Transforming Extreme Heat into Opportunity: A Systems Resilience Framework for Health and Energy in the UK and Japan

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Transforming Extreme Heat into Opportunity: A Systems Resilience Framework for Health and Energy in the UK and Japan

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Abstract: As climate change intensifies, extreme heat is emerging as a systemic threat with cascading effects across health, energy, and infrastructure systems. This study adopts a systems resilience framework to explore how societies can transform this risk into an opportunity for innovation and adaptation. Focusing on the United Kingdom and Japan, we analyse the converging crises affecting urban and rural populations, with special attention to vulnerable groups and mental health risks. By comparing national policies, technological innovations, and community-based strategies, this paper identifies cross-national insights and demonstrates the value of systems thinking. Findings emphasize the need for integrated responses that prioritize equity, co-produced policy, and alignment with climate mitigation goals such as the UK's Net Zero target. While extreme heat presents urgent challenges, it also offers a unique opportunity for systemic transformation—if resilience is designed with intention.

Keywords: climate change, extreme heat, mental health, resilience, technological innovation

1. INTRODUCTION

Extreme heat is no longer a temporary seasonal disturbance; it has evolved into a systemic and accelerating climate threat. As global temperatures rise, heatwaves are becoming more frequent, intense, and prolonged. These thermal extremes have cascading effects that ripple across interconnected systems—including public health, energy infrastructure, urban design, and social equity [1][2]. Such impacts deepen existing vulnerabilities, particularly in the most exposed communities and under-resourced environments.

Countries around the world are struggling to keep up with the mounting pressures of this climate reality. The United Kingdom, historically considered temperate, is now experiencing increasing health burdens related to heat—particularly among vulnerable groups such as older adults, young children, and individuals with chronic conditions [3]. The intensification of urban heat islands further exacerbates disparities in housing quality, access to green infrastructure, and healthcare systems [4]. Meanwhile, rural regions face different but equally pressing challenges, including limited adaptive infrastructure and fewer public health resources.

Japan, by contrast, has a long-standing experience in dealing with extreme heat, shaped by its hot summers, aging population, and dense urban areas. Over the years, Japan has developed comprehensive strategies that range from early warning systems and advanced urban cooling technologies to public education campaigns and climate-responsive building standards [5][6]. While not immune to risk, Japan's multi-layered approach offers critical lessons on institutional and community-level resilience.

This contrast between the UK's evolving climate adaptation efforts and Japan's more established heat-response systems forms the foundation for comparative research. Analyzing both contexts allows us to better understand how national policies, cultural values, and governance mechanisms influence adaptive capacity. Moreover, examining how each country's strengths can inform the other's vulnerabilities offers a unique opportunity for cross-learning and mutual improvement [7].

Extreme heat is not just an environmental challenge—it is a systemic crisis. Yet, it also presents an opportunity for transformation. From passive building cooling designs and integrated mental health tools to strategic rural-urban planning and energy-efficient infrastructure, the urgency of rising temperatures is driving innovation [8]. Tackling this complex issue requires systems thinking approaching heat not as an isolated phenomenon, but as a multi-sectoral challenge that demands coordination across health, planning, technology, and policy domains [9].

The policy environment is also evolving. With the UK legally committed to achieving net-zero emissions by 2050, adapting to extreme heat is no longer a matter of comfort or even safety alone—it has become a question of climate justice and long-term sustainability. Real progress will require the co-production of policy: grounded in data, informed by lived experience, and shaped by inclusive dialogue among governments, researchers, and communities [10]. Only through this systemic, participatory approach can we generate solutions that are resilient, equitable, and future-ready.

This research aims to develop a comprehensive framework for understanding and enhancing systems resilience to extreme heat through a comparative lens. Focusing on the United Kingdom and Japan—two nations experiencing intensifying thermal extremes but with distinct adaptation pathways—the study will examine how health, energy, and infrastructure systems respond to rising temperatures. Using systems mapping, comparative analysis, and the integration of lived experience, the research will identify how each country's strategies can inform the others. Ultimately, the goal is to transform the escalating challenges of extreme heat into opportunities for policy innovation, cross-sector collaboration, and long-term adaptive capacity.

2. COMPARATIVE CASE STUDY DESIGN

Urban and rural sites in Japan and the UK are used to contrast community engagement, digital tools, infrastructure, and policy. The table 1. below summarizes key indicators for prevention from both countries.

2.1 Human Health and Mental Wellbeing

Extreme heat poses serious threats to both physical and mental health, requiring coordinated responses from governments and communities. In Japan, local authorities have introduced innovative measures such as the "Cool Oasis" initiative in Saitama Prefecture, which designates public and private buildings as accessible cooling shelters for vulnerable populations, particularly elderly residents in rural areas [11]. Moreover, Japan leverages digital tools including real-time heat-health alert systems and mobile applications like *Heatshield*, which enable users to track behavioral patterns and receive personalized advice to mitigate heat-related stress and anxiety [11].

