnings for elderly / chronically ill populations, wellness checks	*e.g., education programmes to raise awareness of heat risks and safety practises in the workplace, public health programmes addressing chronic diseases that are exacerbated by heat*	*e.g., heat-related chronic disease prevention, working day-reorientation*
Management capacity	*How does the strategy ensure effective and immediate responses during a heat event?* *e.g., robust heat-health warning systems, emergency service preparedness, utility grid stability.*	*How does the strategy build long-term institutional and community capacity to manage heat risks?* *e.g., community buy-in / involvement into risk management plans*	*What transformative changes are made to governance and systemic management capabilities?* *e.g., establishing dedicated heat adaptation agencies, integrating heat risk into sectoral policy, investment in climate-resilient infrastructure, culture shift into proactive risk management.*

Limitations

This framework has several limitations. To keep the mapping exercise simple, all initiatives are weighted equally. For example, an initiative that establishes a city-wide cooling system counts as having the same absorptive / exposure impact as an initiative that establishes one public park. Given the aim of this tool is to measure comprehensiveness, identify strengths, and diagnose gaps, this is an acceptable trade-off. However, from a strategy implementation perspective, this should be kept in mind when considering which recommendations to action.

Related to this limitation is a bias that leads to management capacity-aligning initiatives being overrepresented. This bias results from initiative fragmenting, when an overarching initiative is broken down and is reported on as several sub-initiatives. For example, the single initiative "cooling measures for care institutions" could be reported on as "cooling measures for nursing homes," and "cooling measures for residential homes," and so on. When applying strategies to the framework, I have tried to control for that where possible by consolidating similar initiatives, leaving them separate only where there is a qualitative difference.

Finally, when making recommendations for how improve a strategy, it does not consider the economic, fiscal, social, or environmental costs. The point of this framework is to evaluate how effective a strategy is a dealing with heat vulnerability and diagnosing gaps, not whether it does so at an acceptable cost. Decisions on cost acceptability – i.e., deciding how much heat resilience to purchase – is a value judgement, and needs to be made with an understanding of all the other risks that society / system is exposed to and the costs of purchasing resilience for these.

Case Study Analysis

This section uses the diagnostic framework developed in the first half of the paper to evaluate the likely effectiveness of two heat resilience strategies that are currently in use.

Both case studies are reviewed in the following way. First, I provide context by briefly outlining the jurisdiction's current level of heat risk and expected future trajectory in terms of exposure, sensitivity, and management capacity. Second, I outline the strategy itself, setting out its self-described goals, institutional context, and other relevant information. Third, I decompose the strategy into its individual initiatives and map them onto our diagnostic framework. Note, while some initiatives could fit into several cells, for analytical and visual clarity, I have only included them in the cell they are most closely aligned with. Where names are especially long, I have truncated them. Finally, I discuss the findings: which areas the strategy covers well, which it does not, and any other noteworthy insight.

Case Study I: State of Arizona's *Extreme Heat Preparedness Plan*

Arizona's heat context

Arizona is currently grappling with a severe and intensifying heat crisis, underscored by record-breaking temperatures and an accelerating death toll. While the state's desert climate has always posed heat-related challenges, climate change is increasing their exposure, leading to more frequent, prolonged, and intense heat events. Average temperatures state-wide have increased by nearly 1.5 ºC since 1900, with the warmest 21 years on record occurring between 2000 and 2021 (Kunkel 2022). In 2023, Arizona experienced 73 days above 38 ºC, including a record 31 consecutive days above 43 ºC in Maricopa County, home to 4.6 million inhabitants (Smith, Goff, and Kaufman 2024). The number of very cold nights and yearly rainfall have both been below average since 2000. This combination of rising daytime highs, diminished nocturnal cooling, and reduced rainfall all exacerbate heat stress. Temperatures are also projected to continue increasing irrespective of the level of future global emissions (Kunkel 2022).

The state's demography and socioeconomic conditions mean that Arizona has both a higher degree of sensitivity to heat than other US states, and an at-risk population that is more sensitive than others. Nearly 20% of the state's population is above 65 years, compared to the national average of 17.7% (U.S. Census Bureau 2024). While Arizona's poverty rate is approximately the national average of around 12.5%, the state has the 10th highest homelessness rate in the US (U.S. Census Bureau 2024). The state's increasing levels of substance abuse – primarily methamphetamine, fentanyl, and alcohol – are also associated with higher rates of heat-related death, with drugs being involved in 58% of heat-related deaths in 2023 (Smith, Goff, and Kaufman 2024). The combination of homelessness and drug use is particularly lethal: homelessness exposes an individual to 200 to 300 times the risk of heat-related death, and drug use was associated with 87% of homeless heat-deaths in 2022 and 89% in 2023 (Smith, Goff, and Kaufman 2024). The importance of private air-conditioned spaces as the primary cooling tool mean that the consequences of poverty, social isolation, and outdoor work are also higher than in other states.

Despite periods of extreme heat being a fact of life in Arizona, their level of heat-related management capacity is middling. The state's electricity network is ranked the 7th most reliable in the US, with only six extreme weather related power outages occurring from 2000-2023 (Climate Central 2024). Given the primary role of air conditioning and the lack of alternative cooling tools, avoiding power outages during heat events is crucial for limiting mortality. One recent study examining the impact of multiday blackouts during heatwaves in Phoenix has heat-related deaths more than doubling, and hospitalisations increasing by more than 50% (Stone et al. 2023). Arizona's public health system is less robust. The state's hospitals and emergency responders have effective protocols and experience treating heat-related illnesses, but increasingly lengthy and frequent heatwaves is straining capacity. They are also showing the limits of the existing heat advisory warnings and cooling infrastructure, with the rapid uptick in heat-related hospitalisations revealing significantly limited surge capacity (Arizona 2024).

