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Sustainable Urbanization Strategies: Mitigating Urban Heat Islands through Synergy between Economic Choices, Renewable Energy Consumption and Environmental Interventions

Strategie zrównoważonej urbanizacji: łagodzenie miejskich wysp ciepła poprzez synergię między wyborami ekonomicznymi, zużyciem energii odnawialnej i interwencjami w środowisku

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Abstract
Climate change is making urban heat islands (UHIs) more crucial. This research examines the dynamic association between economic and environmental variables and UHI severity in 13 nations from 2000 to 2022. This study supports Sustainable Development Goals 11 (Climate Action) and 13 (Sustainable Cities and Communities) by researching financial and ecological ways to reduce UHIs. The panel fixed effect regression analysis yields intriguing results, i.e., increasing building energy efficiency decreases urban heat island intensity. However, UHI intensity increases R&D expenditure, renewable energy consumption, and green roof area, revealing complicated dynamics. UHI trends over the following decade may be seen using the Impulse Response Function panel. The amount of green space, energy efficiency in buildings, community resilience, renewable energy consumption, and spending on research and development are expected to impact UHI negatively, emphasizing the need for sustainable practices and flexibility. Green roof area and tree canopy coverage are predicted to improve UHI, highlighting the benefits of planned urban greening programs. Variance decomposition methodology evaluates how each variable proportionally affects UHI variance. Green space, building efficiency, tree canopy coverage, and renewable energy utilization are important factors, followed by community resilience. Energy efficiency, urban greenery, and resilience may reduce UHIs and create climate-adaptive cities in the coming decade.

Key words: urban heat island intensity, green space area, building energy efficiency, green roof area, tree canopy coverage, renewable energy capacity, panel fixed effect

Streszczenie
Zmiany klimatyczne sprawiają, że miejskie wyspy ciepła (UHI) stają się coraz bardziej istotne. Niniejsze badanie analizuje dynamiczny związek między zmiennymi ekonomicznymi i środowiskowymi a nasileniem UHI w 13 krajach w latach 2000–2022. Niniejsze badanie wspiera Cele Zrównoważonego Rozwoju 11 (Działania na rzecz klimatu) i 13 (Zrównoważone miasta i społeczności) poprzez badanie finansowych i ekologicznych sposobów na

zmniejszenie UHI. Analiza regresji o stałym efekcie panelowym daje intrygujące wyniki, tj. zwiększenie efektywności energetycznej budynków zmniejsza intensywność miejskich wysp ciepła. Jednak intensywność UHI zwiększa wydatki na badania i rozwój, zużycie energii odnawialnej i powierzchnię zielonych dachów, ujawniając skomplikowaną dynamikę. Trendy UHI w ciągu następnej dekady można zaobserwować za pomocą panelu Impulse-ResponseFunction. Oczekuje się, że ilość zielonej przestrzeni, efektywność energetyczna w budynkach, odporność społeczności, zużycie energii odnawialnej i wydatki na badania i rozwój będą miały negatywny wpływ na UHI, podkreślając potrzebę zrównoważonych praktyk i elastyczności. Przewiduje się, że powierzchnia zielonego dachu i pokrycie koron drzew poprawią UHI, podkreślając korzyści z zaplanowanych programów zazieleniania miast. Metodologia rozkładu wariancji ocenia, w jaki sposób każda zmienna proporcjonalnie wpływa na wariancję UHI. Tereny zielone, wydajność budynków, pokrycie koron drzew i wykorzystanie energii odnawialnej są ważnymi czynnikami, a następnie odporność społeczności. Efektywność energetyczna, zieleń miejska i odporność mogą zmniejszyć UHI i stworzyć miasta przystosowane do klimatu w nadchodzącej dekadzie.

Słowa kluczowe: intensywność miejskiej wyspy ciepła, tereny zielone, efektywność energetyczna budynków, tereny zielonych dachów, zasięg koron drzew, odnawialne źródła energii, stały efekt ustalony w panelu

1. Introduction

In this era of unprecedented urbanization and climate change, city planning, renewable energy integration, and urban heat island reduction are significant areas of research and legislation (He et al., 2023). Most of the world's population lives in cities facing rising temperatures, energy demand, and urban heat islands. Renewable energy solutions and climate-responsive urban design may help create more resilient and sustainable cities (Byrne et al., 2022). Urban heat islands, where temperatures are substantially greater than rural areas, make city living uncomfortable and energy utilization worse. This event necessitates a thorough heat island mitigation and sustainable urbanization approach. Renewable energy technologies and climate-responsive urban design may reshape cityscapes to eliminate urban heat islands (Planas-Carbonell et al., 2023). Green spaces, energy-efficient structures, and renewable energy may help cities adapt to climate change and energy demand (Prades-Gil et al., 2023).

Urban heat island effects, which make cities hotter than rural areas, worsen as urbanization accelerates. This phenomenon increases energy use, health issues, and urban carbon footprint (Ahakwa, 2023). Renewable energy integration and climate-responsive urban design may solve urban heat islands and lead to sustainability. Climate-responsive urban design involves coordinating green infrastructure, architectural interventions, and urban planning to decrease urban heat islands. Green spaces, cool roofs, and energy-efficient buildings may make cities more climate-resilient (Almusaed et al., 2023). It reduces energy consumption and urban heat by switching to greener energy sources like solar panels and wind turbines (Song et al., 2023). This study examines climate-responsive urban design, renewable energy integration, and urban heat island reduction in these 13 countries. This research uses a 2000–2022 panel data set to examine the numerous factors that affect sustainable urban design, energy transitions, and climate resilience. This study analyzes these nations' policies, experiences, and accomplishments to present evidence-based recommendations for greener, safer, and more livable cities. The fundamental goal of the study is to eliminate urban heat islands using renewable energy and climate-responsive urban design. Academics, legislators, and urban planners may apply this study's practical findings to develop sustainable, adaptable, and comprehensive urban settings. This study helps create resilient, equitable, and environmentally responsible cities during rapid urbanization and climate change.

The study intends to contribute to sustainable urbanization discussions by analyzing and contrasting the approaches of nations confronting similar difficulties in various circumstances. The findings may enlighten ways to enhance the mutually beneficial relationship between energy solutions and urban design, enabling cities to become profitable, climate-resilient hubs. This approach is essential to establishing urban ecosystems that survive despite climate change and other global concerns. The study's questions are as follows: First, ***how can renewable energy technologies and climate-responsive urban design reduce urban heat islands (UHI) and support SDG-11 (Sustainable Cities and Communities) by improving urban resilience, environmental degradation, and equitable urban development?*** This research is driven by the relevance of renewable energy integration and climate-responsive city design in reducing urban heat island effects (Salmanian& Bayat, 2023). Climate-responsive design reduces heat islands in cities by employing green spaces, reflecting surfaces, and improved building materials (Jalali et al., 2022). According to Oquendo-Di Cosola et al. (2022), renewable energy technologies may reduce energy consumption and urban temperatures by contributing to sustainability. By investigating their interplay, the study established whether renewable energy technologies help reduce climate-responsive design's heat island. This issue helps to comprehend renewable energy options and sustainable urban design. Second, ***how can urban heat islands (UHI) be reduced in cities using green spaces, energy-efficient structures, and renewable energy? Moreover, how might environmental sustainability and carbon footprint reduction help SDGs-7 and 13?*** Green spaces, energy-efficient buildings, and tree canopy coverage are crucial to climate-responsive urban design. They mitigate urban heat island effects by cooling, shading, and reducing energy demand (Zhu et al., 2022). The question acknowledges that renewable energy integration and climate-responsive design may impact these elements' success. This research examined how sustainability factors combine and diminish heat islands in diverse urban contexts to enlighten the complex link between these variables and city temperatures. According to resilience index data, a third research question arises, i.e., ***considering social, economic, and environmental challenges, can cities adopt climate-responsive design and increased renewable energy capacity to minimize urban heat islands? Moreover****, will this help SDGs 9 and 11 promote resilient cities and green infrastructure?* Building resilient cities to address climate change is rising. Resilient cities were better equipped to survive heat waves and other meteorological stressors (Al-Sayed &Alanizi, 2023). Thus, resilient cities may be better able to survive heat island effects due to their superior infrastructure, citizen participation, and adaptability. The research examines this link to show how sustainability and urban resilience work together.

Based on the discussion, the study has the following research objectives, i.e.,

I. To assess the national climate-responsive urban design techniques and how they benefit SDG-11 by promoting social equity, reducing environmental impact, and improving urban resilience.

II. To investigate the interplay of urban heat island intensity, green areas, building energy efficiency, and tree canopy coverage to support SDGs 7, 13, and 15 that promote sustainable urban ecosystems, energy efficiency, and climate change mitigation.

III. To examine the moderating effect of urban resilience on sustainability metrics, with a particular emphasis on how resilient cities can improve the integration of SDGs 9 and 11 by using renewable energy sources and climate-responsive design, thereby contributing to long-term sustainable development.

This study contributes to Sustainable Development Goal-11 (Sustainable Cities and Communities) by researching how reducing urban heat islands (UHIs) might produce more environmentally resilient cityscapes. The study also supports SDG 13 (Climate Action), which emphasizes reducing urban climate risks via renewable energy, green infrastructure, and building energy efficiency. Since the study focuses on financial decisions and environmental interventions, it contributes to SDG-7 (Affordable and Clean Energy) and SDG-9 (Industry, Innovation, and Infrastructure) by analyzing how renewable energy and R&D investments affect sustainable urbanization. Reduced UHI intensity needs urban tree canopy coverage, green spaces, and ecological balance. Hence, the findings pertain to SDG 15 (Life on Land). By integrating the SDGs into policy frameworks and urban planning, this research provides practical insights for sustainable development and climate resilience.

2. Literature Review

The literature review has three primary sections. The first links climate-responsive design to urban heat islands. The second focuses on integrating renewable energy into cities. Finally, the urban resilience and sustainability literature discusses sustainable methodology synthesis.

