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On the economics of rooftop solar PV adoption

Duzgun Agdas, Prabir Barooah *

University of Florida, United States of America

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ABSTRACT

Much has been written on the rooftop solar photovoltaic (PV) adoption in the U.S., but granular economic assessment at large scale is missing. We provide household level PV economic assessment for a medium size city in North Central Florida, and analyze the economic viability of these installations. Results show that a large number of households will not benefit from solar installations. Further, economic viability is heavily reliant on incentives whose future is uncertain at best. Our analysis did not reveal significant variations in economic viability across different household values — a proxy we used to differentiate household wealth. Yet, building permits and installation locations indicate economically disadvantaged communities have much lower installation rates as has been the main conclusion in the earlier literature. We argue economic assessment for PV should extend beyond simple benefit–cost analysis. A more nuanced approach should be taken in PV feasibility assessment, and structuring incentive schemes.

1. Introduction

The cost of solar photovoltaic (PV) technology has fallen dramatically over the recent years, paving the road for widespread household rooftop PV system adoption. These systems can provide sustainable energy that can help mitigate long term climate impact of non-renewable sources of electricity. Despite the increased market penetration and reduced installation costs, rooftop solar adoption rates have been low in many parts of the United States (U.S.) — especially in the Southeast (Penn, 2019). One possible, and perhaps the simplest explanation for this is the economic viability of such system installation. Despite many additional potential benefits of PV systems (e.g., reduced emissions related to energy generation), widespread adoption is unlikely without economic justification for individual households. This is likely to be more impeding for low-income households (LIHs), although solar adoption trends are much quite complex (Reames, 2020).

Analyzing economic viability of rooftop solar PV is challenging. An inherently complicated life-cycle analysis is further exacerbated by dependence on weather, utility pricing strategies that change frequently, and lack of both long term granular data about rooftop solar systems and individual household-level financial data (NREL, 2017). Regardless, a simple back-of-the-envelope computation with some common sense assumptions can provide insight into overall viability of these systems. For instance, the average electricity consumption of a household is 37.5 kWh/day (EIA, 2020) in Florida. Using this number and a "conservative" capacity factor of 15.7% – the reported average for the U.S. NREL (2021), and see Appendix for local capacity factor computations from Florida – leads to the "best" rated capacity of a rooftop PV system to be approximately 9.95 kW.[1] Solar installation cost of such a system at present is approximately $2.5/W (Barbose and Satchwell, 2020), thus an initial investment of $24,875 is required. The return on this investment is in terms of reduced or eliminated energy costs in the form of utility bill reductions, since the net import of utility generated electricity by the house is zero over a year. For the average residence in Florida, the savings over a year are approximately $37.5\ \text{kWh} \times \$0.106 \times 365 \approx \$1,450/\text{year}$, where we have taken 0.106 $/kWh as the average retail price of electricity (https://www.eia.gov/electricity/state/). Note that the current price of electricity is significantly different than this number because of the COVID-19 pandemic and commodity price fluctuations. Since we are using data from 2019, we use a representative electricity price. Without considering time value of money, it will require over 17 years for the initial investment to be fully recovered. Considering the time value of money and power degradation of the PV systems, the break-even period would be even longer, and could exceed the useful life of the solar panels: 20–25 years (Mow, 2018).

These calculations reveal that investing in rooftop PV may not be financially viable for an average home in Florida based on cost of installation and benefits from utility bill reduction. Factors that have kept incentives for rooftop solar low in Florida are also becoming common in other parts of the country. These include lowering of feed-in tariffs,

* Corresponding author.
E-mail addresses: duzgun@ufl.edu (D. Agdas), pbarooah@ufl.edu (P. Barooah).

[1] The panels should produce 9.95 kWh of electric energy in an hour under the most favorable conditions, $37.5\ \text{kWh/day} = 9.95\ \text{kW} \times 24\ \text{h/day} \times 0.157$.

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and introducing solar fees by utilities, such as the "solar participation charge" proposed by the California Public Utilities Commission (CPUC, 2022; Bruggers, 2020). The value of PV itself is not in question here, as even utilities that do not have renewable portfolio standards (RPS) have invested heavily in large-scale solar farms (including utilities in Florida).

Given these factors, several research questions arise. The first research question relates to economic viability analysis of rooftop PV systems that go beyond the simplified analysis presented above. In particular, are rooftop PV systems economically viable for single family households in Florida? If an economic assessment is done to answer this question, what is the sensitivity of this assessment to the various parameters that appear in the analysis? A second and related question is on the assessment of economic viability of rooftop PV systems for low income households. This question is particularly relevant, since the literature on PV adoption economics is mostly intertwined with the energy burden and energy justice implications. Low-income and vulnerable populations spend a disproportional amount of their household income on energy, and in most cases these individuals and families may forgo basic needs to afford utility bills. According to a recent report by Drehobl et al. (2020), 25% of American households face high energy burdens (EB) (i.e., spending more than 6% of household income on energy), while 13% face severe burdens (i.e. spending more than 10% of household income on energy). Solar PV has been thought to be cost a effective and viable alternative to reduce energy costs (O'Shaughnessy et al., 2021). Should the same be true for low income households, solar PV can alleviate the disproportional energy burden faced by low income households and reduce energy injustice (Brown et al., 2020).