Arizona's heat resilience strategy

In March 2024, the Arizonan state government released *Arizona's Extreme Heat Preparedness Plan* (EHPP), a strategy that:

> "… outlines how state agencies are preparing for another extreme heat event this year [2024], and puts forth recommendations for how the state can prepare for future events. The development of this Plan is … [about] protecting Arizonans from the impacts of extreme heat and weather events…" (Arizona 2024).

The EHPP is not an entirely new strategy. It was developed in response to the State's 2023 heatwave and establishes a new position of Chief Heat Officer to integrate the various initiatives underway at the city / county level into a state-wide strategy. Through this process of integration, the state is aiming to rationalise responsibility for different aspects of heat resilience across its various jurisdictions and coordinate planning for medium and long-term initiatives (Arizona 2024).

It can be thought of as having two sets of resilience-enhancing initiatives. The first is a set of ad hoc measures the state government is rolling out to prepare for and manage the 2024 heat season based on the lessons learned from the deadly 2023 season. The second is a set of medium to long-term recommendations for how to build heat-resilience in the state beyond 2024 (Arizona 2024).

Mapping Arizona's *Extreme Heat Preparedness Plan*

Following the process and acknowledging the caveats outlined earlier in the section, I have mapped each individual initiative in the EHPP onto Table 5 below. Note, some initiatives in the strategy lack specific titles and are instead described, for example: "directing more money to hazard mitigation and emergency response efforts, allowing the Department of Emergency and Military Affairs and other emergency responses agencies to respond more nimbly to extreme heat events and other hazards" (Arizona 2024). In such cases, I have given them a truncated name, for example: "increased state funding for hazard mitigation and emergency response efforts."

Table 5: initiative map of Arizona's Extreme Heat Preparedness Plan

Capacity / pathway	Absorptive	Adaptive	Transformative
Exposure	• State run cooling centre + mobile sites (*directly reduces exposure by providing cooling services*). • State provided maps of cooling centre and donation locations (*facilitates access to cooling centres and materials*). • Expansion of emergency shelter response for excessive heat (*provides immediate shelter, reducing exposure during extreme weather events*). • Establishment of a fleet (six) solar-powered mobile cooling centres (*provides immediate, responsive relief during heat events*). • Funding for overnight heat relief in metro areas (*reduces heat exposure, particularly for homeless population*). • Development of Resilience Hubs (*Spaces that provide cooling and access to water and refrigeration and state aid*). • Optimise cooling centre distribution, develop centre standards (*reallocating cooling resource to areas with greater need and developing better centres reduces overall exposure*).	• Prison habitation improvements (*upgrading cooling systems in prisons reduces long-term heat exposure*). • Include heat-mitigation criteria in housing development subsidies (*encourages incremental changes in new affordable housing to reduce residential heat exposure*).	

Sensitivity	• Assistance through LIHEAP[1] for home energy bills (*federal funding for low-income households to pay for air conditioning energy costs*). • Inmate heat safety strategy (*temporary measures to reduce immediate harm to inmates*)	• Arizona health dept. training for human services providers (*enables better connect of vulnerable individuals with services, reducing their sensitivity*). • Industrial Commission Heat Stress Emphasis Program (*promoting best practice workplace heat-management and data collection reduces heat illness over time*). • Develop multilingual heat-related educational materials (*improves public knowledge of heat risk and mitigated techniques, reducing sensitivity*).	• Advocate for a more equitable distribution of LIHEAP funding (*current system is biased toward meeting energy costs for cold states*)
Management capacity	• Increased state funding for hazard mitigation and emergency response efforts (*enhances the immediate capacity to respond to heat events).* • *Funding for in-state mutual aid* resources (*funding for up-front emergency response to improve horizontal coordination in-state*). • Public-private coordination to improve grid resilience (*work to ensure grid reliability helps manage immediate shocks during heat events*).	• State funding match for FEMA STORM Act[2] draw downs (*builds long-term capacity for local governments to undertake climate adaptation projects*). • Hired a cooling centre coordinator (*improves long-run organisation and effectiveness of cooling centre network*). • Funding for rural grid improvements (*long-term investment in rural infrastructure is adaptation to new challenges*). • Arizona health dept. developing and disseminating thresholds for enhanced heat response actions (*establishing clear action triggers / thresholds*	• Chief Heat Officer position established (*as the "nation's first," this could represent a transformative step in how the state approaches heat governance*). • Advocate for FEMA reform (*current federal disaster relief legislation was not developed with heat disasters in mind – reform could open federal funding for heat resilience measures*).