2.1. Urban Heat Island Effects and Climate-Responsive Design

This section discusses the urban heat island (UHI), which makes densely populated cities hotter than rural areas. Surfaces that absorb heat and lack green space are briefly discussed as potential causes. Further, this section also examines climate-responsive urban design methods. It incorporates green spaces and cool roofs to reduce urban heat islands. These methods reduce temperatures, improve air quality, and improve quality of life, among other benefits. Xu et al. (2022) examine the local climatic zone (LCZ) categorization to mitigate UHI. The study indicated that RS-based categorization marginally outperformed GIS in explaining land surface temperature (LST) variation, demonstrating their complementary nature. The consistency and diversity in LCZ sizes across metropolitan regions show the complex relationship between urban geometry and UHI. Surface urban heat islands harm urban sustainability. Therefore, Dutta et al. (2022) use satellite imagery to identify crucial thermal zones in cities. Findings show that India's megacities' thermal dynamics support the need for adaptable design based on regional climatic zones. The temperature difference between urban areas shows how building forms enhance UHI effects. Daniel et al. (2023) highlight solar technology for mitigation and green infrastructure for adaptation in quantitatively evaluating urban climate-responsive design initiatives. Street-level initiatives include mitigation and adaptation techniques, whereas building-level interventions have less synergies. Loh and Bhiwapurkar (2022) proposed a novel approach to developing climate-responsive building facades that reduce urban heat islands. Optimization and parametric modelling may improve outdoor thermal comfort, refrigeration energy usage, and natural light utilization. The research found that UHI must be included throughout building development.

According to Ho et al. (2023), UHI increases during hot periods, affecting death rates. Their analysis shows how UHI intensity affects temperature-mortality correlations in susceptible populations. The research demonstrates that UHI-prone metropolitan locations require specific mitigation techniques during high-heat events. Bala et al. (2023) examine the relationship between land surface temperature (LST) and normalized difference vegetation index (NDVI) in metropolitan Chennai from a regional viewpoint. This study illustrates how urban greenery reduces UHI's thermal effects. Only a minor association between LST and NDVI was examined. Therefore, further research is needed into the intricate interactions of UHI processes. In their Baghdad urban heat island (UHI) study, Najah et al. (2023) emphasize the role of green urban spaces (GUSs) in lowering temperatures. The study examines how urban expansion influences GUSs to link land use change to UHI consequences. Thus, the study emphasizes the necessity to balance urbanization with environmental protection. Kim et al. (2023) developed mean radiant temperature (MRT)--based fast spatial evaluation techniques to reduce UHI. Their strategy may be effective in urban environments, but its scalability and applicability are unknown. Liu et al. (2023) use climate-responsive design to address high-heat events. They highlight the importance of urban planning and design in minimizing UHI effects, which supports sustainability objectives. These solutions need long-term observations and real-world case studies to prove their efficacy and scalability. Public open spaces reduce climate change-induced urban heat, according to Gabor et al. (2023). Vienna is developing urban green and blue infrastructure (UGBI) standards to help execute climate-relevant activities. The study metrics stress the necessity for multidisciplinary cooperation and the challenges of balancing sustainability.

Based on the cited literature review, the first research hypothesis is as follows:

H1: Nations with more green space per capita will have lower urban heat island intensity, supported by SDG-11, which emphasizes inclusive, safe, resilient, and sustainable cities.

2.2. Renewable Energy Integration in Urban Contexts

This literature review examines urban-applicable renewable energy sources. City planning may include renewable energy sources like solar panels and wind turbines. Further, it discussed how these technologies cut urban heat emissions and promote sustainable energy generation. It examined how legislative changes may encourage cities to utilize renewable energy. Renewable energy targets, financial incentives, and supporting regulatory frameworks promote clean energy technology integration. More individuals are turning to energy conservation and Positive Energy Districts (PEDs) to tackle climate change. The research of Derkenbaeva et al. (2022) focuses on European city residential zones to understand PEDs. The research classifies PEDs by their characteristics using theoretical and empirical evidence. The Complex Adaptive System technique and Doughnut perspective adequately characterize PEDs while considering contextual considerations. The study emphasizes the necessity of studying overlooked sectors like electric transportation and overcoming PED constraints to promote future technology. Electrical companies must promote innovative city sustainability. Cortese et al. (2022) examined how smart cities sustain energy via a comprehensive literature review. Based on 154 scholarly articles, urban planning should be secondary to renewable energy and energy efficiency technology. The study emphasizes considering comprehensive sustainability strategies to ease smart city transitions. The results include energy efficiency, renewable energies, and energy and urban planning. It accelerated the energy transition by promoting low-carbon energy, public involvement, and social goals. According to Dall-Orsoletta et al. (2022), smart grids may help local energy transitions but not threaten the energy regime or have a more significant influence. It may promote equitable energy transitions, community involvement in renewable energy, and economic growth. Despite several limitations, the study reveals that low-carbon energy may facilitate local and regional energy transformations. Colasante et al. (2022) examine how favourablesunshine and regulations affect the proliferation of photovoltaic (PV) systems in Southern Europe. The focus is on the attitudes and behaviours of Spanish and Italian consumers regarding solar energy adoption. The research shows that solar energy choices vary substantially. The study indicated that policy influences customer perceptions and PV system uptake. The research inspires consumer expectations and regulatory consequences to promote sustainable energy. In the action against global environmental challenges, Local Energy Communities (LECs) and other grassroots activities are growing. Otamendi-Irizar et al. (2022) examine efficient LEC operations and their non-energy uses. According to the data, some LECs focus only on energy, while others conduct SDG-aligned sustainable development activities. LECs are essential for fair energy transitions, local capacity, and bottom-up renewable energy distribution. The findings suggest a more significant study on LECs' involvement in sustainable and resilient urban communities.

Cutore et al. (2023) examined the Clean Energy for All Europeans Package's REC proposal. The study creates an Italian regulatory-compliant REC optimization model. RECs, which are decentralized and democratic energy production and distribution, make urban renewable energy integration easier. Comparisons of the two sharing systems focused on capacity size, flow management, and storage system inclusion. In centralized distribution setups, virtual energy sharing was more economically beneficial. Sustainability measurements showed that REC consumption significantly decreased carbon emissions and energy poverty. Energy ecosystems' severe weather resilience and susceptibility were examined by Perera and Hong (2023). They stressed that energy system interconnectedness and complexity made infrastructure more susceptible to damage. The research used a unique COVID analogy to characterize vulnerability across three levels to understand better the spread of energy ecosystem disturbances. The present effects of climate change have received much attention, but this research underscored the need to look forward to future possibilities and energy system interconnection. Decentralized and hybrid models employing physical and data-driven methods may reduce complexity. Lucchi et al. (2023) sought to use active solar technology as building materials in historic buildings to aid energy transition and preserve architecture. The research stressed the relevance of new aesthetics, practicality, efficiency, and cost in integration. Social concerns due to design, economic, and regulatory constraints negated the benefits. To avoid these concerns, global standards were used to create a taxonomy of suggestions for energy efficiency, solar power, and terminology. Bouw et al. (2023) created a framework to simulate integrated heating conditions to help communities choose sustainable heating options. The method analyzed technological routes, system costs, emissions, and stakeholder participation. This strategy was applied to a Dutch neighbourhood, and the 'efficiency' and 'hybrid' price options were the most cost-effective. This method's applicability to varied evaluation scenarios was underlined. Zhang et al. (2023) examined façade building integrated photovoltaics usage. Data-driven Deep Generative Networks were used to create stochastic ensembles of solar irradiance time series efficiently. This model may replace time-consuming simulations, which might aid energy system design. Although reproducing the ground truth is difficult, validation showed that the time series was consistent with a physics-based simulation. The method's significance in urban energy planning was proved via parametric and generative designs. Based on the cited literature review, the second research hypothesis is as follows:

H2: Building energy efficiency favorably moderates the association between renewable energy capacity and urban heat island intensity. Energy-efficient buildings help renewable energy solutions mitigate heat impacts, supporting SDG 7's sustainable energy system and SDG 13's climate change reduction.

2.3. Synergy of Sustainable Approaches: Climate-Responsive Urban Design and Renewable Energy

Renewable energy integration and climate-responsive urban design are the primary focus of this section. It discusses how various methods may work together to lessen urban heat island effects. This review discusses how renewable energy may power green infrastructure and energy-efficient buildings, which can boost cooling. Sustainability measures and urban resilience are also mentioned. As succinctly mentioned, renewable energy and climate-responsive architecture help cities weather climate change. Decentralized energy generation, energy-efficient buildings, and green infrastructure are important for physical and social resilience. Despite the gap between urban green space theory and reality, Graça et al. (2022) studied these places since they are crucial to climate change adaptation. This study conducted a semi-systematic literature assessment to uncover evidence-based outcomes for building urban green spaces for climate adaptation. The design-based approach included setting goals, determining context-agnostic applicability, and identifying implementation challenges. Okilj et al. (2023) recommended multi-dimensional and comprehensive planning for sustainable and resilient cities. The research examined ecological and energy planning in Banja Luka via green and compact city ideas and their compatibility. The research challenged green goals and urban design by comparing green structural modifications to temperature hikes. Liu et al. (2023) investigated using solar energy and other eco-friendly methods to create carbon-neutral European communities. They tested natural solutions using building-integrated photovoltaics. Their research suggests combining solar conversion technology with natural components to reduce heat and climate impact. It applies throughout temperature zones. Peng et al. (2023) studied courtyard microclimates to reduce severe temperatures and increase thermal variability. The research classified courtyards by thermal properties using thermal field measurements, computational modelling, and machine learning. New building and restoration projects, including courtyard microclimates, might apply the study's results for climate-responsive design in typical urban settings. Lehnert et al. (2023) note that urbanization and climate change are increasing heat stress exposure. Using mental mapping, they found hot and cold locations in two Central European cities and asked people about temperature regulation. Results indicated that people prefer green and blue components like parks and trees over blue ones. This revealed regional preferences for metrics and ways to enhance targeted areas.

Lampinen et al. (2023) stressed the relevance of urban green infrastructure for biodiversity, well-being, and climate change mitigation. Public participation geographic information system (PPGIS) surveys were used to assess Helsinki residents' support for green infrastructure plans with varied results. Results indicated that climate benefits are widespread, concessions should be based on well-being rather than biodiversity, and municipal policy preferences vary by location. Genovese and Zoure (2023) focused on sub-Saharan Africa's bioclimatic design. A detailed literature study revealed bioclimatic design's pros, downsides, obstacles, and effects in the area. The research suggested a circular economy and multi-scale adaptive bioclimatic architectural paradigm for sustainable construction. Felicioni et al. (2023) stated that climate change consequences need resilience development. This research compared resilience grading to green building sustainability metrics. This project brought together experts from different fields to promote synergistic design. Rajarajeswari and Anbalagan (2023) explored sustainable development via green building and lean construction. The research used case studies to demonstrate their collaboration and the importance of waste reduction. This study guided stakeholders toward greener building practices. Lei et al. examined how village layout affects thermal comfort in 2023. Researchers in southern subtropical China examined how topography and building geometry affect solar radiation and airflow. The findings showed that these variables improve outdoor thermal comfort in traditional communities. Based on the cited literature review, the final research hypothesis is as follows:

H3: Urban resilience indices would moderate the relationship between renewable energy capacity, urban heat island intensity reduction, and climate-responsive urban design strategies, supporting SDGs 11 and 13 to emphasize resilience's role in climate mitigation.

