Evaluating Access to Solar Energy in light of a Just Energy Transition

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Summary

Recent growth in residential solar PV systems in cities has largely contributed to decarbonizing our energy systems. However, the costs and benefits of this transition are not always equitably distributed. Socioeconomic variability has left disadvantaged social groups unable to access the benefits provided by solar PV systems and the stimulative policy measures associated to these systems. To enhance an equitable distribution of future solar PV resources, solar energy policy will need to be more considerate of its distributional impact. This research applies a socio-spatial perspective to understand and evaluate the differences in accessibility to solar PV systems for various social groups in the urban environment.

KEYWORDS: Solar PV, Accessibility, Inequality, Energy Justice, Energy Policy

1 Introduction

Activities in urban areas are estimated to represent 70% of global carbon emissions (IEA, 2021; Pörtner et al., 2022). As the energy system is the largest global contributor to carbon emissions (Ritchie et al., 2020), urban energy systems are at the heart of a successful energy transition (Rutherford and Coutard, 2014). One technology that is expected to play an essential role in the energy transition in urban areas is solar photovoltaics (PV) (Breyer et al., 2017; Sampaio and González, 2017). Global installed solar capacity has grown from 0.81 GW in 2000 to 843 GW in 2021 (BP, 2022). Although this growth has contributed tremendously to reducing carbon emissions, energy justice literature shows that the costs and benefits of the energy transition have not been equitably distributed across different social groups, resulting in unequal adoption of solar PV across cities (Sovacool et al., 2019).

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Inequitable adoption of solar PV can partially be attributed to the lack of access to solar PV systems of less advantaged social groups, thereby missing out on the opportunities to capitalize on the structural and economic benefits presented by solar PV energy (Carley and Konisky, 2020). *Accessibility*, in this context, refers to the freedom of individuals to decide whether or not to participate in different activities (Burns, 1979). Given the importance of solar PV in the energy transition (Breyer et al., 2017; Sampaio and González, 2017), it is essential to ensure an equitable distribution of solar systems to prevent social inequalities from growing larger and attain the societal support required for the energy transition to advance (Gambhir et al., 2018).

Most policy frameworks stimulating the adoption of solar PV systems among residential households have solely focused on increasing overall PV capacity (Brugger and Henry, 2019), thereby failing to address equity concerns. New solar energy policy, therefore, needs to include an equity perspective in the promotion of future solar PV technologies, to reduce inequalities in the distribution of costs and benefits of solar PV resources. This entails increasing the accessibility to solar PV systems among social groups that are currently sidelined due to their socioeconomic status. As many inequalities that exist in cities have a strong spatial nature (Nijman and Wei, 2020), the design of such policy calls for the spatial identification of these social groups (Bouzarovski and Simcock, 2017).

In this research, we bring a social-spatial perspective to evaluate equity in the adoption of residential solar PV, placing the concept of access to solar energy at the core of our research. In energy justice literature, access to energy has a strong equity component (Bouzarovski and Simcock, 2017; Carley and Konisky, 2020), while in technical studies the concept is used to represent physical factors related to access (such as roof area, presence of shade, etc.) (Lee et al., 2016; Lobaccaro et al., 2017). Building upon consumer behaviour theory, we develop a new concept of ”access to solar energy” that considers four key factors influencing the adoption of solar PV. Through spatial analysis, the concept of access is used to evaluate current policies with respect to equity in the adoption of solar PV. Additionally, we utilize this framework to evaluate how accessibility spatially intersects with the technical potential for PV systems. To demonstrate our approach, we selected the city of The Hague in the Netherlands as a suitable case study because of both policy context and data availability.

2 Methodology

2.1 Accessibility framework

To assess accessibility to solar energy across our case study, we introduce a framework based on the Theory of Planned Behaviour (Ajzen, 1991), which is rooted in social science, and expand it to suit the adoption of residential solar PV systems. This theory approaches the decision to adopt solar PV as a form of consumer behaviour based on three elements: attitude towards the behaviour, social norms, and behavioural control. We approach the element of behavioural control as the equivalent of accessibility, as both relate to the ability or capacity to participate in particular activities. Therefore, to assess the level of accessibility to residential solar PV systems, we identify factors that either limit or enhance one’s behavioural control, or in this research’s context, one’s ability to adopt solar PV systems. Identifying these barriers is realized by reviewing the literature on adopting residential PV systems.