In the United Kingdom, the national response leans more heavily on centralized public health strategies. These include general practitioner (GP)-led community outreach programs and municipally run cooling centers designed to serve high-risk populations such as older adults, the homeless, and people with chronic illnesses [12]. While differing in structure, both approaches demonstrate how digital tools and community-based services are becoming critical components of public health adaptation in response to rising temperatures.

2.2 Infrastructure and Technological Innovation

Technological solutions play a pivotal role in reducing the urban heat island effect and managing thermal stress in the built environment. Japan has pioneered passive cooling innovations, including solar chimneys, permeable pavements with water retention capabilities, and widespread urban greening projects aimed at enhancing thermal comfort while minimizing energy use [13]. These interventions reflect an integrated approach to climate-responsive urban design.

By contrast, the UK has focused on upgrading its aging housing infrastructure to improve resilience to extreme heat. As part of the Great British Insulation Scheme under its broader Net Zero initiative, measures such as reflective roof coatings, high-performance insulation, and mechanical ventilation systems have been implemented to improve thermal efficiency and occupant safety [14]. While Japan emphasizes environmental integration in new construction, the UK prioritizes retrofitting its existing building stock—illustrating two context-specific but complementary strategies.

2.3 Equity and Sustainability

Ensuring equitable access to heat adaptation resources remains a pressing issue in both countries. In Japan, the national government has made significant strides in inclusivity by deploying mobile information services and multilingual heat alerts, particularly aimed at reaching isolated rural communities and non-native speakers during heat emergencies [15]. These initiatives help bridge communication gaps and extend critical information to diverse demographic groups.

In the UK, digital vulnerability mapping tools are used by local governments to identify heat-exposed neighborhoods and allocate targeted resources accordingly [16]. These spatial tools allow for a more granular understanding of risk, supporting proactive community engagement and intervention. Both countries are gradually embedding sustainability into their adaptation strategies. This includes scaling up renewable-powered cooling systems and expanding green urban infrastructure, which not only reduce ambient temperatures but also promote social and psychological wellbeing [17]. Such solutions offer dual benefits: mitigating the direct impacts of heat and contributing to broader goals of environmental sustainability and climate resilience.

Based on the developed framework, this study highlights critical components necessary for effective climate adaptation and mitigation across both UK and Japan and rural settings. The system mapping revealed key differences in human awareness, community-based responses (such as cooling strategies and adaptive clothing), and the role of government interventions, including public health services, educational outreach, and policy enforcement [18, 19].

Tabel 1. Comparisons prevention between Japan & UK

Program	Japan	United Kingdom	References
Early Warning Systems	MOEJ & JMA Heatstroke Alert	UKHSA & Met Office Alerts	MOEJ (2020); Met Office (2022)
Community Engagement	Neighborhood patrols, education	NHS & local council outreach	Yamamoto et al. (2021); Wolf et al. (2015)
Digital Tools	Heatstroke Index App, LINE alerts	Met Office notifications	Tanaka et al. (2020); Sellers (2022)
Urban Design	Green roofs, porous pavements	Heat-resistant retrofits	Sugiyama (2016); Zhang & Lin (2019)
Equity Focus	Support for elderly & immigrants	PHE for vulnerable groups	Reed et al. (2009); Sellers (2022)
National Policy	Climate-smart city integration	Net Zero & Heatwave Plans	BEIS (2021); IEA (2020)

3. SYSTEMS MAPPING FRAMEWORK

A systems mapping approach is employed to identify feedback loops and leverage points across health, energy, and infrastructure. Engaging stakeholders—from government and NGOs to local communities—the maps provide a dynamic picture of how interventions interact and cascade through systems. This framework tried make a design system to enhanced approaching model about "Transforming Extreme Heat into Opportunity" (picture 1).