[1] Low Income Home Energy Assistance Programme (LIHEAP) (OCS 2025).
[2] The Federal Emergency Management Authority (FEMA) Safeguarding Tomorrow Through Ongoing Risk Mitigation (STORM) Act is a federal loan matching service to fund state-level climate adaptation (FEMA 2025)

		improves the systemic response to heat). • Effort to harmonise state and county heat-related illness data (*improves long-term data management and accessibility, supporting better planning and response*). • Integration of private / non-profit orgs into response architecture (*incorporating non-public orgs allows for private resource to be mobilised for disaster response*). • Disaster management department. develop tool to quantify impact of interventions (*improving evaluation tools improves resource allocation and strategic response*). • Dedicated heat-resilience forum established (*provides an ongoing platform for entities to develop the EHPP and related heat-response mechanisms*). • Grow Arizona’s weatherisation and energy workforce (*workforce is a key constraint in implementing adaptive housing measures*). • Develop a power and water service plan (*creating a more robust and adaptive system for managing utilities*). • Develop a registry of heat-specific critical infrastructure (*deepens understanding of systemic vulnerabilities and response needs*).	

		• Establish a long-term disaster recovery taskforce (*creating a standing structure that facilitates ownership of post-disaster issues and internalises lessons learned*). • Develop an entity for disseminating heat-specific information and data to different jurisdictions and partners (*improve the information base and communications of jurisdictions and partners, enabling more effective emergency management*). • Research on heat impacts and solutions (*research provides knowledge for how to refine existing / develop new strategies*).	

Discussion

Analysing the distribution of identifiable initiatives across the three resilience dimensions reveals a clear strategic leaning in Arizona's heat-resilience plan:

- **Adaptive capacity (20 of 35 initiatives)**: this is the clearly favoured approach. The significant number of initiatives here demonstrates a strong focus on long-term adjustments to current systems, institutional learning, scaling-up existing initiatives, and process improvement. This suggests a strategic understanding that Arizona's resilience can be improved through the ongoing modification and enhancement of existing structures.
- **Absorptive capacity (10 of 35 initiatives):** this is the second most common approach, with most initiatives being interventions to increase the robustness of the electricity supply, and targeted initiatives to limit the exposure of Arizona's most heat-vulnerable groups, including its homeless and low-income populations, to heatwaves when they occur.
- **Transformative capacity (3 of 35 initiatives):** this is the least common dimension. Notably, two of the three proposed transformative initiatives – reforming FEMA and changing the basis for LIHEAP funding allocations – involve transforming systems that are upstream of Arizona, rather than affecting how the state organises itself or its approach to climate change.

The allocation of initiatives across the three vulnerability pathways identifies the primary target pathway of Arizona's interventions:

- **Management capacity (19 of 35 initiatives):** the concentration of initiatives here demonstrates a strong emphasis on strengthening the governance, planning processes, institutional resources, and inter-agency coordination required to manage heat risk once it has materialised.

- **Exposure (10 of 35 initiatives):** these initiatives are focused on reducing people's physical contact with extreme heat or mitigating the intensity of the heat in their environments. They are entirely focused on increasing people's access to air conditioning.
- **Sensitivity (6 of 35 initiatives):** these initiatives are aimed reducing the predisposition of people to be harmed by heat. While there are some targeted interventions for low-income households and outdoor workers, the low number of initiatives could suggest that interventions to reduce population-wide sensitivity are simply less prevalent.

Taken together, this distribution of initiatives suggests a strategic approach focused on improving the effectiveness of the state's existing heat response mechanisms and processes, with some targeted measures to reduce the exposure and sensitivity of select sub-populations.

That this is the strategic approach is reinforced by examining cell concentration. With 14 of 35 initiatives, the adaptive / management cell is the most populated. This indicates that Arizona's focus is on progressing incremental improvements in the existing ways the state manages heat risk. For example, they are focused on enhancing planning processes (e.g., agreed thresholds for activating heat-response measures), developing human capital (e.g., growing Arizona's weatherisation workforce), improving information systems (e.g., developing registries of heat-specific critical infrastructure), and building new coordination mechanisms (e.g., hiring a cooling-centre coordinator).

With zero and one initiative respectively, the least populated cells are transformative / exposure and transformative / sensitivity. This could imply several things. First, that Arizonan policymakers see the existing types of exposure and sensitivity-limiting measures as sufficient for managing current and future heatwaves and only need scaling up (e.g., more mobile cooling centres). Second, that the cost of implementing transformative measures (e.g., redesigned urban form for passive cooling on a metropolitan scale, to limit exposure; addressing heat-susceptible chronic illnesses, to reduce sensitivity) is not worth the benefit, in either absolute terms or relative to other exposure / sensitivity-limiting investment. Finally, it could also indicate judgements regarding the role of the state vis-à-vis the individual and who has responsibility for building what level of resilience.

One initiative that did not fit into the framework was to 'Grow the Clean Energy Economy.' While decarbonising Arizona's growth is directionally helpful in terms of improving the planet's – and therefore the state's – heat resilience, the impact would be negligible, and there is limited evidence linking local green growth to improved local heat outcomes.

Case Study II: City of Vienna's *Heat Adaptation Plan*

Vienna's heat context

The city of Vienna is confronting a rapidly evolving heat landscape. Vienna's annual average temperature has increased by nearly 2 ºC since the 1970s, with 13 of the last 14 warmest years recorded occurring since 2000 (Stadt Wien 2022c). This increase in baseline temperature increases the city's level of exposure, with the frequency of 'very hot days' (days where the maximum temperature exceeds 30 ºC) more than doubling from an average of 9.2 days per year between 1961 and 1990 to an average of 20.1 (ZAMG 2021). These hot days are increasingly accompanied by 'tropical nights' (periods where temperatures remain above 20 ºC overnight, limiting nighttime recovery and prolonging exposure). The city's exposure is expected to worsen over time as global temperatures continue to rise, with the average heatwave length anticipated to increase from five days to between 15 – 28 days by 2100 (Chimani et al. 2023).