2.2 Socio-spatial analysis

We identify four main factors that influence the element of behavioural control within the context of adopting residential solar PV systems: home-ownership, housing type, affordability, and access to suitable information. These factors are operationalized into measurable indicators based upon available data for each spatial unit (PC5 level)[1]. We perform a spatial clustering analysis to investigate spatial patterns of accessibility to solar PV across our case study. A k-means clustering algorithm is used to form groups where the statistical nature of population groups in spatial units is more similar to members of their own group than to members of any other group. On inspection of the groups, we assign each group a relative accessibility score ranging from 1 to 4, 1 meaning the lowest level of accessibility and 4 being the highest.

3 Results

3.1 Accessibility

Figure 1 illustrates that patterns of accessibility to residential solar PV systems show strong signs of spatial clustering. Analysis of cluster mean values, as presented in Table 1, reveals both clusters 1 and 2 having disadvantageous profiles regarding access to solar PV systems. These are the light and dark brown clusters in the geographical city centre. These clusters are characterized by low home values, a low percentage of home-ownership, and a high concentration of high-rise apartment buildings. Cluster 1 stands out in particular with a low percentage of native inhabitants. The two clusters located near the edges of the city, purple colored, demonstrate more favourable characteristics regarding the adoption of solar PV and thus are assumed to have better access. In these clusters, we observe higher average home values, the highest share of native inhabitants, high levels of owner-occupied homes and low shares of apartment buildings.

Table 1: Mean values of accessibility indicators per cluster.

Indicator	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
Home value (€)	169 000	237 000	339 000	640 000
% with native background	21.8%	58.5%	60.9%	62.7%
% of owner-occupied homes	28.9%	46.1%	63.9%	73.5%
% of apartment buildings	63.8%	77.5%	24.7%	25.9%
Number of solar panels per capita	0.06	0.08	0.22	0.37
% of residential buildings with solar PV	3.78%	3.94%	10.71%	9.99%

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[1] PC5 level is the penultimate most detailed postal code level in Dutch spatial administrative data, containing 5 out of 6 possible digits.

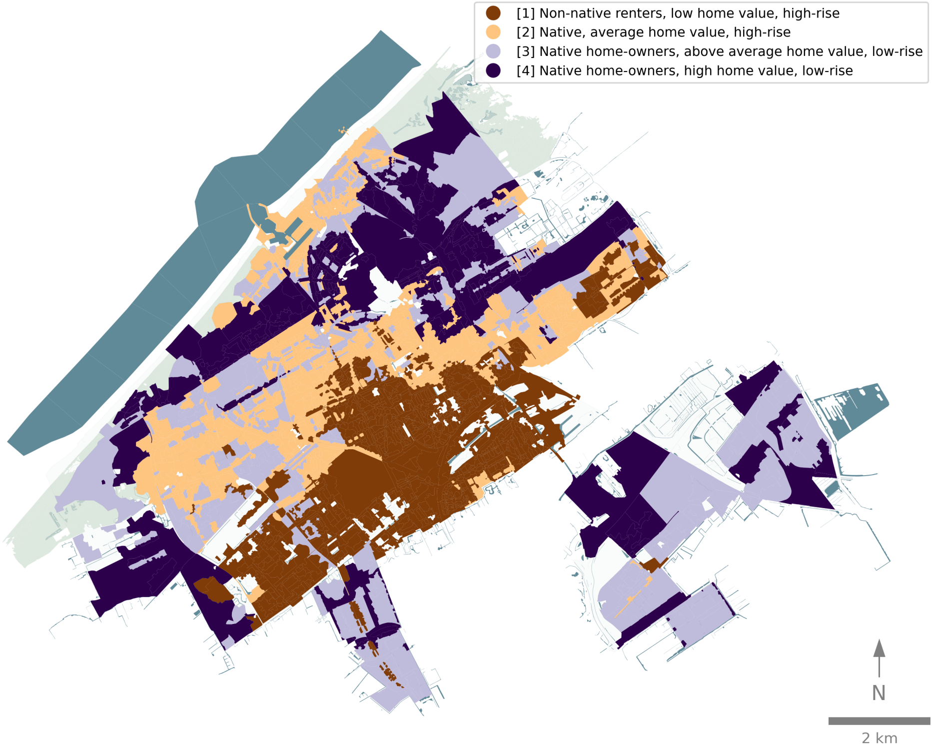

Figure 1: Spatial representation of the accessibility distribution across four clusters for the city of The Hague.

