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Household Income Levels as a Driver of Residential Solar Panel Adoption

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ABSTRACT - ***The traditional electrical grid, also known as PowerGrid, is used to carry power from a few central generators to a large number of users. ThesePowerGrids across U.S. are outdated, have reached their capacities, and need to be upgraded with modern technologies to continue delivery of required levels of energy demand. Furthermore, the overall societal costs resulting from grid blackouts are considered unacceptable (North American Reliability Council (NERC), 2009); therefore, the utility industry needs to respond quickly. The issues are compounded by the current trend of consumers adding distributed generation equipment to the grid, including the growth in solar panels' installations and use of electric vehicles. While presenting a significant societal issue, it also offers a large business opportunity. The global solar power market is growing rapidly, estimated to reach a value of $130.5 billion U.S. dollars by 2021. The global market for total distributed generation as measured by solar panels, wind power, and biofuel was estimated at $246.1 billion in 2011 and is projected to reach $386 billion U.S. dollars in 2021. This research identifies and examines drivers of residential solar panel adoption in California. Regression analysis of 106198 records of solar panel installations in California for the years 2007–2013 was performed against demographic data for 1,733 zip codes.The research has quantified a positive relationship between household income levels and adoption patterns of solar panels in California. The results can be used to better project revenue growth in the renewables sector as well as enhance predictive analysis of utility capital investments. Also, these results could lead to a better understanding of future business models for operating utility assets.***

Keywords -adoption, distributed generation, photovoltaic, SmartGrid, renewables

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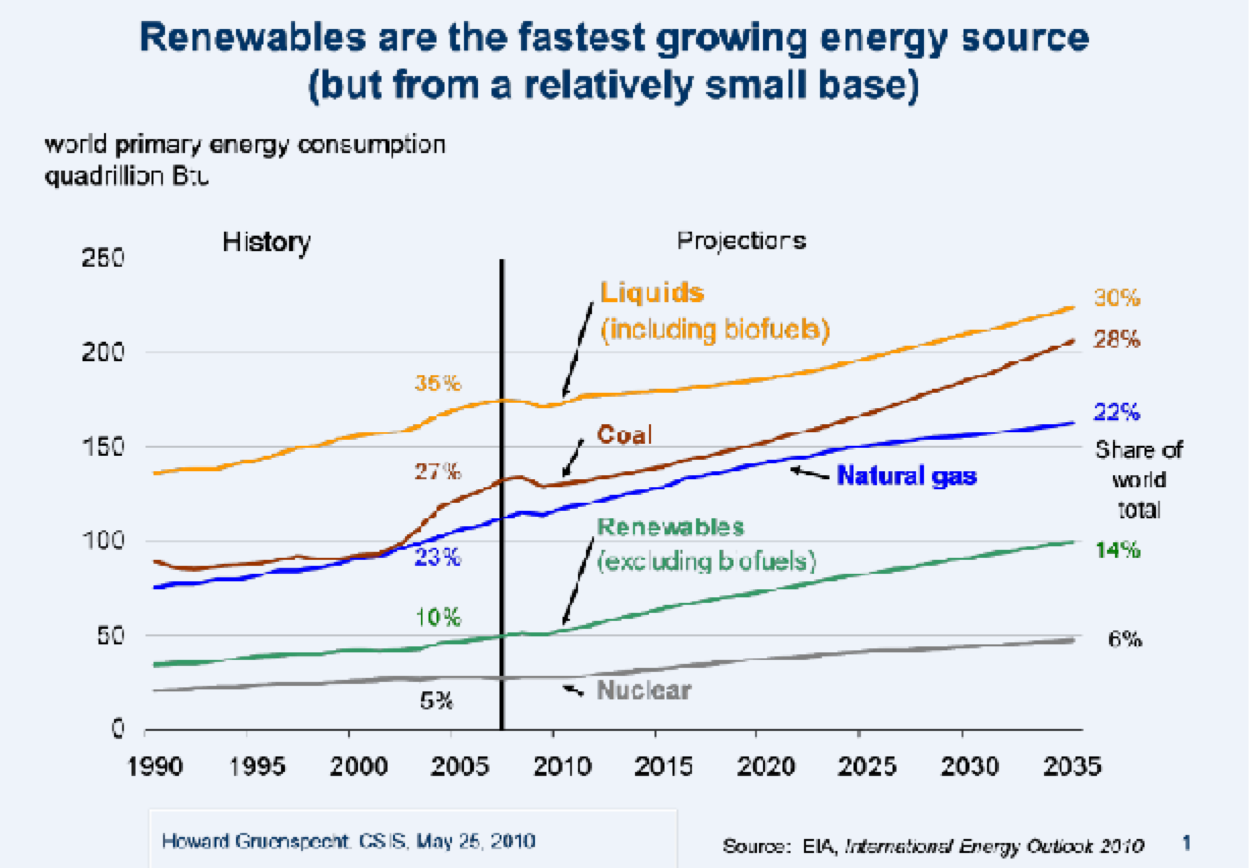
1. INTRODUCTION

