# Economic Evaluation of Urban Heatwave Adaptation Technologies based on SSP Scenarios

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## 1. Research Background

Heatwave phenomena driven by climate change are becoming increasingly frequent, and clear upward trends are also evident in their intensity and duration. South Korea is no exception. In particular, Korean cities are vulnerable to these changes in the intensity and persistence of heatwaves, and projections suggest that heat-related mortality could rise to 5–7.2 times historical levels by the 2050s. Especially Urban density, extensive impervious surfaces, and limited nighttime cooling further amplify exposure, especially among older adults and socioeconomically vulnerable populations. In response, adaptation policies centered on heatwave mitigation technologies have recently expanded. However, research evaluating the effectiveness of such policies remains limited in two key respects.

First, existing evaluations often fail to reflect the distributional nature of climate disasters. Damages from climate hazards tend to be extreme and highly volatile. Because a small number of large events can dominate aggregate losses, economic damages can increase nonlinearly. As the tail of the damage distribution becomes heavier (fat-tailed), climate risk is driven less by a symmetric, mean-centered distribution and more by extreme outcomes. Consequently, analyses that focus only on average effects struggle to capture the true magnitude and variability of climate risk. The presence of rare but catastrophic events implies that comparisons based solely on expected values cannot accurately quantify welfare losses. Continued reliance on mean-based evaluation therefore risks underestimating the real risks associated with greater volatility and extreme deviations.

Second, climate change is expected to intensify further in the future. To ensure the long-run effectiveness of adaptation policies under an accelerating climate crisis, it is necessary to anticipate and assess policy performance ex ante under a range of plausible future scenarios. Yet much of the existing

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literature relies on static analyses grounded in historical data, which is insufficient for managing evolving future climate risks.

The central motivation of this study is to address these limitations and incorporate them explicitly into policy evaluation. In particular, we aim to complement conventional mean-centered approaches by accounting for changes in the variance of the damage distribution. An increase in variance amplifies social risk even when expected damages remain unchanged. From this perspective, urban heat adaptation technologies not only reduce average damages but also perform an “insurance-like function” by dampening damage volatility and thereby reducing risk. This study quantifies the variance-reduction effect and converts it into a “risk premium,” offering a more rational basis for policy appraisal under uncertain future climate conditions.

Accordingly, we evaluate the economic feasibility of urban heat adaptation technologies under three SSP-based future pathways (SSP1-2.6, SSP2-4.5, and SSP3-7.0). We monetize heatwave damages and project future changes in damages using a heatwave resilience index as a mediating mechanism. This scenario-based design allows us to ask not only whether a technology is beneficial on average, but also under what climate trajectory it becomes cost-effective earlier, and how its value changes as extremes intensify. In addition to these three main pathways—selected because their narratives are clearly distinguishable—SSP4 and SSP5 are also commonly considered. SSP4 emphasizes within- and between-region inequality and is characterized by low mitigation challenges but high adaptation challenges. SSP5 assumes a fossil-fuel–driven development trajectory, entailing substantial environmental deterioration. This study focuses on SSP1–SSP3 because (i) SSP3 and SSP4 are similar in terms of adaptive capacity, and (ii) SSP5’s assumed scale of fossil-fuel expansion is, in our view, less plausible given the world’s current fossil-fuel development and emissions trajectories. This choice also supports interpretability: by comparing three clearly separated pathways, we can communicate how policy priorities shift across distinct, policy-relevant futures rather than across marginally different assumptions.

## 2. Data and Methods

We use a panel dataset of 229 municipalities (si/gun/gu) in South Korea for 2016–2022. Key explanatory variables include (i) the Heatwave Resilience Index (HWRI), composed of adaptive capacity and vulnerability-reduction capacity, and (ii) the installed quantity of heat adaptation technologies (cooling fog, cool roofs, rooftop/wall greening, and shade structures).

Rooftop/wall greening, cool roofs, cooling roofs, and shade structures are representative adaptation technologies that have been introduced and scaled up in South Korea by the government (central government and local governments) in response to heatwaves. These technologies reduce heatwave-related damages (e.g., mortality and morbidity) by mitigating the urban heat island effect and lowering perceived temperatures experienced by pedestrians and residents through pathways such as solar reflectance (cooling/heat-shielding), evaporative cooling, and shading.

In addition, HWRI—used as a major explanatory variable in this study—is a composite index that integrates indicators across economic, social, physical, governance, and demographic dimensions to quantify each municipality's capacity to respond to and recover from heatwaves. For climate variables, we use measures such as the 95th percentile of daily maximum WBGT and the number of days exceeding 27°C WBGT, and link these to SSP-based climate projections. That is, by holding each municipality's current socioeconomic structure, HWRI, and technology levels fixed at their present values, we aim to proactively diagnose the potential magnitude of damages that the current response system may face under changing future climate pathways, as well as the economic effectiveness of each adaptation technology and the optimal priority order for investment. This "structure-held-constant" design isolates the effect of changing climate hazards on an otherwise fixed local system, which is informative for stress-testing current policy capacity and for identifying where today's infrastructure and institutions may become insufficient under worsening heat conditions. At the same time, the framework can be extended in future work to allow endogenous adaptation trajectories—such as gradual increases in green coverage or phased technology deployment—once reliable scenario-based projections of local investment capacity and maintenance constraints are available.

Methodologically, we build a prediction model based on panel regressions to estimate the marginal benefits of each technology and compute scenario-specific cost-effectiveness thresholds (CET) and benefit–cost ratios (BCR). Economic evaluation is crucial because adaptation technologies require substantial upfront capital, long-term maintenance, and trade-offs against other public expenditures. Robust cost-effectiveness metrics prevent misallocation, guide prioritization across vulnerable areas, and strengthen fiscal accountability. We further measure the extent to which technology adoption reduces the variance of future damages and quantify the associated risk premium.

## 3. Expected Effects

In this context, our results offer two distinct contributions. First, we provide economic feasibility conditions for urban adaptation technologies under future climate change and demonstrate structural shifts in investment priority rankings across scenarios. Second, by integrating uncertainty analysis

through the incorporation of risk premia, our framework delivers an objective decision-support system for designing climate-resilient urban policy.

By combining municipality-level panel data for 2016–2022 with SSP-based future climate scenarios, this study offers a new evaluation of the economic feasibility of urban heat adaptation technologies and identifies objective investment priorities under uncertainty—yielding substantial academic and policy relevance. By overcoming the limitations of static, mean-centered assessments based solely on historical data, we provide dynamic feasibility conditions under future climate pathways and a clear blueprint for how investment priorities should structurally adjust as climate trajectories worsen. In particular, by quantifying the “insurance value” of adaptation technologies—namely, their ability to curb the extremeness (fat-tailed nature) of climate risk by reducing damage volatility—and integrating this risk premium into uncertainty analysis, our framework demonstrates substantive benefits that have often been underestimated in conventional evaluations. Ultimately, the methodological framework and scenario-based empirical results presented in this study can serve as practical policy guidance for central and local governments seeking to allocate limited budgets efficiently and enhance the credibility of long-term adaptation strategies in an era defined by pervasive climate uncertainty.

**Keywords:** Urban Resilience, Heatwave Risk, Adaptation Investment, Policy Evaluation, Uncertainty Analysis