Diffusion Dynamics of Clean Energy Technologies in Residential Built Environments

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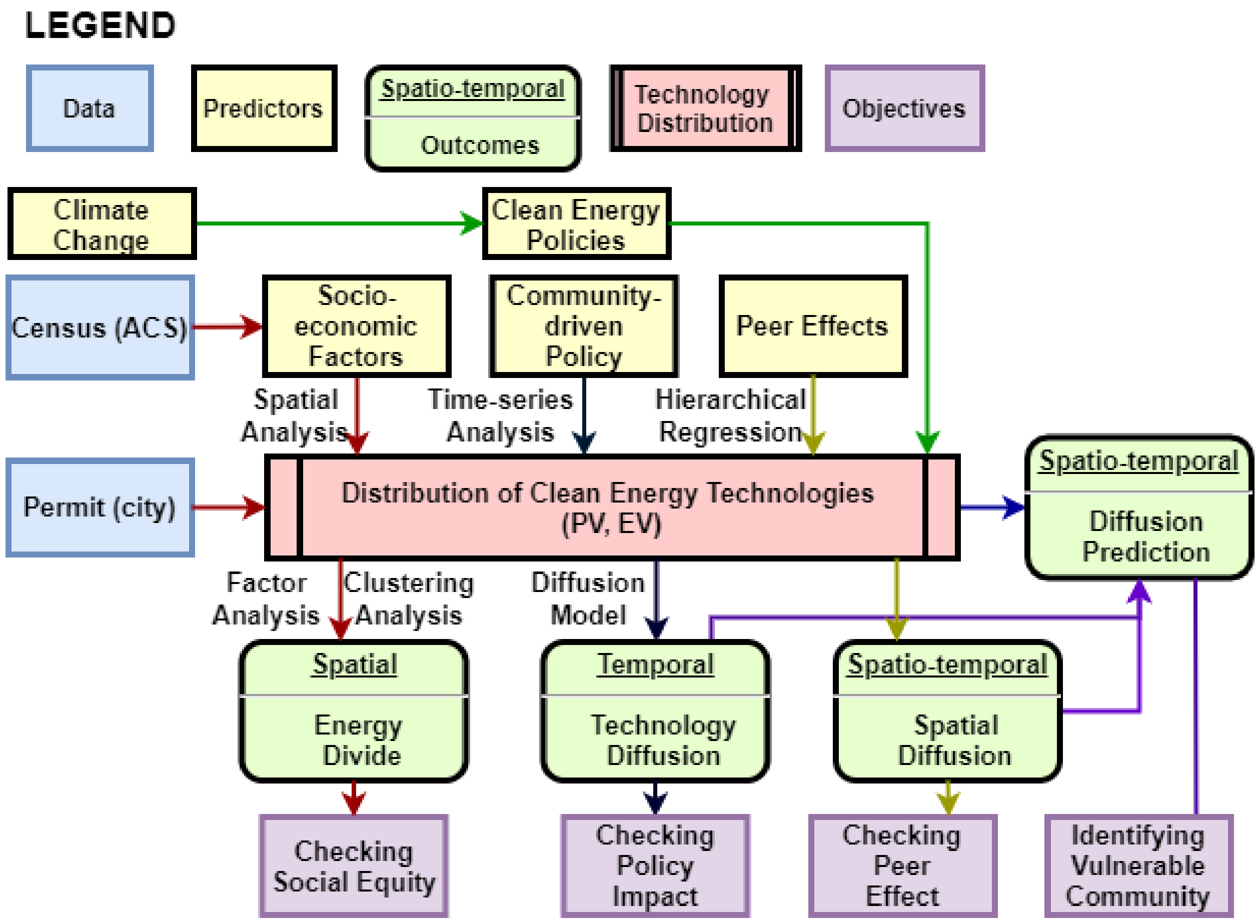
Abstract