The objective of this paper is, thus, twofold: (i) What is the economic viability of solar PV systems for a city in North Central Florida?, and (ii) How does economic viability compare for different household income levels? We do so via analysis of publicly available, granular (household-level) data from City of Gainesville. While economic assessment of rooftop solar exists in literature with accompanying sensitivity studies, to the best of our knowledge these studies are limited to aggregate – typically census tract level – data (Bódis et al., 2019; Comello and Reichelstein, 2017; Ramasamy et al., 2021). Some studies do conduct analysis for households, but uses aggregate data due to lack of site specific data. For instance, Vaishnav et al. (2017) reports analysis for households but uses zip-code level aggregation before analyzing the household data In contrast, all the data used in our analysis are for individual households.

2. Literature review

Solar PV adoption economics is mostly intertwined with the energy burden and energy justice literature (Reames, 2020). Fuel poverty, energy burden, and energy insecurity are terms that indicate having difficulties in affording energy expenditure (Brown et al., 2020). The U.S. Energy Information Administration (EIA) estimates one third of households in the U.S. faces energy insecurity (EIA, 2021). There are differences in how different authors define and compute energy burden for different publications, yet the conclusions are comparable (Drehobl et al., 2020).

Rooftop solar PV can reduce or completely eliminate the energy purchased from utility providers and decrease the energy burden. These systems have been suggested as long-term sustainable solutions to reducing high energy burdens faced by Low-Income Households (LIHs) (Brown et al., 2020; Monyei et al., 2019; Heeter et al., 2021). A significant subset of energy justice literature is dedicated to its interaction with clean energy transition (Jenkins et al., 2016; Carley and Konisky, 2020).

Sunter et al. (2019) discuss the racial disparities in solar adoption — Black and Hispanic communities installed less solar panels for median household income controlled comparisons. They emphasize the potential benefits of appropriate incentives in closing this solar adoption gap, and warn that racial disparity in solar adoption is likely to grow unless proper interventions are devised. The analysis combines Project Sunroof© data with American Communities Survey data at the census tract level. Similarly, O'Shaughnessy et al. (2021) discuss that households with income of $200,000 are four times more likely to adopt PV systems when compared to households with less than $50,000. The authors further discuss the benefits of incentives specific to low- and middle-income households in reducing the inequalities in PV adoption, while arguing the ineffectiveness of non-targeted incentives. The current COVID-19 pandemic has only made the energy insecurity disparities worse (Memmott et al., 2021), and the need to address these issues were further emphasized (Graff and Carley, 2020). While the breadth of literature is an indicator of academic interest in the topic, this interest is not an indicator of the progress in the state of practice.

There are several obstacles in widespread adoption of rooftop PV installations. One is the capital investment requirements. Cost of PV systems are prohibitive for LIHs – a problem exacerbated by incentive misalignment – majority of the households in the U.S. do not earn enough to benefit from tax rebate type incentives in an equatable manner (O'Shaughnessy et al., 2021). Another barrier faced by PV is weather dependency. The efficiency of a solar energy system is reliant on the amount of sunlight available, so it is not practical in every region (Sigrin and Mooney, 2018). There are also variability in how energy generated from PV systems are used. The energy generated can be used immediately, stored using batteries or sent to the electric grid — either sold or used in net metering to offset utility bills, generally done on an annual basis (GRU, 2022). This is one of the under-emphasized detractors of solar PV adoption as these systems viability increase as the household energy consumption increase. In other words, the higher the electricity consumption in a given household, the higher the expected return from solar PV installation. This is highly counterproductive as households that can benefit from solar PV installation more from an energy burden perspective, benefit less financially as household income has a strong positive correlation with household energy consumption — we discuss these points further in Section 4.2.

The main contribution of the paper is providing economic viability assessment of solar PV systems using multiple indicators and accompanying sensitivity analysis at a granular, household level. The rest of the paper is structured as follows. In Section 3 we describe the data and methods used in conducting the analysis. Section 4 presents the results of the analysis, and we conclude our paper with conclusions and policy recommendations.

3. Data and methods

3.1. Data

We combined three separate data sources to conduct the analysis reported here. Below are specifics of each:

3.1.1. Electricity consumption

Gainesville Regional Utilities (GRU) is the utility provider for Gainesville, and the organization publishes household level monthly utility (e.g., electricity, natural gas and water) consumption online (https://data.cityofgainesville.org). Data is available from 2012 to present day and periodically updated. There is no indication of opt-in or opt-out policy, and data collection appears to be for all dwellings within the city. We use this data portal to calculate the electricity consumption and spending for individual dwellings for Gainesville.

Table 1
Assumptions of Project Sunroof.

