Minimizing heatwave risk through an equitable distribution of solar panels

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1. Introduction

Climate change will increase the frequency and severity of extreme heat events and, due to the Urban Heat Island (UHI) effect, urban centers are more susceptible to heat waves and heat stress [1, 2]. The Union of Concerned Scientists estimates that the number of days above 32 °C in the Midwest will increase five-fold by midcentury unless action is taken to reduce carbon emissions and slow climate change [2]. The lack of strong federal climate policies leaves individual states and institutions responsible for acting on climate change. This case study investigates the optimal distribution of rooftop solar panels that minimizes heat wave risk for the City of Chicago.

We chose Chicago as the focus of this work for two reasons. First, Chicago was the epicenter of a deadly heat wave in 1995; one of the deadliest heat waves in United States history. Over 700 people died in this heat wave [3]. Further, the death toll from this heat wave was exacerbated by a combination of social factors including income and isolation. As a result of this heat wave, Chicago officials recognized the need to prepare for future heat waves. This work proposes rooftop solar panels as a possible mitigation strategy. Second, the State of Illinois has programs such as Solar for All and Illinois Shines that aim to provide greater access to clean energy for low-income populations [4]. Thus, the resources to increase rooftop solar penetration already exist but lack guidance based on heat wave risk.

Illinois Solar for All and Illinois Shines are two programs strengthened by the 2021 Climate and Equitable Jobs Act (CEJA) [5]. These policies intend to expand the rooftop solar capacity in Illinois by providing incentives or subsidies for solar installation, with specific allocations for low-income communities. Rooftop solar panels help reduce the percentage of household income spent on energy costs, known as the energy burden, through net-metering policies that pay consumers for excess energy generation [6]. This reduction of energy burden improves resilience to heat waves by increasing access to air-conditioning for low-income households during high-demand times when electricity is most expensive. However, a high penetration of intermittent renewables, such as solar panels, increases price volatility and the energy burden for consumers without solar installations. This is called the "paradox of renewable energy policy" and highlights the need for efficient prioritization of at-risk areas [7]. Therefore, the purpose of this study is to identify areas with the highest heat wave risk so they may be prioritized by programs like Solar for All and Illinois Shines.

In order to identify high-priority areas, we curated economic and demographic data for Chicago, along with satellite data from the National Solar Radiation Database (NSRDB) published by the National Renewable Energy Laboratory (NREL). We perform hierarchical clustering on this data to identify regions of similar risk and suitability for solar panels. Section 3 discusses details of the data selection and processing, section 4 presents the results of the clustering algorithm, and section 5 develops a descriptive typology based on the clustered areas.

2. Literature Review

Various studies have addressed heat wave problem and distribution of solar panels separately till now. An assessment by means of Land Surface Temperature using remote sensing technology [8], the mapping of heat stress by crowdsourcing geospatial data and high spatial resolution data and evaluation of socioeconomic characteristics [9], quantifying synergies between Urban Heat Island effect and heatwaves in urban areas [10] are some of the studies addressing heatwave problem. While these studies mainly discuss about the spatial distribution of heat stress, others have also addressed its implications to the society by assessing socio-economic vulnerability and risk. One of the study [9] has developed sensitivity, adaptive capacity, vulnerability, exposure, and risk indicators and tested the framework on urban area concluding that vulnerability and risk levels differ with changing locational characteristics within the same urban area and hence the high resolution spatial dataset serves a great importance to plan necessary adaptation strategies. This study served as a foreground to choose the high resolution datasets in our study. Our study area is Chicago city which is an highly urbanized area with varying locational characteristics. We reviewed few studies related to Chicago heatwaves. The study by Bernice Ackerman has addressed the effect of Lake Michigan on temperature of its surrounding area and the effect of green cover. It was helpful in identifying the crucial indicators like green cover and presence of water bodies which help surrounding areas to stay relatively cooler and hence could serve as good adaptive capacity indicators.