The recent global climate change has led to the development of various clean energy polices and technologies. Clean energy technologies are proved to increase resiliency in response to the interuption from climate change. However, two concerns have been raised with the current rapid transition of energy systems. First, the transition can inadvertently lead to uneven distribution, and accordingly have the potential to significantly impact on how communities respond to any undesirable climate change-related events. Uneven distribution of the new energy systems could be described as "energy divide" (inequalities in access to energy services) which is the similar to "digital divide" in the late 20th century where uneven distribution of telecommunication infrastructure caused social equity issue where social equity is defined as equal opportunities for different people living in different places. Second, reliability of power supply for the community can inadvertently be affected by the intermittent power generation of photovoltaic (PV) systems and uncertain charging schedules for electric vehicles (EV). Especially regions with higher decentralization trend need attention due to lack of active generation and demand connected. In response to the two concerns, this proposal aims to study diffusion dynamics of clean energy technologies (PV and EV) in the residential built environments. The study targets to help policy makers to better support underserved communities under limited resources by devising equitable clean energy policies while promoting distribution in consideration of appropriate boundaries of reliable electrical system in regard to clean energy technologies. The objectives of the proposed research include:

1. To investigate the current status of distibution of clean energy technologies (PV and EV) and their relationship with socio-economic characteristics;
2. To validate policy interruption impact on their diffusion dynamics;
3. To identify any peer effects on diffusion trends; and
4. To develop a robust spatiotemporal prediction model based on the identified significant factors, which can help identify the most vulnerable communities with regards to the uneven and unbalanced distribution of clean energy technologies.



1. Social Equity in Clean Energy Policies

Clean energy technologies have been introduced and utilized all over the world seeking more reliable and sustainable energy systems in response to climate change. This rapid transition to the new energy system could lead to undesirable impacts on some communities as shown in the case of telecommunication where the digital divide has excluded vulnerable groups of people from knowledge-based societies and economies (Chen and Wellman 2004). In fact, European Union (EU) has already experienced that the uneven deployment of energy poverty and social distribution are correlated where spatial and social distribution is highly uneven (Bouzarovski and Tirado Herrero 2017). In this context, it is necessary to review how residential PV and EV are spatially distributed with a goal to understand the spatial trends of how clean energy policies and incentives have been implemented. This may help identify issues related to social equity; uneven distribution may indicate particular communities being left out from the recent distribution of clean energy technologies, particularly those who are more vulnerable to the climate change.

Methodology

While a number of studies have investigated various aspects of the policies designed to support PV system and EV charger installations, there is still a dearth of studies aimed at investigating the impact of such policies on social equity. Two unanswered questions have emerged: (1) were there certain communities inadvertently left out from incentive opportunities? and (2) do those current policies help to encourage the social equity in clean energy technologies? To answer these questions, the research aims to perform a spatial analysis of the distribution of PV and EV charger installed-buildings in terms of housing and socioeconomic characteristics based on the census tracks of Seattle, WA. In particular, this research aims to explore patterns of the residential (single family and multifamily) regarding PV systems and EV chargers by examining spatial clustering and associations among variables through several data sources. The examined data entails the socioeconomic and housing characteristics based on the American Community Survey of the census.

- Task 1: Map clean energy technologies (PV and EV) to verify distribution patterns
- Task 2: Find the latent variables using Factor analysis
- Task 3: Verify the suitability of the latent variables using clustering analysis
- Task 4: Find the relationship between the distribution patterns and the latent variables using spatial autocorrelation regression model
- Task 5: Find the sensitive communities to each latent variable using Geographically Weighted Regression (GWR)

2. Policy Impact/Peer Effect on Diffusion (PV and EV)

This research is based on a premise that the diffusion of clean energy technologies is largely impacted by two factors: policies and peer effect. First, Clean Energy Transformation Act (CETA) was signed into law by the Governor of Washington in 2019 to remove greenhouse gas emission from electricity supplies by 2045. It plans to eliminate coal power plants by 2025, at least 80% of electricity should be renewable or non-emitting while up to 20% could be alternative compliance option, and finally 100% of electricity should be renewable or non-emitting by 2045. Furthermore, RCW 19.405.120 focuses on low-income energy assistance by requiring utilities in Washington to provide energy assistance funding and programs to low-income households from July, 2021. In this trend, local agencies have been playing the important role. For example, Solarize Northwest is a community-driven, neighborhood group purchase campaign from Spark Northwest (Northwest Sustainable Energy for Economic Development), a 501(c)3 non-profit organization aimed at creating communities of locally-controlled clean energy by Solarize campaigns in cooperation with community organizations, solar contractors, utilities, city governments, and solar lenders. Communities take part in the program by attending workshops, getting site assessments, and contracting for installation. Second, economic incentive differences influence the spatial and temporal patterns of PV adoption while significant spatial spillover effects were found between neighboring counties (Dharshing 2016). Neighboring effect on diffusion of clean energy technologies could be discussed in terms of peer effects which refer to externalities in which the chacteristics or actions of a reference group affect an individual's behaviour or outcomes (Ryan 2017). Peer effects on diffusion of clean energy technologies could be investigated by the spiilover effects between neighboring communities or in terms of individual's surrounding local built environments. In particular, PV is normally installed on the rooftop, visibility of PV could affect neighbor's decision on PV adoption. In this regard, visibility of clean energy technologies could be considered to be passive peer effects while positive word of mouth is categorized to active peer effects. Both of active and passive peer effects were found to influence PV adoption in Texas (Rai et al. 2013).

