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Powered by gentrification: The uneven development of residential rooftop solar in Atlanta, Georgia

Carys Behnke *, Taylor Shelton

Department of Geosciences, Georgia State University, 730 Langdale Hall, Atlanta, GA, 30303, United States of America

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ABSTRACT

Rooftop solar is widely seen to be a crucial piece of the puzzle for addressing both greenhouse gas emissions and reducing household energy burdens. However, studies from across the United States have consistently pointed to inequalities in the adoption of rooftop solar that limit its ability to address these overlapping problems. This paper examines these social and spatial inequalities in rooftop solar adoption in Atlanta, Georgia, using a novel dataset of residential rooftop solar installation permits from 2018 through 2022. Through this analysis, we demonstrate that while more affluent and white neighborhoods are home to the majority of residential rooftop solar installations within the city, the most significant growth in rooftop solar in recent years has been in majority poor and majority Black neighborhoods. But by combining these records with an analysis of property-level characteristics and transaction histories, we are able to show how the installation of rooftop solar, especially in those same neighborhoods, is not, in fact, being driven by a narrowing of racial inequalities in rooftop solar adoption or a greater concern for energy justice. Instead, as gentrification unfolds in previously marginalized neighborhoods, these newcomers become the vanguard of rooftop solar adoption rather than the longstanding residents who would have the most to gain from such technologies. This paper ultimately clarifies the distinction between the *spatial* redistribution and *social* redistribution of renewable energy, and the need for both finer-grained analyses of inequalities in clean energy access and adoption and a greater commitment towards both energy and housing justice.

1. Introduction

Residential energy consumption is one of the United States' primary contributors to greenhouse gas emissions, estimated at approximately 20 % of nationwide emissions [1]. For more than 30 million American households who struggle to afford energy, many of them people of color, the costs of this energy consumption also represent a significant drain on their finances, further reinforcing the persistent racial and class inequalities seen across various domains [2]. With the dual imperatives of addressing climate change and eliminating massive economic inequality, energy systems represent one of many possible points of intervention. In particular, some have pointed to the potential for residential rooftop solar to help transition household energy consumption towards clean and renewable sources while also reducing long term costs and decreasing reliance on for-profit utility companies [3].

Within roughly the last decade, residential rooftop solar generating capacity has increased nearly fifty-fold nationwide, from just 625 MW of generating capacity at the end of 2010 to over 29,000 MW at the close of 2022 [4]. Even still, this represents an incredibly small share of the 1432 terawatts of power that *could* be generated from rooftop solar across the nation, enough to account for close to 40 % of American electricity consumption as of a decade ago [5]. Though this percentage is expected to decrease as more activities shift to electricity from other energy sources, rooftop solar alone cannot come close to generating the full scale of energy needed to maintain current standards of living across the country. Regardless, it is true that rooftop solar represents a crucial piece of the decarbonization and energy justice puzzles. The full potential of residential rooftop solar remains hampered, however, by persistent racial and class inequalities that limit adoption among low-income and minoritized populations. It is these material inequalities – rather than differing attitudes about the potential value of rooftop solar among diverse populations [6] – that drive such unequal adoption, as these investments are difficult, if not impossible, without significant public subsidy for low- and moderate-income households [7–11].

These issues are especially acute in Atlanta, Georgia, the 8th largest metropolitan area in the US and its most extreme example of income

* Corresponding author.
E-mail address: behnkecarys@gmail.com (C. Behnke).

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inequality [12]. Perhaps unsurprisingly, the Atlanta metro also ranks fourth nationally for median energy burden [13], with 28 % of households, or nearly 600,000 total, considered to have a high energy burden, which is defined as instances where household energy expenditures exceed 6 % of the total household income [2]. These aggregate totals belie the concentration of their effects, with predominantly Black neighborhoods on the City of Atlanta's west and south sides having average energy burdens twice as high as the city as a whole [14]. But at present, the adoption of rooftop solar as a potential solution to these issues has lagged within Atlanta and across the state of Georgia.

Georgia currently represents the 7th largest state-level solar producer across the country with over 5000 MW of installed capacity [4], equivalent to 3.2 % of the total solar generation in the US. The state is even home to the largest solar panel manufacturing plant in the western hemisphere [15]. But of its considerable solar generating capacity, only 7.8 % comes from rooftop systems, less than 1 % of the country's overall rooftop solar output [16]. This lack of rooftop generating capacity is not for a lack of potential, however, as Google's Project Sunroof has estimated that 76 % of Georgia's total rooftop space has the potential for viable solar [17] Despite this immense technical potential for rooftop solar, Brown et al. [16] estimate a 92 % gap between the technical and achievable potential for rooftop solar across the entire state of Georgia, which exists in large part because of unfavorable government and utility policies around rooftop solar.

In 2019, the Georgia Public Service Commission enacted a solar net metering program with support from the state's monopoly utility Georgia Power. The program was colloquially given the name "solar cap," as participation was limited to either the first 5000 customers or 32 MW of production capacity, whichever came first. After a period of immense growth in rooftop solar installations seeking to take advantage of the net metering program – including the Solarize Atlanta program meant to reduce costs of installation through bulk purchasing – the participant cap was reached in July 2021, and Georgia Power stopped accepting applications for the program, thereby eliminating one of the most significant financial incentives for installing residential rooftop solar. The PSC declined to renew the program during their 2022 rate hearings [18]. And, as is discussed below, other initiatives aimed at expanding rooftop solar adoption, especially among low- and moderate-income households, have not been taken up in Georgia, further limiting the possibilities for residential rooftop solar. But at the same time that Georgia Power and the Public Service Commission have sought to limit the financial benefits of rooftop solar installation for consumers, the City of Atlanta has sought to frame itself as a climate leader, in the same year adopting the target of 100 % clean energy by 2035 [19]. Since then, the city has made minimal tangible progress on these goals and witnessed its climate plans achieve the ignominious ranking as one of the five least detailed U.S. city climate action plans due to its inconsistent goals and inadequate plans for execution [20]. But if the city has any hope of achieving its stated goal, addressing its relative lack of rooftop solar generating capacity and the inequalities in its distribution is a crucial hurdle with significant implications for addressing housing and energy injustice.

Using data on residential rooftop solar installation permits in Atlanta from 2018 through 2022, this paper provides a spatial and temporal analysis of the distribution of rooftop solar within the city in relation to neighborhood demographics and processes of urban change. Through this analysis, we demonstrate that more affluent and white neighborhoods are home to the majority of residential rooftop solar installations within the city, despite being a minority of the city's population. That being said, the total number of residential rooftop solar installations has grown rapidly in recent years, increasing from just 56 in 2017 to 539 at the close of 2022. Amid these changes, installations in majority Black neighborhoods have also grown rapidly, surging from only 16 % of all installation permits through the end of 2020 to 56 % of all permits issued in 2021 and 2022.

But by also including property-level characteristics and transaction histories in our analysis, we are able to show how the installation of rooftop solar, especially in majority poor and majority Black communities, is not, in fact, being driven by a narrowing of racial inequalities in rooftop solar adoption or a greater concern for energy justice. Instead, as gentrification unfolds in previously marginalized neighborhoods, these newcomers become the vanguard of rooftop solar adoption rather than the longstanding residents who would have the most to gain from such technologies. This paper ultimately clarifies the distinction between *spatial* redistribution and *social* redistribution, and the need for both finer-grained analyses of inequalities in clean energy access and adoption and a greater commitment towards both energy and housing justice. Ultimately, this research provides additional, fine-grained evidence of the continued racial and class inequalities in residential rooftop solar adoption, while also linking these inequalities with specific processes of urban neighborhood change. It also demonstrates the need for more research into the intersecting urban social and environmental processes that help drive the expansion of residential rooftop solar in some places, albeit at the expense of longstanding residents who are unlikely to reap the benefits of clean energy or improved housing conditions within their neighborhoods.

2. Literature review

In approaching the subject of inequalities in rooftop solar adoption across Atlanta, our research draws inspiration from work in both energy justice broadly and energy geographies in particular. While the subsections below focus on two more narrow portions of the literature, it is important to note that our approach is shaped by a desire to quantify and ultimately eliminate injustices in our contemporary energy system, "includ[ing] energy availability and access, affordability, due process, accountability and transparency, and both inter- and intra-generational equity" ([21]: p. 570). And while these inequalities are most pronounced along the usual axes of race and class, as the literature cited below shows, it is important to recognize the multi-dimensional and intersectional inequalities that produce energy injustice in general, and the inequalities that both shape and result from rooftop solar adoption in particular [22].

