Designing Automated Cleaning Solutions for Residential Solar Panel Systems

Mutual Shaping of Residential Solar Technology and Stakeholders in the United States

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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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General Research Problem: Reducing Climate Change through Increased Solar Energy Adoption

How can residential solar energy adoption be increased to reduce the effects of climate change?

Climate change has spawned a global effort to reduce greenhouse gas emissions and reduce the worsening effects of climate change. Although climate change is already damaging and destroying coastal areas worldwide, disrupting the lives of millions, the efforts to reduce greenhouse gas emissions has lagged due to slower progress in sectors of the global economy. One of these is the power and energy sector, which still relies heavily on burning greenhouse gas emitting hydrocarbons like coal, oil, and gas.

Although alternative forms of energy such as nuclear, wind, solar, and hydropower are being constructed at faster and faster paces, there are technical, land, and socio-political limitations on these centralized power generation projects. Around the world in general and in the US especially, there is an effort to exploit the roofs of homes to place solar panels and increase renewable energy production. In 2021 around 49 million MWh of power was generated from residential, business, and other small-scale facilities (*How Much Solar Energy Do Homes Produce?*, 2022). Despite this being less than 1% of all the energy generated in the United States, the industry is rapidly growing. For example, the amount generated in 2021 was already four times more than that generated in 2014 (*How Much Solar Energy Do Homes Produce?*, 2022). Although the technology is inherently limited to regions that get adequate sunlight, the distribution is less centralized, and it can still positively contribute to a diverse energy generation mix for a resilient and climate friendly future.

While residential solar ("rooftop solar") offers promise, there are considerable technical, social, and political challenges that hinder adoption of this technology. The group's technical project will focus on solving issues regarding residential solar panel cleaning/maintenance and long-term efficiency. Dirty solar panels can reduce generation efficiency. Despite this, current methods to clean solar panels and restore efficiency rely heavily on time-intensive and labor-intensive cleaning sessions that increase long-term lifecycle costs. A safe, effective, automatic, and long-term affordable solution must be developed to maintain peak solar panel energy generation potential. The impact of increasing residential solar system efficiency is promising, but to properly benefit society such a system must consider the social and political aspects to the core solar solution and be properly anticipated for.

The overall project will also investigate how various stakeholders have affected and in turn been shaped by the residential solar technology throughout the modern history of the solar movement. This is because how actors have acted in the past will influence and guide how said actors will interact with the system in the future. This STS question will in turn lead to current developments and effectively imagine potential improvements to the social context and technical aspects in Virginia to further push a decarbonized future.

Designing Automated Cleaning Solutions for Residential Solar Panel Systems

How can a system be designed that automatically and affordably cleans solar panels on roofs?

The problem at hand is that innovations in residential solar technology have outpaced the industry's innovations in maintaining said technologies. Currently, commercially available photovoltaic (PV) panels have just over doubled in system efficiency from 10% in 1985 to over 20% today (Han, n.d.). Even more impressively, PV unit costs have consistently decreased over time. From 1980 to 2012, total overall unit costs decreased 97% (Chandler, 2018) and since 2010 there has been a 64% decrease for RS systems in particular (*Documenting a Decade of Cost Declines for PV Systems*, 2021). Despite these remarkable improvements, system efficiency can decrease over time due to environmental factors. In the United States, solar panels can lose up to 7% of their energy generation annually if not cleaned (Hicks, 2021). Bird droppings, debris like leaves, and dust and dirt can build up and decrease energy generation.

Current solutions for cleaning residential solar (RS) projects mainly consist of labor and time-intensive manual cleanings occurring at semi-regular instances, typically recommended at once or twice a year (*Do I Need to Clean My Solar Panels?*, 2016). Rainfall can extend the times between cleanings, but rainfall can be less frequent in the sunniest places in the US like the southwest regions. In addition, rain itself can deposit minerals and particles it draws from local air conditions while falling (*Do I Need to Clean My Solar Panels?*, 2016).

Although the costs of these cleanings are minor relative to the cost of the system, they present a recurring and accumulating "soft cost" for homeowners. Soft costs such as maintenance, permitting, and overhead can account for up to 65% of the total system costs (*Solar Soft Costs Basics*, n.d.)! An affordable and automated system that can regularly clean solar panels would provide greater overall system efficiencies than potentially inconsistent manual cleanings and lead to long-term increased power generation. Although there are automated cleaning solutions for solar panels currently on the market, virtually all of these are marketed towards commercial solar farms. Most said services or products involve expensive robots (*Solar*

Panel Cleaning Technology - Solabot, n.d.) or water-intensive sprinkler systems (*Residential Solar Panel Cleaning Systems| Heliotex*, n.d.). This project will address the gap in automated cleaning solutions for the RS market.

