Identification of Target Market Transformation Efforts for Solar Energy Adoption

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Abstract
In recent years, solar energy has been increasing in usage throughout the world, especially in the United States. Market transformation (a concept based on collaborative efforts between industry advocates and policy-makers to increase adoption through economies of scale) plays a fundamental role in expanding the adoption of solar energy. However, there are currently limited resources to identify the optimal locations for increasing the likelihood of consumers interested in investing in solar energy technologies. The objective of this preliminary study is to develop a visual tool to assist with solar energy market transformation. By combining data from National Renewable Energy Laboratory (NREL), the Database of State Incentives for Renewable and Efficiency (DSIRE), and Energy Information Administration (EIA) a unique process and output was created. The factors considered in this study include net metering policies, cost of electricity, and access to solar irradiance. All the factors were considered on a residential level. The findings suggest the top five states with the highest likelihood for successful market transformation include (in order): Hawaii, California, Arizona, New Mexico, and Nevada.

Keywords
Market transformation, Solar energy, and Energy market

1. Introduction
Solar energy has had enormous growth in the United States and throughout the world. In the United States, there are more than two million solar energy systems installed, with an installed capacity of 71,3000 MW (SEIA, 2019). The solar energy sector in the United States employs more than 240,000 people and generates tens of billions of dollars (NASEO, 2019). The United States Bureau of Labor Statistics estimates that the photovoltaic solar installer will be the fastest-growing job between 2018 and 2028 (Bureau of Labor Statistics, 2020). Along with the increase in the adoption of solar energy comes the development of new technologies, the formation of new companies, and the development of the energy sector. Thus, with the rapid growth of the solar energy sector, it is essential to have tools and resources that maximize the benefits of all stakeholders. Market transformation (a concept based on collaborative efforts between industry advocates and policy-makers to increase adoption through economies of scale) plays a fundamental role. Given that adoption policies can vary by state, its important to understand how location (e.g., net metering policy, cost of electricity, and access to solar irradiation) can influences the likelihood of market transformation and adoption of solar energy technologies.

The goal of this preliminary research study is to develop and showcase a visual tool to assist stakeholders, including industry advocates and policy-makers, as they move forward with their own efforts to increase solar energy adoption. To achieve this objective, data from three sources are used: National Renewable Energy Laboratory (NREL), the Database of State Incentives for Renewable and Efficiency (DSIRE), and Energy Information Administration (EIA). Solar irradiation data was collected from NREL. Data about state net metering policies was obtained from DSIRE. Data on electricity costs was collected from the EIA. A map chart tool will be used to create maps that will contain all three factors combined: net metering policies, cost of electricity, and solar irradiance. The resulting maps can be used as a tool for solar energy policies, in particular for the government programs related to solar market transformation.

2. Background Literature Review

This section will provide a brief overview about market transformation, solar energy, electricity rates, electricity market regulations, and net metering policies.

2.1. Market Transformation

The market transformation includes two relevant factors, on the one hand, the objective of a policy and the strategy of a program. In both cases, the aim is to modify the behavior of the market through programs that seek the use of new and more efficient technologies in energy terms (Blumstein, Goldstone, & Lutzenhiser, 2000; Geller & Nadel, 1994; York & Paulos, 1999). In recent years, the energy sector has undergone significant changes that involve the use of new technologies, consumer engagement, and new energy products and services. Public policies and regulatory frameworks play an essential role in the transition of the energy market. Particularly the increase in solar energy has created new opportunities for a transition to cleaner and more decentralized energy sources (Doris & Gelman, 2011).

2.2. Overview of Solar Energy

Hantula provides an overview of solar energy in the United States and conveys a basic understanding of photovoltaic solar power systems (Hantula, 2009). In recent years, photovoltaic panels have increased their efficiency and decreased their costs. Solar panels transform the electrons from the sun to create continuous currents. Powerfully through an investment that converts direct current into alternating current that can be used in the home. Finally, the excesses can be stored in batteries or be injected into the grid in the case of having net metering programs (Sampaio & González, 2017).