At the same time, we are interested in the geography of rooftop solar adoption and the way that these energy injustices are manifest in the urban landscape and built environment. Following the work of other geographers interested in producing a framework by which to "map the geographies of a low-carbon energy system and so guide choices among different potential energy futures" ([23]: p. 331, [24–27]), we focus on these spatial patterns, processes and relationships because they are fundamental to the current and future structure of our energy system [28]. Though our actual research focuses on a more literal interpretation of energy geographies through a geospatial analysis and mapping of rooftop solar installations, we also seek to show through this mapping how such patterns are mutually constitutive of broader processes of urban social and spatial change.

In the remainder of this section, we highlight work in two distinct literatures that provide insight into this research and its broader significance. First, we review work in an energy justice vein that documents the social and spatial dynamics of rooftop solar adoption. This growing body of work has focused on understanding the current scope of rooftop solar adoption and inequalities therein, especially those inflected with broader racial and class inequalities. Such efforts provide a crucial frame to understand how Atlanta either mirrors national dynamics or represents a novel case for understanding the interplay of different factors in shaping rooftop solar adoption. Second, prefiguring our key arguments later in the paper, we review the literature on (green) gentrification and the role of environmental sustainability in promoting and justifying urban redevelopment and displacement. While most of the work on green gentrification has focused on the role of public green space in fueling gentrification, a small subset of related work has begun to look at cases more similar to the one we are focused on in Atlanta, with an emphasis on energy systems and infrastructural improvements to the built environment.

2.1. Social and spatial dynamics of rooftop solar adoption

Residential rooftop solar is widely understood as a compelling solution to climate change and decarbonization because of its distributed nature. Unlike utility-scale solar, which is both land-intensive and often controlled by the same large corporations that own existing fossil fuel infrastructures [29,30], rooftop solar is both socially and spatially diffuse. While this theoretically provides significant benefits to those who adopt – such as the ability to generate one's own power and decrease both energy bills and general reliance on an increasingly unstable electric grid – the reality is that adoption of residential rooftop solar remains remarkably constrained and concentrated.

Despite the fact that "there exists no comprehensive, annual or geographically explicit data collection efforts that enable scholars, practitioners and policymakers to understand exactly who suffers from these inequalities, to what degree and where they are located" ([21]: p. 572–573), a number of partial efforts provide a reasonably consistent picture. By and large, income/wealth and housing tenure have been singled out by scholars as the most crucial determinants of residential rooftop solar adoption. Given the significant expense often associated with installing rooftop solar – which depending on financial incentives and state-level regulations on net-metering may or may not pay itself back over a relatively lengthy time – it is generally only the affluent who are able to invest in rooftop solar systems. In 2021, homes equipped with rooftop solar across the United States had a median household income of $113,000, or nearly double the nationwide median of $64,000 [31]. Meanwhile, of those households who have installed rooftop solar, only 14 % have annual incomes less than $50,000 [31]. Meanwhile, programs designed to address this wealth economic disparity in rooftop solar adoption, such as solar leasing and community solar, have not been available in Georgia, which has only served to further widen this gap.

The expansion of rooftop solar installation is further constrained by housing tenure, with the vast majority of residential rooftop solar installed on owner-occupied properties. This pattern is visible in Atlanta, where nearly 96 % of homes with rooftop solar are owner-occupied. Apart from the general correlation between income/wealth and homeownership – and the fact people of color have historically been denied the full benefits of homeownership [32,33] – homeowners tend to be much more likely to install rooftop solar through government incentives and tax credits, which are tied to property ownership. Because of the so-called 'split incentive problem', non-occupant landlords have little reason other than their own altruistic environmentalism to install solar panels for tenants, as the benefits would only accrue to those tenants and not the landlord themselves [34]. In a city such as Atlanta, where 55 % of the population are renters, this fact represents an important limitation on future adoption of rooftop solar, especially in terms of ensuring that its benefits are experienced equally, if not weighted towards those who experience the most significant energy burdens and need for clean energy.

But even when controlling for socio-economic status and housing tenure, racial inequalities in rooftop solar remain consistent [7,35,36]. While racial inequalities for all major racial or ethnic groups exist relative to whites, these adoption gaps are most pronounced for Black people and neighborhoods [11]. In arguably the leading study documenting these racial inequalities, Sunter et al. [7] show that 47 % of majority Black census tracts nationwide had no existing rooftop solar installations whatsoever, a figure more than twice as large for any other racial or ethnic group. And, it is important to note, these inequalities don't exist due to the lack of rooftop solar *potential*, as in many cases across the country, the highest potential solar generating capacity exists in lower income and minoritized communities [9,36].

Many studies investigating inequalities in rooftop solar adoption have been limited by the spatial and temporal granularity of the data they use. These studies examine inequalities by looking primarily at census tract-level demographics, simply assigning the characteristics of a particular census tract to a given solar installation, and investigating correlations between variables, which raises the problem of the ecological fallacy. Relatively less common is the study of intra-urban inequalities in solar adoption that takes into account changes within these neighborhoods and the built and social environments of the city [9,10]. Similarly, while Lukanov and Krieger [37] provide a temporally-expansive 20-year analysis of rooftop solar adoption in California, it is one of few studies that examine the evolution of these adoption patterns over time, but in the process forgoing detailed analysis of some of the subtle changes occurring at the neighborhood scale. They demonstrate that even as rooftop solar adoption has increased in lower socio-economic communities in recent years, it has picked up even faster in the wealthier communities where solar was already extensive, showing that the socio-economic and spatial disparities documented by the studies above have actually grown even wider as time has progressed [37].

2.2. Green gentrification and urban-environmental change

Though it is by no means the only – or even primary – way that urban neighborhoods are changing today, gentrification is arguably the most discussed and debated. But one key insight from the last decade and a half of gentrification scholarship is that gentrification isn't just a restructuring of urban social and spatial relations in the built environment, but also a reshaping of relationships with the natural environment [38,39]. As a result, scholars have defined and documented myriad forms of a more environmentally-inflected gentrification process, whether defined as ecological [40], green [41–43], climate [44,45], or (low-) carbon [46,47].

But as Bouzarovski et al. [46] argue, the literature on environmental gentrification tends to be dominated by cases focused on the provision of parks, greenspaces, and other environmental amenities. Indeed, from Dooling's [40] initial formulation of ecological gentrification through an analysis of homeless people displaced by park expansion in Seattle up through the various cases analyzed by Anguelovski et al. [42], these kinds of conventionally 'green' forms of gentrification have tended to take center-stage. Whether because of their visibility as medium to large-scale changes to the landscape or their relatively straightforwardness as state-led projects or something else entirely, this focus has, in turn, led to the neglect of the often smaller-scale, piecemeal "changes to the structural fabric of the residential stock" ([46]: p. 846).

This gap exists in spite of the fact that, as Luke and Heynen [48] state plainly, "Housing is especially important to discussions of energy" (p. 614). Not only do the geographies of household energy production and use reflect larger structural forces, but they also reinforce them and create new avenues for change. While Luke and Huber [49] argue that the adoption of new technologies like rooftop solar help to transform the subjectivities of individuals and households by "extending the logics of accumulation into everyday moments of social reproduction" (p. 1702), it is also important to recognize how these changes are reconfiguring the character of entire neighborhoods and communities.

In their attempt to rectify this gap, Bouzarovski et al. [46] describe processes of 'low-carbon gentrification', whereby the upgrading of material infrastructures of energy provision and efficiency within the built environment leads to, if not also providing discursive cover for pre-existing state-led plans for, the displacement of residents. While the processes they describe differ in numerous ways from those we describe in the case of rooftop solar adoption in Atlanta, the two contexts share in the ways that environmental sustainability initiatives serve not to benefit existing populations who have historically withstood a range of social and environmental injustices but rather are accrued by wealthier newcomers as part of gentrification. Of particular note is how these processes entail a scale-crossing maneuver that justifies the neighborhood or city-scale social transformations and resulting inequality by pointing to the larger-scale benefits of such sustainability efforts.