Methodology

Washington State CETA features social justice and assistance to low-income housholds. It aims at not only equitable distribution of benefits, reduction of burdens to vulnerable communities, but also public health, environmental benefits, and energy resilience. Furthermore, CETA requires that all utilities in the state implement energy assistance funding and programs to low-income households by means of bill reductions and weatherization, energy efficiency, and ownership in distributed energy resources. In this regard, it is necessary to investigate how clean energy policies, programs, or campaigns can affect diffusion of clean energy technologies in different communities. In particular, Solarize Northwest campaign impact on diffusion in Seattle will be investigated using time series analysis including interrupted time series (ITS). This analysis will verify the impact of the campaign on communities with respect to diffusion of PV compared to EV in Seattle. In addition, peer effects on diffusion of clean energy technologies will be investigated to understand how the visibility of PV and EV can influence diffusion of the technologies. The questions are: (1) does the community-driven campaign affect diffusion of PV and EV? and (2) does the passive peer effects of PV visibility affect diffusion in the community?

- Task 1: Find diffusion trends of clean energy technologies (PV and EV) for each neighborhood over the years
- Task 2: Indicate the policy interruption (such as incentive program) on the diffusion trends of clean energy technologies
- Task 3: Analyze the interruption impact of the policy to diffusion using time series models
- Task 4: Analyze the peer effects of neighboring built environments on diffusion using hierarchical regression models

3. Identifying Vulnerable Communities with Uneven Distribution in Spatiotemporal Aspects

Reliability of energy supply has proven to be important especially during emergency situations when, for example, medical services are in high demand. Furthermore, about 1.1 billion people lack access to electricity and 52 billion USD annual investment is needed for the Sustainable Development Goals (SDGs) (IEA 2017). Lack of electricity affects more vulnerable people such as patients. Hurricane Maria caused additional deaths in Puerto Rico in 2017, especially to those who relied on respirators powered by electricity (Robles et al. 2017). It is known that Maria incurred the longest blackout with more than 100 days in the US history (Irfan 2018). Respiratory patients are more vulnerable to power outages that mortality and respiratory hospital admissions increased significantly during the blackout (Lin et al. 2011). These studies and reports suggest that reliable power supply is essential to those vulnerable communities. To that end, decentralized energy network has potential to improve the energy accessibility, and has been increasing due to efficient end-use appliance and low-cost photovoltaic supported by information and communication technologies (ICT) and virtual financial services (Alstone et al. 2015). However, 1.3 billion people currently lack access to electricity, and experience barriers to mobilize the decentralized energy networks to local level.

Methodology

Installations of PV systems and EV chargers are expected to increase, which leads to interruptions to the local electrical grid. To that end, it is important to indentify vulnerable communities in terms of rates of the technology penetrations in different communities. The questions are: (1) what would be the trends of diffusion of PV and EV in each community? and (2) where are the communities that the stakeholders such as policy makers and local utilities should pay attention with respect to the rapid increases of PV and EV? For these questions, this research aims to conduct machine learning techniques to predict diffusion of clean energy technoglogies on socioeconomic features, policy interventions, and peer effects. The predicted diffusion will be matched with target communities as a way to identify relatively vulnerable communities in terms of diffusion of clean energy technologies.

- Task 1: Verify importance of identifying communities with higher decentralization trend
- Task 2: Identify methods to best predict the diffusion of clean energy technologies in consideration of the identified significant factors: socio-economic characteristics, policy interventions, and peer effects
- Task 3: Develop a robust prediction model to identify vulnerable communities with regards to clean energy technology distribution

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