2.3. Electricity Rates

The price of solar panel systems is decreasing in the United States. Still, because of the high relative costs such as installation and other component prices, consumers are not taking advantage (Goodrich, James, & Woodhouse, 2012). Because of the high supply of energy sources as well as weather conditions such as warm winter, rates were lower than in previous years. The year 2015 was the first year that natural gas power generation was more than coal power generation in US history (Staff, 2016). The price of electricity depends on several factors: location, time of year, consumption if the client is regulated or deregulated. Each state has different electricity prices. The average price in March 2020 for the residential sector was 13.08 cents per kilowatt-hour. There are various cost structures that retail companies can use. For example, the tariff structure that increases the cost as the consumer uses more energy. On the other hand, there are cost structures that depend on the time of day. There are time ranges where the electric rate is more expensive.

2.4. Electricity Market Regulation

In the United States, retail markets can be traditionally regulated or competitive. The decision depends on each state. In the traditionally regulated market, customers can not choose their energy providers. Traditionally regulated electricity markets dominate most of the Southeast, Northwest, and much of the West (excluding California). On the contrary, in competitive markets, customers are allowed to choose their electricity providers. Twenty-four states have adopted the competitive market, most of the states of the northeast, California, and Texas (Flores-Espino, Tian, Chernyakhovskiy, Chernyakhovskiy, & Miller, 2016).

2.5. Net Metering Policies

Schelly and colleagues analyze interconnection, and net metering policies within investor-owned utilities. After the Energy Policy Act of 2005, most states in the United States require energy companies to allow net metering. For consumers to take advantage, they must have interconnection and alternative power sources (Schelly, Louie, & Pearce, 2017). Distributed generation refers to the decentralization of energy sources from a single source such as an energy utility company to multiple consumers providing energy into the grid by means such as solar panels. Even though distributed generation prevents the purchase of fossil fuels which in turn reduce CO2 emissions and creates jobs for thousands, the influence of utility companies in states limits this alternative method of energy production. Because the Federal Energy Regulatory Commission (FERC) does not set legal guidelines for all the states, net metering policies are not fully utilized (Rodriguez-Fierro, 2017). Net metering allows users who have excess energy production to inject it into the local network. The energy returned to the electricity grid can generate credit for the consumer, which can then be exchanged for energy bills when the consumer needs to extract energy from the grid. The value of the energy injected into the grid will depend on the policies of each state.

3. Methods

3.1. Data Collection

Data was collected from credible and reliable sources, including the National Renewable Energy Laboratory (NREL), the Database of State Incentives for Renewable and Efficiency (DSIRE), and Energy Information Administration (EIA). The National Renewable Energy Laboratory or NREL provides all the data on Direct Normal Irradiance or DNI (National Renewable Energy Laboratory, 2019). This data is derived from their website, which also offers a graphic map showing solar irradiance around the United States. NREL is managed by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy by the Alliance for Sustainable Energy, LLC.
Database of State Incentives for Renewable and Efficiency or DSIRE provided almost all the information on state regulations on net metering (N.C. Clean Energy Technology Center, 2019). DSIRE started in 1995 at N.C. Clean Energy Technology Center at North Carolina State University, they are funded by the U.S. Department of Energy. Their goal is to inform stakeholders such as homeowners, businesses, solar companies, policymakers, and advocacy groups on clean energy regulations. As NREL researches the science behind solar energy, DSIRE researches policy and presents their findings in public as well as online on their website.
Energy Information Administration or EIA is an independent agency of the Department of Energy (Energy Information Administration, 2019). They provided information on the average cost of electricity from state to state. Their mission is to promote reasonable policymaking, efficient markets, and inform the public on energy usage. The EIA was established in 1974. They host presentations on their findings as well as maintain a website so the global audience can study their research.