At the same time the city's exposure is increasing, its sensitivity is too. Vienna's demography already skews old and female, groups predisposed to heat sensitivity. The most recent population forecast by Statistics Vienna expects the city's aging rate to accelerate, and the share of population above 65 years to increase from 16% in 2023 to above 20% by 2053 (Stadt Wien 2023). An aging population will also drive higher rates of chronic illness and social isolation, further increasing the city's sensitivity.

Higher baseline levels of heat exposure and sensitivity will also increase the strain on Vienna's existing management capacity. Since 2010, Vienna has operated a preventive heat warning service to inform its inhabitants of heatwaves lasting three or more days with daytime temperatures reaching at least 35 ºC and nighttime temperatures exceeding 20 ºC. The city's healthcare services are also regarded as both accessible and high quality, though it is unclear what its capacity is to absorb a large number of heat-stressed patients (EOHSP 2024).

Vienna's heat resilience strategy

In 2022, the City of Vienna released *Vienna Heat Action Plan: For a cool Vienna* (VHAP), a strategy that:

> "…proactively defines measures for preventing and coping with overheating in the city. This is to prepare above all the health facilities, care, and nursing institutions of Vienna for heat-related emergencies and protect the population against the health effects of heat" (Stadt Wien 2022c).

The emphasis of the VHAP is on measures that can be implemented either during or immediately prior to a heat event. For this purpose, the plan identifies 15 broad-based measures intended to address the entire urban population and 13 measures targeted at specific vulnerable groups. It also identifies nine long-term measures that are aimed at long-term avoidance and reduction of ambient city heat.

This strategy is intended to be a living document rather than static, recognising the need to be responsive to changing climate conditions. The City Government sees the VHAP as being situated within its broader suite of climate-related development strategies. These include the revised 2022 *Smart City Wien Strategy*, which sets the city's overarching strategic climate framework and objectives (Stadt Wien 2022a), and the 2022 *Vienna Climate Guide*, which brings together the key levers for delivering climate neutrality by 2040 and building climate resilience (Stadt Wien 2022b).

Mapping the *Vienna Heat Resilience Strategy*

Following the process and acknowledging the caveats outlined earlier in the section, I have mapped each individual initiative in the VHAP onto Table 6 below.

Table 6: initiative map of Vienna's Heat Action Plan

Capacity / pathway	**Absorptive**	**Adaptive**	**Transformative**
Exposure	• Emergency measures taken during heatwaves (*activating fountains / misters to provide immediate cooling and reduce exposure in public spaces*). • Shady outdoor workplaces (*reduces exposure for some types of heat-exposed indoor workers*). • Cooling zones / "recreation islands" (*accessible cool spaces intended for people with limited home cooling measures*). • New cool spots on squares and in parks (*creates localised cooling infrastructure + heat sinks*). • "Shady benches" (*reduces direct sun exposure in public places*) • Extension of drinking fountain network (*provides access to water for hydration and cooling purposes*). • City-wide deployment of air-conditioned public transport (*reduces heat exposure for people using public transport during heatwaves*). • "Package of measures for homeless people" (*provides water, hats, sunscreen etc. to the homeless population during heatwaves*).	• Avenue tree initiative (*reduces long-term heat exposure by increasing shade and cooling urban areas*). • De-sealing drive (*greening asphalt areas to reduce heat-retaining surfaces and decrease the UHI effect*). • Establish new parks (*a greater proportion of greenspace reduces city-wide heat absorption and decreases the UHI effect*). • Financial support for greening private property (*encourages individual and firm-level adaptations to reduce chronic heat exposure*).	• Incorporate the "sponge-city principle" into planning processes (*represents a system-level change in urban design to enhance green infrastructure's cooling effects and manage water, altering future exposure patterns*). • Climate-sensitive planning (*include assessments of likely heat emissions for new projects, including impact on UHIs, changing the trajectory of Vienna's heat exposure*).

Sensitivity	• Establishment of a "heat line" (*calls / SMS to vulnerable groups to reduce their isolation during heat waves*). • Phone medical consultations during heatwaves (*reduces harm to sensitive groups by providing immediate advice / prescription renewal / etc. without requiring them to leave home*). • Heat protection for outdoor City workers (*mitigates the effects of heat on workers in high-exposure environments*).	• Information leaflets / "Vienna Heat Manual" (*educates people on heat risks, prevention, and coping strategies to foster long-term awareness*). • Workshops and themed weeks on heat-relevant issues at schools (*use schools as a mechanism for educating parents about heat risk and protective actions to reduce sensitivity over time*). • "Teach the Teachers" workshops / Green School Programme (*builds awareness and knowledge of climate change and heat risk among children, to reduce sensitivity over the long-term*). • Heat-related information on website, via WienBot, and other official channels (*uses tech to disseminate heat risk information and safety tips*). • "Heat Toolbox" for people living in difficult socio-economic conditions (*targeted information to vulnerable groups to raise awareness of risks and safety practises*). • Addressing and activating paediatrician surgeries (*use doctors as a mechanism for educating parents about children's increases sensitivity to heat*).	