Variable	Assumed value
Analysis period	20 years
Utility rate increase	2.2%
Discount rate	4%
Module efficiency	15.3%
Module rating	250 W
Annual power degradation	0.5%

3.1.2. Household characteristics

City of Gainesville is located within the Alachua County, and the Alachua County Property Appraiser's (ACPA) Office provides detailed household level dwelling data (https://www.acpafl.org). The dataset includes, the assessed value of the property, its size and primary use. Since the focus of the study is single-family homes, only the data for single-family homes were utilized[2]

3.1.3. Solar PV installation costs and earnings potential

We use the Project Sunroof© to compute the solar PV installation costs of individual households whose identifying characteristics determined by combining utility and household characteristics data. Launched in 2015, Project Sunroof© aims to provide useful information assessing the value of rooftop solar on buildings in much of the U.S. and Puerto Rico. The application has a simple interface in which the users are prompted to enter their address and average monthly electric bill. Project Sunroof© uses machine learning (ML) algorithms to estimate roof area using Google Maps. Combining the monthly energy expenses and solar generation potential (using roof size, roof shape, shaded areas, local weather), the interface provides detailed economic assessment of the solar installation based on installation costs, utility cost increases, renewable policies of the utility provider and State and Federal incentives (Google, 2021). Project Sunroof© is intended to be an adoption tool; thus, the focus appears to reduce the decision variables in a simplified manner. Rather than providing total solar generation potential for different array configurations, the application "optimizes" the installation size based on energy consumption estimates and available roof area to maximize economic value. The set of assumptions made in these computations are provided in Table 1.

3.2. Methods

3.2.1. Economic viability assessment methods

In conducting the economic viability of PV systems, we use two measures; *net present value (NPV)* and *internal rate of return (IRR)*. The former is the dollar value of an investment with future benefits discounted to present time, and the latter is a time dependent measure of rate of return for a given investment. While much has been done on the difference between NPV and IRR, former can favor larger investments if used alone (i.e., if NPV was the only assessment tool, larger installation costs with higher up-front investment costs can look more financial viable than smaller installations with comparable return on investment that IRR value can help estimate).[3] NPV is the total discounted cash flows, and computed according to the following formula:

$$NPV = \sum_{t=0}^{N} \frac{C_t}{(1+i)^t}, \qquad (1)$$

where C_t are the annualized cash flows (e.g., installation costs, utility payments) during year t, i is the annual discount rate, and N is the lifetime of the system. IRR is calculated from the very same formula as IRR defined as the discount rate that makes the NPV of all cash flows zero. We ignore *inflation* in our computations throughout this article. Thus, the reported discount rates are all nominal. While we vary utility rate changes in our assessment, we do not address inflation in discount rate selection.

3.2.2. Economic assessment process

In the following we describe process of conducting economic assessment of household level rooftop PV.

- We combine the utility data with county household variables to create the set of variables needed (e.g. address, property value, electricity consumption, utility payment) to interrogate Project Sunroof© to compute PV installation and economics data (e.g., size of the solar panels, installation costs, potential bill savings, NPV). While Project Sunroof© produces many variables, we focus only on NPV for brevity and as a starting point. Simply put, there is too many data points and variables to be included in the length of this article and we want the focus to be solely on overall economic viability throughout the life cycle of solar PV systems — as opposed to splitting installation costs and benefits
- While Project Sunroof© provides an NPV value for the "optimum" sized PV system for a give household, the details of the individual cash flows throughout the life cycle of the PV system is not available. We estimate these variables from disclosed assumptions of Project Sunroof© given in Table 1 and economic indicators provided (e.g., monthly bills, potential savings, residual bill payments etc.) by using an inverse method. We estimate the NPV ourselves by using the explicitly reported variables and assumed values of other parameters so that this synthetic NPV matches the reported NPV by Project Sunroof© reasonably well. This method provides us with good estimates of the parameters that are not reported by Project Sunroof©.
- We then use the parameters estimated in obtaining the synthetic NPV to compute the IRR and also conduct sensitivity analysis on both NPV and IRR.

All the analysis presented here was conducted in Python (Rossum and Drake, 2009) using numpy, Pandas and Seaborn packages (Harris et al., 2020; McKinney et al., 2010; Waskom, 2021).

3.3. Assumptions and limitations

We made a number of assumptions in conducting our economic assessment and following sensitivity analysis. There are also a number of limitations associated with these assumptions that must be acknowledged.

- *Investment Tax Credit (ITC)*: This program provides a 30% tax rebate for systems installed between 2022 and 2032. The ITC will reduce to 26% in 2033 and 22% in 2034 (USDOE, 2022).[4] Changes to ITC incentive will reduce the economic viability of rooftop solar systems, thus we use the current 30% and 0% in our sensitivity analysis.

[2] According to U.S. Census Bureau, a single-family house can be completely detached, semi-detached, a row house, or a town-house. A single-family house must also have a separate heating system and utilities.

[3] For further discussions on comparison between these methods, which are outside the scope of this article, readers are encouraged to consult the following Rapp (1980), Osborne (2010) and Weber (2014).

[4] Since this article was originally written, there has been significant changes to the ITC amount. The program was to provide a 26% tax rebate for systems installed in 2020–2022, 22% tax rebate for systems installed in 2023, and set to expire in 2024 after renewed twice (USDOE, 2020).

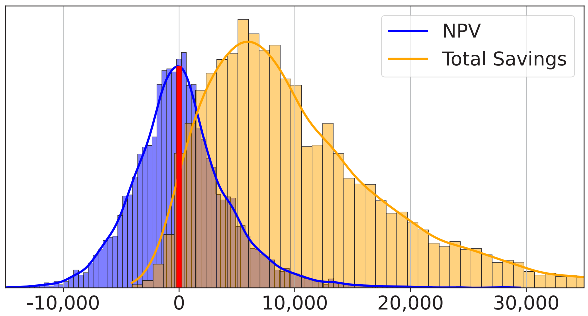

Fig. 1. Economic assessment of rooftop solar investment for city of Gainesville.