The definition of the powerGrid is evolvinginto a new grid paradigm: SmartGrid thatuses two-way flows of electricity and information to create an automated and distributed advanced energy delivery network[1].It is an automated utility delivery and communication infrastructure that connects equipment, systems, customers, and employees. It enables "on-demand" access and control using current and event driven information on customers, assets, and the utility network systems to optimize operations, planning, system situational awareness, reliability, and efficiency [1]. The demand for upgrading the PowerGrid into a SmartGridis driven by several factors, including the need for energy independence as a national security issue [2].Most of the present grids across the U.S. are out-of-date and are desperately in need of technological upgrades to meet demand; consequently, many are dissatisfied with the societal costs of blackouts, prompting the utility industry to quickly adapt [3].

In particular, the recent trend of consumers adding distributed generation equipment can further expose weaknesses in the grid, including the exponential growth of electric vehicles and photovoltaic (PV) panels that are being connected to the grid. Various types of photovoltaic panels are connected to the grid to capitalize on excess electricity, while electric vehicles are connected primarily to charge batteries or store energy. According to recent research [4], both types of equipment have direct implications for consumers obtaining electricity from the grid. For solar power, 20% less sun on a cloudy day can significantly reduce the conversion to electricity[5].Aneighborhood grid of solar power producers has trouble accommodating that two-way, intermittent flow because it was built to deliver power one way at constant voltages and frequencies.

Areas which have high concentration of solar power installations can cause grid voltage to spike, potentially creating problems for electric equipment and motors. While residential consumers might experience flickering light bulbs, sensitive commercial data centers could experience million-dollar work outages.Distributed technologies are expected to increase in use [6] as the cost of installing a distributed generation unit becomes cheaper than upgrading the central generation unit and the associated transmission and distribution network.While the growth in attached renewables poses a significant cost exposure for the PowerGrid operators, it offers a large revenue opportunity for solar equipment vendors and manufacturers in the U.S., where the PV market grew over 700% between 2006 and 2010 [7].

As shown in Figure 1, distributed generation from renewable resources is growing faster than the traditional energy sources, such as nuclear power.By 2020, distributed generation capacity is estimated to reach 19.1gW worldwide[6].In response to the aggregated energy demand worldwide, the projections show that 355 gW needs to be added to the existing generating capacity. Although distributed generation is the fastest growing resource, the 19.1 gW would only make up five percent of the total 355 gW required. A high growth rate of distributed generation as an energy source would come with potentially large implications for the grid [6]. In summary, these drivers call for an increased focus on understanding the implications to the PowerGrid.


Renewables are the fastest growing energy source (but from a relatively small base)

Howard Gruenspecht, CSIS, May 25, 2010

Source: EIA, *International Energy Outlook 2010* 1

Figure 1. Growth of Generation Resources [6].

The literature review outlines a broad body of research on national and global adoption of PV resources; however, there are a limited number of empirical studies available that quantify the relationship between local economic variables and adoption on a state level.While a comprehensive body of research exists around demographic drivers for adoption of solar panels, no study has been identified that validates the accuracy of the models on all recent available utility data in the State of California. Peer-influence in PV adoption was studied on a subset of California Zip codes for 2001-2009 data [8]. Influence of demographical factors were studied on data for the SCE service territory[9]. As a business opportunity, the global solar power market is experiencing rapid growth estimated to reach a value of around $130.5 billion U.S. dollars by 2021[10]. The global market for total distributed generation as measured by solar panels, wind power, and biofuel was estimated at $246.1

billion in 2011, and is projected to reach $386 billion US dollars in 2021 [10]. This distributed generation, which is growing very quickly, has become an issue for utilities and regulators, as well as a risk for society as a whole. Significant investments are required to maintain and expand existing PowerGrids, at the same time as customer demand on high power quality is increasing [11]. Leiter (2000) [12] estimates outage costs for society at $90,000/hour in the airline-reservations industry, at $41,000/hour in the cellular-communications industry, and $6,480,000/hour in brokerage operation. Outages can be caused by numerous factors, and there is a vast body of research on implications of attaching solar panels to the grid [13] [14].A study by Carrasco et al. (2006) [15] highlighted how intermittent distributed generation, such as solar, impacts the power operations of a utility. The study indicates that in particular power systems, where the distributed generation makes up a significant part of the total system, impacts to utility are large.