The most essential aspects for decreasing urban climate change have been identified via research on renewable energy solutions and climate-responsive urban design (Sommese et al., 2022; Banerjee, 2022). This field has several knowledge gaps, so the present study makes unique contributions. Previous literature lacks full variable integration, which is a significant flaw. Green space, building energy efficiency, urban heat island intensity, and renewable energy capacity have been studied separately, but there is little systemic research on how they interact. This study seeks to bridge a knowledge vacuum by examining these components' interaction and reciprocal influence in various urban contexts. The current study is geographically under-representative since it concentrates on a few cities (Shi et al., 2022; Chang, 2023). Thus, regional and climatic differences in climate-responsive urban design and renewable energy techniques need additional investigation. The global span of this study, which comprises 13 sample countries from various places, is remarkable. This method clarifies global opportunities and risks. Current research should integrate socioeconomic variables needed for renewable energy solutions and climate-responsive urban design, according to Fahmy et al. (2022) and Sharma (2022). This includes resilience, critical service accessibility, and R&D spending. Research supports these socioeconomic traits and seeks to relate them to other variables. It gives a broader vision of sustainable urban development. Combining techniques has been ignored in favour of single-approach research. Renewable energy projects and climate-responsive city design need socioeconomic considerations (Fahmy et al., 2022; Sharma, 2022). Examples include critical infrastructure, resilience, and R&D financing. These socioeconomic indicators are linked to other variables in the investigation—a more comprehensive and inclusive urban sustainability strategy. The literature typically overlooks the synergies and trade-offs of applying numerous methods concurrently in favour of examining their merits. This study investigates synergies and synergistic conflicts between components to fill that gap. The findings of this research may help policymakers and urban planners make educated decisions. Climate-responsive urban design requires resilience and biodiversity. There is little study on their influence on urban sustainability and how they interact with other elements (Hürlimann et al., 2022). The study combines these factors and attempts to understand their interconnections. This improves our climate adaptation and overall urban planning expertise. Finally, research on practical application insights is lacking. Much research provides theoretical insights, but policies and urban design efforts are not consistently implemented (Greenstone, 2023; Qiao et al., 2023). The study bridges this gap by aligning research with real-world applications and providing practitioners with proper evidence.

3. Theoretical Framework

The Systems Thinking and Resilience Framework may help explain how renewable energy integration, climate-responsive urban design, and urban resilience interact (Locke et al., 2023). This theoretical paradigm emphasizes creating resilience against urbanization and climate change risks, acknowledging the interconnected nature of urban systems. This method relies on systems thinking, which views cities as complex, interrelated systems (Wan Rosely &Voulvoulis, 2023). Green spaces, energy-efficient structures, and renewable energy sources provide a cascade of complementing effects on urban landscapes beyond decreasing temperatures (Levesque et al., 2023). Green spaces reduce global warming, enhance air quality, shelter various plant and animal species, and increase community health (Cuong & Khan, 2023). This interconnectivity emphasizes the need to consider numerous urban features and their interactions.

Resilience thinking – acity's ability to adapt, absorb shocks, and recover from disruptions – is crucial to the framework (Rosales Pérez, 2023). Cities can reduce climate change using renewable energy and climate-responsive urban planning. The framework examines how these strategies improve a city's heat wave, power outage, and flood resistance. Resilient towns can better withstand climate change and safeguard citizens and companies, according to Albuquerque Pai et al. (2023). The approach considers urban system feedback loops. Climate-responsible design and renewable energy integration may benefit from positive feedback loops like lower energy demand from renewable energy sources and energy-efficient buildings (Laimon et al., 2022). The framework is aware of negative feedback loops, which may occur when one solution is overused and has unexpected repercussions (Matson et al., 2022). Cities can maximize the benefits and minimize the drawbacks of their sustainable programs by understanding and controlling these feedback loops.

In the framework's Socio-Ecological Systems part, humans and nature interact in complex webs in cities. This socio-ecological paradigm examines how urban green areas, energy-efficient structures, and renewable energy sources interact, according to Darwish et al. (2023). These links improve city life by affecting microclimate and dweller satisfaction. The framework recognizes urban-nature connections. Moosavi et al. (2023) stress the need to consider both while designing and executing climate-responsive strategies. The Systems Thinking and Resilience Framework provides a comprehensive view of climate-responsive urban design, renewable energy integration, and urban resilience, according to McGregor and Cowdy (2023).

By highlighting changeable interdependencies, the framework helps academics and practitioners decrease urban heat islands and design resilient urban fabrics that can withstand climate change. This paradigm emphasizes social and ecological aspects, feedback loops, and system dynamics to promote climate-resilient urban development.

4. Materials and Method

Due to rapid urbanization, governments worldwide are rethinking urban planning. Thirteen nations—the US, China, Germany, Australia, Singapore, Brazil, Japan, UK, India, Spain, Italy, Mexico, and Turkiye—represent various geographical, climatic, and developmental features. These countries share urban heat island impacts, which affect health, electricity usage, and city ecosystems. They also want to include renewable energy and climate-responsive urban architecture in their cityscapes.

Along with technological and geographical concerns, this study's independent variables address major urban sustainability issues within sustainable development. Building energy efficiency supports SDG 7 by promoting energy conservation and efficiency in urban structures. More green space and tree canopies promote SDG-11 and SDG-15. These measures boost biodiversity, improve city life, and mitigate climate change. Renewable energy sources help achieve SDG-7 and SDG-13 by reducing fossil fuel use and carbon emissions. Improving urban planning and governance by including community resilience in sustainable urbanization plans strengthens SDG-9 and SDG-11. Research and development help accomplish SDG -9 by advancing technology for sustainable urban solutions. These factors address climate resilience and environmental sustainability. It relates technological and geographical factors to sustainable urban development frameworks and Urban Heat Island Intensity (UHHI).

The study used urban heat island intensity (°C) as the response variable of the study, which measures urban-rural temperature differences. It suggests that renewable energy and climate-responsive city design may mitigate the urban heat island effect, which is worsening due to climate change. Maximum Temperature in Centigrade was used to study urban heat island effects and trends. All data comes from the World Bank's *Climate Change Knowledge Portal* (CCKP, 2023). The independent variables are as follows: Green Space Area per Capita (sq. meters) illustrates urban dwellers' access to parks, gardens, and other green areas. Climate-responsive design includes green spaces to cool and minimize urban heat. The study substitutes it with *Land Area Covered by Forest (% of Land Area, denoted by GREENSP)* to provide a more holistic perspective of a country's natural area availability, which may be linked to green space and its cooling benefits. The data is from the World Bank's database (WDI, 2023). Building Energy Efficiency is another factor that measures city building energy efficiency. Energy-efficient, renewable-energy-compatible buildings reduce energy usage. The study substituted *CO_2 emissions from residential buildings* (% of total fuel combustions, denoted by BEE) to estimate residential energy usage's carbon footprint. The data is from the World Bank (WDI, 2023). Thirdly, climate-responsive design includes green roofs. Green roofs reduce urban temperatures, increase energy efficiency, and offer animal habitat, among other advantages. The study's substitute with *Terrestrial protected areas (% of total land area, denoted by GRA)* shows green roofs and other biodiversity-supporting urban characteristics. The data is from the World Bank database (WDI, 2023). Fourth, urban forests provide shade, decrease temperatures, and improve air quality, aiding climate-responsive urban development. It measures the percentage of land covered by tree canopies. The research employed *The Air Quality Index (e.g., PM2.5 concentration, (micrograms per cubic meter, denoted by TCC)* as a substitute for the tree canopies factor. This variable shows how urban trees and vegetation enhance air quality as vegetation affects air quality. The data is from the World Bank's WDI (2023). Fifth, *Resilience* measures a city's capacity to recover from climate-related calamities. It includes community cohesion, emergency preparation, and infrastructure quality. As a substitute variable, the study used *Access to clean fuels and technologies for cooking (% of the population, denoted by RESIL)* to quantify the proportion of the population with access to potable water, sanitation, medical care, and schooling. A resilient community must have these services. This is from the World Bank's WDI (2023). At least, Cities' Megawatt Renewable Energy Capacity shows solar panels and wind turbines are counted in metropolitan areas' renewable energy capability. Renewable energy reduces GHG emissions and promotes sustainable urban development. The study used two metrics, including a *Renewable Energy Consumption (% of Total Energy Use, denoted by REC)* alternate factor that shows a country's renewable energy consumption. Another factor is *Research and Development expenditures (% of GDP, denoted by RND),* which examines government-funded R&D projects to promote renewable energy technology and integration and provides insights into renewable energy integration. The data is from the World Bank's WDI (2023).

The relationship between UHHI and sustainability is objectively assessed using SDG-aligned sustainability metrics. The variables selected represent urban resilience and sustainable infrastructure (SDG 11), climate action via green policies (SDG 13), and renewable energy efficiency (SDG 7). Community resilience measures urban adaptability and sustainability. Methodically combining SDG-aligned data, the study provides a solid factual framework for understanding sustainable urbanization routes.
A panel data regression analysis will be expertly deployed to delve into the intricate relationship between Urban Heat Island Intensity (UHHI) and its potential determinants. The panel data approach serves as a robust analytical framework due to its simultaneous incorporation of cross-sectional and time dimensions, catering to the exploration of cross-country variations and temporal fluctuations in the variables of interest. The overarching structure of the panel data regression equation is as follows:

$$UHHI_{it} = \beta_0 + \beta_1 GREENSP_{it} + \beta 2BEE_{it} + \beta_3 GRA_{it} + \beta_4 TCC_{it} + \beta_5 RESIL_{it} + \beta_6 REC_{it} + \beta_7 RND_{it} + \varepsilon_{it} \quad (1)$$

Where:

- $UHHI_{it}$ signifies the Urban Heat Island Intensity in country i during year t.
- $GREENSP_{it}$ encapsulates the Green Space Area Covered by Forest (% of Land Area) in country i and year t.
- BEE_{it} represents the Building Energy Efficiency measured by CO_2 Emissions from Residential Buildings (metric tons per capita) in country i and year t.
- GRA_{it} is the Green Roof Area measured by Terrestrial Protected Areas (% of Total Land Area) in country i and year t.
- TCC_{it} denotes the Tree Canopy Coverage (% of Land Area) in country i and year t.
- $RESIL_{it}$ signifies the Resilience Factor measured with Access to Basic Services (% of Population) in country i and year t.
- REC_{it} embodies the Renewable Energy Consumption (% of Total Energy Use) in countryi and year t.
- RND_{it} captures the Research and Development Funding (% of GDP) in country i and year t.
- β_0, β_1, β_2, β_3, β_4, β_5, β_6, β_7 are the regression coefficients awaiting estimation.
- ε_{it} pertains to the error term.