- *Discount Rate*: The default discount rate used by Project Sunroof© is 4% and we use the rates 3%, 4% and 5% in our sensitivity analysis. These numbers are chosen arbitrarily but our goal is to assess the impact of discount rate on NPV rather than providing accurate economic estimates. Selecting a discount rate, particularly incorporating inflation (e.g., using nominal interest in NPV computations that incorporates inflation rate to the real interest rate), is challenging and beyond the scope of this paper. It is worth noting that these rates are somewhat conservative as much higher discount rates are used in NPV analysis about renewables (California Public Utilities Commission, 2021).
- *Utility Rate Increase*: Project Sunroof© uses 2.2% for utility rate increase and while this number is plausible, and we kept it as our central utility increase rate. Historically; however, the utility rates in Florida has not increased at this rate. According to EIA(https://www.eia.gov/electricity/sales_revenue_price/), average residential retail price for electricity in State of Florida increased from $.0859/kWh to $.1127/kWh.[5] from 2001 to 2020. This is an annualized increase of 1.3%. Thus, we vary the utility rate increase at 1%, 2.2% and 3%.
- *Maintenance, Module Efficiency, and Power Degradation*: We assumed there will not be any maintenance costs associated with the PV systems and while this is a naive assumption, not much exists on the maintenance of PV systems particularly considering majority of the systems installed are not close to the end of their useful life. Regardless, it is unlikely in the 20 years a PV system is assumed to be used there will be no maintenance costs but this should be considered as an external risk that cannot be accurately estimated at this stage. Project Sunroof© uses module efficiency rating of 15.3 and an annual power degradation of 0.5%. Both of these numbers are within the reported values of earlier literature (NREL, 2021)
- *Buy Only Financing*: We only consider the outright purchase option for the PV system financing. Simply put other sourcing options (e.g., lease, or financing the purchase) will increase the cost of adoption as the added cost of financing will have to be borne. Thus, they were excluded from our analyses.

4. Results

4.1. Economics of solar

Project Sunroof© provides both total savings (i.e., savings not corrected for time value of money) and net present value for solar PV viability (see Fig. 1). The most obvious observation here is the difference in the two variable reported. Time value of money can be an abstract concept, but it is necessary to consider for long term investments. While *majority* of the households in Gainesville have potential savings, 11,083/11,440 (97%), NPV is positive for a much smaller subset, 5657/11.440 (49%). In other terms, for about half of the residences, it does not make financial sense to install rooftop PV at present, if the decision is to made purely on a financial basis. NPV values are sensitive to variable values used in analyses, and point NPV estimates should not be used in financial decision-making. It should also be noted that the values reported in Fig. 1 are valid for ITC of 26%, which is currently at 30%. We provide this figure to show the importance of time-value of money more so than providing sound financial assessment. In the following sections, we adjust this NPV value for ITC rate of 30%.

We also check the NPV (estimated) and IRR values against the installation costs to gauge the impact of initial investment amount on the financial performance indicators. For small PV systems, module costs account for a smaller fraction of total costs, while non-module costs are much higher (inverters, engineering and labor, permits, profits of the installer, etc.). This gap is much greater in smaller systems when compared to larger systems. For instance, National Renewable Energy Laboratory (NREL) estimates that in 2021, only 7.1–15.4% (for 3 kW and 11 kW systems respectively) of the total installed cost of a residential PV system is due to the modules, while the same number is 29.2–39.8% (5MW and 100MW systems respectively) for utility-scale systems (Ramasamy et al., 2021). Higher returns can thus be expected from larger installations,[6] and larger households with greater overall energy demand will have higher return. As expected, the NPV numbers appear to favor the larger installations, and the IRR values are more uniform (see Fig. 2). It is interesting to note the negative NPV values are much greater for the larger systems further supporting the discussions put forward about the need to use different discount rates to account for different risk profiles and opportunity costs.

4.1.1. Sensitivity analysis

We conduct the sensitivity analysis by varying the discount rate, utility rate increase and the incentive rates (Fig. 3). The NPV values are highly sensitive to variables analyzed, and overall, PV installation are viable for a large number of households only for the *high return* scenario (i.e., the difference between the discount rate and utility rate increase is the smallest, thus the future cash flows are more valuable and federal incentives do not expire). For the *low return* scenario (i.e., the difference of discount rate and utility rate increase are the largest), a majority of the households will lose money by installing PV systems even with the federal incentives in place. This analysis also showcases the vitality of the incentives to overall financial viability of PV installation as we show the NPV values for both high and low return scenarios without ITC. The high return scenario has financial viability for a small subset of homes (14%), and **no installation is financially viable** for the low return scenario.However, it should be noted that negative NPV might not necessarily indicate financial viability picture completely. Because the discount rate is “selected” for analyses, a negative NPV may still indicate some financial gain or return on investment. It should also be noted that the “Baseline” NPV values shown here different than those shown in Fig. 1, as we adjusted the ITC values for this plot. Moreover, all figures except for Fig. 1 use a subset of the dataset to eliminate the outliers. We explain this process in detail in Section 4.2.1.