Capital investments must be proactive and based on statistical projections to ensure the investments are reliable [11]. Hence, to better forecast and quantify the required capital investments, factors that influence growth of distributed generation need to be identified [16]. In summary, the $380 billion dollar industry opportunity combined with significant societal risks calls for an immediate need to improve methods and frameworks which help predict the growth patterns of distributed generation.

2. RESEARCH PROBLEM

This research aims to determine what influence household income has on the adoption of distributed generation, in particular the growth of residential solar panels in California. Existing research focuses on national or global trends of PV studies; no other study has been found that assesses all the service areas of Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E). The scope of this research is limited to the State of California, which is one of the States with the highest annual solar power potential in the United States [17] [18]. Chart 1 shows the number of completed residential PV installation by year in California.

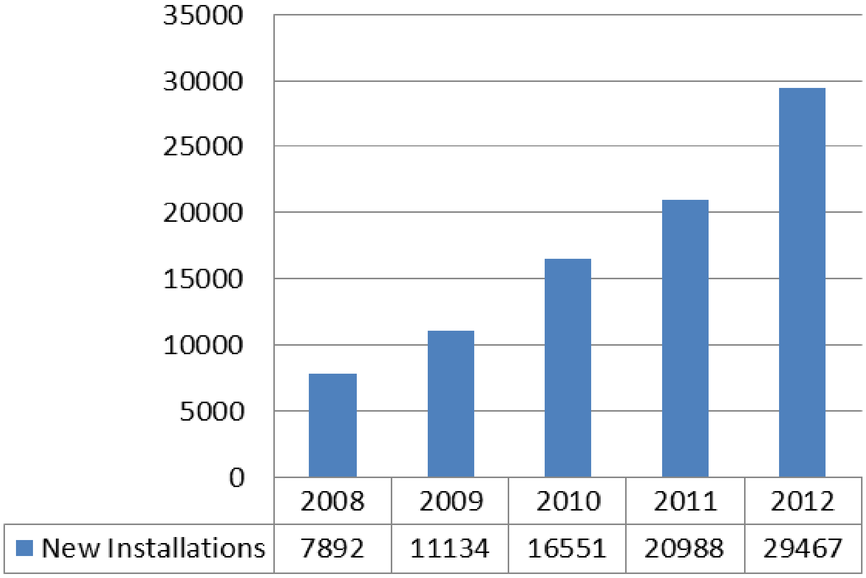


Chart 1. Number of Completed Residential (≥10 kWh) PV Installations by Year in California. Source: *California Solar Institute (2013).*

Furthermore, limiting the scope to California allows for using a unique archival database, the California Solar Initiative (CSI) [19], which has detailed zip code level data on solar panel installations across the state. While conclusions can be drawn about the trend and growth patterns of increased costs for utilities resulting from PV adoption, studies of actual costs incurred are outside the scope of the study. Individual incentives and price mechanisms leveraged by suppliers could skew the results for the PV adoption rate. The diverse demographics within a zip code of Southern California may impair the ability to analyze a homogenous data set and make generalizations for the full population within a zip code. This research was a quantitative study; further qualitative or longitudinal research across several utilities may provide additional insight.

3. DATA SOURCES

106,198 data records of residential (≤10 kW) completed solar panel installations during the years 2007-2013 were obtained from the California Solar Initiative[19] database. All available utilities were included; Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E), which represent about 68 percent of California's electric load. Started but not completed projects were excluded. Large commercial installations (>10 kW) were excluded for the purpose of analyzing correlation with household income.American Community Survey (ACS) data was used to determine Median Household Income levels. ACS replaced the Census for purpose of collecting Household Income data. The ACS provides annual survey data, which does not include data from cities with a population less than 65,000. For the purpose of analyzing a complete set of California Zip codes, the five-year ACS data is used for 2007-2011, withstated median income in the past 12 months, in 2011 inflation adjusted dollars.Since the multiyear estimates represent estimates for the period, the controls are not a single year's housing or population estimates from the Population Estimates Program; rather, they are an average of these estimates over the period. The dataset was downloaded from the U.S. Census Bureau online database [20].