Given the inherently dynamic nature of panel data, the Fixed Effects (FE) panel regression technique emerges as the analytical vanguard. The Fixed Effects model acknowledges the existence of unobservable time-invariant country-specific effects, effectively addressing and circumventing concerns regarding unobserved country-specific heterogeneity that remains constant across time. This technique facilitates the exploration of the interplay between UHHI and the independent variables and considers the nuanced differences among countries. Moreover, the Hausman test will be judiciously administered as part of the rigorous analysis. This essential test serveshelp to choose between Fixed Effects (FE) and Random Effects (RE) models. In cases where the Hausman test rejects the null hypothesis, indicating that the random effects assumption does not hold, the Fixed Effects model is the apt choice, ensuring robust and unbiased parameter estimates. This research used Fixed-Effects panel regression and the Hausman test to determine the link between urban heat island intensity and several substitutable parameters in thirteen countries from 2000 to 2022. This scientific method ensures a complete understanding of the complicated mechanisms by which renewable energy, urban architecture, and other variables diminish the urban heat island effect.
Panel Impulse Response Function (IRF) may analyze time-varying panel dataset correlations. This study employed the IRF to evaluate different explanatory variables on UHHI in the near run. Researchers may utilize this method to study how shock or deviation changes affect UHHI alterations. Administration of a standardized shock to each variable and evaluation of the ensuing effect on UHHI over several years lets the IRF illuminate the immediate and cumulative responses of UHHI to changes in the independent variables. The trajectories of multiple variables may reveal linkages and patterns that would otherwise be hidden. Statisticians utilize variation Decomposition Analysis to identify which variables explain a dependent variable's variation more and less. The VDA was used to determine how much of the 10-year Urban Heat Island Intensity trend is due to temperature, population increase, and other variables. Through VDA, researchers gain insights into the dominance and relative importance of UHHI's persistence versus the influences of other variables. The analysis provides a numerical breakdown of the proportions of UHHI variance explained by each factor, thereby highlighting the extent to which independent variables collectively contribute to UHHI dynamics.

5. Results and Discussion

Table 1 shows the descriptive statistics of the variable. The mean UHHI, representing the average maximum temperature in centigrade within urban areas, is approximately 21.49. This variable's distribution displays a mild positive skewness (0.316) and low kurtosis (1.343), suggesting a relatively symmetrical distribution with limited extreme values. Over the analyzed period, the trend in UHHI might indicate urbanization patterns, with potential implications for energy consumption and climate resilience. The mean percentage of land covered by forest (32.64%) underscores the importance of green spaces in urban planning and environmental sustainability. The positively skewed distribution (skewness = 1.169) with moderately high kurtosis (kurtosis = 3.534) suggests that while most countries have moderate forest coverage, some may exhibit higher-than-average coverage, potentially due to varying policies and geographic characteristics. The trend in forest coverage reflects efforts to balance urbanization with ecological preservation.

Table 1. Descriptive Statistics, source: Author's estimate.

Methods	UHHI	GREENSP	BEE	GRA	TCC	RESIL	REC	RND
Mean	21.48993	32.64349	10.06239	18.53071	23.03061	90.42258	14.63726	1.662432
Maximum	32.03000	68.49383	21.76339	37.79964	95.24264	100.0000	50.05000	3.450180

Minimum	11.81000	12.21014	1.003698	0.218489	6.673639	22.10000	0.330000	0.283840
Std. Dev.	7.238664	15.48018	5.955617	10.40116	19.89034	18.49627	12.95662	0.861178
Skewness	0.316455	1.169318	0.354402	0.020808	1.953114	-2.221608	1.430161	0.359800
Kurtosis	1.342639	3.534168	1.844929	2.155836	5.915481	6.944261	4.025654	2.072610

The mean BEE, measured by CO_2 emissions from residential buildings (metric tons per capita), is approximately 10.06. The distribution's moderate skewness (0.354) indicates that while emissions vary, they do not deviate significantly from the mean. The upward trend in BEE values would signify increased energy-efficient building practices, aligning with global sustainability goals and reduced carbon footprints. Rising Building Energy Efficiency (BEE) is signaling a trend toward more ecologically friendly city development through international climate agreements and UN SDGs. BEE upgrades assist SDG 7 by emphasizing energy-efficient technologies and renewable energy in urban structures. This shift promotes green building materials, energy-efficient designs, and smart urban planning, supporting SDG 9. Further, it can accomplish SDG 13 and make cities more climate-resilient by lowering carbon emissions and energy consumption. Improved BEE minimizes resource depletion, promotes urban livability, and assures sustainable urban growth, which benefits SDG 11. BEE, green building certifications, passive design, and smart energy grids improve sustainability pathways, becoming more important as cities worldwide strive for low-carbon urban transitions. This research emphasizes technology breakthroughs and legislative incentives to accelerate BEE improvements in line with international sustainability guidelines.

GRA, representing the percentage of total land area occupied by green roofs in the studied countries, has an average value of 18.53. The near-zero skewness (0.021) and relatively moderate kurtosis (2.156) suggest a distribution with few extreme values. A rising trend in GRA might signal a growing emphasis on sustainable urban infrastructure, which can contribute to improved energy efficiency, air quality, and aesthetics. The mean TCC indicates the percentage of land area covered by tree canopies, which are approximately 23.03. The positively skewed distribution (skewness = 1.953) and high kurtosis (kurtosis = 5.915) imply that some countries could have notably higher tree canopy coverage compared to the mean. An increasing TCC trend would reflect efforts to combat urban heat islands, enhance air quality, and provide natural habitats. RESIL, measured by access to basic services as a percentage of the population has a high mean value of 90.42. The negatively skewed distribution (skewness = -2.222) and high kurtosis (kurtosis = 6.944) suggest that while most countries exhibit high resilience, a few may have lower-than-average access to basic services. A consistent or improving trend in RESIL would indicate positive developments in ensuring societal well-being and preparedness against shocks. The average REC as a percentage of GDP is 14.64. This variable's distribution displays positive skewness (1.430) and moderate kurtosis (4.026), indicating potential variations in renewable energy adoption across countries. An ascending trend in REC underscores the shift toward cleaner energy sources, aligning with global efforts to mitigate climate change and reduce dependence on fossil fuels. RND, measured as a percentage of GDP allocated to research and development, has a mean of 1.662. The distribution's positive skewness (0.360) and moderate kurtosis (2.073) indicate that some countries might invest more heavily in R&D than others. An increasing RND trend signifies a commitment to innovation and technological advancement, fostering economic growth and competitiveness. Table 2 shows the panel fixed effect regression after confirming the Hausman test specification.

The coefficient for BEE is -0.072, indicating that higher building energy efficiency, measured by lower CO_2 emissions from residential buildings, is associated with a decrease in Urban Heat Island Intensity (UHHI). This relationship holds important economic and environmental implications for urban development. One of the key economic benefits of improving building energy efficiency is reducing operational costs. Buildings that are energy-efficient consume less energy for heating, cooling, and lighting (Wan et al., 2023). Lower energy consumption reduces utility bills for building occupants and owners, thereby contributing to cost savings. By lowering energy expenses, individuals and businesses have more disposable income that can be invested elsewhere in the economy. Energy-efficient homes cost more (De Mello, 2023). These buildings attract more buyers and tenants because of lower utility expenses. Building energy efficiency enhancements may increase real estate demand and pricing for purchasers and renters. This might boost real estate-related economic activity and property owner wealth. Energy efficiency projects may enhance construction, engineering, and energy services jobs (Cagno et al., 2022). The demand for competent energy-efficient building retrofitters and designers drives job opportunities in this industry. Energy efficiency may encourage innovation in building techniques, materials, and technology, creating new business possibilities and boosting the economy (Singh et al., 2023). The negative BEE coefficient for UHHI indicates that residential buildings emit less CO_2. Energy efficiency in buildings and reduced heat intensity have significant ecological effects. Energy-efficient building design reduces fossil fuel consumption, a major GHG gas emitter. Energy-efficient architecture improves air quality and reduces climate change (Baba et al., 2022). Energy-efficient building design aims to improve climate resilience. These features include better insulation, reflective roofing materials, and efficient cooling systems. Such design elements can help mitigate the heat island effect by reducing the absorption and retention of heat within urban areas. This, in turn, contributes to more comfortable living conditions for residents and reduces the strain on energy resources during peak demand periods (Elaouzy& El Fadar, 2022). Building energy efficiency promotes responsible resource management. Lower energy consumption reduces electricity and natural gas demand, often generated through resource-intensive processes. By consuming less energy, energy-efficient buildings help conserve non-renewable resources and alleviate pressure on energy infrastructure (Islam et al., 2022).

Table 2. Panel Fixed Effect Regression Estimates, source: Author's estimate.

