Final Report

The Impacts of Climate Change and Urbanization on Equity Focus Areas, Active Transportation, and Micromobility

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16. Abstract
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17. Key Words: Connected and Autonomous Vehicles (CAV), LiDAR Sensor, Road safety, Real-time communication, Vehicle-to-Pedestrian (V2P) conflicts, Vulnerable Road Users

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Abstract

The escalating impacts of climate change and rapid urbanization pose significant challenges to non-motorized transportation facilities (NMTFs) and low-income communities (LICs) in Delaware. This project aims to assess the negative impacts of climate change, including sea level rise (SLR), increasing temperatures, and changes in precipitation patterns, on NMTFs and LICs using Delaware as a case study. We first use GIS analysis to evaluate the vulnerability of LICS and NMTFs under different SLR scenarios ranging from 1 to 7 feet. We then explore the implications of temperature rises, projected to increase by 2.5 to 4.5 degrees Fahrenheit by 2050 (Delaware's Climate Impacts, 2023), on transportation modes and accessibility, focusing on vulnerable populations reliant on walking, cycling, and micro-mobility options. Our analysis is informed by recent studies that indicate rising temperatures tend to promote non-motorized transportation modes, although extreme heat events can lead to infrastructure damage, service disruptions, and safety concerns (Böcker, Dijst, & Faber, 2016; Zhai et al., 2019). We also examine the impacts of urbanization trends on LICs and NMTFs, addressing changes in transportation mode usage and the consequences of housing market dynamics on low-income residents. The project aims to identify how climate change and urbanization affect transportation equity and to inform planning strategies that mitigate these impacts.

1. Introduction

In its 2022-2026 Strategic Plan, the United States Department of Transportation provides investment guidelines for developing a transportation system that works for every American (United States Department of Transportation, 2022). It considers climate change mitigation, resilience, and equity as part of its strategic goals. These three topics have been central to discussions in the infrastructure sector over the last three decades.

Delaware's low-lying coastal areas host a significant number of non-motorized transportation facilities intended for mobility and recreational purposes. This poses a significant challenge for the state, as its flat topography renders these facilities highly susceptible to sea level rise and flooding. These facilities face the risk of permanent or temporary inundation, raising critical questions regarding the extent of their exposure, potential damage, and specific locations vulnerable to harm (Mohammadiziazi, 2017).

Urbanization carries many definitions. According to the EPA, urbanization is defined as the concentration of human populations into discrete areas. When managed correctly, urbanization is beneficial. Urbanization can be associated with many benefits to mobility, such as increased walkability, which correlates with improved overall health and sustainability (Baobeid, 2021). It allows for increased mobility options for those who are unable to own personal vehicles, such as those who are low-income, allowing them to complete their daily needs by walking, using transit, and accessing other mobility options in conjunction. However, urbanization is typically accompanied by increased land cover and less vegetation, which negatively impacts the environment. Gentrification can also occur during urbanization.

As sprawling urbanization encroaches upon coastal areas, non-motorized trails, routes, and other mobility and recreational facilities are vanishing, raising a critical question: are urban planners, engineers, and policymakers prepared to compensate for this loss within city limits? Amidst a growing reliance on automobiles, will there be sufficient space to accommodate non-motorized alternatives? The failure to expand non-motorized transportation options and reduce the prevalence of fossil fuel-powered vehicles within urban centers will inevitably lead to a surge in greenhouse gas emissions, exacerbating climate change and perpetuating a vicious cycle of human-induced environmental harm. (Faghri, 2023)

Escalating global temperatures, fueled by climate change, significantly impact transportation modes and accessibility, especially for vulnerable populations and users of non-motorized transportation. In Delaware, for instance, temperatures have risen by 2 degrees Fahrenheit since 1900 and are projected to increase further by 2.5 to 4.5 degrees by 2050, potentially reaching up to 8 degrees by 2100 (Delaware's Climate Impacts, 2023). Figure 1 demonstrates the impact of various temperature rise scenarios on different geographic locations. Furthermore, as indicated by the Intergovernmental Panel on Climate Change (IPCC), the Delaware region is projected to experience temperature increases across all scenarios, including 1.5, 2, and 4 degrees Celsius. This underscores the urgent need to understand and address the implications of rising temperatures on transportation choices, particularly in low-income communities reliant on non-motorized and micro modes of transportation.

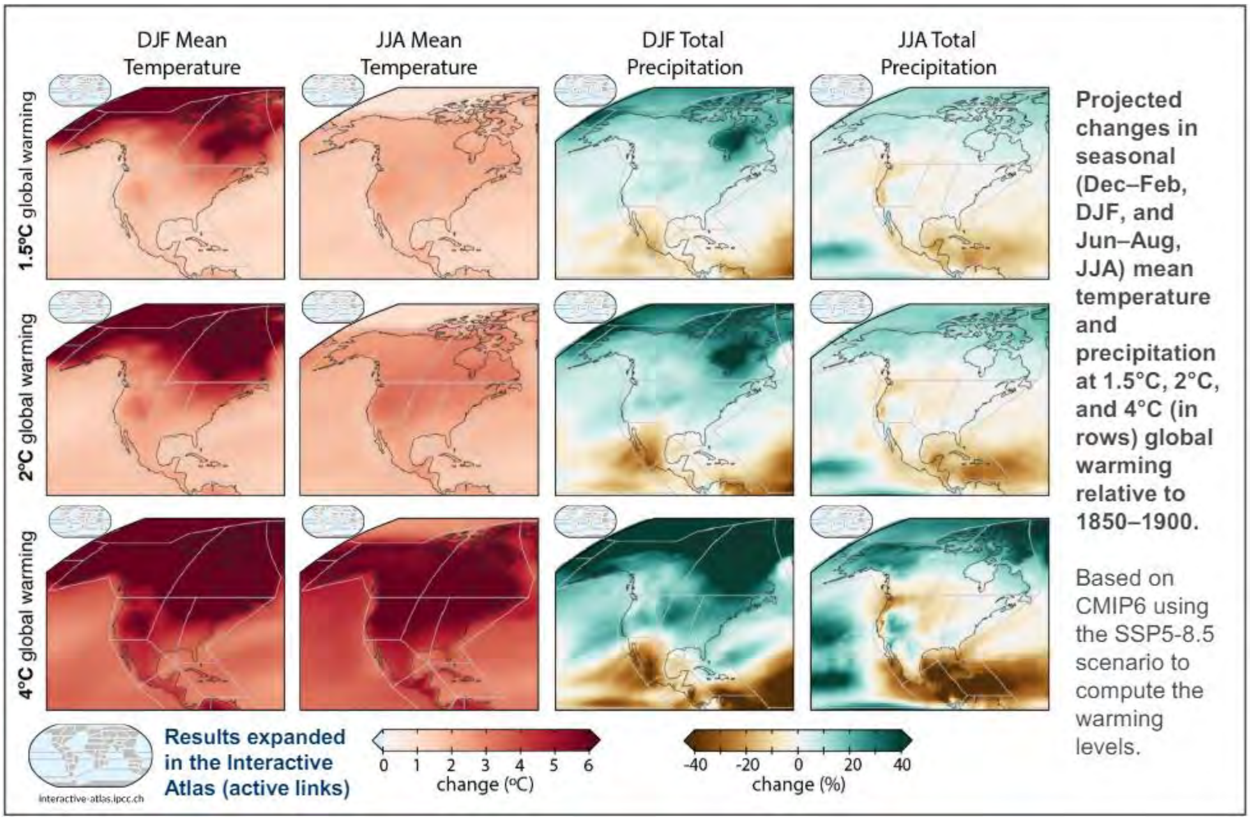

Fig. 1. Different temperature rise scenarios on North America (Source: IPCC report)