We then compute the IRR for different households using different utility rate increases and different tax incentive rates. Because IRR is calculated by estimating the discount rate that makes the NPV zero,

[5] Note that this number is different than the average electricity price reported for Florida in 1 as this figure is for residential electricity. The overall average is likely lower as commercial rates can be lower than residential rates.

[6] We chose these intervals to allow for group-wise comparisons. There were very few installations cost over $60,000, and thus, all installations over this amount was grouped together.

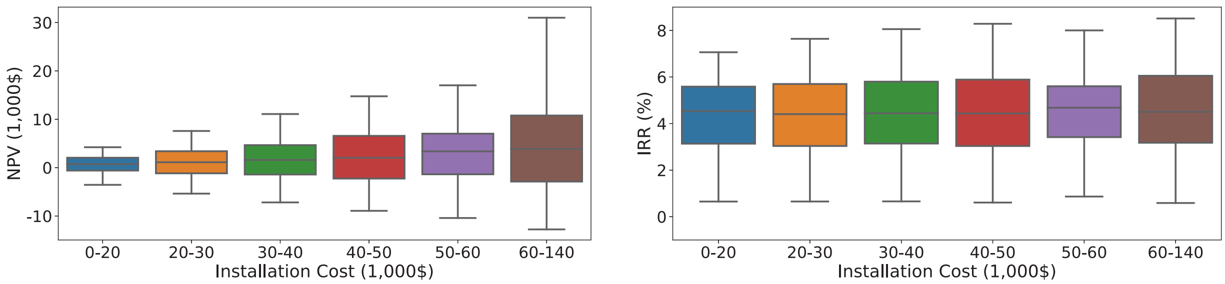

Fig. 2. Financial indicators vs. installation cost for Gainesville.

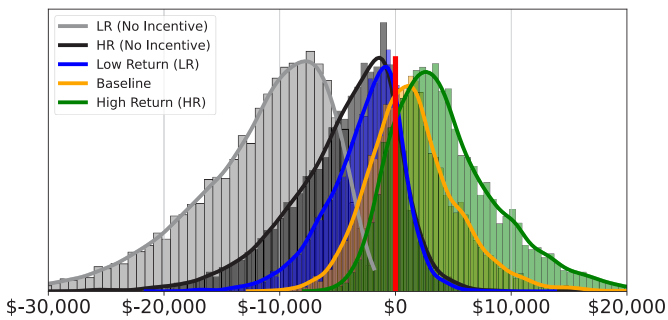

Fig. 3. Sensitivity for NPV values for Gainesville.

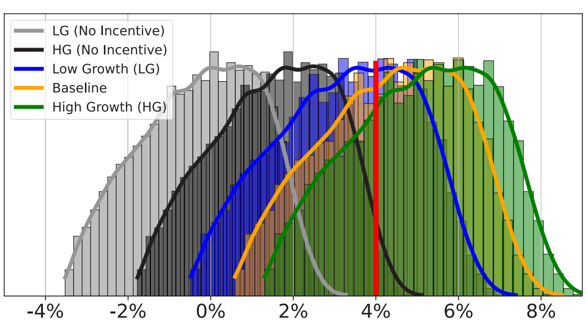

Fig. 4. Sensitivity for IRR values for different utility growth rates and incentives for Gainesville.

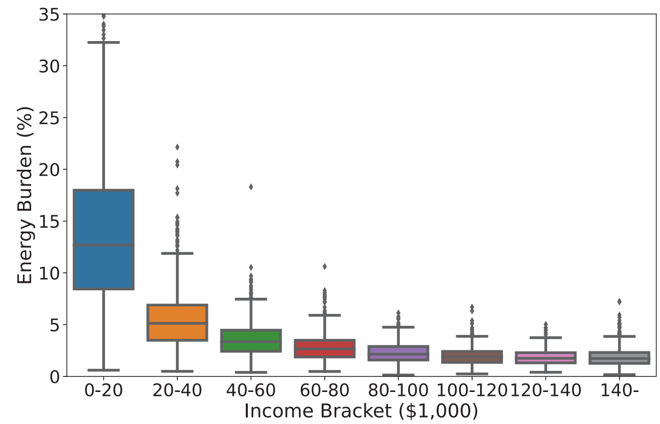

Fig. 5. Energy burden vs. income bracket using RECS data.

the interpretation should be a comparison of the IRR to the discount rates used in NPV computations. The higher IRR when compared to discount rate indicates better financial performance. Here the best case scenario would be the highest utility rate increase as this will maximize the future benefits of solar installation and vice-versa. The results are mixed again (Fig. 4). IRR values are highly sensitive to changes in utility rate changes and more importantly incentives. Even under *high growth* scenario (i.e., the largest utility rate increase at 3%), without the ITC, the mean IRR is approximately 1.6%. In most cases, this is less than typical inflation or conservative investment rates, and not an acceptable return for any long-term financial investment vehicle.