3.2. Data Analysis

Various technologies allow the visualization of statistical data on geographic maps, such as GeoChart, GeoMaps, Google Visualization, and 3D Maps (Król, 2016, 2019). The data analysis relied heavily on the map chart tool to create individual factor maps that allow each state to be compared. Numerical equivalence was applied to categorical DSIRE net metering data in order to create a unique map and integrate it into the combined factor map.
Map chart tools works by identifying country names or country states and then adding color to a map template. Color is added based on categories or number containers. For both methods, colors can be chosen to be a scale of the same color or a wide range of variable colors. The spreadsheet has two columns; one with the names of countries or providences and the other with numbers or categories. Numbers are parsed to have containers of equal sizes, such as auto-generated histograms. The containers are then colored in the map template. In this investigation, state names and data values are used to create maps. They are color scaled to show the increasing value of the data points.
About the net metering provided by DSIRE, net metering data was provided in a categorical format. In some cases, numerical values were missing; thus, assumptions had to be made. For some values, the maximum is 100% of a user's energy needs. Average monthly energy consumption was found using EIA data. Multiplied by the average kilowatts obtained by the solar panels, the calculations found the average energy consumption of a user. Others were given values of 0 due to the lack of state regulation on net metering. Then, from all these values, five categories were created to compare the net metering. States with a value of 5 have the best net metering policies, which means they get the most credit for energy. States with a value of 1 have a lower limit on their potential energy credit.
The combined factor map was created by summing at the z-scores of each category for each state. The cost of electricity z-scores was inverted (i.e. 1 becomes -1) to allow higher costs to take a more significant portion out of the total. The states with the highest sum have the best circumstances for solar energy net metering. Each of the factors included a "weighted" value. The global horizontal irradiance (GHI) measures how much solar energy is hitting a specific are. The residential cost of electricity is in cents per kilowatt-hour. The net metering factor corresponds to the maximum amount of energy that a prosumer is allowed to receive credit for the energy produced. Another variable relates to net metering was created to measure the maximum amount of residential net-metered energy in each state.
Each of the variables was standardizing using z-scores for each state. Finally, the combination of the factors corresponds to the summation of each of the z-scores for net metering, electricity cost, and global horizontal irradiance. The combination of the variables is put together on a single map.

4. Results

This section shows the results obtained from the data analysis and construction of the map charts for the net metering, cost of electricity, global horizontal irradiance, and the combination of the three variables.

4.1. Net Metering Maps

The residential net metering map, shown in 1, was created by using DSIRE's net metering data for each state and map chart tool. The legend shows practical categories by placing each state in a number 1 through 5 with 5 representing the optimal locations and 1 representing the limited locations. Each category is roughly ten states in order to better compare state to state. Table 1 shows the states with the best net metering policies. The second column shows the maximum value of energy that a consumer can receive on credit, and the third column shows the category assigned to each of the states. The five states with the worse residential net metering are Texas, Tennessee, South Dakota, New Jersey, and Alabama. None of them have statewide regulation on net metering.