4. RESEARCH METHODOLOGY

Regression analysis was used to establish the relationship between Median Household income and Number of Installed PV units by Zip Code. All PV data was analyzed by year for identifying any trends in the significance of income.Regression analysis was performed to identify any relationship withincome levels for individuals born in the State of California as well as foreign born. Furthermore, to analyze the impacts of any local adoption patterns in high-income areas, the total aggregated number installed PV units by year and zip code was calculated using the completed number of PV installations.

	Hypothesis	Dependent variable	Independent variables
1	Areas with higher income will have higher adoption of PV units	Number of installed PV Units	Median Household Income Median Individual Income
2	Areas with higher median household income and existing installed base of PV units will have higher adoption of PV units	Number of installed PV Units	Median Household Income and Total Number of installed PV units in previous years

Table 1. Hypothesis for PV Adoption.

The two central hypothesesare 1) areas with higher income will have higher adoption of PV units, and 2) areas with higher median household income and existing installed base of PV units will have higher adoption of PV. These two hypotheses are tested with dependent and independent variables are shown in Table 1.

Hypothesis 1 is tested using linear correlation as

$$y_i = \beta_1 X_i + m + \varepsilon_i$$

Where

Y_1 is the expected PV unit growth in the Zip Code
$\beta_2$denotes the regression coefficient for Median household income or Median individual income
X_{i2} is the Median Household income Zip Code
m is a constant and $\varepsilon_i$is theerror term.

For testing hypothesis 2 we use multivariate linear regression [21] represented as:

$$y_{i+1} = \beta_0 + \beta_i x_{i1} + \cdots + \beta_p x_{ip} + \varepsilon_i = X_i^T \beta + \varepsilon_i \quad \text{i=1,…,n.}$$

Where

Y_1 is the expected PV unit growth in the Zip Code
X_i is the total installed PV base in Zip Code
$B_i$denotes the regression coefficient for accumulated installed PV units in Zip Code
$\beta_p$denotes the regression coefficient for median household income
X_{i2} is the median household income Zip Code.
$\varepsilon_i$is the error term.

5. RESULTS AND FINDINGS

The findings of the regression analysis indicate that areas with higher median household income have higher adoption of PV units, which is in support of previous research [9]. Median household income consistently also prove to be a stronger indicator of future PV adoption in comparison to individual income.

Hypothesis 1:

This hypothesis is that areas with higher income will have higher adoption of PV units. It is analyzed with data in Table 2 which shows the correlation between median household income and number of completed residential (≥10 kWh) PV installations by year in California. Chart 2 shows that the correlation between median household income and PV adoption between 2007 and 2013 is 0.37.

	All Years	2007	2008	2009	2010	2011	2012
Median Individual Income in Zip Code Entire Population	0.31	0.27	0.34	0.35	0.32	0.29	0.25
Median Household Income in Zip code Entire Population	0.37	0.32	0.38	0.39	0.39	0.38	0.34
Born in State Median Individual income in Zip Code	0.23	0.20	0.26	0.27	0.25	0.22	0.19
Foreign Born Median individual income in Zip code	0.21	0.20	0.25	0.24	0.22	0.20	0.17

Table 2. Pearson Correlation between Median Household Income and number of Completed Residential (≥10 kWh) PV Installations by Year in California.

In contrast to household income, the Pearson correlation between median individual income and PV installations remains downwards since 2009, from 0.35 to 0.25. Notably it peaks in 2009 before the drop. There is no indication in the CSI data that suggest that income differences in certain demographical groups present a significant factor in PV adoption.