4.2. Solar adoption and energy burden

It is critical that sustainable solutions to energy affordability issues are accessible to all members of the society. In an attempt to quantify the local energy burden and solar adoption intersection, we compare the locally available data to robust national data. We start this analysis by estimating Energy Burden (EB) using the Residential Energy Consumption Survey (RECS) data. We define EB as follows:

$$EB := \frac{\text{annual energy expenditure (\$)}}{\text{annual household income (\$)}} \tag{2}$$

The RECS survey was created and maintained by the United States Department of Energy, and contains energy related data on residential properties across the U.S. (https://www.eia.gov/consumption/residential/about.php). Data from this survey has been used in earlier literature in calculating energy burden (Mohr, 2018). The RECS data contains detailed information about household characteristics, energy consumption and cost data — the household income is grouped into eight intervals rather than granular values. We compute the energy burden according to Eq. (2) for a household in the data using the central value for the income range in place of income in the denominator. That is, if the household was in range 1 (0–20,000), we used the central value of $10,000 as the representative income for the households in this category (Fig. 5). To test whether this method is viable, we checked whether the EB values calculated with this method would show similar trends to earlier literature findings. We estimated that 25% of the households experience EB of 6%, while 13% experience EB of 10% — consistent with earlier findings from Drehobl et al. (2020) that uses data from American Housing Survey (AHS). RECS data also appears to support additional relationships among household income and energy consumption trends. For instance, higher income households are likely to use more energy, whereas lower income areas are likely to have higher energy use intensity values (Goldstein et al., 2020; Porse et al., 2016). To test whether these two hypothesis can be proven with the RECS data, we ran linear regression models to compare the relationship among income levels, energy use and energy use intensity. The corresponding formulas are $Total\ Energy\ Use = 51000 + Income \times 7186$ and $Energy\ Use\ Intensity\ =\ 46.9 - Income \times 1.2$. Both models were statistically significant with R^2 values of 0.97 and 0.78 respectively, and model significance and intercept and predictor significance levels of <0.01.

While this EB measure is valuable, different proxies for estimating EB might be necessary as household income data availability and reliability are of concern (Berkland et al., 2018). Two of these potential surrogates are the dwelling value and size. This information is not

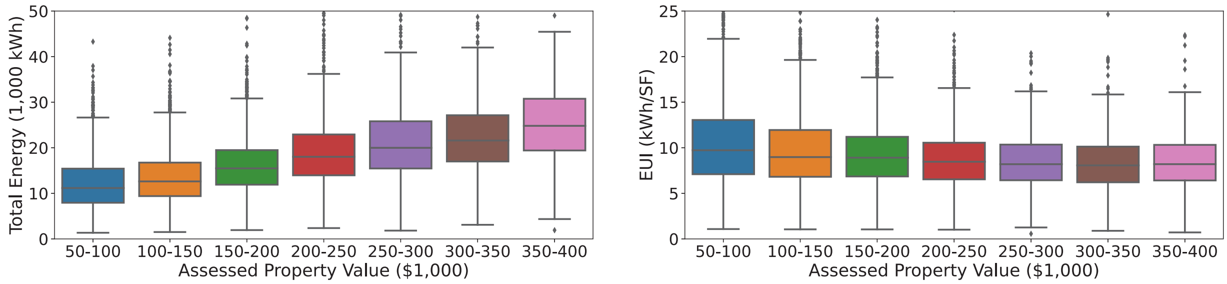

Fig. 6. Total energy and energy intensity vs property value (Gainesville, FL)

available in the RECS dataset, but available for city of Gainesville. Thus, we move forward with the analysis of estimating surrogate energy burden using these variables.

4.2.1. Energy consumption trends in Gainesville

We use property value as the surrogate income/wealth indicator as it seems to have similar correlations to total energy use and energy intensity, and household income as indicated by the RECS dataset. More expensive properties use more energy, yet their energy use intensity is lower (Fig. 6). These are familiar results to the relationship among total energy, energy use intensity, and household income that we discussed in the previous section. These findings gave us the confidence that local data can be used to infer energy justice implications of solar adoption trends.

Some additional assumptions and shortcomings needed to be acknowledged here. First, we assume the assessed value of the house by the County for property tax purposes is a good indicator of its market value. While there are limits to how much the County can increase the property values to match true market value, ownership changes are not subject to this rule.[7] So, the assessed value may be lower than the actual market rate, but for the sake of comparative assessment, we believe they would be adequate (Alachua County, 2018). We limited analysis to households with assessed value of $50,000 or greater to better capture the market value of the houses, since it is likely that houses with very low assessed value have not been updated for a long time and thus the reported values do not represent current reality. Similarly, we also eliminate houses with property value of greater than $400,000 as these are the outlier cut-off points.[8] Similarly, we excluded properties with average monthly bills of less than $20 and more than $1000. We also limit our assessment to households that has potential solar savings according to Project Sunroof©. After this elimination procedure, total number of households used in the analysis decreased from 11,440 to 9935. Lastly, we combined natural gas and electricity consumption values for the households that use natural gas in addition to electricity using the conversion rate of 29.3 kwh/Therms.

4.2.2. Surrogate energy burden for Gainesville

We define a surrogate energy burden for Gainesville as follows:

$$\hat{EB} := \frac{\text{annual energy consumption (kWh)}}{\text{assessed property value (\$)}} \quad (3)$$

Here the annual energy consumption – the sum of electricity and natural gas that is converted to kWh for 2019 – and property values assessed by the County are used to determine the alternative energy burden for the city of Gainesville. The results are as expected. Energy burden is much higher for the properties with the lower assessed values (Fig. 7). Another observation is the much greater range of energy burden values of the properties with the lower end of the assessed value spectrum.