On a team level, this technical problem matters because it will further the team's design, testing, and system integration skills. The team earlier in the semester had gone through a comprehensive ideation, brainstorming, and points-based selection process. From this, the team is planning on creating a scale prototype instead of a full-scale model for testing and funding purposes. Once a scale model as seen is tested and improved upon, the team plans to build a full-scale model. For the scale model, the team is planning on sourcing some components from third-party suppliers. This will involve close collaboration between team members to create a working prototype while balancing the constraints of proprietary parts with "off the shelf" generic components. Technologies and techniques such as additive manufacturing, rapid prototyping, and mechatronics will be used in pursuit of a working proof-of-concept.

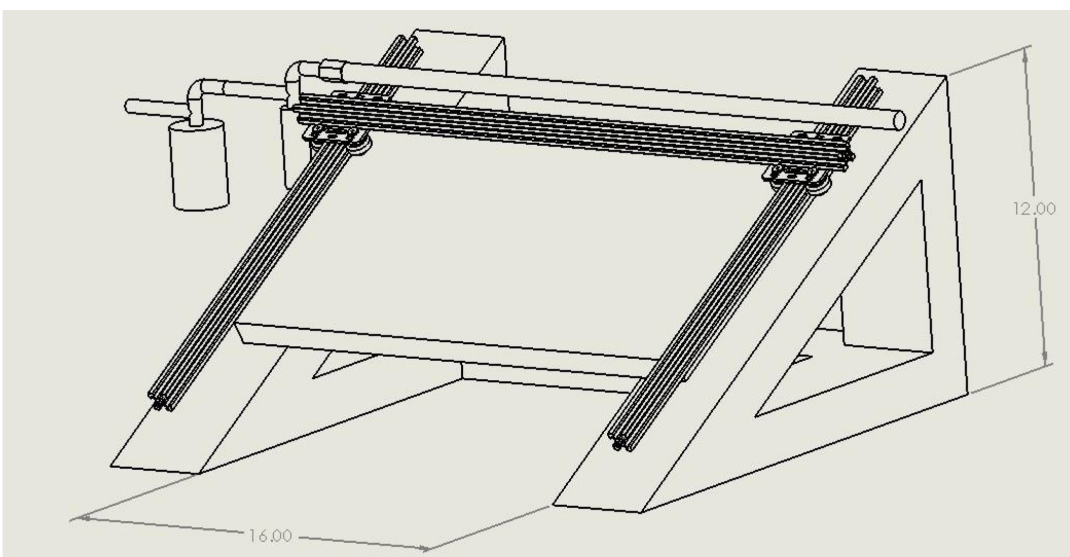

Figure 1: Conceptual Sketch of the Cleaning System. The central board represents a solar panel while the triangular beams represent roof trusses

The team proposes a wiper blade that moves laterally back-and-forth over the solar panel, as shown in Figure 1. The wiper blade is attached on rails that will be mounted on the sides of said solar panel. A motor connected to the blade will be responsible for the necessary movement. At the top of the solar panel there will be a simple piping system that releases a cleaning water/mild detergent mixture over the solar panel. There will either be no separate pump or a small pump to power the liquid distribution system. The purpose of this cleaning solution will be to further increase the main system's cleaning abilities. Contained in this system will be some type of control system. Through this the owner will be able to clean the panel(s) when he/she so desires or place it on an automated cleaning schedule.

The team plans on building a scale model first as a proof of concept. From there, larger models will be developed, analyzed in CAD software, and built according to the determined design parameters and the common solar panel sizes available on the RS market. Ideally, the team will build a full-scale working model by the end of the school year.

This proposed solution is important because further developments in this technology will provide increased opportunity for the growth of RS. The lack of an "ecosystem" of accessories, services, and support for a core product (i.e., car, truck, boat, software, computer, camera, etc.) will discourage a potential user from adopting a system. This applies to solar panels as well. Increased options on the American RS market for easy cleaning solutions will signal a mature market for potential customers and hence support further utilization of the sun's energy.

Mutual Shaping of Residential Solar Technology and Stakeholders in the United States

How have different relevant actor groups shaped residential solar technologies in the United States?