But, as Rice et al. [47] argue, the result of these processes of gentrification may not actually be environmentally beneficial after all. In fact, even with the adoption of clean energy or energy efficiency technologies and the greater accessibility to transit or other low-carbon transportation typically associated with dense urban living, gentrification could very well produce a net increase in carbon emissions. The combination of the persistent high-consumption lifestyles of the wealthy, regardless of where they live, alongside the displacement of low-income residents to suburban peripheries where their carbon footprints are likely to expand, means that the search for sustainable urban lifestyles by the affluent may actually yield a net negative not only in terms of social equity but also on the terms of environmental sustainability alone. In considering the intertwining of gentrification with the decarbonization of residential buildings as we do in the remainder of this paper, it is therefore necessary to recognize that "there is no climate justice without a clear and central focus on housing justice" ([47]: p. 160).

3. Data and methodology

In order to examine the uneven geographies of residential rooftop solar in Atlanta, we draw on a novel dataset of solar installation permits from the City of Atlanta, covering the time period from January 2018 through December 2022. Accessed via the city's online permitting portal,[1] the data included information on the date of permit approval, permit status, address of installation, the name of the applicant, and descriptions of the PV system types. Dates and addresses were the primary data points taken from this source, though names on the permits were used to cross reference for address and ownership accuracy. In particular, the presence of address-level geographies allows us to overcome what Lukanov and Krieger [37] note as one of the major challenges of creating comparable studies of solar PV adoption: geospatial data granularity. After cleaning and filtering the data for duplicates or miscategorized commercial installations, our dataset includes a total of 539 different residential rooftop solar installation permits from January 2018 through December 2022.

While the temporal extent of this data leaves out some early rooftop solar adopters within the city, there is no systematic way of capturing permits prior to this time period. Tidwell et al.'s [50] SolarView dataset – the only extant dataset that predates this time period, which was built from the now-defunct Open PV project from the National Renewable Energy Laboratory (NREL) and the similarly out-of-date Solar Map of Georgia from the Southface Institute – contains a number of inaccuracies and installations that could not be confirmed, and so were left out of this analysis. It should be noted, however, that of those data points in the SolarView data that could be confirmed, their spatial distribution tends to reinforce and confirm the spatial dynamics described later in the paper, with these early adopters being substantially more concentrated in whiter and wealthier parts of the city.

In addition to the solar installation permits, we also used neighborhood-level demographic information taken from the US Census Bureau's American Community Survey (ACS) 2015–2019 5-year estimates. Despite not being the most up-to-date ACS product available, we opted for this vintage due to systemic accuracy issues introduced by the 2020 Census [51]. In addition, we used decennial census data from both 2000 and 2010 to calculate change over time in certain demographic variables.

However, our paper's major methodological contribution is using the address-level information from the solar installation permits and linking it to property-level data from the Fulton and DeKalb County Tax Assessors' offices. Using the listed addresses for these installation permits, we then cross-referenced each property to determine a variety of characteristics for the properties in question: present and historical ownership and appraised values (for both land and improvements), owner or renter-occupancy, sales histories, and dates of construction. To identify whether units were owner or renter-occupied, we cross-referenced the address of the solar installation with the listed owner address in the tax assessor records. Where these two addresses matched, we identified the property as owner-occupied; if not, it was marked as renter-occupied. Data on property transactions, as well as changes in appraised values, allow us to make inferences about changes to the properties, such as flips, rebuilds, or other upgrades. Changes in property value are especially useful as they can represent a much more timely indicator of early-stage gentrification processes than Census demographics [52].

4. Analysis and results

In the remainder of this section, we provide the results of our multi-part analysis of rooftop solar in Atlanta and its uneven development. In the first subsection, we document the general spatial patterns in the data and the neighborhoods with the highest rooftop solar concentrations In the following subsection, we introduce temporality into our analysis. In doing so, we can see the rapid growth of rooftop solar in Atlanta in the last couple of years and how this time period has corresponded with a significant change in the geography and spatial distribution of rooftop solar installations. In the final two subsections, we link these changes to ongoing processes of gentrification and neighborhood change across Atlanta. While the penultimate subsection analyzes changes in neighborhood-level demographics across the city, the final subsection drills down to a handful of case study neighborhoods and properties representative of these larger changes seen across the city.

4.1. General spatial patterns

With a total of 539 solar installations as of early 2022, Atlanta has one of the lowest solar adoption rates of any major U.S. city, failing to make the list of the top 50 cities nationwide by either total or per capita solar generating capacity [53]. However, the city's rooftop solar market has grown substantially over the past five years, going from just 56 residential installations in 2017 to at least 539 by the close of 2022, an increase of over 860 % in the past five years. The distribution of rooftop solar across the city is considerably uneven, collecting in eastside neighborhoods like Kirkwood, Lake Claire, Morningside-Lenox Park, Virginia-Highland, and Ansley Park (see Table 1 and Fig. 1). These are predominantly affluent and white areas often referred to as Atlanta's 'intown' neighborhoods, a colloquial signifier of their ostensible progressiveness relative to the more reactionary white suburbs that were produced in response to desegregation in the mid-20th century [54,55].

In many respects, the geography of Atlanta's residential rooftop solar follows patterns seen nationwide, with whiter and more affluent neighborhoods disproportionately being home to the majority of rooftop solar generating capacity. Similar to nationwide trends of higher income households maintaining the highest rates of solar [8], higher income tracts are overrepresented in rooftop solar adoption. Over 58 % of the homes with rooftop solar in Atlanta are in census tracts with median household incomes greater than the citywide median, even though these tracts are home to just 44 % of the city's housing units. For those neighborhoods with a median household income more than double the citywide median, they represent 16.5 % of the rooftop solar installations and just 12 % of the total housing units. Meanwhile, roughly 17 % of the city's total rooftop solar is in census tracts where most residents make less than 50 % of the city's median household income, or less than $32,000, despite these tracts being home to one-third of the city's total housing stock.

While having extraneous income clearly opens additional

[1] The online permitting portal can be accessed from: https://aca-prod.accela.com/ATLANTA_GA/Cap/CapHome.aspx?module=Building&TabName=Building.

Table 1
Top neighborhoods by total number of residential rooftop solar installations, along with neighborhood demographic information (via the Atlanta Regional Commission).[a]

Rank	Neighborhood	Total # of Rooftop Solar Installations	% Black Population (Change 2010–2021)	% Poverty (Change 2010–2021)	Median Household Income (Change 2010–2021)
1	Kirkwood	33	26.2 % (−27 %)	9.1 % (−5.8 %)	$97,567 (+$46,586)
2	Morningside-Lenox Park	25	4.9 % (no change)	6.2 % (+1.7 %)	$127,788 (+$24,832)
3	Lake Claire	23	8.9 % (−2 %)	6.9 % (no change)	$161,783 (+$58,529)
4	Virginia-Highland	19	5.1 % (−1.2 %)	7.7 % (−2 %)	$97,380 (+$28,019)
5	Grant Park	16	31.6 % (−6.2 %)	10.7 % (−3.9 %)	$95,867 (+$27,038)
6	Ormewood Park	14	15.5 % (−22.6 %)	8 % (−18.3 %)	$125,214 (+$57,967)
7	East Atlanta	13	37.8 % (−16.8 %)	16 % (−5.5 %)	$74,063 (+$34,538)
8	Old Fourth Ward	13	37.9 % (−9.9 %)	22.6 % (−8.2 %)	$73,443 (+$31,399)
9-T	Pittsburgh	10	75.2 % (−17.3 %)	24.8 % (−23.6 %)	$39,353 (+$21,237)
9-T	Ansley Park	10	7.1 % (−3.4 %)	5.6 % (−2.5 %)	$122,070 (+$32,810)
9-T	Midwest Cascade	10	97 % (+2.7 %)	16.7 % (+2.3 %)	$67,230 (+$14,416)

[a] While the total number of rooftop solar installations is aggregated to the city-defined neighborhoods, data on demographics comes from the Atlanta Regional Commission's Neighborhood Statistical Area (NSA) definitions, which occasionally vary slightly from the city's official neighborhoods. In most instances this difference is extremely minimal, with the exception of the Pittsburgh neighborhood, whose NSA is grouped together with the adjacent Adair Park neighborhood. Adair Park is generally somewhat whiter and wealthier than Pittsburgh, and therefore the actual numbers for Pittsburgh are likely higher for the share of Black population and poverty rate, and lower for median household income.

possibilities for purchasing solar, these income discrepancies are made more important in the Atlanta context because of the lack of proactive policies for increasing adoption. In addition to those policies mentioned previously that are not implemented in Georgia, such as solar leasing and community solar, similarly, there is no solar rebate available in the state of Georgia, nor is there any opportunity left for new customers to participate in Georgia Power's net metering program. While there is currently a 30 % federal tax credit available through the Inflation Reduction Act of 2022, this still leaves thousands of dollars in upfront costs with slow payoffs that a majority of households can't afford, ultimately hampering continued growth.

