



Unequal urban heat burdens impede climate justice and equity goals

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Extreme heat is among the deadliest of weather-related hazards, exerting far-reaching impacts on the natural environment and human society globally. Its risk has been rising worldwide over the past decades, particularly in densely populated urban settlements in which more than half the world's population live.^{1,2} This rise is primarily attributed to anthropogenic greenhouse gas (GHG) emissions, of which the dominant share is contributed by the Global North.¹ The Global North comprises economically developed countries with higher levels of industrialization, technology, infrastructures, energy consumption, and GHG emissions (e.g., North America and West Europe) whose cities are major emission hotspots.¹ Besides, emission transfers via international trade from the Global South, encompassing countries with lower economic development and energy consumption, higher poverty, and more vulnerable infrastructures (e.g., India and Brazil) compared with the Global North, contribute a nonnegligible share of GHGs.¹ However, GHG-driven heat risks are sweeping globally, with the Global South bearing even more severe risks. This inconsistency between larger GHG emissions from the Global North and graver burden of extreme heat in the Global South raises concerns about climate justice and equity. Here, we conduct a global-scale investigation to reveal unequal urban heat burdens between the Global North and the Global South by examining 13,126 worldwide urban settlements based on high-resolution (1 km) datasets between 1979 and 2016 (Figure 1). From this, we provide recommendations for achieving sustainable development goals (SDGs), especially for climate justice and equity.

The frequency of extreme heat days (daily nighttime temperature exceeding its local 90th percentile) is surging in nearly all urban areas, with larger increases in Global South than in Global North cities (10.82 versus 7.96 days/decade) between 1979 and 2016 (Figures 1A and 1B). The overall increment in Global South cities is 37% larger than in the Global North (increased by 41.1 versus 30 days in 38 years). This larger increment is likely related to tropical soil drying (especially in the Southern Hemisphere) and increased atmospheric variability in the tropics-subtropics of the Northern Hemisphere, which respond to a weakening meridional temperature gradient under global warming.³ The trend difference in heat extremes suggests that Global South urban residents are facing more severe exacerbation of heat risks than in those in the Global North. Compared with short-lived events, consecutive exposure to persistent long-lived heat events causes more severe consequences. The increasing trend in long-lived heatwave frequency (≥ 6 days) in Global South cities is 64% higher than in the Global North (3.26 versus 1.99 days/decade), indicating a stronger trend disparity than that of short-lived events. These uneven increases between the Global North and the Global South are also robustly observed in other definitions, for example, based on daily daytime/mean temperatures or more extreme high-temperature thresholds (95th/97.5th percentiles). This North-South disparity highlights the inequalities in health risks that urban residents may be burdened with, which can be exacerbated if considering larger populations in Global South cities.

Global urban population exposure to extreme heat (the yearly number of extreme heat days multiplied by population count) has increased sharply from 57.88 billion person days in an earlier 10-year period (1979–1988) to 189.29 billion person days in a more recent period (2007–2016), indicating a massive increment of 227.04% (comparatively, urban population increased by 56.23%). Also, the exposure increment exhibits evident regional disparities, with the Global South experiencing more than twice that of the Global North

(262.96% versus 120.67%, in comparison to urban population increments of 68.15% versus 20.68%). During 1979–2016, global urban population exposure increased by 48.15 billion person days/decade, of which 87.21% is contributed by Global South cities, while Global North cities accounted for only 12.79%. The increasing exposure trend in the Global South is 6.8 times that of the Global North (41.99 versus 6.16 billion person days/decade). This unequal increase between the Global North and the Global South suggests that poorer and more vulnerable urban residents in the Global South suffer from more devastating impacts of climate change even though they are less responsible for causing them.

The United Nations SDGs outline 17 goals that aim to tackle economic, social, and environmental challenges and advance people's well-being. However, the progress of achieving SDGs is hindered by intensifying heat extremes and their unequal burdens between the Global North and the Global South. Specifically, extreme heat can cause lethal illnesses (e.g., heat stroke and exhaustion) and even death. It deteriorates the working and living environment of urban residents, particularly for poor and vulnerable populations, thereby posing a significant challenge to SDG3: good health and well-being. Urban areas are usually compacted with massive impervious surfaces (e.g., concretes, pavements, and buildings) and inadequate greeneries, which limits the ability to alleviate heat domes over cities. This limitation calls for a pressing need to build and fortify sustainable cooling infrastructures for resilient communities that align with SDG11: sustainable cities and communities. Elevated heat risks are primarily caused by anthropogenic GHG emissions, mostly from urban areas. Urgent actions like implementing clean energy and strengthening resilience and adaptivity are needed to mitigate these hazards (SDG13: urgent action to combat climate change and its impacts).

Different countries disproportionately contribute anthropogenic emissions, with the Global North generating >92% of all global emissions.⁴ Increasing global heat risks are mainly attributed to these anthropogenic emissions.⁴ The adverse impacts of these hazards are unevenly distributed across countries and people, with more vulnerable groups in the Global South bearing heavier burdens and susceptibilities. The inter-country disparities in emissions and impacts impede the realization of climate equity and SDG10: reduced inequalities. North-South inequality becomes even more severe when focusing on per-capita GHG emissions and per-capita exposure (i.e., number of extreme heat days). Many Global South countries contribute to the least amount of global GHG emissions. They have larger populations, suffer from more severe risks, and confront pressing mitigation and adaptation needs. In contrast, Global North countries with smaller populations but much larger emissions witness fewer climate change impacts. These features would be exaggerated under future population growth and climate warming. These trends may increase the likelihood of "less emission but more vulnerable and heavier heat burden" for Global South and "more emission but less vulnerable and lighter heat burden" for Global North, thus obstructing the realization of climate justice and SDG16: peace, justice, and strong institutions.