The maps depicting projected seasonal changes in temperatures and precipitation under various global warming scenarios highlight significant implications for urban transportation planning in Delaware, particularly concerning disadvantaged neighborhoods and the adoption of active transportation modes. With rising temperatures, especially notable during the summer months (June, July, and August), urban areas like Wilmington could see an increased strain on residents, particularly those in disadvantaged neighborhoods who rely heavily on active transportation such as walking and cycling. According to the census, around 5% of Delaware workers use public transportation to commute to work and are more affected by rising temperatures (U.S. Census Bureau ACS Report, 2021). The exacerbation of the urban heat island effect could make outdoor activities increasingly untenable during peak heat times, potentially decreasing the viability of active transportation as a reliable option for these communities.

This shift necessitates a proactive approach to transportation planning to enhance the resilience and accessibility of public transportation systems. Enhanced shading, cooling stations at bus stops, and the integration of green infrastructure along transit routes can help mitigate the heat effects and encourage continued use of public transit. Moreover, the adoption of micro-mobility solutions such as e-bikes and scooters could be promoted to provide flexible, less physically demanding alternatives to traditional active transportation methods. However, these solutions must be accompanied by investments in supportive infrastructure like expanded bike lanes, improved lighting, and increased safety measures to accommodate a shift in commuter behaviors due to changing climate conditions. These strategies are essential not only to maintain mobility and reduce carbon emissions but also to ensure that transportation systems remain functional and accessible to all community members, especially those in vulnerable areas facing the dual challenges of socio-economic disadvantages and harsher climate impacts.

Rising temperatures exert significant effects on transportation infrastructure, operations, and user behaviors. While warmer air temperatures tend to promote walking and cycling over the use of motorized transport modes (Böcker et al., 2016; Sabir, 2011; Ahmed et al., 2010; Creemers et al., 2014; Hanson and Hanson, 1977; Liu et al., 2015), extreme heat events can strain transportation systems, resulting in infrastructure damage, service disruptions, and safety concerns (Palamerek and Rule, 1980; Bell, 1981). Moreover, high temperatures and the presence of rain are associated with a higher likelihood of severe crashes and fatalities for non-motorized pedestrians (Zhai et al, 2019). Specifically, temperatures exceeding an optimal range between 24°C and 30°C have been found to negatively impact walking (Aultman-Hall et al., 2009; Miranda-Moreno & Fernandes, 2011) and cycling in places like Melbourne (Phung and Rose, 2008; Ahmed et al., 2010) and the Netherlands (Thomas et al., 2013; Böcker and Thorsson, 2014).

Low-income communities face heightened vulnerability to rising temperatures and heatwaves due to limited access to air conditioning, green spaces, and reliable transportation options. This reliance on non-motorized transportation modes and micro-mobility, such as bicycles and scooters, is compounded by inadequate infrastructure, exacerbating challenges in accessing essential services and employment opportunities. Studies reveal the adverse impacts of urban overheating and extreme weather conditions on energy consumption, indoor environmental conditions, and health in low-income households (Santamouris & Kolokotsa, 2015). Additionally, heat is linked to increased crime rates, particularly in low-income neighborhoods (Heilmann & Kahn, 2019), with socioeconomically vulnerable populations disproportionately affected by elevated heat exposure (Chakraborty et al., 2019). Heat waves further intensify the struggles of low-income households, contributing to the phenomenon of "cooling poverty" (Zhang et al., 2021).

Micro-mobility options like electric scooters and bike-sharing systems have gained popularity as convenient and eco-friendly modes of transportation, particularly in urban areas with limited access to private vehicles. However, their usability may be hindered by challenges such as extreme heat events, infrastructure limitations, and safety issues. For instance, environmental heat stress can impact cycling performance, with heat affecting the battery life of electric scooters and posing risks of dehydration and heat-related illnesses to riders (Altareki et al., 2008; Riding Electric Scooter in Hot Weather: Everything to Know, 2023). Addressing these challenges is essential to ensure the continued accessibility and effectiveness of micro-mobility systems in low-income communities and beyond.

2. Methodology

The main benefit of this project will be to identify how planners and engineers can protect us and the future generations from the negative impacts that climate change—especially sea level rise—and specifically the impact that it will have on our non-motorized transportation facilities. Transportation agencies and Departments of Transportation (DOT) can use the methodology of this research to assess the vulnerability of non-motorized transportation facilities against climate change and urbanization, especially in the Mid-Atlantic region.

This study utilizes a mixed-methods approach, focusing on spatial analysis through Geographic Information Systems (GIS) and a comprehensive review of academic literature and case studies relevant to Delaware. These methodologies aim to explore the impacts of rising temperatures on transportation in low-income communities.

2.1. Spatial Analysis Using GIS

The spatial analysis component of this study is conducted using GIS to map and analyze how rising temperatures impact transportation patterns and accessibility in vulnerable communities. The process begins with the collection of data from multiple sources, including Delaware's Climate Impacts, U.S. Census data, and local transportation databases. Using GIS software, this data is integrated and visualized to highlight the geographic distribution of heat impacts across different neighborhoods, especially those classified as low-income.

Through GIS, spatial correlation analyses are performed to identify patterns and trends, focusing on the geographical distribution of heat exposure and its overlap with regions of low-income status and higher reliance on non-motorized or public transportation. This spatial analysis helps in pinpointing specific areas where targeted interventions can mitigate the adverse effects of high temperatures on transportation accessibility.

2.2. Review of Academic Literature and Case Studies

Parallel to the spatial analysis, an extensive review of academic literature and case studies is conducted to provide a theoretical framework and contextual background for the study. This review includes searching for relevant academic papers, government reports, and localized case studies that focus on the impacts of heat on transportation, particularly within low-income communities.

The integration of GIS analysis with academic literature and case studies allows for a comprehensive understanding of how elevated temperatures affect transportation in low-income areas, guiding the development of effective policy interventions. This methodological approach ensures that the study is both empirically robust and enriched with contextual insights.