4.2. *Solar's changing geographies*

As stated above, the market for rooftop solar has grown exponentially in recent history, though this has been especially concentrated in the last two years. From 2018 through 2020, the city saw 151 residential rooftop solar installations. That number was exceeded in both 2021 and 2022, which saw a total of 215 and 173 new installations, respectively, leading to the 539 total installations in our dataset (see Fig. 2). But these aggregate numbers showing the massive growth in Atlanta's rooftop solar market disguise changes in the spatial pattern of where these installations are taking place. Since the second quarter of 2021, a majority of the new rooftop solar permits have been in the west and south sides of Atlanta, in contrast with the spatial patterns of earlier adopters noted above. In an incredibly segregated and unequal city such as Atlanta, this spatial shift has also been a demographic and socio-economic shift.

Regarding the racial composition of the neighborhoods with solar permits, 55 % of all permits in our dataset are within majority white census tracts. But prior to 2021, that number was 84 %, with only 20 permits located in majority Black neighborhoods, and another five in plurality Black tracts. Of the 388 solar permits added in 2021 and 2022, 56 % were in majority or plurality Black neighborhoods (see Fig. 3). Many of these installations are located in historically Black neighborhoods such as Pittsburgh, Mozley Park, and Rockdale, all with 90 % + Black populations. These proportions are almost exactly mirrored in socio-economic data, partly because of the historically tight linkage between race and class, but especially in a place like Atlanta.

This sudden change in trend represents a distinct difference from national trends of significantly lower adoption rates among Black and lower income households, though it does generally accord with Gao and Zhou's [11] more recent finding that the gap between Black and white *neighborhoods* appears to be narrowing. On its face, this seems to suggest that through a spatial redistribution of rooftop solar into the city's predominantly Black neighborhoods Atlanta may be making progress in closing the racial gap in residential rooftop solar adoption and evening the solar-generating playing field. It is important, however, that such analysis not rely on aggregated figures that fail to consider the relationship between individual property and its larger neighborhood and urban context. That is, just because a majority Black neighborhood is installing solar at a quicker rate doesn't mean that it is necessarily Black *people* who are doing it. So, in addition to adding the temporal changes in neighborhood context into the equation, because the data on solar installations made available through the City of Atlanta's permitting portal have address-level locations attached to them, we can combine this data with parcel data from local tax assessors' offices to gain a better understanding of the context of residential rooftop solar. This tax assessor data helps us understand the housing context in which rooftop solar is adopted, and how rooftop solar reflects and/or contributes to housing market changes within the city. In effect, it helps us to disentangle the reality of spatial redistribution from the question of social redistribution.

4.3. *Changing neighborhoods*

As of the end of 2022, 224 out of the 539 homes with solar in Atlanta are in census tracts making less than the citywide median household income of roughly $64,000, over 40 % of which are in tracts that earn less than half of that amount. While the median value of these homes is nearly $200,000 less than the citywide median and might be interpreted as part of the broader shift in the racial and class makeup of rooftop solar adopters across the city, drilling down into the sales histories of these

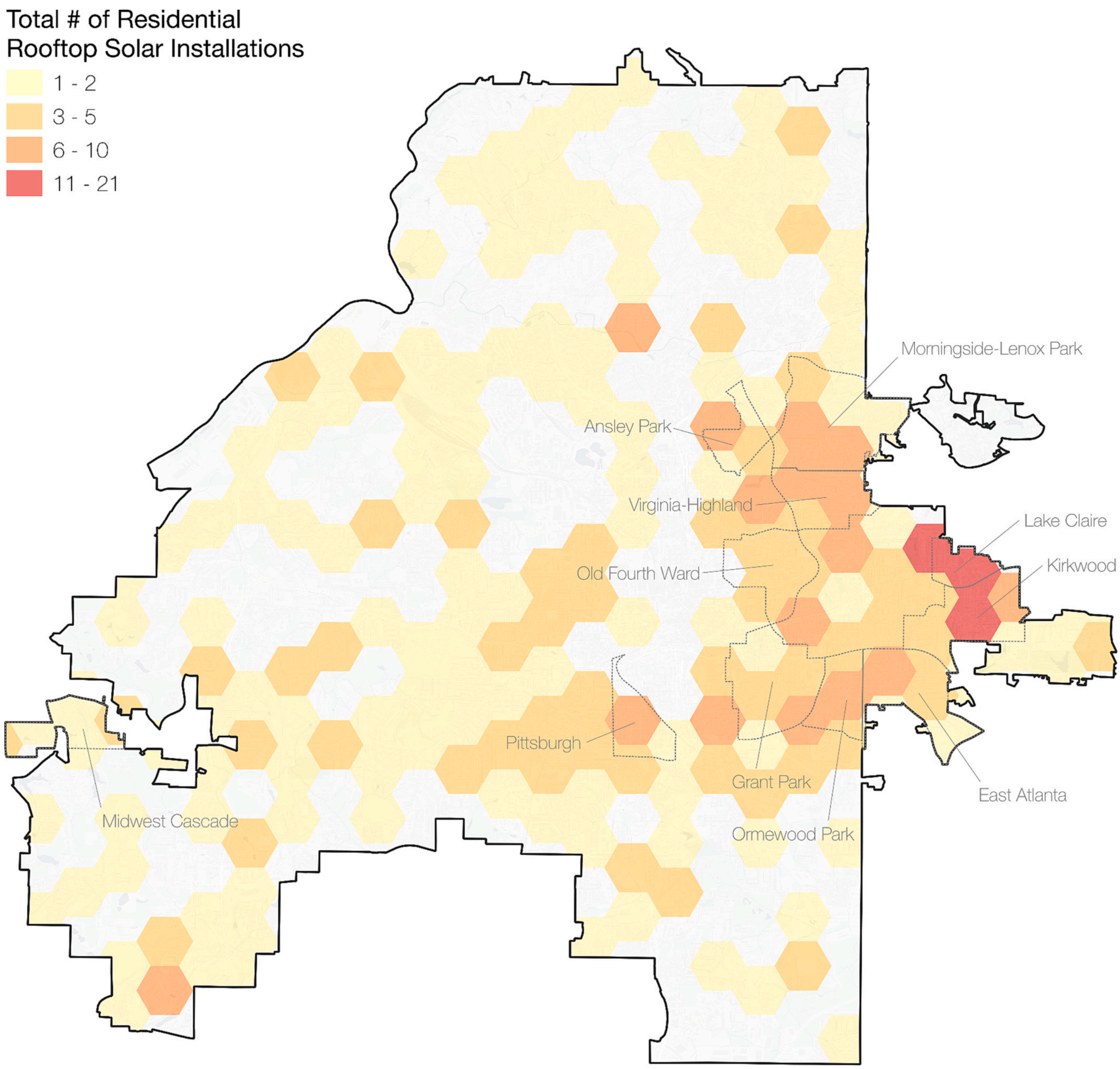

Fig. 1. Spatial distribution of residential rooftop solar installations across the City of Atlanta.

homes helps us to understand the social dynamics at the property level. Doing so reveals that in the last 15 years, 65 % of the homes in these middle to lower-income tracts have sold for less than $50,000, many of which sold for less than $25,000. But these same properties have also experienced an average appreciation in appraised value of 800 % over the same time period, with median appreciation being an only slightly more modest 460 %.