4. FINDING AND DISCUSSION

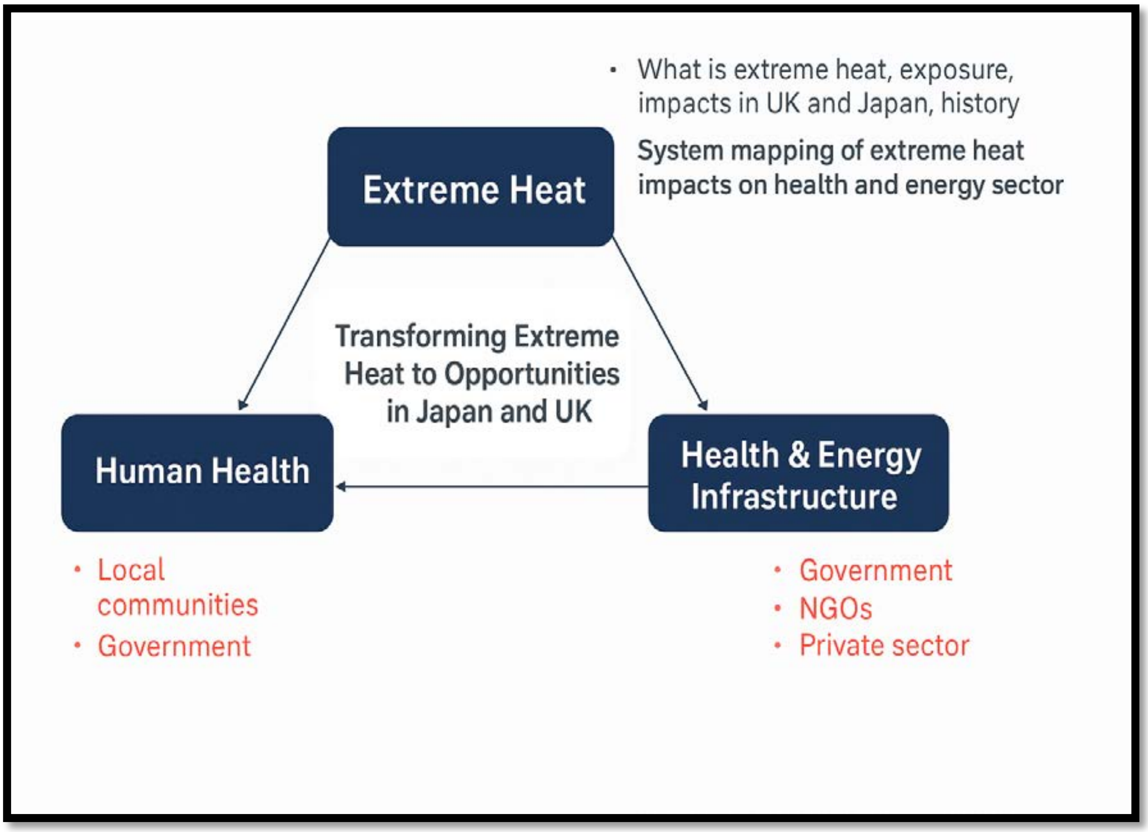
Equity emerged as a central concern, particularly in the unequal experiences and adaptive capacities of urban versus rural populations facing climate stress [20, 21]. Tools such as social vulnerability mapping, behavioral assessments, and cost–benefit analysis proved valuable in identifying and addressing community-specific needs [22, 23].

Additionally, the development of innovative solutions—such as a mental health support app for the elderly—demonstrated the potential of technology in enhancing resilience to extreme heat [24, 25]. The study also identified best practices in energy infrastructure, including the feasibility and effectiveness of solar chimneys, rooftop greening, heat storage systems, and energy-efficient glazing in public facilities such as hospitals and government buildings [26, 27]. These interventions support a broader transition toward net-zero emissions by emphasizing sustainability, inclusive stakeholder engagement, and evidence-based policymaking [28]. The synthesis of findings across all work packages underscores the importance of interdisciplinary approaches to building resilient, equitable, and climate-responsive communities.

systems, climatic conditions, and infrastructural capacities are converging on the urgent need to adapt health and energy systems to rising temperatures.

The comparative analysis highlights key differences in national responses: Japan's approach is more centralized and technology-driven, integrating smart city initiatives, solar chimneys, and neighborhood-based surveillance through mobile apps and community volunteers. In contrast, the UK adopts a more decentralized, policy-aligned model, emphasizing rural equity, NHS involvement, and green zoning in urban areas aligned with its Net Zero Strategy.

Picture 1. Framework Transforming Extreme Heat into Opportunity



5. CONCLUSION

This conceptual paper introduces a systems-based triangle framework for addressing extreme heat risks, emphasizing the interconnected pillars of system mapping, equity, and sustainability. By applying this model to the cases of Japan and the UK, we demonstrate how nations with distinct governance

These differences underscore the need for adaptive flexibility in implementing heat strategies, depending on social infrastructure and policy context.

Both countries, however, demonstrate critical overlaps in priorities—particularly in strengthening health system preparedness and upgrading energy infrastructure to handle peak cooling demands. Our framework captures these shared and divergent pathways by situating health and infrastructure at the base of a triangle where equity and sustainability guide transformation, and system mapping enables responsive coordination across sectors.

Going forward, the framework provides a valuable tool for researchers, planners, and policymakers to evaluate gaps in readiness, design interventions, and foster stakeholder collaboration. The next phase involves participatory system mapping workshops to co-produce insights with affected communities and institutions in both Japan and the UK. Furthermore, developing comparative metrics for equity and sustainability outcomes will help institutionalize this framework for international application and support evidence-based climate resilience strategies.

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