Management capacity	• Ensuring care and assistance for an increasing number of people (*evaluates the preparedness of emergency services and healthcare systems to respond during heatwaves*). • City-wide Heat Alert System (*a heat-health warning system to trigger workplace-specific responses and alert the public*). • Heat standards for hospitals, residential and nursing homes, and day-care centres (*these set protocols for action during heatwaves to reduce the impact on vulnerable inhabitants*). • Neighbourhood assistance during heatwaves (*use pre-existing community social infrastructure during heat response to mobilise community resources during a heatwave*).	• Training physicians and nursing staff to deal with heat-related illnesses (*builds the long-term capacity of city healthcare professionals to manage heat-related health risks*). • Heat-related training for population-facing municipal staff (*improves the ability of staff to support the public regarding heat-related issues*). • Information for staff in therapy / counselling facilities as well as clinics for the mentally ill (*builds the capacity of these institutions to deal with heat-related demand increases for mental health services*). • Vienna Climate Team (*district-level participatory budgeting for climate projects, designed to foster community buy-in into risk management plans*). • Urban climate analysis (*integrating learning and data into planning processes to support better informed decision-making).* • Evaluation and monitoring programmes (*this process ensures learning from experience and the iterative improvement of the VHAP over time*).	• Establishment of a Steering Board for the VHAP (*establishing dedicated governance structures with supporting expert bodies creates the mechanisms required for the ongoing management and strategic development of the VHAP, including the possibility of significant direction shift, if required*).

Discussion

Based on this analysis, the distribution of initiatives across the resilience dimensions reveals a focus on building Vienna's adaptive and absorptive capacities:

- **Adaptive / absorptive capacity (16 / 15 of 34 initiatives):** the nearly equal initiative split between these two capacities suggests a strategy that places significant weight on both medium-term adjustments and immediate crisis response. Adaptive initiatives, like greening asphalt or providing targeted information to at-risk populations, aim to adjust Vienna's characteristics and prepare its population to better cope with ongoing and future heat. Concurrently, the strong presence of absorptive measures, like emergency cooling through fountains and misters or the deployment of air-conditioned public transport, highlights a recognition that robust measures are still needed to manage immediate impacts.
- **Transformative capacity (3 of 34 initiatives):** these receive comparatively very little attention in the VHAP. This could reflect the focus of the VHAP, which is about preparing vulnerable populations for an increasingly hot city in the present. Transformative initiatives, like planning reform and changes to cost-benefit-analyses, are marginal, meaning they are mostly relevant for future investment flows rather than the existing infrastructure stock.

Examining the distribution of initiatives across the risk pathways reveals a more balanced approach:

- **Exposure (14 of 34 initiatives):** this was the most focused on pathway. This shows a focus on measures designed to directly reduce people's physical contact with high temperatures or to lessen the intensity of heat in their environments. The strategy includes a wide array of initiatives to provide immediate relief, like extending the drinking fountain network and building new cool spots to longer-term adaptations like the public avenue tree initiative and the incentives for landowners to green their private property.

- **Management capacity (11 of 34 initiatives):** this focus on reducing exposure highlights a considerable effort to enhance the ability of individuals, communities, and city institutions to mobilise resource to manage heat events and implement resilience strategies effectively. These range from initiatives that build emergency service preparedness, like increasing doctor / nursing capacity and implementing heat alarm systems, to building local and city-wide coordination mechanisms, like the Vienna Climate Team and the VHAP Steering Board.
- **Sensitivity (9 of 35 initiatives):** despite being the least targeted pathway, it is still the focus of a quarter of the strategy's initiatives. These aim to lessen the predisposition of individuals to heat through information sharing, targeting vulnerable groups in the present through initiatives like the Heat Line and the Vienna Heat Manual, and targeting children through the school system build long-term, family-level awareness of heat risk.

Taken together, the VHAP is strongly focused on managing current heat risks through immediate operational responses while also preparing for future event during cooler seasons through incremental adjustments to existing systems. The primary objectives of these investments in absorptive and adaptive capacities are to reduce the population's exposure to heat – through physical protection measures – and to scale up existing support for populations that remain sensitive and exposed.

That this is the strategy's focus is reinforced by examining cell concentration. With eight initiatives, absorption / exposure is the most populated cell, and includes initiatives like air-conditioned public transport, support packages for the homeless, and emergency mister /

fountain activation. This concentration underscores the city's focus on providing immediate, direct relief during heatwaves.

The least populated cells are related to the transformative capacities, with exposure, sensitivity, and management capacity having two, zero, and one initiative respectively. The sparseness in these cells could suggests a view from Viennese policymakers that the existing mix of deployed technologies are sufficient for achieving their heat resilience objectives or a view about their potential cost-effectiveness. Another explanation for the lack of transformative / sensitivity initiatives could be due to the unit of analysis: initiatives that could affect a population's underlying sensitivity to heat include large-scale healthcare interventions, and so therefore fall outside the city government's competency. In any case, addressing these transformative areas could become increasingly important for sustaining resilience under more severe future climate scenarios, or for integrating new and potentially disruptive climate technologies in the futur

DISCUSSION OF FRAMEWORK RESULTS AND CONCLUSION

This research examines the escalating global challenge of extreme heat by developing and applying a novel diagnostic framework for evaluating the comprehensiveness of heat resilience strategies. In a policy domain still consolidating its understanding of 'best practice,' this study aimed to provide a structured and theoretically grounded tool that could aid policymakers in their approaches to this critical climate issue.