SDGs emphasize the need for global partnerships and inclusive growth, highlighting the importance of reducing inequality, promoting sustainable cities, and combating climate change. However, achieving SDGs and climate justice and equity requires both the Global North and the Global South to enhance mutual trust and cooperation. This would include building a climate change community of shared interests, destiny, and responsibility featuring socioeconomic

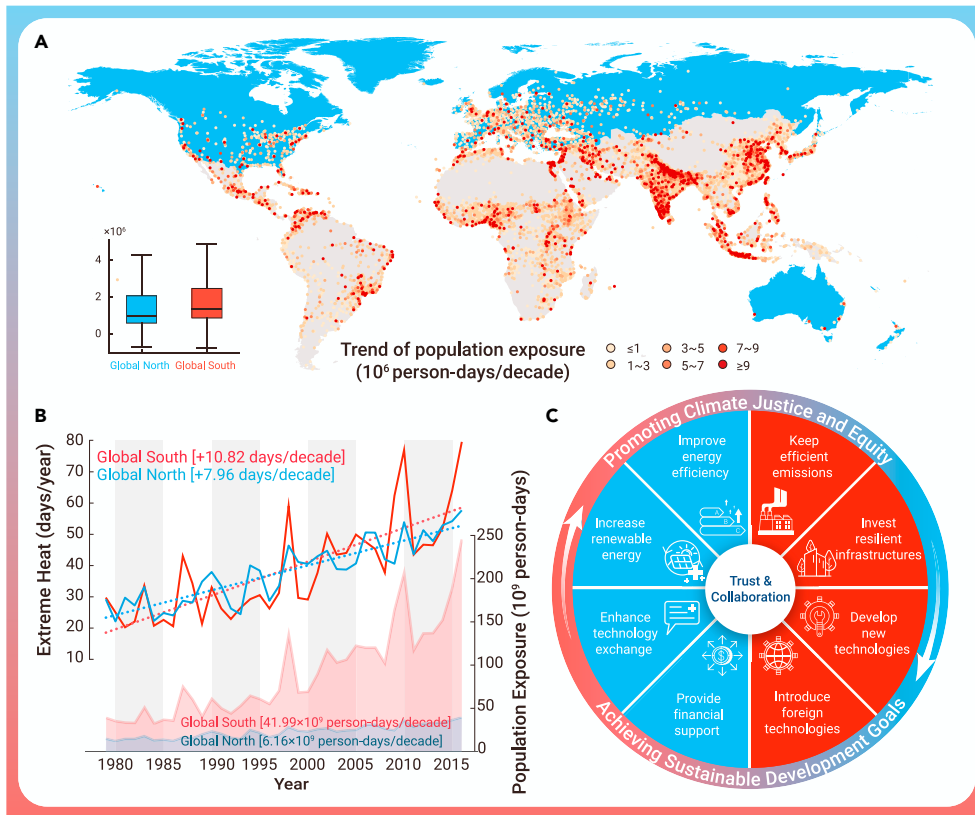


Figure 1. Unequal urban heat burdens between Global North and Global South urban settlements (A) Trend of urban population exposure to extreme heat in Global North/South urban settlements. (B) Yearly averaged extreme heat days (curve) and aggregated population exposure (shading) in Global North/South urban settlements. (C) Future needs of Global North/South countries to achieve SDGs and climate justice and equity. For details of calculation, please refer to <https://doi.org/10.5281/zenodo.8164665>.

integration, technological innovation, and knowledge sharing (Figure 1C). Note that the North-South division is not solely based on geographic location but also power, resources, responsibilities, and vulnerabilities. The Global North includes high-income countries that have the most advanced technologies and resilient infrastructures and that are responsible for the largest energy consumption and emissions. In contrast, Global South countries usually have denser populations and poorer infrastructures and account for less emissions.

Global North countries should take more responsibility in reducing emissions and provide technological and financial assistance. They provide the largest share of GHG emissions accumulated in the atmosphere,⁴ which is the primary driver of increasing heat risks globally. To alleviate anthropogenic-warming-elevated heat hazards, Global North countries must lead in cutting emissions by improving energy efficiency and increasing renewable energy shares (e.g., wind and solar power) in their energy mixes. In addition, Global North countries are leading the development of clean energy and low-carbon technologies and financial feasibility. They should further scale up their technology exchange and cooperation with poor and emerging Global South countries. Financial support or transfers toward the Global South via international collaborations are also important for boosting the ambition and action of less affordable Global South countries to mitigate increasing heat risks at lower costs.

Global South countries should improve their infrastructures and capacities to cope with climate change risks. Despite contributing to a small share of accumulated emissions, they are usually burdened with vulnerable infrastructures of low resilience and adaptivity, leaving them particularly vulnerable to unequally increasing heat exposure. To improve their capacities to mitigate climate change, Global South countries are suggested to increase both domestic and international investments in climate-resilient infrastructures (e.g., heat-resistant buildings, efficient cooling systems, green roofs and walls, and permeable pave-

ments). These countries are struggling with the complexity of blooming energy consumption while keeping low GHG emissions. They need to develop their own new technologies or introduce foreign technologies (e.g., renewable, clean, and efficient energies, sustainable transportation, and emission monitor technologies)⁵ to ensure sustainable development while controlling emissions. We advocate for deepening the socioeconomic cooperation and technology exchange between different countries to create a more resilient and sustainable community with a shared future.

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DECLARATION OF INTERESTS

The authors declare no competing interests.