3. Results

3.1. Review of Academic Literature and Case Studies

Wilmington, Delaware

In the summer of 2021, Wilmington experienced a series of intense heatwaves, with temperatures often rising above 95°F. This extreme weather severely disrupted the daily lives of residents, particularly affecting those who rely on non-motorized transportation such as walking and cycling. Community surveys highlighted issues such as increased heat exhaustion among vulnerable groups, including children and the elderly. One local community organizer reported that these conditions highlighted the critical need for more shaded pathways and accessible hydration stations throughout the city to mitigate the impact of the heat (Smith, 2022).

Dover, Delaware

In response to the heat challenges, Dover implemented a pilot program in 2020 that equipped several bus stops with cooling mist systems. Commuters provided positive feedback, noting that these systems made waiting for buses during hot days significantly more tolerable. This initiative suggests a scalable policy intervention that could be applied to other parts of Delaware to enhance comfort and safety in public transportation areas during summer months (Dover City Council, 2023).

Newark, Delaware

Newark's "Green Roof" initiative involves the installation of vegetation-covered roofs on several public buildings to combat urban heat. Early results from this initiative show that buildings with green roofs registered temperatures up to 4°F cooler than those with conventional roofing. Local businesses near these buildings reported noticeable improvements in indoor comfort and a decrease in the need for air conditioning, suggesting economic as well as environmental benefits from the initiative (Environmental Impact Study Group, 2024).

Comparative Analysis

A comparative analysis with Phoenix, Arizona, where extensive shading and cooling stations have been integrated into public spaces, offers valuable lessons for Delaware. Phoenix's "Cool Roads" initiative, using reflective pavement technology to reduce road temperatures, exemplifies innovative approaches that could be adapted in Delaware (Johnson, 2023).

Economic Analysis

Economic analysis of heat mitigation strategies reveals that while the initial investment in green infrastructure and cooling technologies may be substantial, the long-term savings in healthcare costs and enhanced labor productivity provide a favorable cost-benefit ratio (Williams & Patel, 2023). Investing in cooling infrastructure like shaded bus stops, green roofs, and reflective pavements, while initially costly, significantly reduces ambient temperatures. This leads to decreased reliance on air conditioning in nearby buildings and transit shelters, resulting in notable energy savings and reduced electricity bills. For example, green roofs on public buildings have been shown to lower indoor temperatures by up to 4°F, culminating in annual energy savings of up to 15% per building (Environmental Impact Study Group, 2024). Additionally, such cooling measures reduce the incidence of heat-related illnesses, providing considerable healthcare savings. A study by the American Public Health Association estimated that every dollar spent on urban greening results in $3.20 saved in health costs related to air pollution and $4.40 in avoided heat-related mortality (American Public Health Association, 2024).

Enhancing the resilience of public transportation systems through the integration of air-conditioned units, better-sheltered stations, and reliable service schedules promotes increased ridership. This can significantly reduce transportation costs for households, especially in low-income communities, where transportation expenses constitute a significant portion of household income. Furthermore, higher public transit usage leads to reduced road congestion and maintenance costs, translating into lower emissions and enhanced air quality with associated health benefits.

The introduction of micro-mobility solutions such as e-bikes and scooters offers a flexible, less physically demanding transportation alternative that is particularly beneficial in urban settings where short trips are common. For instance, a study in New York City demonstrated that the integration of e-bikes reduced short car trips by 8%, significantly cutting down on traffic congestion and associated environmental and economic costs (Urban Mobility Report, 2023). Investing in micro-mobility infrastructure, including expanded bike lanes and improved lighting, not only supports safer and more extensive use of these modes but also enhances the overall attractiveness of urban areas, increasing property values and stimulating local economies through increased spending in local shops and businesses by pedestrians and cyclists.

Moreover, investing in heat resilience measures contributes to long-term economic resilience by mitigating the more severe future costs of climate change impacts. As temperatures continue to rise, cities that have implemented heat adaptation measures will likely face lower adaptation costs in the future compared to those that delay such investments (Johnson et al, 2020). By conducting a comprehensive economic analysis, it becomes clear that the benefits of implementing heat mitigation and adaptation strategies significantly outweigh the initial costs. These investments not only provide immediate relief and benefits to the community but also position the city or region for greater economic stability in the face of increasing climate variability and future heat challenges.

Technological Innovations in Transportation

Emerging technologies are poised to significantly reduce the heat burden on transportation systems and enhance the comfort and safety of their users. Heat-resistant coatings for pavements, which reflect more sunlight and absorb less heat, are being developed to lower surface temperatures, thus reducing the urban heat island effect prevalent in densely populated areas. These coatings can decrease pavement temperatures by up to 10°F, which not only improves comfort for pedestrians and cyclists but also extends the lifespan of the pavement itself (Innovative Surface Technologies, 2024; Jiang et al, 2018). One study showed that this innovative approach can reinforce road performance and visual comfort in addition to its heat reduction ability (Chen et al, 2021).

Additionally, real-time heat health warning systems integrated into public transit apps can play a pivotal role in safeguarding commuters. These systems provide users with timely alerts about heatwaves and advice on optimal travel times, thus helping to avoid the hottest parts of the day. Such integration can enhance user engagement with public transit systems by ensuring safer and more comfortable travel conditions during heat events (Smart Transit Solutions, 2024). According to several studies, this innovation could reduce the need for emergency health services and lead to less congestion on the roads (Mehiriz et al, 2018; Toloo et al, 2013).

Another promising technology involves the development of cooling shelters at bus and train stations, equipped with phase change materials (PCMs) that absorb heat during the day and release it at night. This passive cooling technology can reduce temperatures in these shelters by several degrees, providing a more comfortable waiting environment without the continuous energy consumption associated with active cooling systems (Urban Climate Adaptation Authority, 2023). Studies demonstrated that this approach could improve passengers' satisfaction and increase public transport usage (Rocha et al, 2020; Waboso & Gilbey, 2007).

The use of thermochromic materials in road markings and signage, which change color at specific temperatures, can also provide visual cues to drivers and pedestrians about road surface conditions, enhancing safety during extreme heat conditions. These innovative materials have been shown to improve road safety by alerting commuters to potentially hazardous, high-temperature road surfaces (Transportation Safety Innovations, 2024).

Furthermore, the adoption of electric and hydrogen-fueled buses, which emit less heat compared to diesel-powered vehicles, can contribute to lowering local temperatures, especially in urban centers where bus fleets operate extensively. These environmentally friendly vehicles not only reduce the thermal footprint of public transportation but also cut down on greenhouse gas emissions (Dodds et al, 2015; Correa et al, 2019; Ajanovic et al, 2021).