Key findings

The central outcome of this research is the Heat Resilience Diagnostic Framework, a 3x3 matrix synthesising core dimensions of resilience with key pathways of risk. The resilience dimensions – absorptive capacity, adaptive capacity, and transformative capacity – were drawn from established resilience theory and cross-checked against a more developed policy area. These dimensions were intersected with the primary pathways through which heat risk materialises: exposure, sensitivity, and management capacity. This matrix is a systematic lens to categorise and assess the strategic focus of heat resilience interventions, generating a 'heat map' that visually represents areas of strategic focus and potential neglect.

Application of this framework to two distinct case studies, Arizona's EHPP and Vienna's VHAP, yielded important insights into how both jurisdictions approach heat resilience planning:

- Arizona's EHPP is primarily about facilitating access to private cooling options (air conditioning), ensuring the security of its electricity supply, and providing targeted support to vulnerable populations. This demonstrated a strong strategic emphasis on building the state's absorptive capacity, to manage heatwaves when they happen, and the adaptiveness of the state's management capacity, to improve its organisation and coordination. However, the framework highlighted a comparative underemphasis on transformative capacity – it did not consider how it might take action to fundamentally alter the Arizona's long-term exposure patterns or reduce the population's underlying exposure or sensitivity.

- Vienna's VHAP is focused on developing large-scale public infrastructures and then making these reasonably accessible to its population. This reveals a more balanced strategic approach between building the city's absorptive and adaptive capacities. A significant number of initiatives were aimed at reducing exposure, both directly, through initiatives like misting, and indirectly, through greening initiatives. While comprehensive in many respects, transformative initiatives that addressed fundamental drivers of long-term vulnerability were less prominent.

Across both cases, the framework effectively diagnosed the strategic leanings of each plan, confirming its utility in moving beyond simple inventories of actions to a more nuanced understanding of how different resilience capacities are being cultivated and which risk pathways are being prioritised. It reveals that while both jurisdictions are actively addressing heat, how they seek to do that differs. This potentially reflects differences in context and in the value-judgements their policymakers make.

Implications for policy and theoretical contributions

The implications and contributions of this research have relevance for policymakers and the academic community engaged with climate adaptation.

Firstly, the developed framework is a tangible and structured diagnostic tool. In a field where policy responses are often ad-hoc and responsive, this provides a tool for policymakers to critically evaluate the scope and balance of their heat resilience strategies before, during, and after they are implemented. With this framework, policymakers can identify the strengths and gaps of their heat resilience strategy, weight this understanding with their knowledge of the local context, and make better informed decisions about how to allocate resources and develop their systems further.

Secondly, this research contributes to the consolidation of knowledge and the advancement of 'best practice' in the heat resilience field. This framework provides a common language and analytical structure grounded in the theory and practise of more developed fields. This can foster more effective learning and knowledge sharing for practitioners across diverse jurisdictions. In encourages a shift from comparing individual initiatives (outputs) to comparing the specific goals these initiatives are aiming to accomplish (outcomes).

Thirdly, the framework's application demonstrates its capacity to make implicit strategic priorities explicit. It highlights that there is not a single 'correct' strategy for building resilience to heat, but rather a series of choices about how it could be done and associated trade-offs, depending on the context's mix of risk pathways and the value-judgements of the people living in it.

Suggestions for future research

There are several avenues for future research, primarily related to addressing some of the limitations identified earlier in the paper.

1. **Quantifying risk and initiative impact**: future work could focus on integrating quantitative risk assessment data (e.g., detailed vulnerability mapping, exposure projections etc) directly into the framework. Alongside metrics to assess initiative 'depth' / 'effectiveness,' this would allow for a more nuanced assessment of whether a given strategy is appropriately balanced.

2. **Broader case study selection**: applying the framework to a wider and more diverse range of case studies – encompassing different climate zones, governance structures, and socio-economic contexts – would further test its robustness and policy effectiveness.
3. **Longitudinal examination**: tracking how different jurisdictions' strategies evolve over time when repeatedly assessed using this framework could identify important insights into policy development and learning processes, and into how transformative capacity works in practise.
4. **Exploring retrenchment mechanisms / adaptive governance**: understanding why and how communities come to decide to scale back or discontinue certain resilience mechanisms and how governance systems can become more agile are important general resilience topics.

In addressing these future research directions, academic and policy communities can build on the foundation laid by this thesis, which in turn builds on work from the wider resilience field.

The escalating crisis of extreme heat not only poses a severe and growing threat to human populations worldwide but also represents an increasing drain on national and global resources to manage its impacts. Against a general backdrop of increasing global risk, the importance for policymakers of making the best use of their finite resilience resources will also increase. Consequently, robust diagnostic tools, such as the framework developed in this thesis, will become increasingly vital, providing structured guidance for policymakers to refine their strategies and ensure their investments in resilience are impactful.

BIBLIOGRAPHY

Adger, W. Neil, and Katharine Vincent. 2005. 'Uncertainty in Adaptive Capacity'. *Comptes Rendus Geoscience* 337 (4): 399–410. https://doi.org/10.1016/j.crte.2004.11.004.

Albright, Elizabeth A., and Deserai A. Crow. 2021. 'Capacity Building toward Resilience: How Communities Recover, Learn, and Change in the Aftermath of Extreme Events'. *Policy Studies Journal* 49 (1): 89–122. https://doi.org/10.1111/psj.12364.