So despite appearing as though the median value of homes with solar has decreased drastically because of the much higher value in majority white neighborhoods, these trends have run parallel with a sharp and sudden increase in home values and sale prices for those homes in lower-income areas, suggesting that these properties and the neighborhoods in which they are situated are being swept up in the City of Atlanta's rapidly accelerating process of gentrification. This gentrification is partly driven by a bevy of properties foreclosed on during the Great Recession and subsequently flipped by real estate speculators, but also by increasing in-migration of more affluent residents from the coasts. As a result, the city of Atlanta's median household income has recently surpassed that of its surrounding suburbs for the first time in decades, as the suburbs have increasingly become the home of poor and working-class people of color who were priced out of the city rather than the affluent bastions of white supremacy that we've typically associated them with [56].

In sequence with this, the racial composition of Atlanta has also changed rapidly as home prices and cost of living continue to increase, alongside both the movement and pushing out of Black residents to the suburbs. This has resulted in Atlanta changing from a Black majority city to a plurality Black city. According to the *Atlanta Journal-Constitution*, Atlanta's population has grown by over 70,000 people in the last decade, of which 50 % of new residents were white and just 9 % were Black [57]. A number of neighborhoods across the city have seen drastic changes in racial composition over the past ten years, leaving some historically Black neighborhoods with a white majority or no racial majority. Of the 539 homes with rooftop solar, 188 (or 35 %) are in

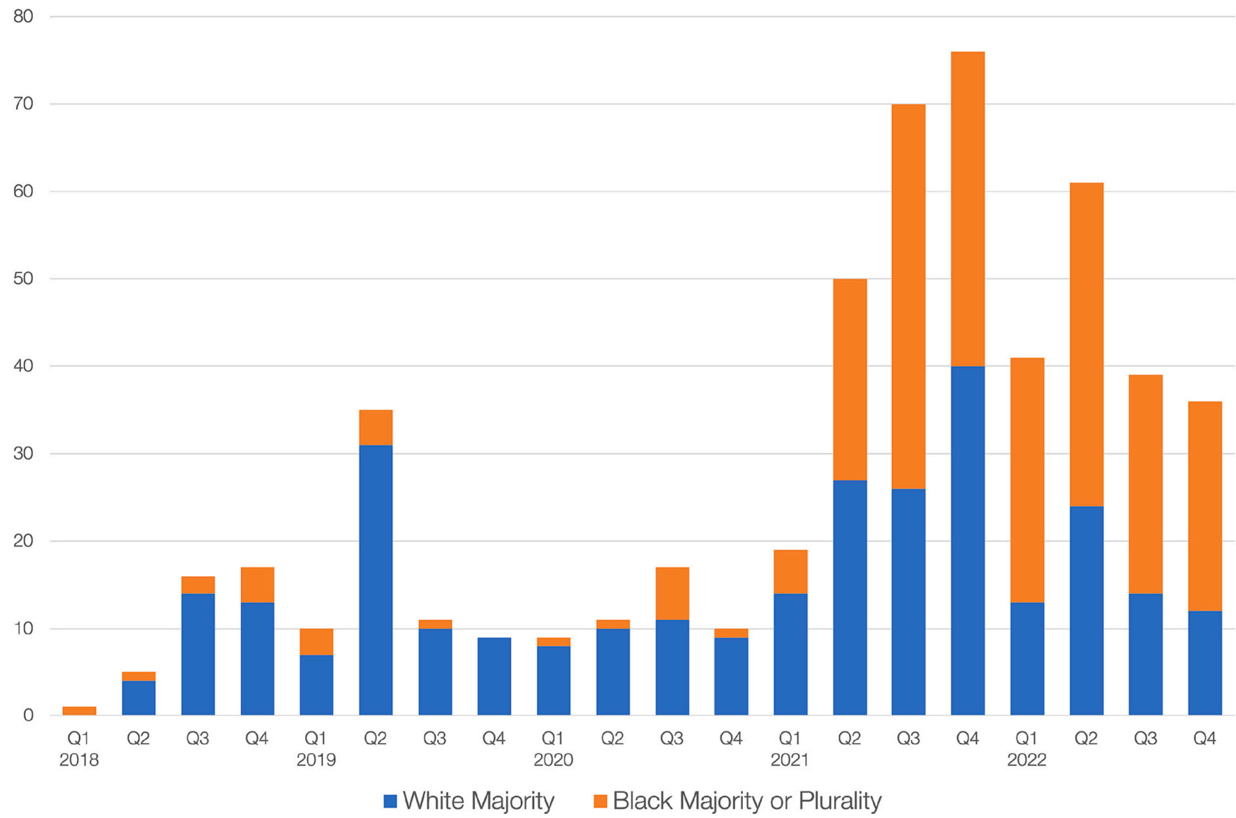

Fig. 2. Number of rooftop solar permits over time categorized by neighborhood racial composition.

census tracts that have lost more than 10 % of their Black population since 2000. The eastside of Atlanta – including neighborhoods such as Old Fourth Ward, Reynoldstown, Edgewood, Kirkwood, and East Atlanta – has seen some of the highest rates of racial change *and* the greatest number of rooftop solar installations.

But even in neighborhoods where racial transition hasn't occurred, rooftop solar is strongly associated with either ongoing or potential gentrification pressures. Of the 243 homes in the majority or plurality Black tracts, all but 35 are classified as already undergoing or being under threat of gentrification (see Fig. 4), according to the displacement typology developed by the Urban Displacement Project at UC-Berkeley [58]. This figure is so startling in part because so much of the City of Atlanta falls within these categories due to the widespread and almost totalizing nature of gentrification within the city limits. 81 % of Atlanta's census tracts have seen an increase in median household income between 2010 and 2019, with 53 % seeing increases greater than $10,000 and 22.5 % more than $25,000. These tracts hold 84 % of the city's rooftop solar, or 455 of the 539 homes in our dataset. These changes are especially pronounced in many of the previously majority Black neighborhoods that have seen recent jumps in home value alongside an increasingly white population, with median household incomes rising between $30,000 and $50,000 in the past ten years. These changes in socio-economic status have been consistent even in some of the tracts with stable Black majorities, as the city's reputation as a home for the Black middle and upper class has attracted newcomers who have dramatically different class positions than their longstanding neighbors.

These changes suggest that rather than solar power becoming increasingly accessible to low-income residents in historically Black neighborhoods, the only thing changing is these neighborhoods' racial and class composition. So rather than longtime residents of these neighborhoods being served by this transition, Atlanta's changing demographics mean that the clean energy transition in Atlanta is one afforded to an increasingly wealthy and white population. Using neighborhood and property-level case studies, the following section further reinforces how the adoption of rooftop solar across historically Black neighborhoods in Atlanta isn't being driven by longstanding residents but rather by newcomers who are frequently benefitting from, if not outright enabling, larger speculative real estate markets to develop in these once marginalized neighborhoods.

4.4. Neighborhood and property case studies

Old Fourth Ward is a historically Black neighborhood in central Atlanta, just east of downtown and the central business district. Once the center of Atlanta's Black middle and upper-class, the birthplace of Martin Luther King, Jr., and a landmark for civil rights activism, Old Fourth Ward has been the site of considerable racial and social restructuring in the last two decades. Thanks in large part to the emergence of Atlanta's Eastside Beltline trail and the gentrification that came with it [59,60], Old Fourth Ward has lost approximately half of its Black population since 2000, with its share of white population roughly tripling to the point that the neighborhood is now majority white [61]. This racial transition was also pushed along by hundreds of foreclosures in the aftermath of the 2008 recession, pushing out massive numbers of residents in the following years. While these properties were then bought at low prices, the median sales price of homes in this area has since increased by $200,000 to $500,000, depending on which part of the neighborhood one is looking at.