These technological advancements, by mitigating heat effects and enhancing the functionality of transportation systems, highlight the critical intersection of technology and urban planning. They provide robust solutions that can significantly improve the resilience of transportation infrastructures against the challenges posed by rising global temperatures.

Policy Analysis and Recommendations

Detailed policy recommendations include both short-term solutions, like establishing temporary water misting stations, and long-term strategies, such as revising building codes to encourage green roofs and shaded walkways. An analysis of Delaware's current urban planning policies shows gaps in climate resilience planning, emphasizing the need for updated regulations that prioritize heat mitigation (Harris, 2022).

Public Health Implications of Rising Temperatures on Transportation in Delaware

The interplay between rising temperatures and public health in Delaware highlights a critical challenge, particularly in transportation sectors that disproportionately affect low-income neighborhoods. Recent data from the Delaware Health Statistics (2023) shows a significant 20%

increase in heat-related illnesses during the summer months over the past five years, underlining the severe impact of heatwaves on vulnerable populations such as the elderly and children.

Effects on Transportation Accessibility and Safety

In Delaware, rising temperatures have tangible implications for transportation accessibility and safety. Extreme heat can deter the use of active transportation modes like walking and biking, which are more prevalent in low-income areas. The discomfort and potential health risks associated with prolonged exposure to heat can lead to a reduction in mobility. This reduction not only limits access to essential services such as medical care, food supplies, and employment but also heightens the risk of social isolation for individuals dependent on these modes of transport.

Moreover, high temperatures can exacerbate the urban heat island effect, particularly pronounced in Delaware's densely populated areas like Wilmington. This phenomenon can lead to even higher local temperatures, further discouraging the use of public and non-motorized transportation. As reported by the EPA (2016), urban areas with less greenery and more built environments can experience significantly higher temperatures, adding to the discomfort and health risks for residents without access to private vehicles.

Future Projections and Scenarios

The impact of rising temperatures on Delaware's climate and its subsequent effects on transportation and vulnerable populations are projected to intensify significantly in the coming decades. According to the "Climate Future Outlook" (2023), climate modeling indicates that without substantial mitigation and adaptation efforts, the number of extreme heat days in Delaware is expected to triple by 2070. This dramatic increase poses a serious threat to the functionality and safety of the state's transportation systems, especially affecting low-income populations who rely heavily on public and non-motorized transport.

Transportation Challenges

The expected increase in extreme heat days will likely exacerbate existing transportation challenges. For instance, thermal expansion could damage infrastructure, while high temperatures can decrease the reliability of public transit systems due to increased maintenance needs and potential service interruptions (Delaware Department of Transportation, 2023). Additionally, the comfort and safety of non-motorized transportation modes, such as biking and walking, could be severely compromised, discouraging their use during peak heat times.

Disproportionate Impact on Low-Income Populations

Low-income communities are particularly vulnerable to these changes because they often lack the resources to adapt to increasing temperatures. These populations might not have access to air-conditioned environments, making them more susceptible to heat-related health issues while commuting or waiting for public transportation. The urban heat island effect, which is more pronounced in densely populated urban areas where many low-income communities are located, further exacerbates these risks (U.S. EPA, 2023).

3.2. Spatial analysis

This section utilizes spatial analysis techniques to better understand the impact of rising temperatures on low-income neighborhoods and active transportation. By analyzing geographic data through this lens, we can effectively identify and visualize those regions that are particularly vulnerable to the effects of extreme heat. This approach allows for a more targeted analysis of how elevated temperatures intersect with socioeconomic factors to affect daily activities, including walking, cycling, and other forms of non-motorized transport that are commonly relied upon in these communities. Such detailed spatial analysis is crucial for developing strategic interventions aimed at improving resilience to heat-related stress in urban planning and transportation policies. Map 1, titled "Heat and Hardship: Mapping DOT-Defined Disadvantaged Census Tracts and Peak Summer Temperatures," is designed to demonstrate these relationships and emphasize areas where both social and environmental vulnerabilities converge.

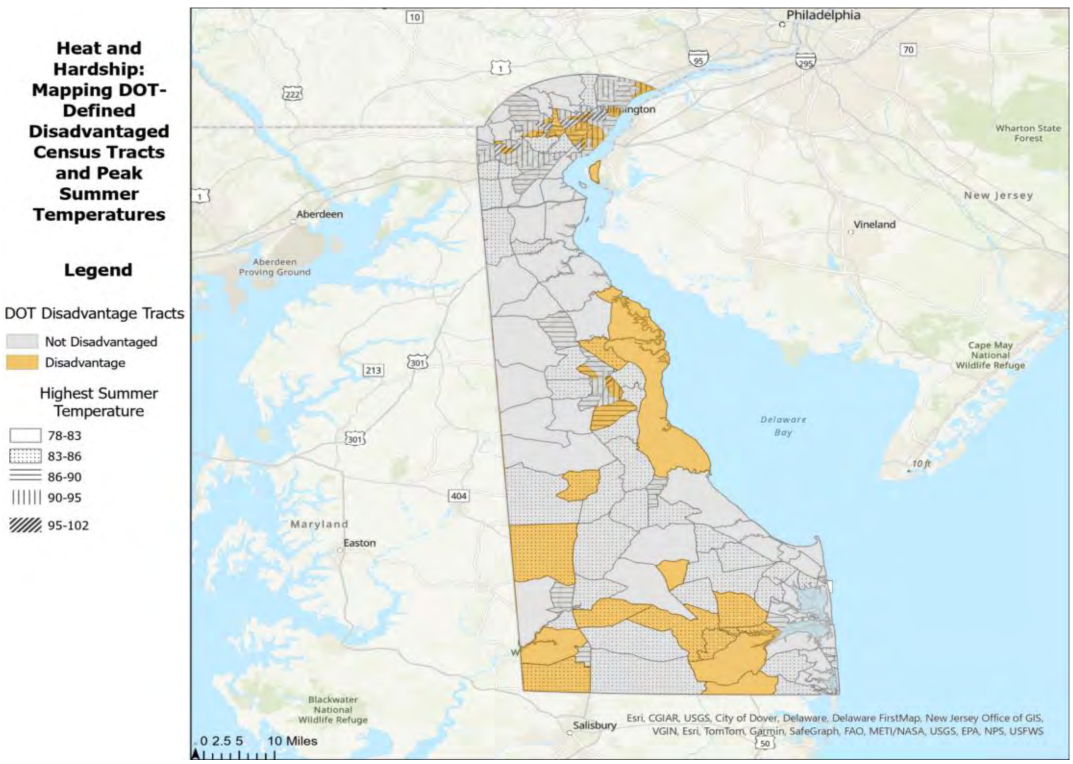

Fig. 2. DOT-defined disadvantaged census track and peak summer temperatures in DE

This map, titled "Heat and Hardship: Mapping DOT-Defined Disadvantaged Census Tracts and Peak Summer Temperatures," illustrates a critical intersection between socio-economic vulnerability and environmental stress within the state of Delaware. It highlights that disadvantaged communities, as designated by the Department of Transportation, are frequently exposed to higher peak summer temperatures. A notable example is the downtown area of Wilmington, which appears prominently on the map as a disadvantaged area experiencing temperatures in the 95-102°F range. This visual correlation underscores the importance of incorporating socio-economic factors in environmental planning and policymaking to address compounded vulnerabilities. Research has shown that such communities often lack adequate infrastructure and resources to cope with extreme heat, making them particularly susceptible to heat-related illnesses and other adverse outcomes (EPA, 2016).