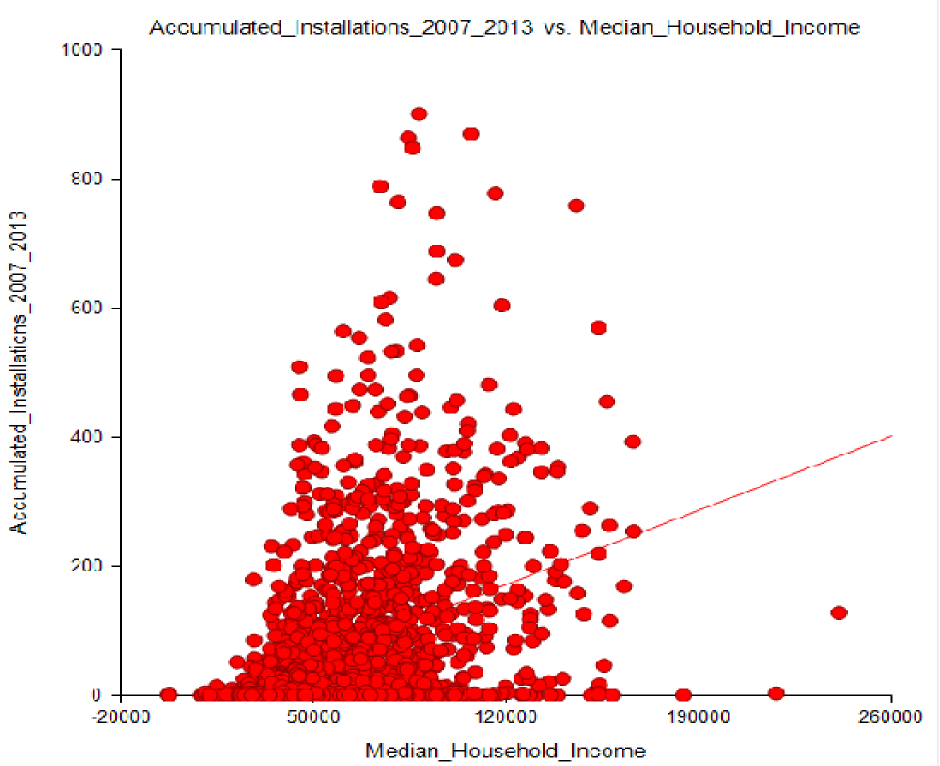


*Chart 2.*The Pearson Correlation between Median household income and PV adoption 2007-2013 is 0.37.

Hypothesis 2

This hypothesis is that areas with higher median household income and existing installed base of PV units will have higher adoption of PV units. It is analyzed with data in Table 3 which shows the correlation between atotal installed PV base in Zip Code and number of completed residential (≥10 kWh) PV installations in subsequent year in California. Chart 3 shows the correlation between total numbers of installed PV units in California Zip codes in 2011 and growth volume of PV units in 2012 in the same Zip codes.

Year (Y)	2008	2009	2010	2011
Correlation (p) between composite median household income installed PV units during year Y in Zip Code with number of PV installs subsequent year (Y+1)	0.67	0.73	0.82	0.81

Table 3. Correlation between atotal installed PV base in Zip Code and number of Completed Residential (≥10 kWh) PV Installations in subsequent year in California.

The results for the second hypothesis indicate that a model including household incomeand installed number of PV units in any given area is an increasingly significant predictor of future PV growth.