Old Fourth Ward has also been a notable site of residential rooftop solar installation within Atlanta. A total of 13 homes within the neighborhood have installed solar, with six of these installations coming in the last two years of our data from 2021 to 2022. The fact that a majority of the neighborhood's solar was already installed by the end of 2020 points to the advanced state of gentrification within the neighborhood, for which the presence of rooftop solar serves as one additional indicator. Of

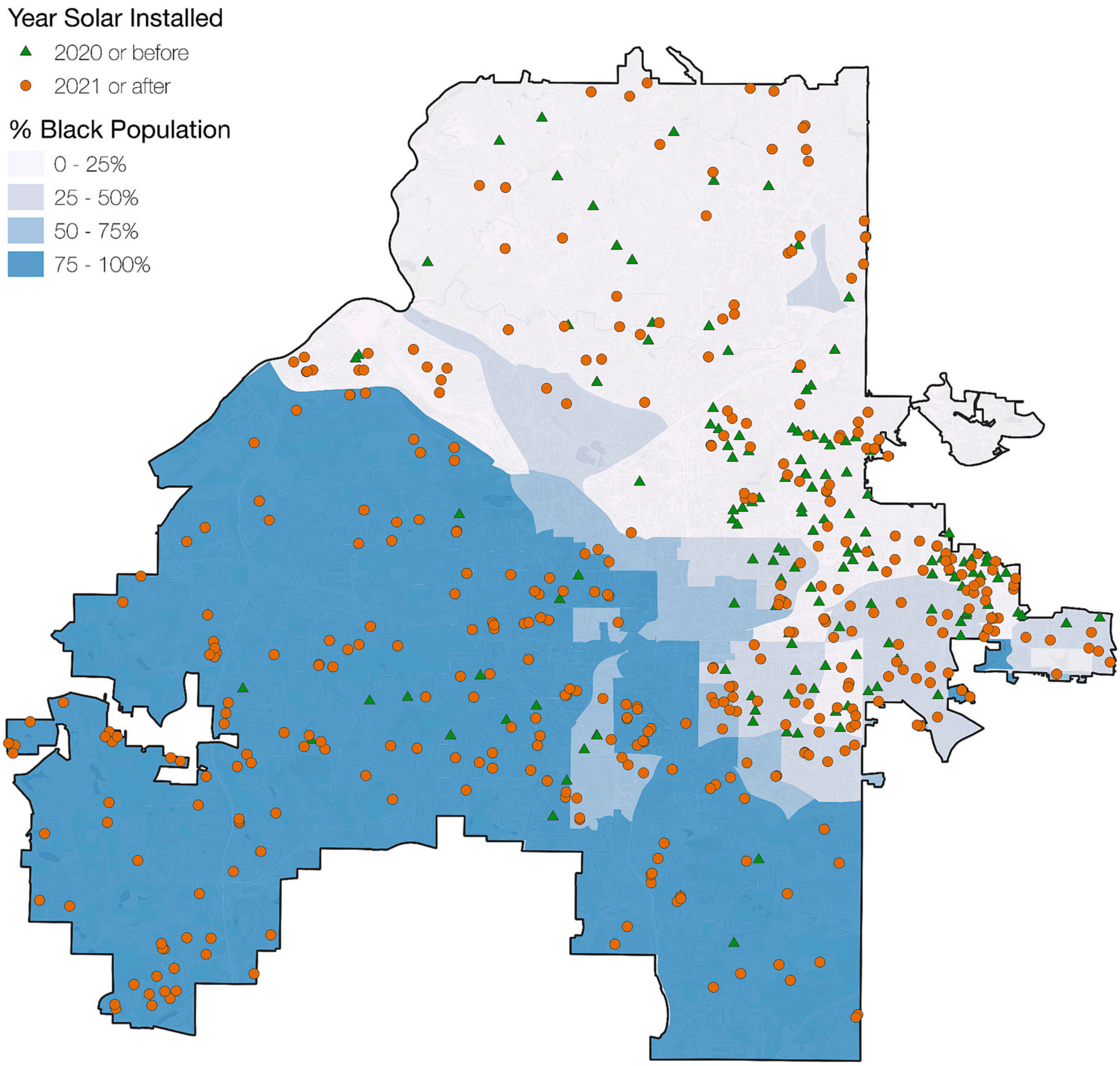

Fig. 3. Distribution of rooftop solar permits over time relative to share of Black population.

these 13 homes, the average value is over $700,000, with only three of the homes valued under $500,000 and two being valued over $1,000,000, prices that were practically unheard of in the city, much less the neighborhood, until the last decade.

But perhaps even more than their significantly inflated value, the connection between rooftop solar and gentrification is driven home by the sales histories of each of these 13 properties. Of these 13, all but two have been sold since the Great Recession in 2008, with some turning over multiple times. This turnover in residents generally indicates that the homeowners responsible for installing solar on their rooftops are not longstanding residents but rather relative (or, in some cases, very recent) newcomers. One of these homes, located at 670 Willoughby Way NE, is a 2200 square foot single family residence in a modernist style, newly built in 2016 on a previously vacant lot purchased for $200,000 the year prior. Purchased for $765,000 by its current owners, who were among the first residents in the area to install rooftop solar back in 2018, the property is now valued at $997,500.

Another notable example of how rooftop solar is imbricated with broader neighborhood changes lies a couple of miles further to the east in the city's Kirkwood neighborhood. Kirkwood is an area that saw massive white flight in the 1960s and 70s, leading to the neighborhood having a Black majority for several decades [55]. But along with other neighborhoods like Old Fourth Ward facing the pressures of gentrification, Kirkwood has now had a reversal in this trend, losing 27 % of its Black population over the last decade. Today, Kirkwood has more residential rooftop solar installed than any of the other 240-plus neighborhoods across the city, with 33 total installations. Most of these are occupied by white homeowners who have installed solar just in the most recent 2021–2022 period. But again, this concentration of rooftop solar in a once-Black neighborhood comes at a cost of those residents who were displaced, whether they were homeowners who were foreclosed on in the wake of the Great Recession or renters who felt the more general pain of rising costs as whiter and more affluent residents moved in.

Alternatively, on the other side of the city, the historically Black Pittsburgh neighborhood southwest of downtown has gone from having no rooftop solar at the end of 2020 to having 10 installations as of the end of 2022, tying it for the lead among majority Black neighborhoods. Unlike the homes in Old Fourth Ward, the properties with solar in Pittsburgh have an average value of just $288,000. And while the change in the values of homes is not nearly as steep, in some cases, they