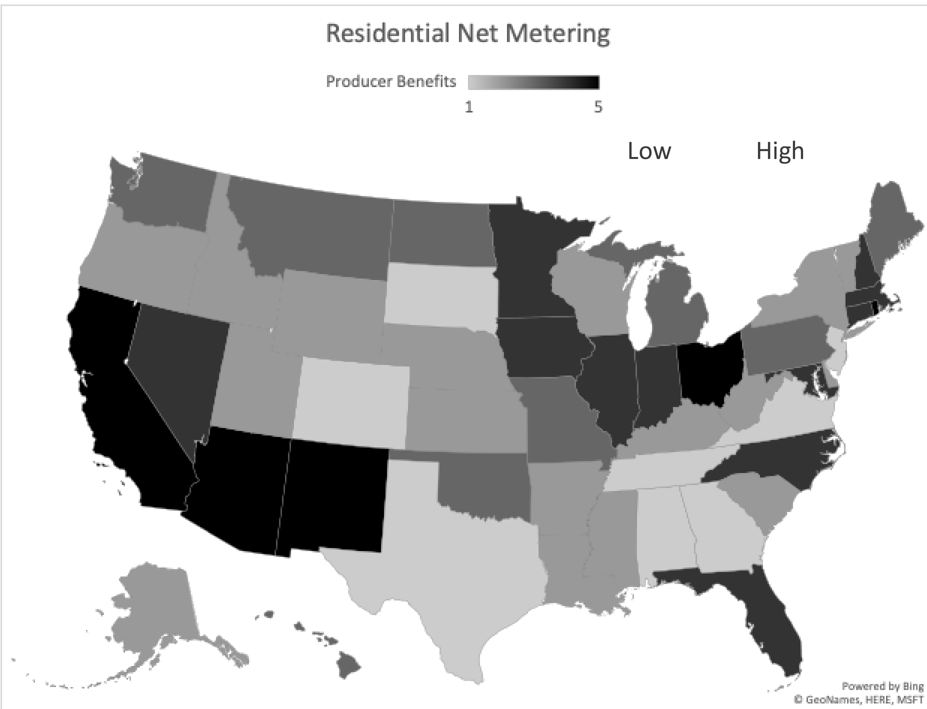

Figure 1: Residential Net Metering Map

Table 1 States with the best net metering policies

State	Maximum energy credit (kW)	Net Metering Category
New Mexico	80000	5
California	48183	5
Rhode Island	10000	5
Arizona	8608	5
Ohio	7225	5

4.2. Cost of Electricity Maps

The residential cost of electricity map, shown in figure 2, was created by using NREL's electricity cost prices and map chart tool. The legend shows the cost of electricity in cents per kilowatt hour. The five states with the most expensive costs are Hawaii, Alaska, Connecticut, Massachusetts, and New Hampshire. Table 2 shows the states where the cost of electricity is the highest with values between 32.48 and 19.20 cents per kWh. The five states with the least expensive costs are Louisiana, Washington, Arkansas, Idaho, and Oklahoma.

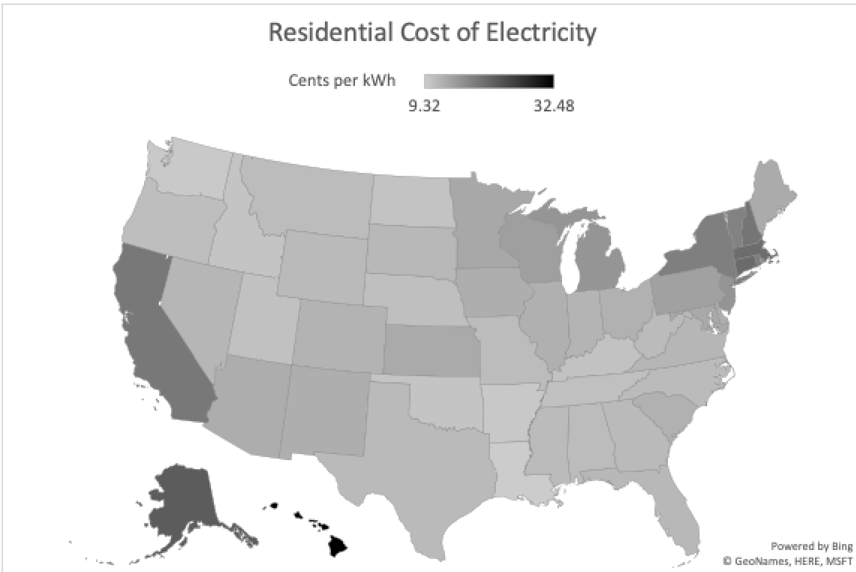

Figure 2: Residential Cost of Electricity Map

Table 2 States with higher electricity cost

State	Electricity Cost (cents per kWh)
Hawaii	32.48
Alaska	22.06
Connecticut	20.29
Massachusetts	20.06
New Hampshire	19.2

4.3. Solar Irradiance

The solar global horizontal irradiance map is shown in figure 3. The legend shows the average watts per meter squared (W/m^2) for each state. The higher value means more solar energy. The five states with the best are Arizona, New Mexico, California, Hawaii, and Nevada. Table 3 shows the GHI value for the five states with the highest values. On another hand, the five states with the worse are Maine, Vermont, Nebraska, New Hampshire, and Minnesota.