Dependent Variable: UHHI				
Variables	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Constant	20.371	0.961	21.192	0.000

Dependent Variable: UHHI				
Variables	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
GREENSP	-0.001	0.029	-0.059	0.952
BEE	-0.072	0.027	-2.680	0.007
GRA	0.052	0.017	2.962	0.003
TCC	-0.026	0.010	-2.600	0.009
RESIL	0.008	0.005	1.505	0.133
REC	0.023	0.009	2.541	0.011
RND	0.274	0.145	1.892	0.059
Cross-section fixed (dummy variables)				
R^2	0.996	F-statistic		4774.590
Adjusted R^2	0.996	Prob(F-statistic)		0.000
Hausman Test Estimates				
Chi-square Value	d.f	Prob.value		
19.536	7	0.000		

With a GRA coefficient of 0.052, increasing terrestrial protected area green roofs has little connection with UHHI. Despite appearances, this relationship has significant ecological and economic effects for sustainable city growth. Green roofs may cost extra money (Parsi et al., 2022). Since green roofs cost more to install and maintain, they may have a positive coefficient. Even though plant growth cools UHHI, it may increase the price (Hussien et al., 2023). Green roof soil and plant maintenance require considerable technological and structural upgrades. Ekmekcioğlu (2023) suggests that these changes in building layout may inadvertently affect heat distribution in urban areas. Increased weight and structural changes may explain the strong link between the green roof area and UHHI. Shade and evapotranspiration cool green roofs, although they may retain heat. Tan and Wang (2023) suggest that green roof design and materials may impact heat retention. Green roofs may sometimes capture and hold heat, contributing to higher UHHI. This is crucial if plants and soil retain more heat than they cool. Urban environments vary in height, materials, and land use. A green roof may change the climate (Fleck et al., 2022). These microclimates generate temperature gradients that may raise UHHI in particular areas, depending on wind patterns and nearby surfaces. Green roofs may lower UHHI depending on their surface interactions. Heat diffusion may be altered by nearby paved areas or reflecting surfaces.

The TCC coefficient of -0.026 shows that when UHHI falls, canopy tree coverage increases, shading roads, walkways, and buildings. Cooler surfaces may absorb less heat, lowering UHHI. Trees shade the area, making it cooler and more comfortable to live and stroll in. A city's quality of life may affect its potential to attract residents and tourists, according to Lachapelle et al. (2023). Urban communities with plenty of trees and greenery are more desirable. Larger tree canopies boost aesthetic value and quality of life; hence, real estate in these places sells for more. Trees unite people, increasing demand for houses and companies (Reidman et al., 2022). Preserving and extending tree canopy coverage may boost real estate markets and pricing. When there are more trees, they filter poisons and release oxygen, improving air quality. Poor air quality may induce costly respiratory illnesses, which may have economic benefits. Reducing healthcare costs may boost residents' discretionary income and economic well-being. Tree leaves release water vapour into the sky, reducing heat (Robineau et al., 2022). This cooling process controls local temperatures by increasing humidity and releasing heat. Trees absorb pollutants and store carbon dioxide, improving air quality, and evapotranspiration may cool cities with a thick canopy, reducing the Urban Heat Island effect (Gao et al., 2022). Pollution reduction improves air quality, benefiting humans and the environment. Air quality improvement may make a city more resilient and eco-friendly. Tree-canopy environments may attract many plant and animal species. By aiding pollination and pest control, biodiversity strengthens ecosystems. A diverse urban ecology can improve environmental sustainability (Estrada-Carmona et al., 2022).

UHHI rises somewhat with renewable energy use (REC coefficient = 0.023). Renewable energy use may indicate increased economic activity and energy demand in the studied country. Manufacturing, transportation, and infrastructure development require more energy as the economy grows (Park et al., 2022). Due to this increasing energy consumption, commercial activities, transportation networks, and industrial processes may create additional heat. Renewable energy sources like solar photovoltaic panels can generate heat during energy conversion. Localized heat waves may be exacerbated by this heat release in cities (Elavarasan et al., 2022). Renewable energy infrastructure like wind turbines and solar farms may also change land use patterns and raise UHHI. Renewable energy-dependent cities may grow quickly. Hotter cities may result from land cover changes, energy dynamics, and increased impermeable surfaces, according to Ghosh et al. (2022). Even though renewable energy sources are cleaner and greener, specific installations and technology may cause localized heat. Closely packed solar panels or concentrated solar power systems may emit localized heat (Fikri et al., 2022). When renewable energy installations are concentrated in urban areas, this heat production may considerably impact UHHI.

Table 3. Robust Least Squares Regression Estimates by Country, authors estimate

Country	GREENSP	BEE	GRA	TCC	RESIL	REC	RND	Adj. R^2	Rn^2-Stat (Prob)
United States	-0.014 (0.675)	-0.081 (0.005)	0.045 (0.049)	-0.017 (0.321)	0.006 (0.541)	0.019 (0.178)	0.201 (0.008)	0.512	765.012 (0.000)
China	-0.002 (0.921)	-0.069 (0.007)	0.062 (0.004)	-0.028 (0.009)	0.013 (0.224)	0.027 (0.002)	0.256 (0.003)	0.786	4221.158 (0.000)

Country	GREENSP	BEE	GRA	TCC	RESIL	REC	RND	Adj. R^2	Rn²-Stat (Prob)
Germany	-0.009 (0.743)	-0.062 (0.011)	0.038 (0.119)	-0.021 (0.045)	0.007 (0.511)	0.023 (0.005)	0.192 (0.014)	0.503	621.025 (0.000)
Australia	-0.007 (0.812)	-0.053 (0.039)	0.049 (0.007)	-0.026 (0.002)	0.011 (0.291)	0.021 (0.006)	0.273 (0.005)	0.793	4925.019 (0.000)
Singapore	-0.005 (0.859)	-0.072 (0.003)	0.058 (0.001)	-0.024 (0.011)	0.009 (0.428)	0.031 (0.003)	0.214 (0.012)	0.801	4290.274 (0.000)
Brazil	-0.012 (0.698)	-0.075 (0.002)	0.034 (0.132)	-0.019 (0.251)	0.014 (0.216)	0.018 (0.267)	0.237 (0.005)	0.358	325.214 (0.000)
Japan	-0.010 (0.049)	-0.066 (0.009)	0.041 (0.042)	-0.022 (0.017)	0.005 (0.592)	0.026 (0.004)	0.211 (0.009)	0.796	5225.978 (0.000)
United Kingdom	-0.013 (0.005)	-0.078 (0.002)	0.047 (0.008)	-0.025 (0.003)	0.010 (0.338)	0.020 (0.013)	0.262 (0.006)	0.849	6358.580 (0.000)
India	-0.003 (0.048)	-0.071 (0.005)	0.053 (0.002)	-0.027 (0.006)	0.008 (0.472)	0.022 (0.009)	0.251 (0.002)	0.821	4925.792 (0.000)
Spain	-0.006 (0.043)	-0.063 (0.013)	0.039 (0.047)	-0.018 (0.299)	0.012 (0.307)	0.017 (0.313)	0.222 (0.007)	0.596	1121.412 (0.000)
Italy	-0.011 (0.711)	-0.059 (0.021)	0.042 (0.015)	-0.020 (0.041)	0.009 (0.412)	0.024 (0.005)	0.248 (0.004)	0.758	4882.549 (0.000)
Mexico	-0.008 (0.791)	-0.074 (0.004)	0.037 (0.108)	-0.023 (0.012)	0.011 (0.279)	0.019 (0.164)	0.236 (0.008)	0.401	512.286 (0.000)
Turkiye	-0.004 (0.882)	-0.068 (0.006)	0.048 (0.003)	-0.029 (0.007)	0.007 (0.538)	0.025 (0.003)	0.229 (0.005)	0.724	4573.614 (0.000)

Note: Dependent Variable: UHHI (Urban Heat Island Intensity). Small bracket shows probability value.

A relationship between higher R&D investment and a minor rise in UHHI is indicated by the RND coefficient of 0.274. Spending more on research and development is a frequent indicator of confidence about the future of technology and the economy. Greater construction, more significant energy usage, and more transportation are the outcomes of urbanization, which happens in parallel with increasing economies. The increased heat production that accompanies increasing economic activity implies that these factors may aggravate the Urban Heat Island effect. A possible result of research and development is the introduction of new technology, which may enhance the production of heat (Lebrouhi et al., 2022). Technologically sophisticated firms or procedures may produce thermoelectricity. New construction materials or methods may accidentally change urban heat dispersion. Technological advances may have unanticipated effects on urban life. Despite energy-saving developments, certain technologies may enhance localized heat intensity (Nwaila et al., 2022). Heat from new energy systems, industrial operations, or infrastructure expansions may be sacrificed for efficiency or sustainability. Research and development may provide heat-reducing innovations. This may include reflective surface technology, superb roofing materials, and energy-efficient cooling systems (Morales-Inzunza et al., 2023).

The model includes cross-section fixed effect dummy variables for unobserved national variation. This controls for country-specific variables that may affect UHHI. The R-squared value of 0.996 shows that the model accounts for much UHHI variation using the specified variables. The F-statistic value indicates the statistical model's significance throughout the model. The Hausman test shows that the fixed-effects model varies considerably from the random-effects model. This suggests that the fixed-effects model is better at explaining UHHI differences. Table 3 shows the robust least squares regression estimates by country for ready reference.

Robust Least Squares (RLS) regression in thirteen countries demonstrates a complicated relationship between urban heat island intensity (UHHI) and other environmental factors. Green Space Area (GREENSP) significantly influences UHHI in Turkey, India, Spain, and Japan, but not in the UK or India. In keeping with urban sustainability measures emphasizing green infrastructure, various countries have proven that increasing green space significantly reduces UHHI. The positive correlation between the Green Space Area and reduced UHHI shows the relevance of urban greening in lowering heat island effects, especially in highly populated regions. Green Space Area non-nations like Brazil, Germany, and the US are statistically insignificant, suggesting that other urban attributes may be more relevant in influencing urban heat island intensity. Because they minimize building heat, energy-efficient structures lessen UHHI. All countries show a negative impact from building energy efficiency (BEE). R&D investment supports this, demonstrating a positive and statistically significant influence across all countries. This suggests that urban planning technologies might drastically reduce heat waves. Renewable energy consumption (REC) and tree canopy coverage (TCC) have negative impacts, although their severity varies. The cooling effects of urban greening efforts and tree coverage make TCC particularly significant in Singapore, China, and Australia but not in Mexico or Germany. Renewable energy consumption considerably impacts India, China, and Japan, supporting the hypothesis that clean energy may lower UHHI. However, in B
Brazil and Spain, this effect is not statistically significant.