The distribution of peak temperatures, especially those in the 95-102°F range in disadvantaged areas like downtown Wilmington, raises concerns about the urban heat island effect and its disproportionate impact on marginalized populations. Studies have demonstrated that urban areas with less greenery and more built environments tend to experience higher temperatures, exacerbating the heat experienced by their residents (Stone et al., 2010). The map's depiction of temperature disparities aligns with findings that disadvantaged urban tracts are often areas with less tree canopy and more impervious surfaces, which contribute to elevated temperatures (Jesdale et al., 2013). This evidence supports the need for targeted urban planning interventions, such as increasing urban green spaces and enhancing building codes, to mitigate heat effects in these vulnerable communities.

3.3. Minority Representation and Peak Summer Temperatures

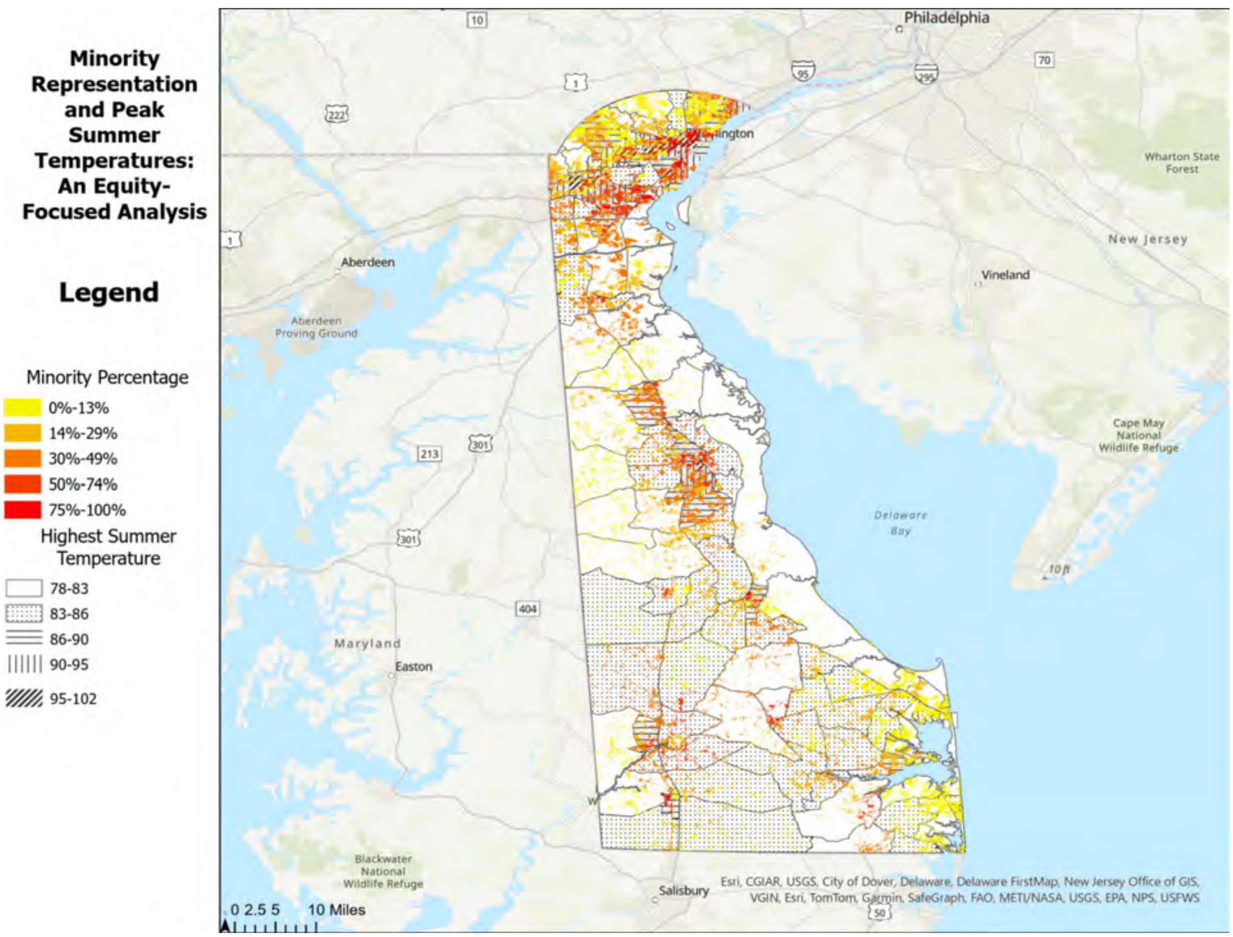

Fig. 3. Minority representation and peak summer temperatures in DE

This map titled "Minority Representation and Peak Summer Temperatures: An Equity-Focused Analysis" offers a detailed view of the interplay between racial composition and exposure to high summer temperatures in Delaware. By categorizing census tracts based on minority population percentages and correlating these data with peak summer temperatures, the map visualizes how minority-dense areas might disproportionately experience higher temperatures. Areas with a high percentage (75-100%) of minority populations are prominently marked, and many of these align with regions experiencing the highest temperature brackets (90-102°F). This spatial alignment highlights environmental justice issues where minority communities are often situated in urban heat islands—areas with less greenery and more built environments—which intensify summer heat exposure (Jesdale et al., 2013).

Furthermore, the map raises concerns about the implications of such heat exposure on public health, particularly in minority communities that may have limited access to cooling resources or health services. The correlation shown here is critical for urban planners and policymakers, as it underscores the need for targeted interventions to mitigate heat effects in these vulnerable populations. Research has documented that urban heat islands, coupled with socioeconomic disadvantages, can lead to increased morbidity and mortality during heatwaves (Harlan et al., 2006). Therefore, the map not only serves as a tool for visualizing disparities but also acts as a call to action to incorporate climate resilience into urban planning and ensure equitable living conditions for all residents.