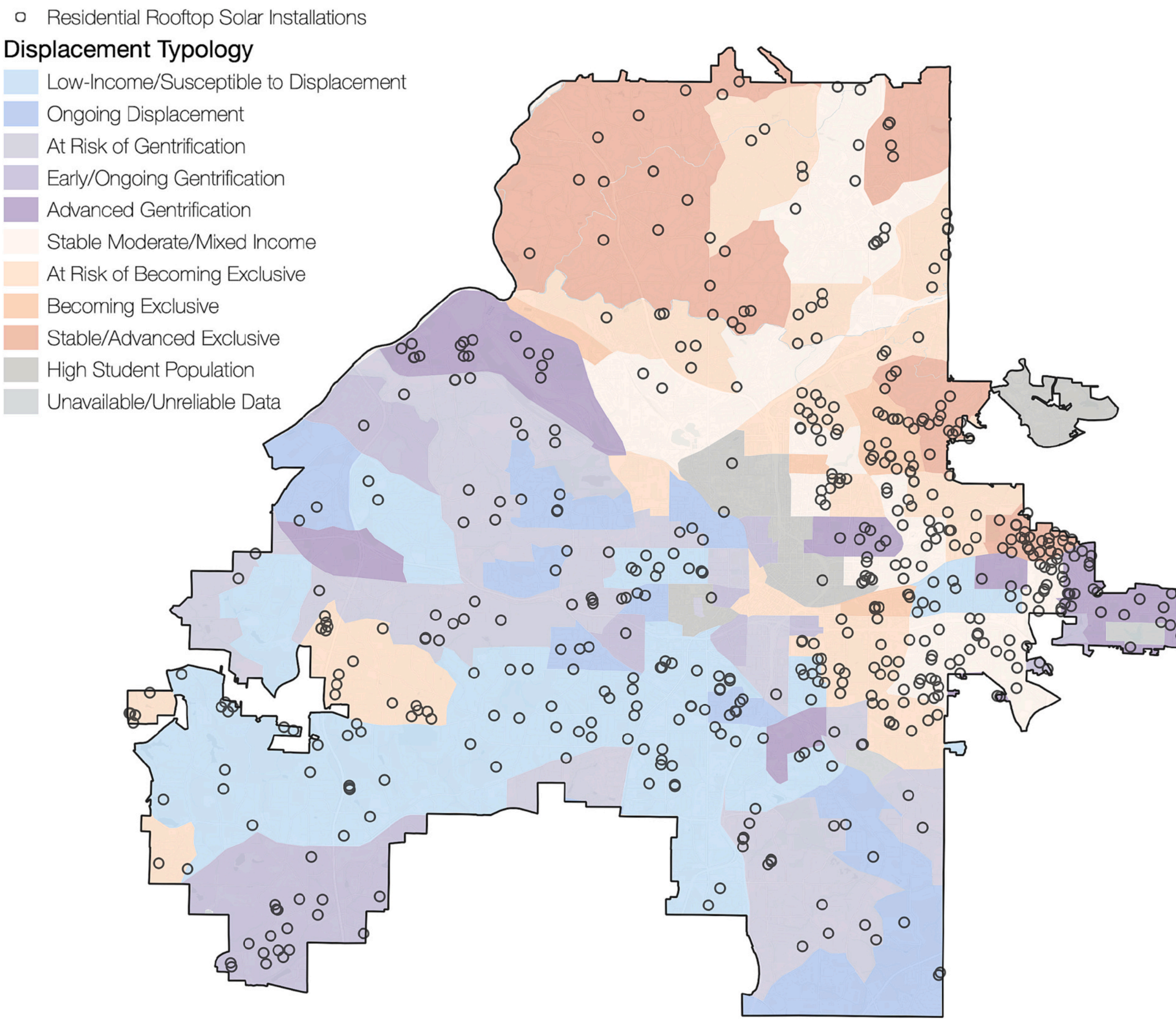

Fig. 4. Distribution of rooftop solar permits relative to neighborhood displacement typology.

represent order of magnitude increases. As one writer for the *Atlanta Journal-Constitution* noted, Pittsburgh saw its average home value fall from $85,000 in 2006 to just $13,000 in 2012 as a result of the financial crisis and Great Recession, which set the stage for the frenzy of speculative activity that's characterized the neighborhood as a whole, but especially those properties that have installed rooftop solar in recent years [62]. Despite being in the earlier stages of gentrification, these properties – and the neighborhood writ-large – have been no stranger to speculative real estate activity. Of the 10 homes with solar in Pittsburgh, every single one has been owned by a bank and/or corporation in the recent past *and* has experienced a foreclosure. All but one of these properties have turned over in the last five years, during which our data on solar installations was collected, again pointing to the fact that it isn't longstanding residents in these majority Black spaces who are making the move to adopt clean energy.

Taking a closer look at two representative examples helps to illuminate these pathways by which distressed properties have been treated like speculative assets before being targeted for upgrading and gentrification (see Fig. 5). The modest 1500 square foot, three-bedroom home at 967 Welch Street SW was sold 'on contract' and repossessed three different times between 2000 and 2003 before being foreclosed on in both 2006 and again in 2007. In 2010, the property went into the City of Atlanta's land bank, where it sat untouched for several years before being transferred to the Annie E. Casey Foundation, a national charitable foundation that has focused on community development in a handful of southside Atlanta neighborhoods. In 2017, the Annie E. Casey Foundation sold the home for less than $23,000 to a young Black professional as part of their homeownership and community development programs, who then went on to make improvements to the house, including installing solar panels. This case is instructive because even as the property was ultimately transferred out of the cycle of speculation that marks its history for most of the last 20 years, it is still contributing to the overall gentrification of Pittsburgh, with its appraised value now reaching $275,000. All in all, the house at 967 Welch Street SW had a total of 15 different owners from 1997 to 2017, with half of these being non-individual owners.

Another notable example is the four-bedroom, three-bathroom house at 1076 Ira Street SW. After being owned by the same individual for over 20 years, the house sold for $160,000 in May 2005 before being foreclosed on by Lasalle Bank less than two years later. After bouncing between different LLC owners for a couple of years, the house similarly ended up in the city's land bank in 2009, where it sat for a decade before being transferred to APF Properties LLC in 2019 and then sold in August 2021 to an individual, with the home now being appraised at over $400,000. However, APF Properties LLC is not a typical real estate LLC but a subsidiary of the Atlanta Police Foundation. This property is one of several in the Pittsburgh neighborhood that have been bought and sold by the APF in recent years as part of a deliberate strategy to increase police presence in historically disinvested Black neighborhoods by subsidizing police officers to buy homes in these areas [63,64].

Fig. 5. Visual comparison of properties in the Pittsburgh neighborhood before and after gentrification (images via Google Street View).

The intended effect of this APF program is to enable the further gentrification of Pittsburgh and other neighborhoods, both by participating directly in the real estate market as well as creating ostensibly safer neighborhoods that are more welcoming to investment and wealthier, whiter newcomers. Even when entities like APF or the Annie E. Casey Foundation are not themselves flipping homes or speculating in order to extract profits, their interventions in the housing market can still contribute to ongoing gentrification processes. Similarly, even if newcomers to the neighborhood purchase a home and make the investment to install rooftop solar independent of the desire for increased property values, that is nonetheless the likely result. These actions impact not only the value of the property itself but also the values of the surrounding properties, which can introduce additional financial pressures for nearby legacy homeowners, renters, and even mom-and-pop landlords via increased property taxes and rents, especially in the absence of any protective measures, which are almost entirely absent in the Atlanta context.

At the same time as the roll out of rooftop solar in Atlanta's historically Black neighborhoods has been dependent upon gentrification and displacement of existing residents, wealthier and whiter neighborhoods, like Virginia-Highland and Morningside/Lenox Park in the city's northeast quadrant, have been able to grow their rooftop solar generation without the same kinds of housing market volatility. A total of 43 homes across these two neighborhoods have rooftop solar installations as of the end of 2022, only seven of which have sold in the last five years. Of the 43 properties, over half have not changed hands in the last decade, with 13 having had the same owner for at least the last 15 years, with a handful dating back to the 1980s. But of the 38 with available data on ownership history, only five have had corporate or bank ownership at some point in the last two decades. At the scale of the city, of the 243 homes with solar in majority or plurality Black neighborhoods, 129 (or 53 %) have been owned by a bank (indicating foreclosure), a corporation, or a mixture of the two at some point in the home's recent history. Meanwhile, only 33 % of the 297 properties in majority white neighborhoods have been owned by a bank and/or corporation, indicating a greater degree of homeownership and stability over time but, most importantly, a pronounced lack of speculative activity (see Fig. 6).[2]

That being said, a comparable share of properties with rooftop solar between majority white and majority or plurality Black neighborhoods have been sold in the last ten years, which provides a rough approximation of the influence of newcomers on rooftop solar adoption. Of the 231 properties in majority or plurality Black neighborhoods with identifiable sales histories in our dataset, a total of 154 (or 66 %) have sold in the last ten years, as compared to 176 properties out of 290 with identifiable sales histories in majority white neighborhoods, or 60 %. However, the gap between the two is somewhat larger when looking at only the last five years of sales from the start of 2018 through the end of 2022. 42 % of homes with rooftop solar in majority or plurality Black neighborhoods are owned by newcomers within these last five years, while only 29 % of properties in majority white neighborhoods are. Despite these mostly similar figures across demographically different neighborhoods, the most important factor to consider in differentiating them is that newcomers into majority white neighborhoods have not represented significant changes to the racial or class character of these parts of Atlanta in the same way that newcomers to neighborhoods like

[2] Of the 99 properties in majority white neighborhoods with a previous bank and/or LLC owner, 47 of these are located in just six gentrified or gentrifying eastside neighborhoods that have only become predominantly white in recent years: East Atlanta, Edgewood, Kirkwood, Old Fourth Ward, Ormewood Park and Reynoldstown. The concentration of previously bank and/or LLC-owned properties in such gentrifying neighborhoods highlights precisely the role of these forms of property speculation in helping to facilitate the racial and class transition of previously Black and low-income neighborhoods.