The technical aspects of this problem alone will not solve issues with increasing solar energy production. In the Residential Solar (henceforth abbreviated as "RS") context, there are social and political factors that must be addressed to increase acceptance and access to these technical solutions. The STS section will focus on analyzing and tracking the mutual sociotechnical and political shaping of RS in Virginia through homeowners' associations (HOAs), local governments, and the state government. It will show how these actors have interacted with the technology and other actors in the past. In addition, it will show how they could interact with each other in the future as this technology further develops and matures. The impact of increased RS adoption is promising, but to properly benefit society such a system must consider the social and political aspects to the core solar solution and be properly anticipated for.

The literature about the actors involved in RS technologies dates back almost as far as RS technologies were developed. One early law paper named *Solar Energy and Restrictive Covenants: The Conflict between Public Policy and Private Zoning* from 1979 describes the effect that "private covenants" (homeowners' agreements) and the HOAs enforcing them had in hindering solar roof adoptions during the 1970s. It describes policy suggestions on how other actors (namely, state governments) could act to encourage adoption of this technology (Wiley, 1979). A more general technical and political history of solar energy in the United States can be found in the literature review paper published by Tabassum et. al. titled *Solar Energy in the*

United States: Development, Challenges, and Future Prospects (Tabassum et al., 2021). More current work such as *The dynamics of political power: The socio-technical transition of California's electricity system to renewable energy* (Gottschamer & Zhang, 2020) and Stirling's *Transforming power: Social Science and the politics of energy choices* (Stirling, 2014) help shed light on how various actors, from power grid operators, industrial trade groups, manufacturers, and activists have guided the adoption and technical goals of RS technology according to their own goals. Even factors such as class and overall societal social standing have been discussed in articles; some have shown that RS adoption is more strongly correlated to certain political and economic backgrounds than others (Ebeling, 2011). This portion of the project will seek to fill in how HOAs, local governments, and the state government have influenced how RS technologies have and are being adopted and improved in the Commonwealth of Virginia.

As with all technologies, the success of their adoption depends on how they are adapted and shaped by the societies that they are created and used in. Residential solar systems are no different. If advocates want to increase access and adoption of RS, then they must negotiate and adapt the technology to the needs HOAs and the local and state governments. These actors can interact with each other so that all (or most) parties come to accept it. Exploring this topic will help to identify points at which RS adoption and development is being hindered. Recognizing these points can in turn help further bolster RS usage and augment the green energy transition in the state.

Analysis and Evidence Collection Methods

Evidence for this research will be collected by analyzing the positions of local HOAs (to the best of my ability) and the local and state governments in relation to developments of the technology and politics. News articles and online interactions of various kinds (comments, forum posts, videos, etc.) will be analyzed in addition to various pieces of literature representing state and local governments in the commonwealth. Various analyses of literature and current discussions within society on an official (news articles, press releases, etc.) and unofficial level (social media) will be conducted to determine how technical and social adoption of this technology has progressed and may continue to progress in the future in Virginia. Quantitative and qualitative data will be analyzed in relation to technical developments to find mutual shaping between the stated social groups and the technology.

Conclusion

In summary, this overall project will focus on solving the issue of societal decarbonization through a specific technical and STS-related work. The technical portion will involve the author in a chosen team developing an affordable and semi-autonomous physical cleaning system for residential solar (RS) panels. This proposed system will involve a laterally moving wiper blade moving up and down to remove debris; this moving blade's effectiveness will be supplemented with an ancillary liquid drip system to passively dispense a mild detergent/water mixture.

The STS research topic will research the past and current ways that Virginia's HOAs, local governments, and the state government are involved in the residential solar panel actor-network and how they may continue to affect the development and adoption of residential solar technologies. Literature has painted a limited but useful picture of how socio-technical systems were developed and negotiated with during the process of creating and implementing RS technologies. This should be applied to Virginia's specific market and societal conditions to better understand how to drive clean energy.

The author seeks to learn more about how all factors in society, culture, and technology have influenced the changes in this specific technology and how the collective choices have led to where the RS and solar industries in general are today. For the technical project, the group hopes to learn how to best solve the issue of maintaining clean solar panels and pick up valuable design, testing, and prototyping experiences along the way. Both portions of the overall project ultimately tie back to determining *how solar energy adoption can be increased to reduce the effects of climate change.* Determining more efficient ways to clean this energy generating infrastructure will directly impact how quickly society can move away from carbon-intensive energy sources like oil, gas, and coal. Researching the aforementioned actors involved in the Virginia residential solar field will hopefully help spur further adoption and productive utilization of these innovations. Further research may be done to build upon these technical and STS projects to further push for a carbon-neutral economy and society in the country in general and Virginia in particular.

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