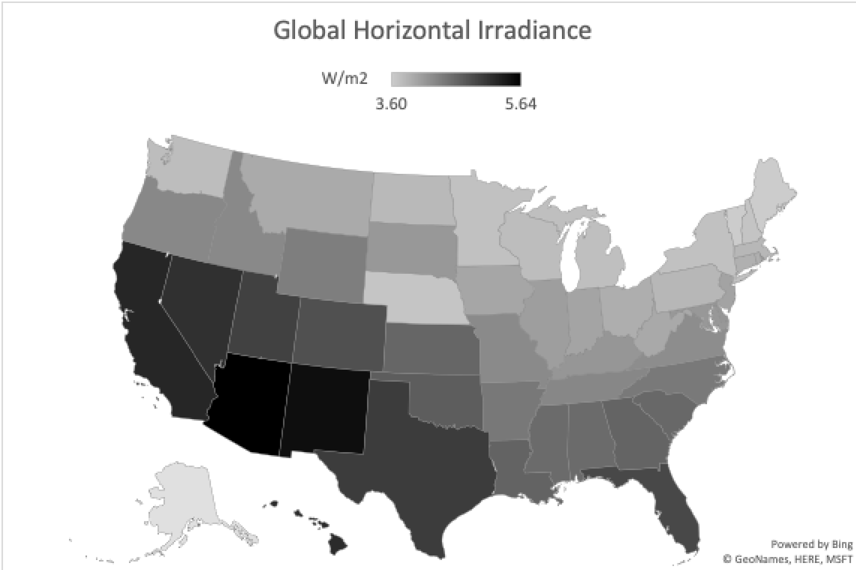

Figure 3: Solar Irradiance Map

Table 3 States with higher GHI

State	GHI (W/m^2)
Arizona	5.64
New Mexico	5.50
California	5.26
Hawaii	5.22
Nevada	5.16

4.4. Combined Maps

The map chart in figure 5 shows a combination of the three variables used in the previous sections: net metering, cost of electricity, and global horizontal irradiance. The legend shows that the darker shades represent locations where the transformation of the market is most likely to be successful. In contrast, the lighter tones represent the locations where the market transformation is least likely to take place. The top five states, in order, are Hawaii, California, Arizona, New Mexico, and Nevada. Table 4 shows the z-score values for each of the analyzed variables. The state of Hawaii has a significant difference compared with the other states in the value of the combined z-score due to the high cost of electricity. The five worst states are Alaska, Nebraska, South Dakota, Tennessee and Virginia.

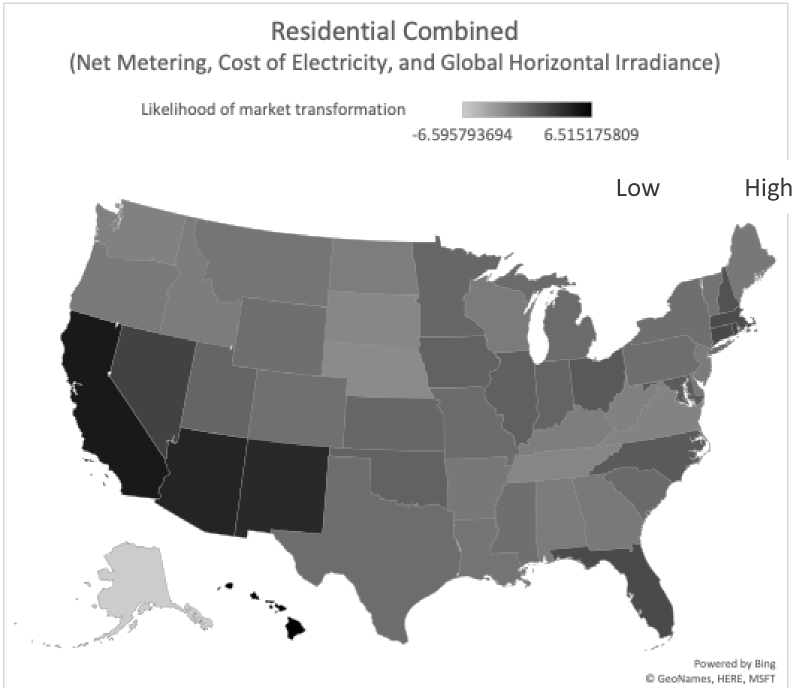

Figure 4 Residential Combined Factor Map

Table 4 States with a higher likelihood of market transformation

State	Z-Net metering	Z-GHI	Z-Electricity cost	Z-Combined
Hawaii	0.1913	1.7364	4.5875	6.5152
California	1.7855	1.8239	1.3114	4.9209
Arizona	1.7855	2.5370	-0.1505	4.1720
New Mexico	1.7855	2.2777	-0.1722	3.8910
Nevada	0.9884	1.6409	-0.3869	2.2424