By analysis of current solar PV adoption levels across the different clusters (see Table 1 and Figure 2), we observe significantly lower levels of PV adoption in the clusters where accessibility is low, while levels of adoption are much higher in clusters where access to solar PV is assumed to be higher. We observe low levels of solar panels per capita, and adoption rates of solar PV systems among residential buildings in clusters 1 and 2. Whereas adoption levels in clusters 3 and 4 are significantly higher. This same pattern is displayed in Figure 2, by the presence of red colored areas in the city centre (low accessibility, low adoption), as opposed to blue colored areas along the city edges (high accessibility, high adoption).

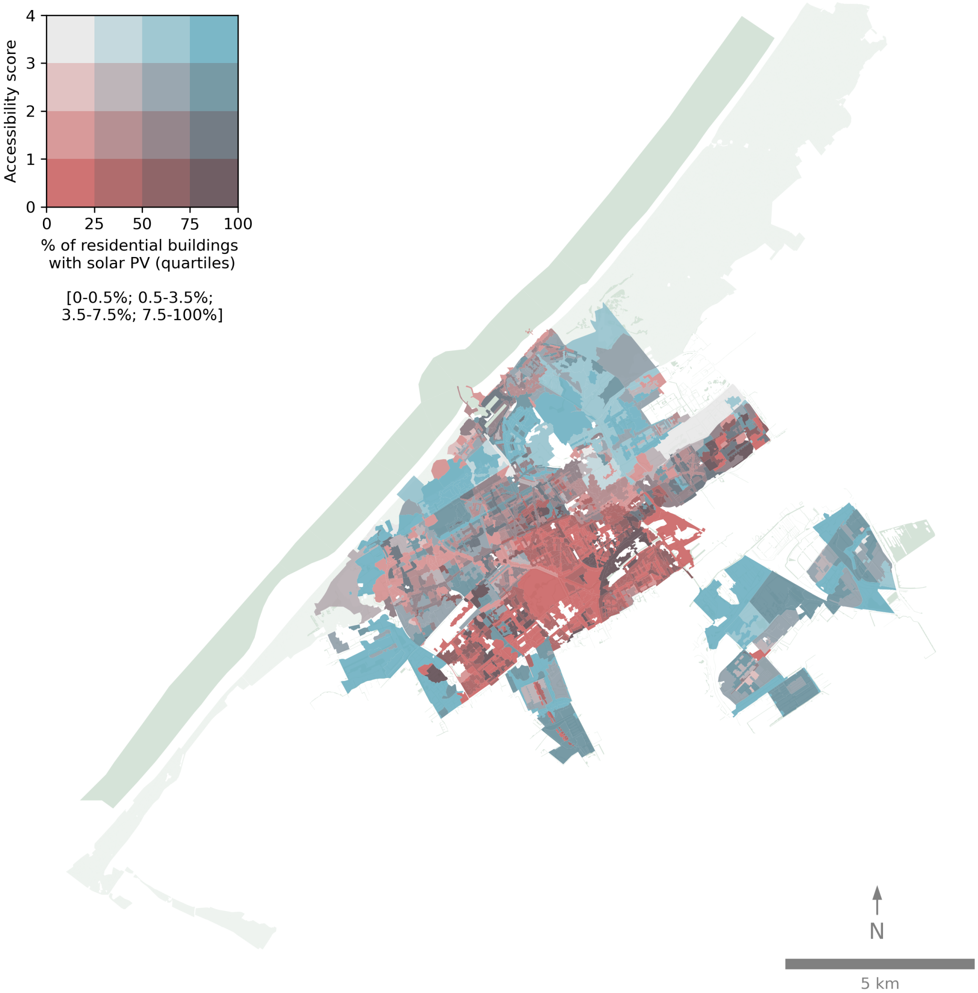

Figure 2: Spatial representation of the intersection of accessibility with adoption of residential solar PV systems across the city of The Hague. Each color shade is representative of two variables as displayed in the legend on the top left.

3.2 Accessibility versus technical potential

Figure 3 depicts the spatial distribution of the concentration of rooftop technical PV potential across the city of The Hague. It can be observed that areas with relatively high concentrations of technical potential tend to be situated in the geographical city centre where accessibility to solar PV is low, while lower concentrations of technical PV potential are encountered around the city's edges, where accessibility is higher. This is confirmed by Table 2, showing that over 58% of technical potential is situated in clusters 1 and 2. In contrast, only 41.5% is located in clusters 3 and 4. These results suggest that most technical PV potential in The Hague is located in areas where households have difficulty exploiting it.