[7] Unless there is a sale, increase in the assessed value of a property is generally limited to the lower of 3% and the Consumer Price Index.

[8] $50,000 was a common sense lower limit, and the $400,000 was chosen as the upper limit using the more traditional outlier upper bound of $\mu + 1.5\times\ IQR$ as a reference point, and represents less than 5% of all properties.

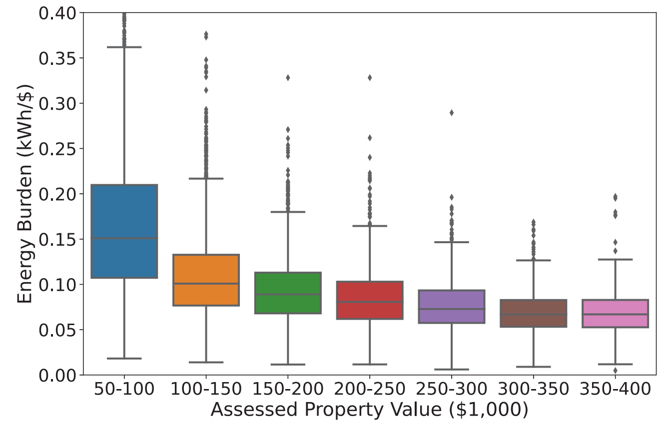

Fig. 7. Surrogate energy burden for Gainesville.

Lastly we check the NPV and IRR values for solar PV installation for different property values (Fig. 8). The results here are mixed. While the NPV favors higher value properties, IRR trends are much less conclusive. As we established earlier, higher value properties have higher energy use and they are likely to have larger installations. Similarly, we have shown that larger installations have higher NPV values. This might simply be caused by larger investments upfront. Simply put, same return on investment with different initial investment values will result in different NPV values. And in this case, the difference in NPV values for different property values might be because of this. It is safe to assume that there is no greater benefit — rather it is not clear whether higher value houses will benefit from solar installation when compared to lesser valued homes.

Thus, while energy consumption and energy burden trends correlate relatively strongly with property value, difference of solar potential with difference of income levels is inconclusive. Perhaps a more specific study can be designed to study energy burden topic in greater detail with additional variables (e.g., property ownership, household characteristics, building age etc.) that can lead to more conclusive results.

5. Discussions

The analysis in the previous section shows that viability of a solar PV installation from a purely economic perspective is questionable for Gainesville, Florida. While the recent increase in solar ITC tax rebate has improved the financial viability, even with optimistic assumptions, a large number of households in Gainesville, FL will not financially benefit from installing rooftop solar PV systems. More importantly, the economic viability of these systems are highly sensitive to parameters we analyzed, which brings a potential risk component to the economic viability question.

Since the data used were from Gainesville, FL, a natural question arises as to how generalizable these conclusions are. Our analysis

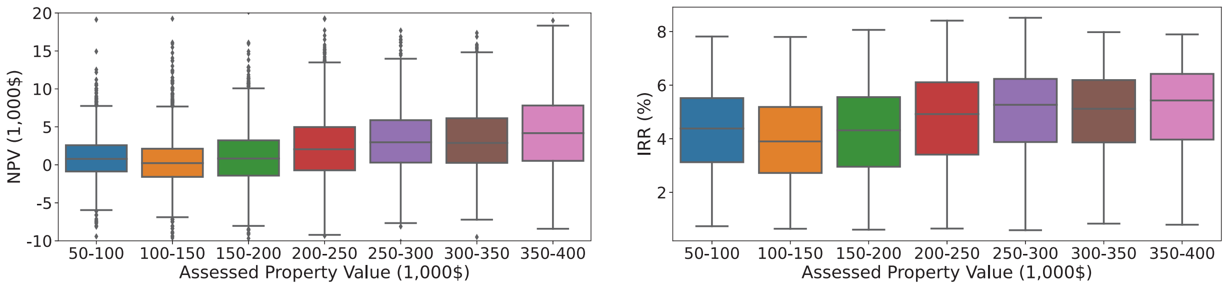

Fig. 8. NPV and IRR vs. property value (Gainesville, FL)

calculates the economic benefit of the PV systems solely from utility bill reductions, making the utility rate the most critical determinant of the economic benefit. The retail price of electricity for the city of Gainesville is one of the highest in the state of Florida (https://www.flpublicpower.com/electric-bill-comparisons). So the benefits are lower in other cities in the state. Apart from cost of utility-supplied electricity, *net metering* rules also critically affect economic benefit of PV installations. Under net metering rules that are prevalent in most states of the U.S., consumers do not benefit by investing in over capacity since the additional energy exported by a home to the utility does not earn the customer much, if at all. For instance, in case of Florida Power and Light (FPL), one of the largest utilities in the U.S. that serves the Southeast, the excess energy generated by a customer's rooftop PV system over a year will be credited "..at the annual average cost of generation" (Florida Power and Light, 2022), which is far lower than the retail price of electricity.