5. Discussion and Conclusions

The maps created are beneficial to advocates of the solar energy industry. The government could access this data for the generation of new programs related to solar energy and the transformation of the market. These programs can be at the state or federal level, as needed. At the same time, new business ventures could access this data to help target future customers. Knowing the places where photovoltaic installations would be most successful will end up maximizing benefits and accelerating the transition to cleaner energy with fewer emissions of polluting gases and more efficient. Given this is a preliminary study, future research will be considered. One of the possible expansions of this research would be to use more factors to consider. Depending on the user, climatic factors could be taken into account. Some geographic locations have more hail and snow that could wear down the panels faster than places with drier climates. Snow-covered PV systems increase the forecast error of system performance (Bosman & Darling, 2018). These climatic variables could have a significant impact on the performance of photovoltaic systems, therefore reducing the benefit perceived by residential customers. Because the cost of installing solar panels is similar across the United States, maintenance costs are more important than upfront costs. Maintenance costs vary according to the commercial offer that exists in each of the states, as having a lower offer, the prices would be higher. Maintenance costs would significantly impact the operation phase of photovoltaic systems. Currently, PV systems owners need predictive maintenance tools to optimize the investment made in solar panels (Bosman, Leon-Salas, Hutzel, & Soto, 2020). So mixing maintenance tools with the maps presented will be benefits users of PV energy. Another possible factor that could substantially affect these maps is the cost of the land. In high-population-density areas like New York and Los Angeles, the land is expensive, so people do not have room to install solar panels. Also, the study can be expanded to include other energy policies such as policies around microgrids and peer-to-peer trade. At the same time, the displayed maps can be created at a more granular level, evaluating counties, cities, or specific regions. Besides, future researches can include other countries and add other users, such as commercial and utility organizations. Additionally, some of the factors may have more weight than others, depending on the particular interests of the stakeholders. Besides, statistical models can be created for variable selection and weight assignment. Finally, this study is the first step in creating visual tools with statistical information to identify the states that are most likely to undergo a successful transformation of the solar energy market. In addition, the maps allow policy-makers to determine where it needs to develop new programs and policies to intensify the use of solar energy, allowing for a faster transition to the use of clean energy.

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Biographies

Esteban Soto has a master's degree in Industrial Management and a bachelor's degree in Industrial Engineering from the University of Concepcion, Chile. He is currently pursuing a Ph.D. in Technology at Purdue University. Before beginning his doctoral studies, he worked at the Ministry of Energy of Chile in charge of the implementation of the Energetic Efficiency program in the Biobio Region. Soto is a co-founder and former CEO of a startup that works on the development of new technologies to reduce emissions of particulate matter produced by the combustion of biomass. His research areas of interest include renewable energy, solar energy, and new models for exchanging energy among peers.

Keita Arakawa is a third-year undergraduate at Purdue University studying Industrial Engineering Technology with a minor in Statistics. His vision for the future includes a broader usage of alternative energy in daily life which fuels his research projects as a student. Arakawa's research has been published in the Journal of Purdue Undergraduate Research. In addition, he mentors peer undergraduate researchers through the Purdue University Honors College. In his free time, he leads exercise classes at the university wellness center. In the future, Arakawa plans to focus his efforts on the implementation of Kaizen philosophy in the workplace by researching its effects on the employees.

Dr. Lisa Bosman, PhD in Industrial Engineering, is an Assistant Professor within the Purdue Polytechnic Institute (formerly, the College of Technology) at Purdue University. Dr. Bosman's engineering research focuses on the development of information systems to enable the integration of grid optimization, solar energy performance modeling, and decision making. Prior to joining higher education, Dr. Bosman spent several years working in industry as a manufacturing engineer with well-known companies including Harley-Davidson Motor Company, John Deere, and Oshkosh Truck. Dr. Bosman has authored over 50 publications in international and national journals and conferences. In addition, she has obtained over $1M USD in research funding from agencies including the National Foundation (NSF), Environmental Protection Agency (EPA), and the National Aeronautics and Space Administration (NASA). She has been an invited speaker and workshop facilitator for over 20 engagements.