Table 4. IRF Estimates, source: authors estimate

Years	UHHI	GREENSP	BEE	GRA	TCC	RESIL	REC	RND
2024	0.482	0	0	0	0	0	0	0
2025	0.266	-0.005399	-0.017248	0.001914	-0.050621	-0.026647	-0.025335	0.009904

2026	0.364	-0.011059	-0.011131	0.003692	-0.014286	-0.041815	-0.018666	0.001686
2027	0.317	-0.015747	-0.019091	0.005996	-0.022360	-0.053471	-0.021550	0.003561
2028	0.339	-0.019853	-0.017771	0.006813	-0.010485	-0.059168	-0.019131	0.000921
2029	0.327	-0.023187	-0.020737	0.007484	-0.009120	-0.062100	-0.018960	0.000975
2030	0.332	-0.025927	-0.021085	0.007605	-0.003555	-0.062156	-0.017621	0.000121
2031	0.329	-0.028074	-0.022356	0.007535	-0.000690	-0.060578	-0.016834	3.21E-05
2032	0.330	-0.029728	-0.022891	0.007235	0.002888	-0.057690	-0.015839	-0.000151
2033	0.329	-0.030944	-0.023552	0.006826	0.005635	-0.054055	-0.015039	-6.28E-05

Essential service accessibility is crucial for urban growth, but the Resilience Factor (RESIL) is insufficient in most countries, suggesting that it does little to fight urban heat islands. These results help us understand how environmental variables impact UHHI in various country settings. They stress customizing mitigation strategies to each country's urban and economic conditions, such as creating green spaces and improving building energy efficiency. The findings emphasize integrating sustainable urban policy with technological innovation to reduce UHHI and promote environmentally resilient city development. Urban planning requires context-specific methods since relevance differs by country. Urban heat islands are a significant health and environmental issue in urbanizing regions. Policies may address this by adjusting to local environmental, infrastructural, and technological conditions. Given the diversity of urban contexts, this comprehensive approach ensures that environmental factors and UHHI are not oversimplified. Table 4 shows the panel IRF estimates.

UHHI should rise significantly in 2024. Even when other variables remain constant, UHHI may be affected by unanticipated factors like regional climate or urban growth. UHHI rose slightly in 2025, while GREENSP, BEE, and TCC fell. The cooling benefits of reduced green space, building efficiency, and tree canopy coverage may be outweighed, increasing UHHI. Land use changes, energy consumption, and urbanization may explain these decreases. Impulse responses show a modest rise in UHHI and slight declines in GREENSP, BEE, and TCC. Since cooling devices and energy efficiency can affect heat intensity, urban design should prioritize them. The other factors fade over time. RESIL gains are small, but REC and RND also change. Due to cumulative effects, heat mitigation and sustainable urban development need a comprehensive plan considering several components. Financially, the decline in GREENSP may indicate land use changes or urbanization, which reduce natural cooling and increase UHHI. Decreased BEE may indicate that buildings are less energy efficient, which could increase energy consumption and heat production. These changes need green space and energy-efficient infrastructure. From an ecological perspective, a drop in TCC may indicate fewer canopy trees, affecting shade and heat absorption. Urban vegetation must be preserved and expanded to reduce heat intensity. REC and RND consequences emphasize the challenges of treating UHHI concerns while fostering sustainable development and economic growth. UHHI's next-decade variance decomposition study is given in Table 5.

Table 5. VDA Estimates for UHHI, source authors estimate

Years	S.E.	UHHI	GREENSP	BEE	GRA	TCC	RESIL	REC	RND
2024	0.482	100	0	0	0	0	0	0	0
2025	0.555	98.590	0.009	0.096	0.001	0.831	0.230	0.208	0.031
2026	0.666	98.443	0.034	0.094	0.003	0.623	0.553	0.223	0.022
2027	0.740	97.925	0.072	0.143	0.009	0.594	0.968	0.264	0.020
2028	0.817	97.588	0.118	0.164	0.014	0.504	1.318	0.272	0.017
2029	0.884	97.256	0.170	0.195	0.019	0.442	1.621	0.278	0.014
2030	0.947	97.013	0.223	0.220	0.023	0.386	1.842	0.277	0.012
2031	1.005	96.825	0.275	0.244	0.026	0.343	1.997	0.274	0.011
2032	1.061	96.699	0.326	0.266	0.028	0.309	2.090	0.268	0.010
2033	1.113	96.6184	0.373	0.286	0.029	0.283	2.135	0.262	0.009

Starting with 2024, the analysis indicates that the entirety of UHHI's variance is explained by its past values. This implies that, for this specific year, external factors represented by the other variables might not be significantly affecting UHHI. The immediate influence of the current UHHI value on its future variations highlights the importance of understanding existing conditions. As we progress to the year 2025, a shift becomes apparent. While UHHI's past values still contribute significantly (98.6%) to its variance, other variables begin to show their influence. Green Space Area (GREENSP) plays a minor role, contributing 0.009% to UHHI's variance. This emphasizes the potential cooling effects of green spaces and their contribution to mitigating UHHI. Similarly, Building Energy Efficiency (BEE) contributes 0.096%, indicating the modest impact of energy-efficient practices on reducing heat intensity. Tree Canopy Coverage (TCC) contributes a minimal 0.001%, suggesting the role of vegetation in shading and cooling urban areas. Moreover, Resilience (RESIL) exhibits a larger impact of 0.23%, emphasizing the importance of access to basic services and overall urban adaptability in influencing UHHI. This trend continues over subsequent years, where UHHI's variance remains largely explained by its past values, reflecting the persistence of temperature dynamics. Nevertheless, the collective influence of GREENSP, BEE, TCC, and other variables gains prominence. Although each variable's impact remains relatively small, their cumulative contributions shape UHHI's trajectory over time. From an economic standpoint, these results underscore the continuous role of current UHHI values in shaping future outcomes, suggesting that addressing current heat intensity challenges

remains pivotal. However, the influence of various environmental factors is becoming evident. The significance of green spaces, energy-efficient practices, tree canopy coverage, and urban resilience stands out as they contribute modestly to mitigating UHHI. Environmental considerations are crucial. Given green spaces' cooling effects and the need to conserve urban vegetation, development must balance with nature. Resilient urban design and energy-efficient structures may also lower UHHI.
According to the results, sustainable urbanization involves integrated economic, ecological, and technological efforts. The findings show that SDG-aligned urban sustainability projects must balance economic growth and environmental protection. Energy efficiency, green spaces, and resilient communities reduce UHI. These efforts support goals 11 and 13. The study shows that SDG 7 may optimize renewable energy and research and development efforts to promote climate resilience, notwithstanding a projected positive link with UHHI. These results recommend data-driven SDG-aligned city design for metropolitan authorities to promote urban sustainability and climate adaptation.

6. Conclusions and Policy Recommendations

This study examines the complex relationship between UHHI and economic and environmental factors in thirteen countries from 2000 to 2022. Examining many significant patterns helps explain UHHI's complexity and interactions with other factors. Panel fixed effect regression illustrates associate relationships with UHHI. The negative associations between UHHI and building energy efficiency and tree canopy coverage show that energy-efficient methods and urban vegetation may reduce heat intensity. UHHI is positively correlated with green roof area, renewable energy consumption, and R&D spending, demonstrating the intricate interplay of environmental variables on urban temperature dynamics. IRF analysis improves understanding by forecasting near-term UHHI tendencies. Numerous factors will affect UHHI in the future. To reduce UHHI, sustainable practices and urban adaptation, green space area, building energy efficiency, resilience, green energy demand, and research and development expenditures are stressed. UHHI benefits from strategic urban greening efforts, which include green space areas and tree canopy coverage. The VDA calculates the relative value of each variable in explaining UHHI variance, adding to these results. Many factors affect UHHI dynamics, while resilience is critical. Green energy, building energy efficiency, tree canopy coverage, and green space area all contribute. These findings demonstrate the complexity of UHHI and the need for sustainable urban planning in limiting its effects. Given rapid urbanization and climate change, this research helps policymakers and stakeholders build resilient and livable cities. Heat intensity may be addressed, and a sustainable urban future can be realized via energy-efficient measures, innovative urban greening, and adaptability.
The study demonstrates that greater green space per capita helps lower city heat intensity, so governments should prioritize building and preserving urban green areas. Governments and city planners should create legislative frameworks to guarantee that new urban developments include adequate green space for all socioeconomic groups. Rebates or incentives for urban afforestation, rooftop gardens, and vertical forests might encourage the private sector to assist green cities. Energy efficiency in buildings reduces urban heat, prompting another legislative idea. The study emphasizes the importance of energy efficiency standards in building laws, encouraging reflecting surfaces, passive cooling, and high-performance insulating materials. The government should mandate energy-efficient building designs for new and retrofitted projects. Performance-based incentives and low-interest green loans should encourage property developers and households to invest in energy-efficient equipment. The study shows that renewable energy capacity and climate-responsive city design reduce urban heat islands. Policymakers should prioritize integrating renewable energy sources like solar panels, wind turbines, and others into urban infrastructure faster. Local governments should undertake grid upgrading, net metering, and feed-in tariffs to maximize local renewable energy sources.
Urban planning guidelines should help urban infrastructure use natural ventilation and shade to cool, integrate renewable energy, and construct climate-responsive buildings. Urban resilience indices minimize heat island effects. Therefore, robust locations suffer less damage. Resilience-focused policy initiatives incorporating adaptable urban design solutions may help cities survive climate change-induced heat stress. Government climate adaptation infrastructure expenditures should prioritize permeable pavements, heat-reflective surfaces, and intelligent cooling networks that respond to temperature. Credible data-driven monitoring systems that track weather and other environmental elements should support urban resilience strategies so policymakers can avoid urban heat. These policy ideas align with the study's empirical findings and address the identified heat intensity reduction links between green space, building efficiency, renewable energy, and urban resilience. Practical findings from these concentrated initiatives may enhance sustainable urban design and climate-responsive policy.

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References

1. AHAKWA I, 2023, The role of economic production, energy consumption, and trade openness in urbanization-environment nexus: a heterogeneous analysis on developing economies along the Belt and Road route, *Environmental Science and Pollution Research* 30(17), 49798–49816.
2. ALBUQUERQUE PAI A., ANAND A., PAZHOOTHUNDATHIL N., ASHOK L, 2023, Leadership perspectives on resilience capabilities for navigating disruption, *Journal of Asia Business Studies,* https://doi.org/10.1108/JABS-03-2023-0081.
3. ALMUSAED A., ALMSSAD A., ALASADI A., YITMEN I., AL-SAMARAEE S, 2023, Assessing the role and efficiency of thermal insulation by the 'BIO-GREEN PANEL' in enhancing sustainability in a built environment, *Sustainability* 15(13), 10418.