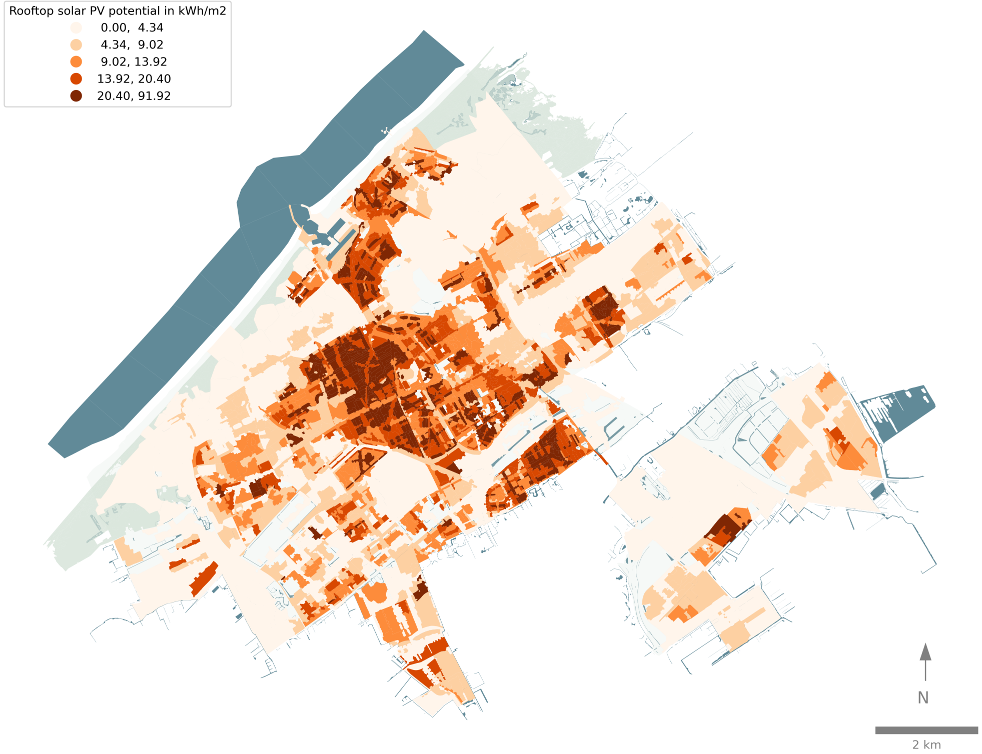

Figure 3: Distribution of technical rooftop solar PV potential per unit area (quantiles). (kWh/m2)

Table 2: Share of technical PV potential versus share of solar panels and share of population.

Indicator	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
Percentage of technical PV potential	30.4%	28.1%	25.3%	16.2%
Percentage of population	37.7%	27.9%	25.4%	9.2%
Percentage of solar panels	16.2%	16.5%	43.4%	23.9%

4 Discussion and conclusion

Despite the potential of solar PV to contribute to the urban energy transition, the lack of attention to equity concerns in policy efforts to stimulate the uptake of solar PV has reinforced social inequalities within cities. The inaccessibility to solar PV systems among certain social groups has left these groups unable to access the benefits provided by solar PV systems and the stimulative policy measures associated to these systems. This research employs a socio-spatial perspective on equity in solar PV systems and provides a reproducible framework to evaluate accessibility for other urban areas. For our case study of The Hague in the Netherlands, our findings confirm the unequal distribution of solar PV across social groups. We find that a significant part of the technical PV potential available in The Hague (58.5%) is located in areas characterized by poor access to solar PV, which indicates the presence of large amounts of untapped potential in socioeconomically less advantaged areas. In contrast to socioeconomically more advantaged groups, disadvantaged groups have been underserved by stimulative policy measures, which is troublesome and unjust in times of rising energy prices. This trend has to be reversed to prevent social inequalities from locking in. Further, these findings open up a discussion for policymaking approaches to stimulate community-based adoption of solar PV in spatially dominant clusters of inaccessibility, accelerating the transition.

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Biographies

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Juliana Goncalves is an Assistant Professor at the TU Delft Faculty of Architecture & the Built Environment and the Centre for Urban Science and Policy (CUSP). Her research seeks to understand the socio-spatial dimension of the urban environment to support integrated decision-making in cities.

Trivik Verma is an Assistant Professor at Delft University of Technology. His research focuses on tackling challenges of urbanisation in an equitable and just manner. Specifically, using methods in spatial data science, complex network analyses and participatory mapping to develop computational tools for advancing theories and practices of urban science.