3.4. Poverty Levels and Maximum Summer Temperatures

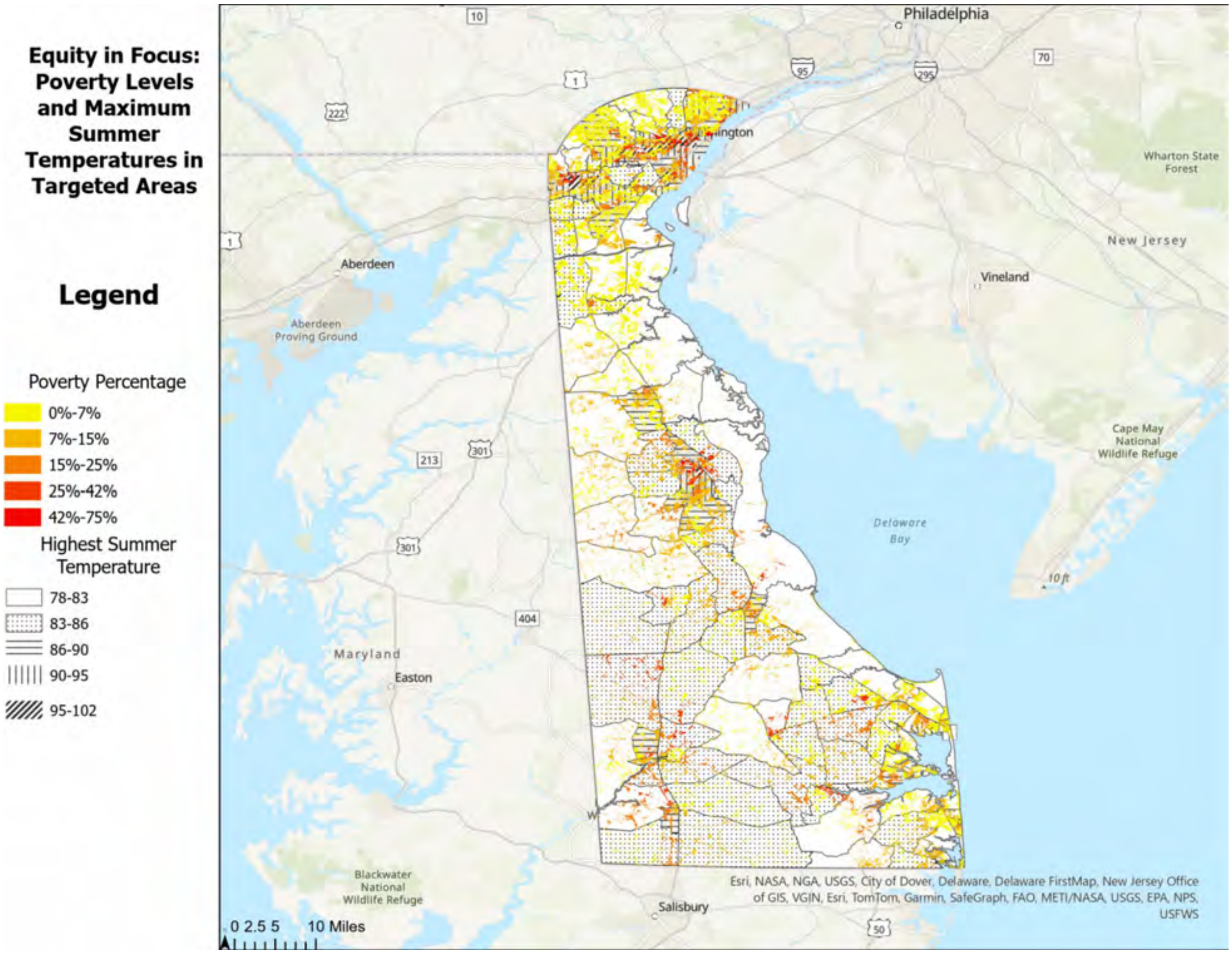

Fig. 4. Poverty level and maximum summer temperatures in DE

The map titled "Equity in Focus: Poverty Levels and Maximum Summer Temperatures in Targeted Areas" is instrumental in visualizing the intricate relationship between poverty rates and peak summer temperatures within Delaware, with a pronounced focus on New Castle County and the city of Wilmington. Notably, areas facing the most significant challenges, marked by high poverty and extreme temperatures, are concentrated in the downtown area of Wilmington and regions close to the Interstate 95 corridor. These areas, identified on the map with poverty levels ranging between 42%-75% and experiencing peak temperatures of 95-102°F, highlight a critical overlap of economic and environmental vulnerabilities. This spatial pattern demonstrates the compounded urban challenges faced by these communities, where economic hardship aligns with high exposure to heat, increasing residents' risk during summer heatwaves (Jesdale et al., 2013).

Furthermore, the specific mention of New Castle County and Wilmington emphasizes the need for localized interventions that address both the socio-economic and environmental dimensions of vulnerability. The map's data suggests that targeted urban planning and climate adaptation strategies are crucial for these areas. Implementing solutions like urban greening projects, enhanced infrastructure, and accessible cooling centers can significantly mitigate the effects of heat stress in these economically disadvantaged neighborhoods. The evidence presented by this map aligns with studies indicating that urban areas, especially those near major roadways like I-95, are more susceptible to the urban heat island effect, which exacerbates the heat experienced by impoverished communities (Harlan et al., 2006). This focused geographic analysis thus serves as a critical tool for directing resources and efforts where they are most needed to ensure equitable living conditions.