Prior research has shown works that study the distributional disparities in residential rooftop solar potential in four major cities in Chicago and a few other cities [11]. The study found that the highest rooftop potential in Chicago was in census tracts with higher percentages of low and moderate income (LMI) households. The LMI households represented 51% of solar suitable households in Chicago. However, the lower penetration of solar LMI communities substantially decreases the overall attainment of renewable energy and energy equity goals in Chicago. DeepSolar, a machine learning framework that efficiently constructs a solar deployment dataset for the United States has found that the solar deployment density is strongly correlated and decreases with the Gini index, a measure of income inequality [12]. This points out how socio-economic inequality causes disparities in solar distribution. Most states across the United States have developed one or more policies to incentivize distributed solar PV investments. Many states have adopted various additional financial incentives to encourage and support the deployment of customer-owned distributed solar energy systems [13]. These policies and incentives are similar to Illinois Shine and Solar for All programs in Illinois which the current study focuses on. However, it has also been shown that the distribution of low-carbon technology subsidies and their associated benefits can be highly uneven across socioeconomic groups, revealing a persistent inequality issue. The high income community usually have the resources and knowledge required to avail the benefits of such subsidies and hence tend to be more benefited than their low income counterparts [14]. This escalates the need for equitable distribution of the solar incentives across different socioeconomic communities. Hence, this study aims to find the 'high risk' areas in Chicago and help facilitate equitable distribution of solar panels through the Illinois Shine and Solar for all programs.

3. Methods and Data

In this section we review the data we collected for the City of Chicago and the methods we used to cluster Chicago's census tracts into priority areas for solar panel distribution. We used the hazard-exposure-vulnerability framework asserted by the International Panel on Climate Change (IPCC) to categorize the datasets used in this work [15, 16].

3.1. Hazard

Hazards are the climate-related events the may lead to adverse outcomes for people, such as losses of life, function, property, infrastructure, and resources [15]. In this work, we focus on the risk of heat stress and the potential for heat-related deaths, for which temperature is the primary hazard. We gathered hourly temperature data for each community area in Chicago for the years 2000 to 2020 using the NSRDB [17]. In order to capture the temperature difference among Chicago's community areas during heatwaves, we set a temperature threshold of 32°C and filtered out the data below this threshold. We defined a heatwave temperature anomaly,

$$H_a = T_{ca} - T_{city}, \tag{1}$$

where T_{ca} is the temperature of the community area and T_{city} is the mean temperature of the city (i.e. the mean of all community areas), in celsius. We then took the mean of the hourly H_a to use in our clustering algorithm. Figure 3.1 shows the variations in temperature during heatwaves in Chicago.

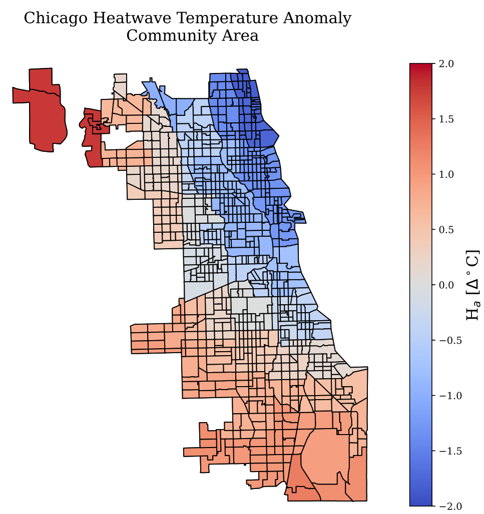

Figure 1. The temperature variations among community areas in Chicago during heatwaves. Higher values indicate warmer temperatures than the city mean temperature and lower values indicate cooler temperatures.

A positive H_a indicates regions that experience higher temperatures during heatwaves and a negative H_a indicates regions with lower heatwave temperatures, with respect to the citywide average temperature. The region near O'Hare International Airport experiences the highest temperatures, nearly 2°C above the citywide average. The temperature anomalies are further adjusted by subtracting the minimum temperature difference such that the coolest area of the city has an $\bar{H}_a$ value of zero and other values indicate the temperature above this minimum value. This is done to ensure good behavior from the clustering process.

3.2. Exposure

Exposure is the presence of people or important assets in places that could be adversely affected by climate hazards [15].