Despite our findings in this article, the solar adoption trends in Gainesville have been consistent with the earlier literature findings. Of the 472 permits issued from 2002 to 2019, only 17 (1.9%) solar installations have been within the low income communities. The low income communities with household income of 100%–150% Federal Poverty Line (FPL) faces average energy burden of 11.3%, and this number jumps to 30% for the households between 0%–100% FPL. Moreover, the home ownership of these neighborhoods is also low as 88% of the residents are renters. This might explain some of the discrepancies, as *split incentive* problem in rental property energy efficiency topic is well discussed (Bird and Hernández, 2012). However, without further information any conclusions cannot be drawn here.[9]

5.1. Beyond traditional economic assessment

The economic analysis here only focuses on *manifest* costs and benefits that are easy to estimate. Namely, the costs are simply the installation cost while the benefits are simply reduction in utility bill. There are additional sources of costs such as interest rates (if financing is used), though they are easy to incorporate. Similarly, there are additional benefits such as the value a homeowner places on environmental stewardship. But these are more difficult to assess and quantify.

Another value that rooftop solar can provide that is especially valuable in the Southeastern U.S. is energy resilience to hurricanes, when equipped with a battery. The sky is often clear after a hurricane, though blackouts are common that persist for days after the hurricane. Also, a rooftop PV system has a much higher likelihood to survive a hurricane than the likelihood of a blackout. For example, after hurricane Irma struck Florida, more than 60% of the households lost grid-supplied electricity but less than 7% of the residential buildings suffered any kind of damage (Barooah, 2021). This makes rooftop PV systems viable candidates for hurricane resilient energy supply until power systems are fully functional. Recent tragedies in Florida nursing homes (see https://time.com/4941998/florida-nursing-home-victims-family/), and prolonged power outages faced in Puerto Rico indicate that energy access post-disaster is critical. Furthermore, disasters disproportionately impact vulnerable and low-income communities (Heeter et al., 2021), making PV a strong candidate to address intermediate energy access issue following disasters. The current pandemic and increase in remote work also has put a premium on uninterrupted energy access and energy resilience (Agdas and Barooah, 2020).

9 This information was furnished by the local Government officials through private correspondence.

6. Conclusion and policy implications

We provide granular assessment of economic viability of rooftop solar for a medium-sized city in North Central Florida. Our analysis indicates that economic benefits of rooftop solar as it is usually construed – dollars saved due to offsetting utility generated electricity by locally generated electricity – might not be sufficient to make rooftop PV an attractive investment for the majority of the dwellings. To encourage rooftop PV adoption, additional financial incentives or cost reduction will be needed. Furthermore, our analysis did not show significantly higher potential economic benefit for higher valued households, a surrogate we used for higher income households. This result is particularly relevant in designing policies to improve energy burden faced by low income households. We also believe the PV installation decision-making should not be based solely on a narrow economic metric. A more nuanced approach is needed that takes into account additional values such as resiliency to natural disasters.

CRediT authorship contribution statement

Duzgun Agdas: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft, Writing – review & editing. **Prabir Barooah:** Conceptualization, Resources, Methodology, Writing – original draft, Writing – review & editing.

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.

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Table 2
Capacity factor for different installations in Gainesville, FL.

Array	2017	2018	2019	2020
Building 300	14.4	13.1	13.3	12.5
Building 304	15.1	9.9	5.1	3.5
Building 306	14.8	10.4	9.9	12.6

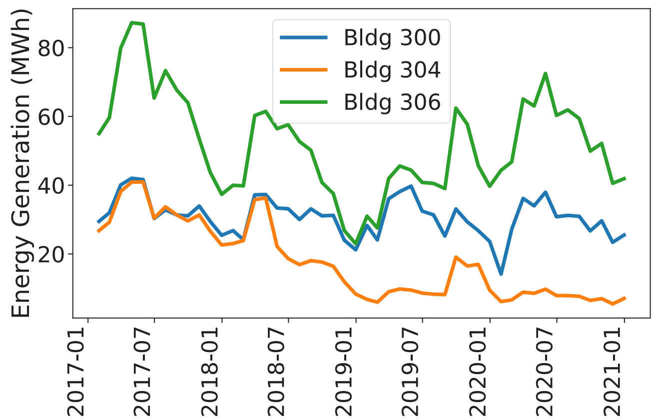

Fig. 9. Monthly energy generation over time in three PV installations in Gainesville.

Appendix. Capacity factor for PV systems in Gainesville, FL

According a National Renewable Energy Laboratory (NREL) report (NREL, 2021) the capacity factor (CF) of rooftop PV systems can vary from 12.7% to 19.6%, depending primarily on geographic location. To obtain an estimate for Gainesville, FL, we collected years long generation data from a rooftop PV system installed in the University of Florida campus at 5-minute resolution. The system in question consists of three separate PV arrays of various capacity, each on a distinct building, with a combined capacity of 100.2 kW. The buildings on which the PV panels are mounted are residential buildings occupied by graduate students with families, and as such the power demand profile of these buildings can be expected to be similar to that of a typical residential building.

The capacity factor of the installations is roughly 15% in 2017 — the first year of full data availability. The capacity factor for all panels seem to be reducing substantially over time (see Table 2). Fig. 9 shows the energy generated by each of three installation over every month from 2017 to 2021. While the reasons for these variations are not clear, this data shows that large variations in capacity factor are possible, and substantial variation over time can occur even in the same installation.

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