Multiple regression analysis gives an estimated model

$$Y_{i+1} = -.028 + 2.172E\text{-}05 * I_i + 1.13 * Y_i$$

Where

Y=number of completed PV installations
I = median household income

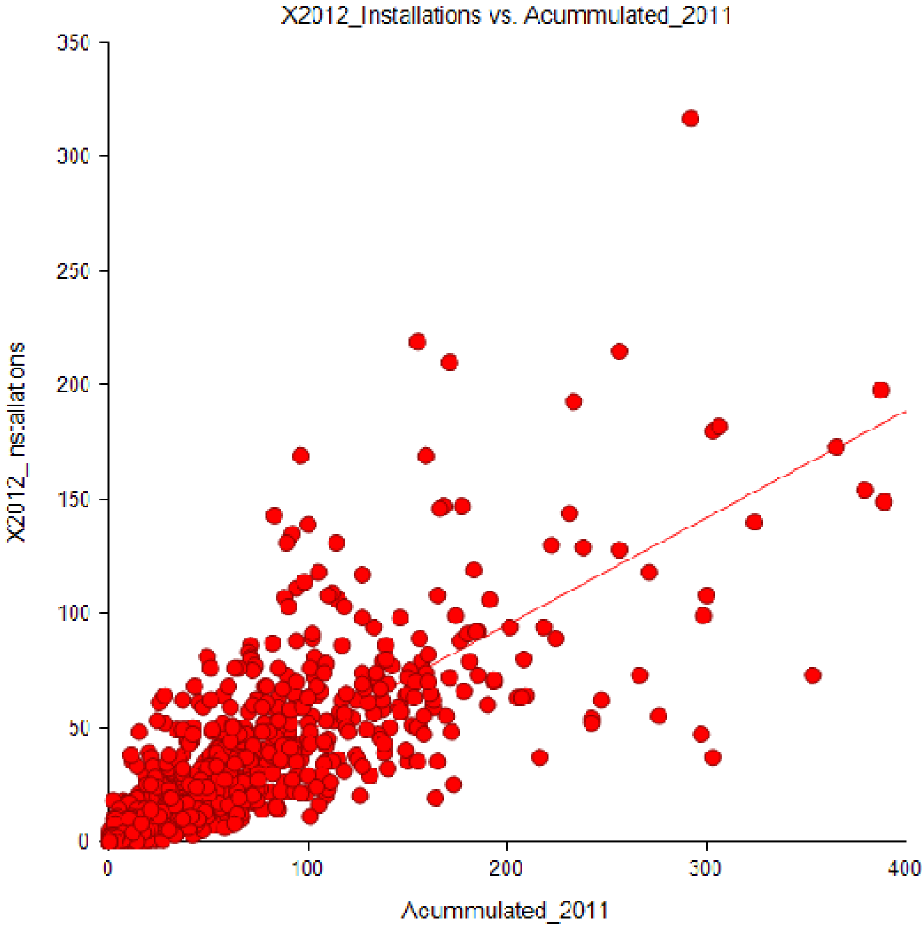


Chart 3. Correlation between total numbers of installed PV Units in California Zip codes 2011 and growth volume of PV units 2012 in the same Zip codes.

Several factors could explain the proliferation of continued PV growth in high-income areas with an existing large installed base, including a 'Neighborhood Factor' driven by peer-influence and targeted vendor marketing efforts.The findings indicate increasingly stronger peer-influence compared toa 2010 studyby Bollinger &Gillingham,(2010)[8], that identified R-squared values up to 0.74 for installed PV base as a predictor for future adoption, using street-level data in a smaller selection of California zip codes.

6. CONCLUSIONS

This research concludes that median household income continues to be a significant factor in predicting adoption of solar panels in the state of California. In contrast, 2007-2011 data indicate that individual median income is becoming less of a significant factor in determining PV growth.

The results can be used to better project revenue growth in the renewables sector as well as enhance predictive analysis around requirements of utility capital investments.While earlier studies have found positive relationships between consumer preference for renewables and age, voter affiliation and, population density, none of the studies included data from utilities in the state of California. No other study has been identified which examines the unique relationships between household income and individual income during this time period. Furthermore, no other empirical study has been conducted using recent ACS Community Survey data for Median Household and individual income (2007-2011) in combination with all available archival data in the California Solar Initiative [19] database.

The study relied only on data related to solar panel installations and does not include other renewable sources, or other types green technology. Since every type of renewable product has unique costs for the consumer, one has to be careful generalizing the results across renewables. While no empirical evidence exists, it is reasonable to assume that not all consumers who purchase solar panels take advantage of the state tax credit program and hence would not be registered in the California Solar Initiative [19] database. Consequently, the data may be skewed to the benefit of consumers who make use of state tax credit programs more actively. Moreover, the financing options available to consumers for purchasing solar panels are constantly changing. Vendors offer programs with low monthly payments, avoiding up-front costs. Data has not been adjusted to mirror the relative cost changes for consumers resulting from vendor incentive programs. The findings of this study will allow both utilities and vendors in California to more accurately predict future growth rates of solar panels. Renewables vendors will benefit from being able to better target consumers in areas likely to purchase solar panels. Utilities will be able to revise their operational budgets for maintenance and prioritize asset upgrades in areas expected to experience higher renewables growth.

From a renewables growth perspective in California, it would be valuable to expand the analysis to include more granular scales around party affiliation, such as the Green Party. Time series regression analysis could be used to determine if changes in voter base follow the same geographical patterns as solar panels. In addition, a model that takes into consideration the importance of home ownership versus apartment complex would allow for additional fine-tuning of predictive models. Finally, to fully understand the impact of these economic indicators, future studies should run time series regression models that also account for the changing financial payment plans and incentives offered by vendors. This would be particularly useful in examining trends at a larger scale, across states and countries.

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