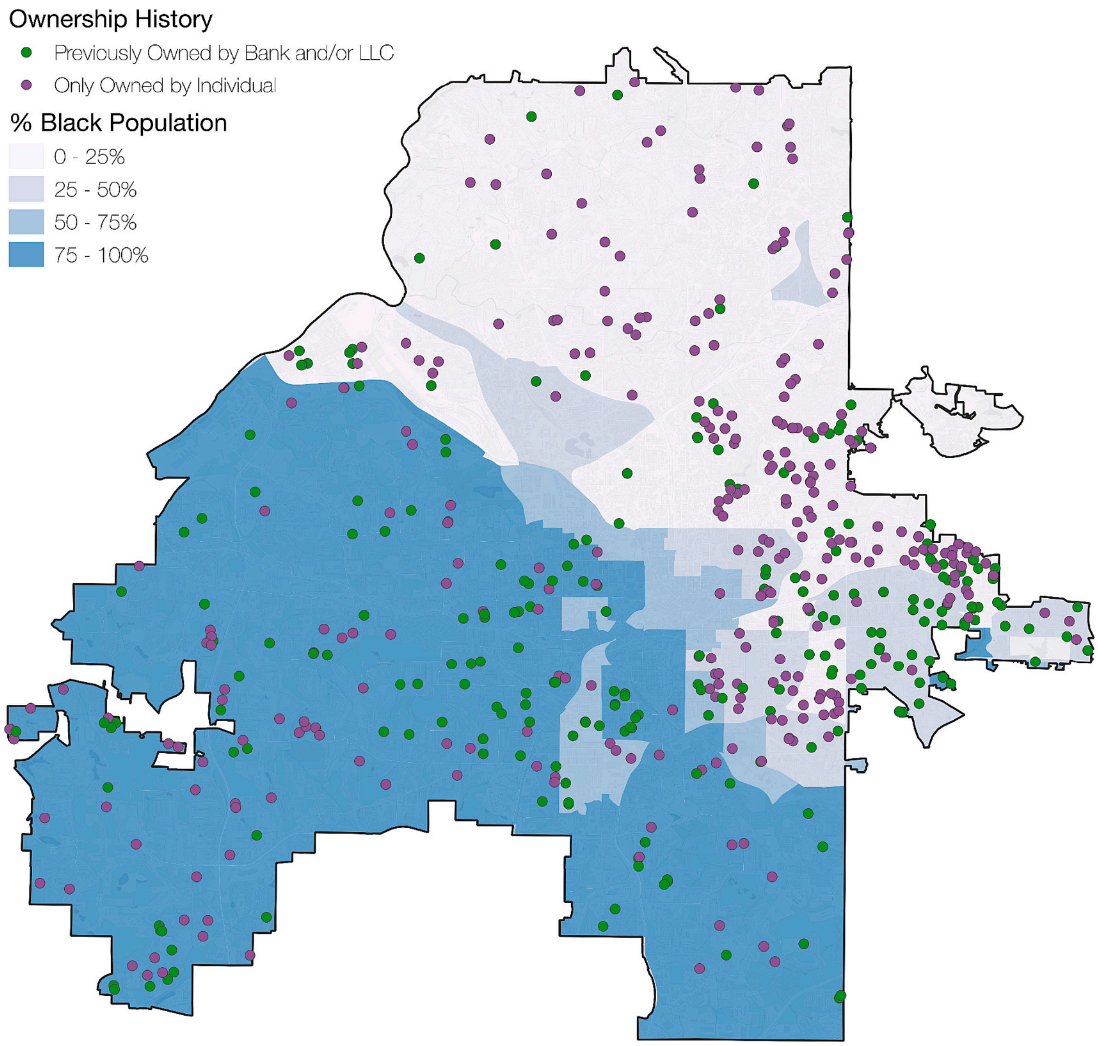

Fig. 6. Distribution of rooftop solar permits by ownership history relative to share of Black population.

Old Fourth Ward or Pittsburgh have. That is, newcomers in neighborhoods like Virginia-Highland and Morningside/Lenox Park are largely *maintaining* the character of the neighborhood through their actions in the housing and rooftop solar market, while in majority Black neighborhoods the new arrivals are simultaneously enabled by long histories of racial discrimination and predatory real estate practices, while also perpetuating them.

Together, these neighborhood and property-level stories show that not only does the growth of rooftop solar extend few benefits to legacy residents of majority poor and majority Black neighborhoods, it is intimately tied to the direct or indirect displacement of those residents from their homes and neighborhoods. Its tie persists due to the fact that installations most frequently occur on properties that have seen considerable turnover in recent years driven by speculative market pressures and are now owned and occupied by relative newcomers to these neighborhoods. The diverging experiences we've documented above are reflective of the broader inequality in urban housing markets and the particular exploitation of historically Black neighborhoods, which have seen significant increases in new buyers purchasing previously foreclosed, LLC-owned, or flipped homes that were made affordable due to the losses in the neighborhood caused by the Great Recession. These are the homes with rooftop solar that were part of the sudden increase in rooftop solar installations in 2021–2022, showing it's not higher rates of adoption by the majority low-income and Black residents in these neighborhoods, but rather middle and upper-class newcomers who are driving the uptake of these clean energy technologies. That is, while the geographic profile of residential rooftop solar in Atlanta has shifted dramatically in recent years towards the city's long-marginalized majority Black neighborhoods, the social profile of adopters remains largely the same, but markedly different from the demographics of their neighbors and longstanding residents.

5. Conclusion

Ultimately, our research has documented the current state of residential rooftop solar adoption across Atlanta, Georgia. In addition to showing the generally uneven distribution of residential rooftop solar, we have also demonstrated that its adoption has been rapidly increasing in majority Black and predominantly low-income neighborhoods. But this shift has only represented a *spatial* redistribution of renewable energy generating capacity across the city, not a *social* redistribution of its benefits. Instead of leveling the solar-generating playing field, the growth of rooftop solar in these communities has been spurred by – and ultimately helped to reinforce – the broader process of uneven development shaping Atlanta's urban fabric, specifically in the form of gentrification in historically Black neighborhoods. That is, rather than being adopted by energy-burdened legacy residents who have the most to gain from such clean energy, rooftop solar is coming to these neighborhoods alongside (and because of) wealthy newcomers, and generally at the expense of longtime residents. And because of the benefits of rooftop solar from the perspective of property valuation, its adoption ultimately furthers the appreciation of homes in these gentrifying neighborhoods, placing them even further out of reach of longstanding residents in these places.

All of that being said, unlike discussions of green gentrification focused on outdoor natural amenities like public parks and greenspaces, there's nothing in our analysis of Atlanta to suggest that the adoption of rooftop solar is what is *causing* gentrification.[3] The driving force behind gentrification has been, and remains, the spatially uneven development of urban space and the necessity of capital to move between valorized and de-valorized spaces in search of a new kind of spatial fix [65]. But as a result of these larger changes in the housing market and the built environment has come increased adoption of clean energy like rooftop solar systems, which are increasingly concentrated in historically disinvested majority Black neighborhoods. So while we are in no way arguing that rooftop solar be blamed for ongoing housing market inequalities, our findings do suggest that rooftop solar installations could provide another method for tracking gentrification via a kind of 'early warning system' [66].

Cumulatively, these findings call into question whether the status quo for rooftop solar adoption in Atlanta (and likely other cities) represents true social or economic sustainability alongside its contributions to environmental sustainability. Even though the production of more renewable energy and decreasing reliance on for-profit utilities who use coal, natural gas, or nuclear energy is a positive step towards the necessary end of society-wide decarbonization, if it comes only because of the displacement of longtime residents, it may not be worth that trade off. Therefore, the spatial redistribution of rooftop solar into historically Black communities across Atlanta without the concomitant social redistribution of its benefits to actual marginalized people in no way represents a form of what Luke and Heynen [48] call "energy reparations". Like the patterns they document in New Orleans, solar adoption in Atlanta has reproduced racialized inequality with a climate-friendly veneer rather than fundamentally challenging the structures of contemporary climate injustice.

If the historic harms caused by both housing and energy injustice in Atlanta are to be repaired and redressed, it is absolutely necessary to disentangle residential decarbonization and decentralized energy production from the whims of the speculative housing market, and private property ownership more generally. As long as one's ability to adopt rooftop solar is primarily dependent on access to not only homeownership, but also the additional capital to afford solar installation in the absence of public subsidies, all but the wealthiest residents will remain locked out of both the environmental and economic benefits from these new sources of energy, only further entrenching existing racial and class inequalities.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

[3] There are, of course, significant debates within the literature on green gentrification about whether greening precipitates or follows the gentrification process. See Rigolon and Collins [67] for a deeper examination of these questions.

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