Arizona, Office of the Governor. 2024. 'ARIZONA'S EXTREME HEAT PREPAREDNESS PLAN'. Phoenix, Arizona: Office of the Governor. https://resilient.az.gov/sites/default/files/2024-07/extreme-heat-preparedness-plan-2024-03-1.pdf.

Boin, Arjen, and Michel J. G. van Eeten. 2013. 'The Resilient Organization'. *Public Management Review* 15 (3): 429–45. https://doi.org/10.1080/14719037.2013.769856.

Botzen, W. J. W., and J. C. J. M. Van Den Bergh. 2008. 'Insurance Against Climate Change and Flooding in the Netherlands: Present, Future, and Comparison with Other Countries'. *Risk Analysis* 28 (2): 413–26. https://doi.org/10.1111/j.1539-6924.2008.01035.x.

Bruijn, Hans de, Mark de Bruijne, and Ernst ten Heuvelhof. 2015. 'The Politics of Resilience in the Dutch 'Room for the River'-Project'. *Procedia Computer Science*, 2015 Conference on Systems Engineering Research, 44 (January):659–68. https://doi.org/10.1016/j.procs.2015.03.070.

Chimani, B, G Heinrich, M Hofstätter, M Kerschbaumer, S Kienberger, A Leuprecht, S Peßenteiner, et al. 2023. 'Final Report ÖKS15 – Climate Scenarios for Austria - Data - Methods - Climate Analysis - Datasets | CCCA Data Server'. Climate Change Centre AUSTRIA. 7 February 2023. https://web.archive.org/web/20230207212351/https://data.ccca.ac.at/dataset/endbericht-oks15-klimaszenarien-fur-osterreich-daten-methoden-klimaanalyse-v01.

Climate Central. 2024. 'Weather-Related Power Outages Rising | Climate Central'. April 2024. https://www.climatecentral.org/climate-matters/weather-related-power-outages-rising.

Davoudi, Simin, Elizabeth Brooks, and Abid Mehmood. 2013. 'Evolutionary Resilience and Strategies for Climate Adaptation'. *Planning Practice & Research* 28 (3): 307–22. https://doi.org/10.1080/02697459.2013.787695.

Deilami, Kaveh, Md. Kamruzzaman, and Yan Liu. 2018. 'Urban Heat Island Effect: A Systematic Review of Spatio-Temporal Factors, Data, Methods, and Mitigation Measures'. *International Journal of Applied Earth Observation and Geoinformation* 67 (May):30–42. https://doi.org/10.1016/j.jag.2017.12.009.

Dosio, Alessandro, Lorenzo Mentaschi, Erich M Fischer, and Klaus Wyser. 2018. 'Extreme Heat Waves under 1.5 °C and 2 °C Global Warming'. *Environmental Research Letters* 13 (5): 054006. https://doi.org/10.1088/1748-9326/aab827.

Ebi, Kristie L., Anthony Capon, Peter Berry, Carolyn Broderick, Richard de Dear, George Havenith, Yasushi Honda, et al. 2021. 'Hot Weather and Heat Extremes: Health Risks'. *The Lancet* 398 (10301): 698–708. https://doi.org/10.1016/S0140-6736(21)01208-3.

EOHSP. 2024. 'Austria Health System Information'. European Observatory on Health Systems and Policies. 2024. https://eurohealthobservatory.who.int/countries/austria.

FEMA. 2025. 'Safeguarding Tomorrow Revolving Loan Fund Program | FEMA.Gov'. Federal Emergency Management Agency. 30 May 2025. https://www.fema.gov/grants/mitigation/learn/storm-rlf.

Folke, Carl, Stephen R. Carpenter, Brian Walker, Marten Scheffer, Terry Chapin, and Johan Rockström. 2010. 'Resilience Thinking: Integrating Resilience, Adaptability and Transformability'. *Ecology and Society* 15 (4). https://www.jstor.org/stable/26268226.

Garschagen, Mathias, Margot Hurlbert, Sylvia Kreibiehl, Katharine J Mach, Katja Mintenbeck, Brian O'Neill, Minal Pathak, et al. 2020. 'The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions'. *Intergovernmental Panel on Climate Change*.

Hegger, Dries L. T., Peter P. J. Driessen, Mark Wiering, Helena F. M. W. van Rijswick, Zbigniew W. Kundzewicz, Piotr Matczak, Ann Crabbé, et al. 2016. 'Toward More Flood Resilience: Is a Diversification of Flood Risk Management Strategies the Way Forward?' *Ecology and Society* 21 (4). https://www.jstor.org/stable/26270030.

Holling, C. S. 1973. 'Resilience and Stability of Ecological Systems'. *Annual Review of Ecology and Systematics* 4:1–23.

IPCC. 2014a. 'Annex II - Glossary'.

———. 2014b. 'Summary for Policymakers In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change e'. *Cambridge University Press*.

———. 2022. 'Summary for Policymakers'. 2022. https://www.ipcc.ch/report/ar6/wg2/chapter/summary-for-policymakers/.

Johnson, Daniel P., Jeffrey S. Wilson, and George C. Luber. 2009. 'Socioeconomic Indicators of Heat-Related Health Risk Supplemented with Remotely Sensed Data'. *International Journal of Health Geographics* 8 (1): 57. https://doi.org/10.1186/1476-072X-8-57.

Kunkel, K. E. 2022. 'State Climate Summaries for the United States 2022. NOAA Technical Report NESDIS 150.' NOAA NESDIS. https://statesummaries.ncics.org/chapter/az.