4. AL-SAYED M.M., ALANIZI A, 2023, Resilient cities to mitigate effects of climate change, in: *IOP Conference Series: Earth and Environmental Science* 1129(1), 012029.
5. BABA F.M., GE H., WANG L.L., ZMEUREANU R, 2022, Do high energy-efficient buildings increase overheating risk in cold climates? Causes and mitigation measures required under recent and future climates, *Building and Environment* 219, 109230.
6. BALA R. S., SATHYANARAYANAN S., JEYPARAKASH S. T., 2023, Understanding the relationship between Urban Heat Island and Urban Vegetation by reviewing three decades of satellite images for the Chennai Metropolitan Area, *IOP Conference Series: Earth and Environmental Science* 1210(1), 012029.
7. BANERJEE S., YIK S.K., DZYUBAN Y., CRANK P.J., YI R.P.X., CHOW W.T, 2022, Analysing impacts of urban morphological variables and density on outdoor microclimate for tropical cities: A review and a framework proposal for future research directions, *Building and Environment* 225, 109646.
8. BOUW K., TIGCHELAAR C., FAAIJ A, 2023, A new approach for modelling techno-economic performance of integrated energy systems on district scale for informed decision-making in a multi-stakeholder context, *Renewable and Sustainable Energy Transition* 3, 100045.
9. BYRNE J., TAMINIAU J., NYANGON J, 2022, American policy conflict in the hothouse: Exploring the politics of climate inaction and polycentric rebellion, *Energy Research & Social Science* 89, 102551.
10. CAGNO E., FRANZÒ S., STORONI E., TRIANNI A, 2022, A characterisation framework of energy services offered by energy service companies, *Applied Energy* 324, 119674.
11. CCKP, 2023, *Maximum temperature*, Climate Change Knowledge Portal, World Bank, Washington D.C., https://climateknowledgeportal.worldbank.org (19.08.2023).
12. CHANG Y., XIAO J., LI X., WENG Q, 2023, Monitoring diurnal dynamics of surface urban heat island for urban agglomerations using ECOSTRESS land surface temperature observations, *Sustainable Cities and Society* 98, 104833.
13. COLASANTE A., D'ADAMO I., MORONE P, 2022, What drives the solar energy transition? The effect of policies, incentives and behavior in a cross-country comparison, *Energy Research & Social Science* 85, 102405.
14. CORTESE T.T., ALMEIDA J.F., BATISTA G.Q., STOROPOLI J.E., LIU A., YIGITCANLAR T, 2022, Understanding sustainable energy in the context of smart cities: A PRISMA review, *Energies* 15(7), 2382.
15. CUONG V.H., KHAN W.A, 2023, Exploring the relationship between green spaces and mental health in urban environments, *Journal of Sustainable Urban Futures* 13(6), 22–33.
16. CUTORE E., VOLPE R., SGROI R., FICHERA A, 2023, Energy management and sustainability assessment of renewable energy communities: The Italian context, *Energy Conversion and Management* 278, 116713.
17. DALL-ORSOLETTA A., CUNHA J., ARAÚJO M., FERREIRA P, 2022, A systematic review of social innovation and community energy transitions, *Energy Research & Social Science* 88, 102625.
18. DANIEL R., CORTESÃO J., STEENEVELD G., STREMKE S., LENZHOLZER S., 2023, Performance of urban climate-responsive design interventions in combining climate adaptation and mitigation, *Building and Environment* 236, 110227.
19. DARWISH S., ALLEN R.R., LEMPKE M, 2023, Necessary complexity in the Anthropocene: new approaches in socio-ecological systems thinking, Do No Harm, and fragility integration, *Development in Practice* 33(5), 534–547.
20. DE MELLO L, 2023, Real estate in a post-pandemic world: How can policies make housing more environmentally sustainable and affordable?,*Hacienda Pública Española / Review of Public Economics* 244(1), 111–139.
21. DUTTA K., BASU D., AGRAWAL S, 2022, Evaluation of seasonal variability in magnitude of urban heat islands using local climate zone classification and surface albedo, *International Journal of Environmental Science and Technology* 19(9), 8677–8698.
22. EKMEKCIOĞLU Ö., 2023, On the identification of most appropriate green roof types for urbanized cities using multi-tier decision analysis: A case study of Istanbul, Turkey, *Sustainable Cities and Society* 96, 104707.
23. ELAOUZY Y., EL FADAR A., 2022, Energy, economic and environmental benefits of integrating passive design strategies into buildings: A review, *Renewable and Sustainable Energy Reviews* 167, 112828.
24. ELAVARASAN R.M., PUGAZHENDHI R., IRFAN M., MIHET-POPA L., KHAN I.A., CAMPANA P.E., 2022, State-of-the-art sustainable approaches for deeper decarbonization in Europe–An endowment to climate neutral vision, *Renewable and Sustainable Energy Reviews* 159, 112204.
25. ESTRADA-CARMONA N., SÁNCHEZ A.C., REMANS R., JONES S.K., 2022, Complex agricultural landscapes host more biodiversity than simple ones: A global meta-analysis, *Proceedings of the National Academy of Sciences* 119(38), e2203385119.
26. FAHMY M., ELWY I., MAHMOUD S., 2022, Back from parcel planning to future heritage of urban courtyard: The 5th generation of Egyptian cities as a sustainable design manifesto for neo-arid neighbourhoods, *Sustainable Cities and Society* 87, 104155.
27. FIKRI M.A., SAMYKANO M., PANDEY A.K., KADIRGAMA K., KUMAR R.R., SELVARAJ J., SAIDUR R., 2022, Recent progresses and challenges in cooling techniques of concentrated photovoltaic thermal system: A review with special treatment on phase change materials (PCMs) based cooling, *Solar Energy Materials and Solar Cells* 241, 111739.
28. FLECK R., GILL R., PETTIT T.J., TORPY F.R., IRGA P.J., 2022, Bio-solar green roofs increase solar energy output: The sunny side of integrating sustainable technologies, *Building and Environment* 226, 109703.
29. GABOR A., REINWALD F., DAMYANOVIC D., 2023, Methodological Framework for Fostering the Implementation of Climate-Responsive Public Spaces and Streetscapes to Support Multifunctional Design, *Sustainability* 15(4), 3775, https://doi.org/10.3390/su15043775.
30. GAO Z., ZAITCHIK B.F., HOU Y., CHEN W., 2022, Toward park design optimization to mitigate the urban heat Island: Assessment of the cooling effect in five US cities, *Sustainable Cities and Society* 81, 103870.
31. GENOVESE P., ZOURE A., 2023, Architecture trends and challenges in sub-Saharan Africa's construction industry: A theoretical guideline of a bioclimatic architecture evolution based on the multi-scale approach and circular economy, *Renewable and Sustainable Energy Reviews* 184, 113593.
32. GHOSH S., KUMAR D., KUMARI R., 2022, Assessing spatiotemporal dynamics of land surface temperature and satellite-derived indices for new town development and suburbanization planning, *Urban Governance* 2(1), 144–156.
33. GRAÇA M., CRUZ S., MONTEIRO A., NESET T., 2022, Designing urban green spaces for climate adaptation: A critical review of research outputs, *Urban Climate* 42, 101126.
34. GREENSTONE C., 2023, Digging up the Past: Re-Visiting the Potential Role Green Roofs can Play in Mitigating the Urban Heat Island (UHI) Effect: A Case Study of the Central Business District (CBD), Durban, South Africa, *African Journal of Inter/Multidisciplinary Studies* 5(1), 1–13.
35. HE B.J., WANG W., SHARIFI A., LIU X., 2023, Progress, knowledge gap and future directions of urban heat mitigation and adaptation research through a bibliometric review of history and evolution, *Energy and Buildings* 287, 112976.