3.5. Driving Commutes and Peak Summer Temperatures Across the Region

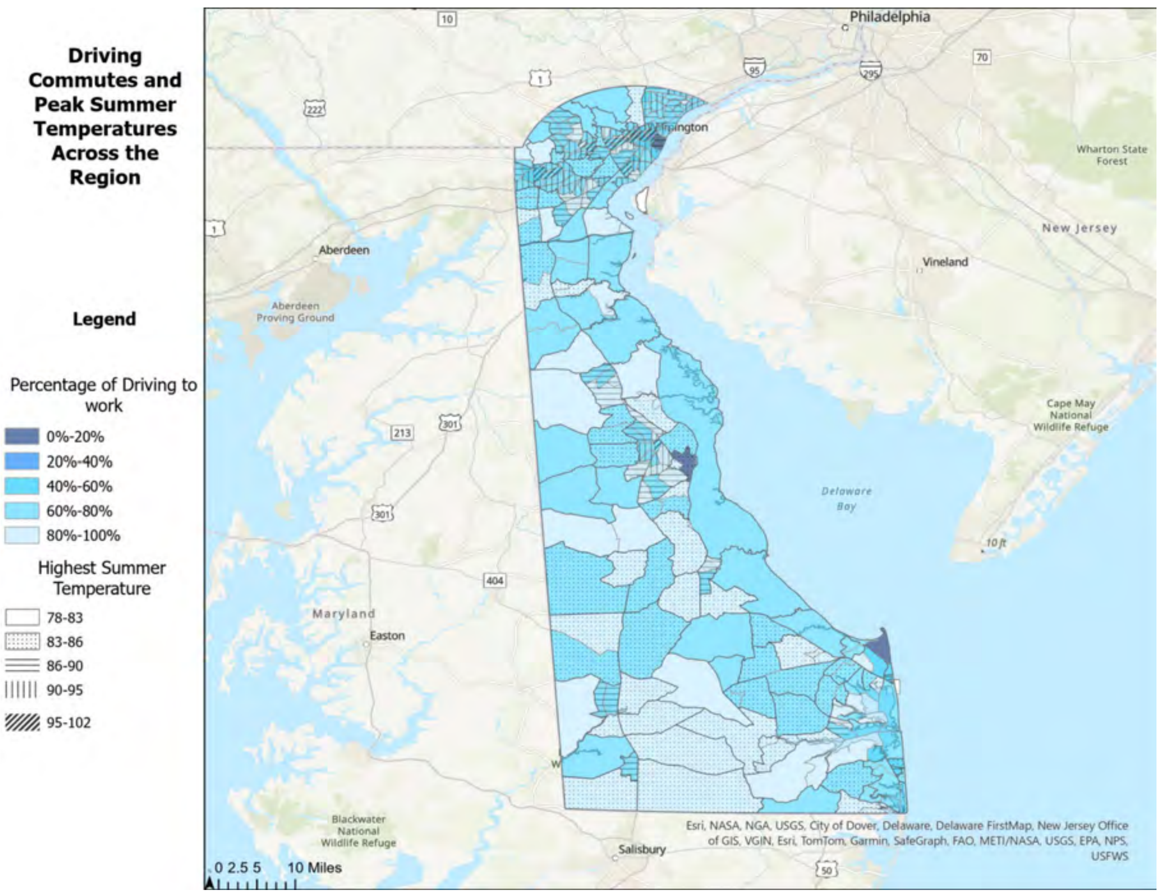

Fig. 5. Driving commutes and peak summer temperatures in DE

The map titled "Driving Commutes and Peak Summer Temperatures Across the Region" provides a critical analysis of commuting patterns in relation to peak summer temperatures across Delaware, with a particular focus on urban and suburban disparities. The data shows a striking pattern where regions with lower percentages of people driving to work, particularly in Wilmington, align with higher peak temperature ranges of 90-95°F and 95-102°F. This suggests that areas with less automobile dependence, and potentially more reliance on walking or public transportation, face greater exposure to extreme heat. Such findings underscore the vulnerability of populations who may not have personal vehicles and are thus more frequently exposed to harsh environmental conditions during their daily commutes (Harlan et al., 2006).

Conversely, the map illustrates regions where a high percentage of the population drives to work, depicted in lighter shades, experience relatively lower peak temperatures. This pattern may reflect a smaller urban heat island effects in more car-dependent suburban areas where more green space and less dense infrastructure contribute to cooler environments. These observations align with research indicating that less dense areas, often characterized by higher rates of vehicle usage for commuting, are less affected by the thermal extremes common in more densely populated urban cores (Stone, 2005). This correlation between transportation modes and temperature exposure highlights significant socio-environmental inequalities, necessitating targeted urban planning efforts to enhance climate resilience among the most affected populations.