Table 1. Summary of curated data for the city of Chicago

Dataset	Risk Aspect Aspect	Spatial Resolution	Factor	Source
Temperature	Hazard	Community Area	Aggravating	[17]
Population density	Exposure	Census tract	Aggravating	[18]
Percent tree canopy	Vulnerability	Community area	Mitigating	[19]
Energy burden	Vulnerability	Census tract	Aggravating	[20]
Age	Vulnerability	Census Tract	Aggravating	[18]
Cooling centers	Vulnerability	Community Area	Mitigating	[18]
Social network	Vulnerability	Community Area	Mitigating	[18]
Crime rate	Vulnerability	Community Area	Aggravating	[18]
Percent qualified roof area	Vulnerability	Census Tract	Mitigating	[21]

3.3. Vulnerability

Vulnerabilities are the factors that predispose certain groups or areas to adverse outcomes. We consider several physical and social vulnerabilities. Studies that mapped heat stress and heatwave risk tend to focus on weather effects (hazards) alone [2, 8, 22, 23]. One study incorporated a hazard-exposure-vulnerability framework by treating land use and building purpose as proxies for exposure and vulnerability, along with population age [9]. Conversely, studies that map the disparities in solar panel distribution do so along a social axis, without climate differences.

3.3.1. Energy Burden Energy burden is the ratio of household energy costs to household income. We created a map of energy burden in Chicago using data from Climate and Energy Justice Screening Tool (CEJST) [20]. Energy burden affects access to electricity, especially during heatwaves when demand and cost of electricity are highest. Rooftop solar panels can reduce energy costs and therefore improve access to cooling during heatwaves. Figure 3.3.1 shows the distribution of energy burden throughout Chicago.

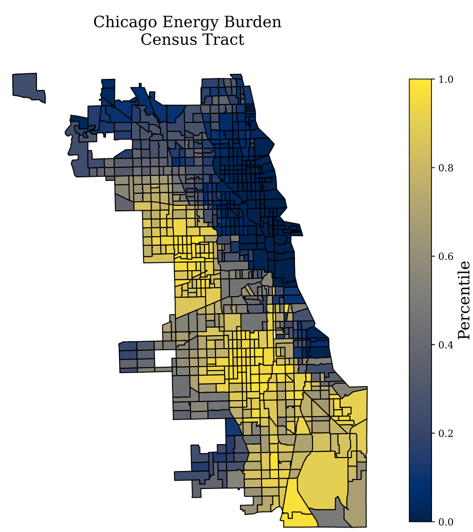

Figure 2. Energy burden throughout Chicago as a percentile. A region in the zeroth percentile has the least energy burden and a region in the 100th percentile has more energy burden than any other region.

3.3.2. Tree Canopy Urban tree cover effectively mitigate land surface temperatures in cities [24–26]. Tree canopy reduces temperature by preventing ground heat storage through shade and encouraging evapotranspiration [26]. Thus, areas with greater tree cover are less vulnerable heatwaves. Figure 3.3.2 shows the distribution of trees in Chicago from the Morton Arboretum Tree Census [19].

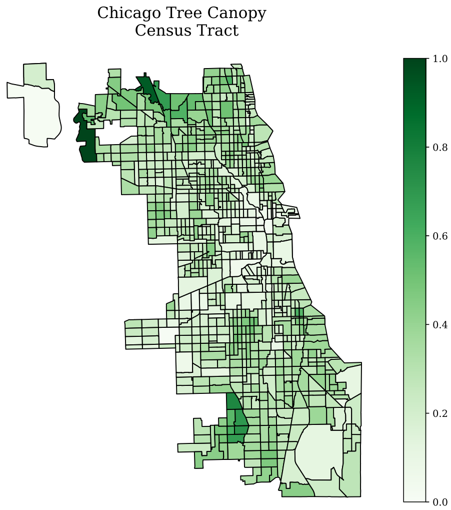

Figure 3. Distribution of trees in Chicago by percentile. A region in the zeroth percentile has the least tree canopy and a region in the 100th percentile has more tree cover than any other region.

4. Results

5. Discussion

6. Conclusion

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