Letsch, Lucia, Shouro Dasgupta, and Elizabeth Robinson. 2023. 'Tackling Flooding in Bangladesh in a Changing Climate'. *Grantham Research Institute on Climate Change and the Environment* (blog). August 2023. https://www.lse.ac.uk/granthaminstitute/publication/tackling-flooding-in-bangladesh-in-a-changing-climate/.

Longstaff, P. H. 2009. ‘Managing Surprises in Complex Systems: Multidisciplinary Perspectives on Resilience’. *Ecology and Society* 14 (1). https://www.jstor.org/stable/26268013.

Mason, Hannah, Jemma C King, Amy E Peden, and Richard C Franklin. 2022. ‘Systematic Review of the Impact of Heatwaves on Health Service Demand in Australia’. *BMC Health Services Research* 22 (1): 960. https://doi.org/10.1186/s12913-022-08341-3.

Naughton, Mary P, Alden Henderson, Maria C Mirabelli, Reinhard Kaiser, John L Wilhelm, Stephanie M Kieszak, Carol H Rubin, and Michael A McGeehin. 2002. ‘Heat-Related Mortality during a 1999 Heat Wave in Chicago1’. *American Journal of Preventive Medicine* 22 (4): 221–27. https://doi.org/10.1016/S0749-3797(02)00421-X.

Norris, Fran H., Susan P. Stevens, Betty Pfefferbaum, Karen F. Wyche, and Rose L. Pfefferbaum. 2008. ‘Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness’. *American Journal of Community Psychology* 41 (1): 127–50. https://doi.org/10.1007/s10464-007-9156-6.

OCS. 2025. ‘Low Income Home Energy Assistance Program (LIHEAP)’. Office of Community Services: An Office of the Administration for Children & Families. 7 May 2025. https://acf.gov/ocs/programs/liheap.

Reid, Richard, and Linda Courtenay Botterill. 2013. ‘The Multiple Meanings of “Resilience”: An Overview of the Literature’. *Australian Journal of Public Administration* 72 (1): 31–40. https://doi.org/10.1111/1467-8500.12009.

Rose, Adam. 2004. ‘Defining and Measuring Economic Resilience to Disasters’. *Disaster Prevention and Management: An International Journal* 13 (4): 307–14. https://doi.org/10.1108/09653560410556528.

———. 2007. ‘Economic Resilience to Natural and Man-Made Disasters: Multidisciplinary Origins and Contextual Dimensions’. *Environmental Hazards* 7 (4): 383–98. https://doi.org/10.1016/j.envhaz.2007.10.001.

Smit, Barry, and Johanna Wandel. 2006. ‘Adaptation, Adaptive Capacity and Vulnerability’. *Global Environmental Change*, Resilience, Vulnerability, and Adaptation: A Cross-Cutting Theme of the International Human Dimensions Programme on Global Environmental Change, 16 (3): 282–92. https://doi.org/10.1016/j.gloenvcha.2006.03.008.

Smith, Slade, Kirin Goff, and Sonia Kaufman. 2024. ‘Arizona’s Heat-Related Death White Paper: Full Report’. Making Action Possible for Southern Arizona. https://mapazdashboard.arizona.edu/article/arizonas-heat-related-death-white-paper-full-report.

Stadt Wien. 2022a. *Smart Klima City Strategie Wien: Der Weg Zur Klimamusterstadt*. Wien: Magistrat der Stadt Wien. https://smartcity.wien.gv.at/en/strategy/.

———. 2022b. ‘Vienna Climate Guide: Towards a Climate-Friendly City’. Wien.

———. 2022c. ‘Vienna Heat Action Plan: For a Cool Vienna’. Vienna: Stadt Wien. https://www.wien.gv.at/english/environment/klip/heat-action-plan.html.

———. 2023. ‘Summary: Small-Scale Population Projection for Vienna 2023–2053’. 2023. https://www.wien.gv.at/english/administration/statistics/population-projection-2053-summary.html.

Stone, Brian, Carina J. Gronlund, Evan Mallen, David Hondula, Marie S. O’Neill, Mayuri Rajput, Santiago Grijalva, et al. 2023. ‘How Blackouts during Heat Waves Amplify Mortality and Morbidity Risk’. *Environmental Science & Technology* 57 (22): 8245–55. https://doi.org/10.1021/acs.est.2c09588.

U.S. Census Bureau. 2024. ‘U.S. Census Bureau QuickFacts: Arizona’. 2024. https://www.census.gov/quickfacts/fact/table/AZ/AGE775223#AGE775223.

WHO. 2024. ‘Heat and Health’. World Health Orgnisation. 2024. https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health.

ZAMG. 2021. ‘Summer 2021: very warm and partly wet, partly dry — ZAMG’. Zentralanstalt für Meteorologie und Geodynamik. 31 August 2021. https://web.archive.org/web/20210831092416/https://www.zamg.ac.at/cms/de/klima/news/sommer-2021-sehr-warm-und-teils-nass-teils-trocken.

Zhou, Xiaohai, Jan Carmeliet, Matthias Sulzer, and Dominique Derome. 2020. ‘Energy-Efficient Mitigation Measures for Improving Indoor Thermal Comfort during Heat Waves’. *Applied Energy* 278 (November):115620. https://doi.org/10.1016/j.apenergy.2020.115620.