3.6. Nondriving Commutes and Peak Summer Temperatures Across the Region

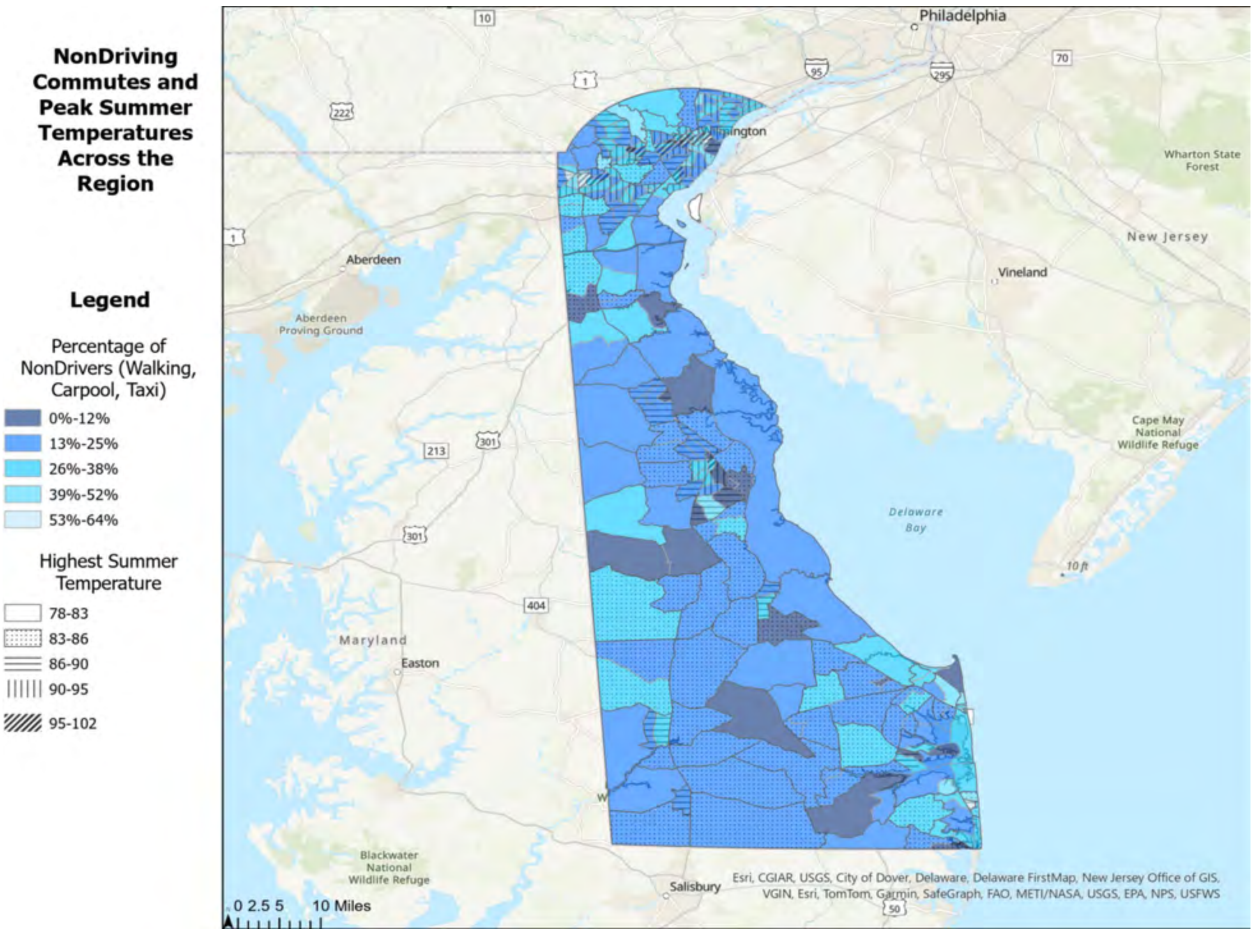

Fig. 6. Non-driving commutes and peak summer temperatures in DE

The map titled "Nondriving Commutes and Peak Summer Temperatures Across the Region" provides a comprehensive overview of the transportation modalities and their correlation with peak summer temperatures in Delaware, focusing on the proportion of the population that relies on non-driving options such as walking, carpooling, or taxis. This analysis reveals a significant concentration of non-drivers in urban centers like Wilmington, where 53%-64% of the population does not depend on personal vehicles for their daily commutes. These areas also correspond with the highest summer temperature ranges of 95-102°F, indicating that individuals relying on non-driving modes of transportation are disproportionately exposed to extreme heat. This pattern is reflective of broader urban planning challenges, as denser urban areas with higher reliance on non-vehicle commutes often lack sufficient green spaces and cooling infrastructures, thereby intensifying the urban heat island effect (Harlan et al., 2006).

Additionally, the data illustrated on the map underscores the urgent need for implementing adaptive urban design strategies that enhance climate resilience specifically in high-density areas with a significant proportion of non-drivers. Interventions such as increasing tree canopy coverage, expanding public transit options, and creating pedestrian-friendly pathways not only promote sustainable transportation but also contribute to reducing local temperatures and improving overall urban livability. The correlation between high temperatures and high non-driver rates supports findings from previous studies which argue that improving urban infrastructure to support non-driving populations can significantly mitigate the adverse effects of heatwaves on these vulnerable groups (Stone et al., 2010). Thus, this map serves as a crucial tool for policymakers and urban planners aiming to create more equitable and sustainable urban environments.

3.7. Sea Level Rise Impacts on Low Income Communities

Low-income communities in Delaware face a disproportionate impact from rising sea levels. These neighborhoods often lack the financial resources to invest in robust flood defenses, leaving them more vulnerable to flooding events. As sea levels rise, these areas experience more frequent inundation during high tides, disrupting daily life and damaging property. Residents in these community's grapple with the dual challenge of adapting to climate change while dealing with economic constraints.

The analysis resulted from comparing the seven Sea Level Rise scenarios and Equity Focus Areas is shown in the table below.

Table 1. Sea Level Rise scenarios

SLR Scenario	**Number of Parcels Impacted**			
	Kent	**New Castle**	**Sussex**	**Total**
1	179	48	174	401
2	379	80	279	738
3	494	302	369	1165
4	582	444	445	1471
5	635	565	481	1681
6	696	890	625	2211
7	759	1068	676	2503

In Scenario 1, Kent has 179 impacted parcels, New Castle has 48, and Sussex has 174, resulting in a grand total of 401 parcels. In Scenario 7, Kent has 759 impacted parcels, New Castle has 1068, and Sussex has 676, with a total of 2503 parcels.

4. Discussion

The spatial analysis conducted across various maps demonstrates a pronounced vulnerability of non-driving and low-income populations to peak summer temperatures, particularly in urban areas like Wilmington. This vulnerability is notably exacerbated in regions where reliance on public or non-motorized transport is high, aligning these areas with extreme heat exposure. The evidence suggests that these populations are disproportionately affected due to their greater physical exposure to heat when commuting and a lack of adequate infrastructure to mitigate these conditions. For instance, areas with high non-driving rates, such as downtown Wilmington, experience some of the highest summer temperatures recorded in the region, significantly impacting the daily lives and health of these communities (Harlan et al., 2006). The spatial confluence of high poverty rates, substantial minority populations, and elevated heat exposure further highlights the intersectional nature of climate vulnerability, necessitating multifaceted policy responses.

Moreover, the correlation between lower rates of driving and higher temperature exposure underscores the critical role urban planning and design play in shaping thermal environments. Urban areas with dense, impervious surfaces and limited greenery experience amplified heat effects, which disproportionately affect those without personal vehicles. These findings align with research indicating that the urban heat island effect is more pronounced in densely built environments, which often lack the natural landscape features necessary to moderate environmental temperatures (Stone, 2005).

4.1. Policy Recommendations

Considering these findings, it is imperative for policymakers and urban planners to prioritize the development of resilient urban environments that address the needs of the most vulnerable populations. Strategies should include:

1. Enhancing Green Infrastructure equally: Implementing urban greening projects such as parks, green roofs, and street trees can reduce surface and air temperatures. Additionally, these green spaces provide communal areas for relief during heatwaves, particularly in densely populated urban areas that lack sufficient private outdoor spaces.

2. Improving Public Transit and Pedestrian Infrastructure: Expanding and enhancing the accessibility and quality of public transit can reduce reliance on personal vehicles, thereby decreasing the urban heat island effect and improving air quality. Simultaneously, investing in pedestrian-friendly infrastructure, like shaded walkways and ample street crossings, can make non-driving commutes safer and more comfortable.

3. Targeted Cooling Interventions: Establishing cooling centers and public water features in strategic locations, particularly in neighborhoods identified as high-risk areas, can provide immediate relief during peak heat periods. These facilities should be easily accessible to those without personal transportation.

4. Building and Zoning Regulations: Updating building codes to encourage or mandate the use of reflective materials, proper insulation, and ventilation can help keep indoor environments cooler without excessive reliance on air conditioning. Similarly, zoning laws should encourage mixed-use developments that reduce the need for long commutes, thus limiting exposure to outdoor heat.

By implementing these policies, cities can not only improve living conditions but also enhance long-term resilience against the increasing frequency and intensity of heatwaves expected under climate change scenarios. These strategic interventions will foster equitable urban environments where all residents, regardless of socio-economic status or mobility, can thrive.

4.2. Conclusions

This study underscores the urgent need to adapt our urban transportation systems to the escalating challenge of rising temperatures, particularly in low-income communities that disproportionately rely on non-motorized and micro-mobility transportation options. The spatial analyses performed reveal a distinct overlap between socio-economic vulnerabilities and high heat exposure, necessitating targeted interventions to enhance urban resilience. Our comprehensive review of academic literature and case studies, as detailed in Section 3.1, has enriched our understanding of the multifaceted impacts of heat on urban transportation, providing a robust theoretical framework that supports our findings and recommendations. By integrating greener infrastructure, enhancing micro-mobility solutions, and implementing cooling strategies, we can significantly ameliorate the adverse effects of heat on urban transportation accessibility and safety. Moreover, the insights derived from this research not only contribute to a broader understanding of climate impacts on urban systems but also serve as a critical guide for policymakers and urban planners aiming to forge more sustainable and equitable urban environments in the face of global climate change. Thus, proactive adaptation strategies are essential to safeguard the mobility and health of the most vulnerable urban populations, ensuring that our cities remain livable and functional as temperatures continue to rise.

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