36. HO J.Y., SHI Y., LAU K.K., NG E.Y., REN C., GOGGINS W.B., 2023, Urban heat island effect-related mortality under extreme heat and non-extreme heat scenarios: A 2010–2019 case study in Hong Kong, *Science of The Total Environment* 858, 159791.
37. HÜRLIMANN A.C., NIELSEN J., MOOSAVI S., BUSH J., WARREN-MYERS G., MARCH A., 2022, Climate change preparedness across sectors of the built environment–A review of literature, *Environmental Science & Policy* 128 277–289.
38. HUSSIEN A., JANNAT N., MUSHTAHA E., AL-SHAMMAA A., 2023, A holistic plan of flat roof to green-roof conversion: Towards a sustainable built environment, *Ecological Engineering* 190, 106925.
39. ISLAM M.M., IRFAN M., SHAHBAZ M., VO X.V., 2022, Renewable and non-renewable energy consumption in Bangladesh: The relative influencing profiles of economic factors, urbanization, physical infrastructure and institutional quality, *Renewable Energy* 184, 1130–1149.
40. JALALI Z., GHAFFARIANHOSEINI A., GHAFFARIANHOSEINI A., DONN M., ALMHAFDY A., WALKER C., BERARDI U., 2022, What we know and do not know about New Zealand's urban microclimate: A critical review, *Energy and Buildings,* 112430.
41. KIM J.Y., PARK C.Y., HYUN J.H., KIM S.H., YUN S.H., LEE D.K., KIM J.Y., 2023, Landscape Design for Improved Thermal Environment: An Optimized Tree Arrangement Design for Climate-Responsive Outdoor Spaces in Residential Buildings Complexes, *Sustainable Cities and Society* 97, 104762.
42. LACHAPELLE J.A., KRAYENHOFF E.S., MIDDEL A., COSEO P., WARLAND J., 2023, Maximizing the pedestrian radiative cooling benefit per street tree, *Landscape and Urban Planning* 230, 104608.
43. LAIMON M., YUSAF T., MAI T., GOH S., ALREFAE W., 2022, A systems thinking approach to address sustainability challenges to the energy sector, *International Journal of Thermofluids* 15, 100161.
44. LAMPINEN J., GARCÍA-ANTÚNEZ O., LECHNER A.M., STAHL OLAFSSON A., GULSRUD N.M., RAYMOND C.M., 2023, Mapping public support for urban green infrastructure policies across the biodiversity-climate-society nexus, *Landscape and Urban Planning* 239, 104856.
45. LEBROUHI B.E., DJOUPO J.J., LAMRANI B., BENABDELAZIZ K., KOUSKSOU T., 2022, Global hydrogen development – A technological and geopolitical overview, *International Journal of Hydrogen Energy* 47(11), 7016–7048.
46. LEHNERT M., PANEK J., KOPP J., GELETIC J., KVETONOVA V., JUREK M., 2023, Thermal comfort in urban areas on hot summer days and its improvement through participatory mapping: A case study of two Central European cities, *Landscape and Urban Planning* 233, 104713.
47. LEI Y., ZHOU H., LI Q., LIU Y., LI J., WANG C., 2023, Investigation and Evaluation of Insolation and Ventilation Conditions of Streetscapes of Traditional Settlements in Subtropical China, *Buildings* 13(7), 1611.
48. LEVESQUE A., OSORIO S., HERKEL S., PAHLE M., 2023, Rethinking the role of efficiency for the decarbonization of buildings is essential, *Joule* 7(6), 1087-1092.
49. LIU H., SKANDALOS N., BRASLINA L., KAPSALIS V., KARAMANIS D., 2023, Integrating Solar Energy and Nature-Based Solutions for Climate-Neutral Urban Environments, *Solar* 3(3), 382-415,https://doi.org/10.3390/solar3030022.
50. LIU S., YIN S., HUA J., REN C., 2023, Climate-responsive architectural and urban design strategies for adapting to extreme hot events, *Adapting the Built Environment for Climate Change*, 253-272.
51. LOCKE J., DSILVA J., ZARMUKHAMBETOVA S, 2023, Decarbonization Strategies in the UAE Built Environment: An Evidence-Based Analysis Using COP26 and COP27 Recommendations, *Sustainability* 15(15): 11603.
52. LOH N., BHIWAPURKAR P, 2022, Urban heat-mitigating building form and façade framework, *Architectural Science Review* 65(1), 57–71.
53. LUCCHI E., BAIANI S., ALTAMURA P, 2023, Design criteria for the integration of active solar technologies in the historic built environment: Taxonomy of international recommendations, *Energy and Buildings* 278, 112651.
54. MATSON P.A., STANKOV I., HASSMILLER LICH K., FLESSA S., LOWY J., THORNTON R.L., 2022, A systems framework depicting how complex neighborhood dynamics and contextual factors could impact the effectiveness of an alcohol outlet zoning policy, *American Journal of Community Psychology* 70(1–2), 18–32.
55. MCGREGOR A., COWDY M., 2023, Biourbanism | cities as nature: A resilience model for Anthromes, *Science Talks* 7, 100238.
56. MOOSAVI S., HURLIMANN A., NIELSEN J., BUSH J., WARREN-MYERS G., MARCH A., 2023, Transforming the agency and influence of landscape architects in climate change actions: An empirical analysis of barriers and facilitators, *Landscape and Urban Planning* 234, 104735.
57. MORALES-INZUNZA S., GONZÁLEZ-TREVIZO M.E., MARTÍNEZ-TORRES K.E., LUNA-LEÓN A., TAMAYO-PÉREZ U.J., FERNÁNDEZ-MELCHOR F., SANTAMOURIS M., 2023, On the potential of cool materials in the urban heat island context: Scalability challenges and technological setbacks towards building decarbonization, *Energy and Buildings* 296, 113330.
58. NWAILA G.T., FRIMMEL H.E., ZHANG S.E., BOURDEAU J.E., TOLMAY L.C., DURRHEIM R.J., GHORBANI Y., 2022, The minerals industry in the era of digital transition: An energy-efficient and environmentally conscious approach, *Resources Policy* 78, 102851.
59. OKILJ U., ČVORO M., ČVORO S., ULJAREVIĆ Z., 2023, The Green Dimension of a Compact City: Temperature Changes in the Urban Area of Banja Luka, *Buildings* 13(8), 1947.
60. OQUENDO-DI COSOLA V., OLIVIERI F., RUIZ-GARCIA L., 2022, A systematic review of the impact of green walls on urban comfort: Temperature reduction and noise attenuation, *Renewable and Sustainable Energy Reviews* 162, 112463.
61. OTAMENDI-IRIZAR I., GRIJALBA O., ARIAS A., PENNESE C., HERNÁNDEZ R., 2022, How can local energy communities promote sustainable development in European cities?,*Energy Research & Social Science* 84, 102363.
62. PARK C., LIM S., SHIN J., LEE C.Y., 2022, How much hydrogen should be supplied in the transportation market? Focusing on hydrogen fuel cell vehicle demand in South Korea, *Technological Forecasting and Social Change* 181, 121750.
63. PARSI S.S., LAL K.M., KOSBAB B.D., INGERSOLL E.D., SHIRVAN K., WHITTAKER A.S., 2022, Seismic isolation: A pathway to standardized advanced nuclear reactors, *Nuclear Engineering and Design* 387, 111445.
64. PENG Z., DEBNATH R., BARDHAN R., STEEMERS K., 2023, Machine learning-based evaluation of dynamic thermal-tempering performance and thermal diversity for 107 Cambridge courtyards, *Sustainable Cities and Society* 88, 104275.
65. PERERA A., HONG T., 2023, Vulnerability and resilience of urban energy ecosystems to extreme climate events: A systematic review and perspectives, *Renewable and Sustainable Energy Reviews* 173, 113038.
66. PLANAS-CARBONELL A., ANGUELOVSKI I., OSCILOWICZ E., PÉREZ-DEL-PULGAR C., SHOKRY G., 2023, From greening the climate-adaptive city to green climate gentrification? Civic perceptions of short-lived benefits and exclusionary protection, *Urban Climate* 48, 101295.

67. PRADES-GIL C., VIANA-FONS J.D., MASIP X., CAZORLA-MARÍN A., GÓMEZ-NAVARRO T., 2023, An agile heating and cooling energy demand model for residential buildings, *Renewable and Sustainable Energy Reviews* 175, 113166.
68. QIAO Z., LU Y., HE T., WU F., XU X., LIU L., HAN D., 2023, Spatial expansion paths of urban heat islands in Chinese cities: Analysis from a dynamic topological perspective, *Resources, Conservation and Recycling* 188, 106680.
69. RAJARAJESWARI C., ANBALAGAN C., 2023, Integration of the green and lean principles for more sustainable development: A case study, *Materials Today: Proceedings*.
70. RIEDMAN E., ROMAN L.A., PEARSALL H., MASLIN M., IFILL T., DENTICE D., 2022, Why don't people plant trees? Uncovering barriers to participation in urban tree planting initiatives, *Urban Forestry & Urban Greening* 73, 127597.
71. PRADES-GIL C., VIANA-FONS J.D., MASIP X., CAZORLA-MARÍN A., GÓMEZ-NAVARRO T, 2023, An agile heating and cooling energy demand model for residential buildings. Case study in a mediterranean city residential sector, *Renewable and Sustainable Energy Reviews* 175, 113166.
72. QIAO Z., LU Y., HE T., WU F., XU X., LIU L., HAN D, 2023, Spatial expansion paths of urban heat islands in Chinese cities: Analysis from a dynamic topological perspective for the improvement of climate resilience, *Resources, Conservation and Recycling* 188, 106680.
73. RIEDMAN E., ROMAN L.A., PEARSALL H., MASLIN M., IFILL T., DENTICE D., 2022, Why don't people plant trees? Uncovering barriers to participation in urban tree planting initiatives, *Urban Forestry & Urban Greening* 73, 127597.
74. ROBINEAU T., RODLER A., MORILLE B., RAMIER D., SAGE J., MUSY M., BERTHIER E, 2022, Coupling hydrological and microclimate models to simulate evapotranspiration from urban green areas and air temperature at the district scale, *Urban Climate* 44, 101179.
75. ROSALES PÉREZ N, 2023, Analysis of the extent to which resilience has been embedded into Mexico City planning, *Economía, sociedad y territorio* 23(71), 131–158.
76. SALMANIAN M., BAYAT A., 2023, Urban heat island: a primary guide for urban designers, *Future Energy* 2(4), 10–23.
77. SHARMA A.K., 2022, Synergies Between Traditional Urbanism and Climate Responsive Design, in: Traditional Urbanism Response to Climate Change, Advances in 21st Century Human Settlements, Springer, Singapore, https://doi.org/10.1007/978-981-19-4089-7_5.
78. SHI Z., YANG J., ZHANG Y., XIAO X., XIA J.C., 2022, Urban ventilation corridors and spatiotemporal divergence patterns of urban heat island intensity: a local climate zone perspective, *Environmental Science and Pollution Research* 29(49), 74394–74406.
79. SINGH A.K., RAZA S.A., NAKONIECZNY J., SHAHZAD U., 2023, Role of financial inclusion, green innovation, and energy efficiency for environmental performance? Evidence from developed and emerging economies in the lens of sustainable development, *Structural Change and Economic Dynamics* 64, 213–224.
80. SOMMESE F., BADARNAH L., AUSIELLO G., 2022, A critical review of biomimetic building envelopes: Towards a bio-adaptive model from nature to architecture, *Renewable and Sustainable Energy Reviews* 169, 112850.
81. SONG Y., ZENG M., WANGX., SHI P., FEI M., ZHU J., 2023, Hierarchical Engineering of Sorption-Based Atmospheric Water Harvesters, *Advanced Materials,* 2209134.
82. TAN K., WANG J., 2023, Substrate modified with biochar improves the hydrothermal properties of green roofs, *Environmental Research* 216, 114405.
83. TAWFEEQ NAJAH F., FAKHRI KHALAF ABDULLAH S., AMEEN ABDULKAREEM T., 2023, Urban Land Use Changes: Effect of Green Urban Spaces Transformation on Urban Heat Islands in Baghdad, *Alexandria Engineering Journal* 66, 555–571.
84. WAN ROSELY W.I.H., VOULVOULIS N., 2023, Systems thinking for the sustainability transformation of urban water systems, *Critical Reviews in Environmental Science and Technology* 53(11), 1127–1147.
85. WAN S., DING G., RUNESON G., LIU Y., 2022, Sustainable Buildings' Energy-Efficient retrofitting: A study of large office buildings in Beijing, *Sustainability* 14(2), 1021.
86. WDI, 2022, *World development indicators*, World Bank, Washington D.C.
87. XU X., QIU W., LI W., HUANG D., LI X., YANG S., 2022, Comparing satellite image and GIS data classified local climate zones to assess urban heat island: A case study of Guangzhou, *Frontiers in Environmental Science* 10, 1029445.
88. ZHANG Y., SCHLUETER A., WAIBEL C., 2023, SolarGAN: Synthetic annual solar irradiance time series on urban building facades via Deep Generative Networks, *Energy and AI* 12, 100223.
89. ZHU S., YANG Y., YAN Y., CAUSONE F., JIN X., ZHOU X., SHI X., 2022, An evidence-based framework for designing urban green infrastructure morphology to reduce urban building energy use in a hot-humid climate, *Building and Environment* 219, 109181.