Utilizing the Triboelectric Effect to Deliver Small-Scale Renewable Energy

We Don't Want It: Resistance to Solar in the Rural Charlottesville, Va Region

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Mechanical Engineering

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November 8, 2024

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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

How can the energy transition be encouraged?

Climate change is the issue of our generation. Caused in large part by greenhouse gas (GHG) emissions, climate change affects everyone around the world through an increase in hot extremes (virtually certain), global sea level rise and glacier retreat (very likely), increase in heavy precipitation (likely), and increase in fire weather conditions and drought (medium confidence) (Calvin et al., 2023). Climate change has caused "destruction of homes and infrastructure, and loss of property and income, human health and food security, with adverse effects on gender and social equity. (high confidence)" (Calvin et al., 2023, p. 6). One solution to address the emission of GHGs causing climate change is transitioning the energy system from being powered by GHG emitting fossil fuels to renewable energy sources, which is called the energy transition (high confidence) (Calvin et al., 2023).

To encourage the energy transition, efforts have focused on industrial scale renewable energy projects. While these projects emit less GHGs than traditional fossil fuel sources, they take up vast amounts of land (Capellán-Pérez et al., 2017). In the rural United States, solar projects have faced backlash from local citizens causing project delays and cancelations (Susskind et al., 2022). Understanding and addressing these issues is critical for expanding the use of solar and thereby encouraging a vital part of the energy transition. One potential solution to the need for renewable energy that does not face the controversy of large scale rural solar projects are small, site-scale renewable energy generation technologies. The proposed technology utilizes static electricity, otherwise known as the triboelectric effect, to generate this vital electricity close to where it is being used at a site-scale, mitigating the need for controversial industrial scale renewable energy projects if widely adopted.

Utilizing the Triboelectric Effect to Deliver Small-Scale Renewable Energy

What is the optimum design for a small-scale wind powered triboelectric energy generation system?

Even though renewable energy sources will assist in mitigating the emission of GHGs, typical renewable energy generation requires “at least 10 times as much land per unit of power produced than coal or natural gas fired power plants, including land disturbed to produce and transport the fossil fuels” (Gross, 2020). The need for more land to produce the same amount of electricity limits deployment within cities.

Triboelectric generators are a potential technology to enable small-scale renewable energy. The triboelectric effect, more often called static electricity, occurs when two materials come in contact with each other and gain opposing surface charges from the contact. This is what happens when a balloon is rubbed on a person’s head and their hair follows the balloon- the opposite charges on the different materials create an attraction that causes their hair to follow the balloon. To harness the static energy, the two materials that have experienced friction are connected via a conductor, creating a circuit similar to a capacitor. This causes a voltage differential to be observed across the conductor, which leads to power generation.

Triboelectric generators are versatile: all they require is the repeated contact and separation of dissimilar triboelectric materials, which are common and easy to obtain (e.g. hair and a balloon, socks and carpet, etc.). To determine how dissimilar two given materials are triboelectrically, which determines the maximum energy generated, a triboelectric series can be consulted (Zou et al., 2019). One example of a triboelectric application is a pressure plate that when stepped on, generates electricity (Shepard, 2017). While the team found this use of the technology exciting, a different direction was decided on for this project. The proposed project will utilize biomimicry to design a triboelectric system that can generate electricity from low-speed winds, which are typically encountered in cities and around residential buildings.

The triboelectric team is composed of eight people working with Professor Sarah Sun and Professor Thomas Ward in the Mechanical Engineering department. The system design can be broken into three parts: the material selection and research, the physical and aerodynamic design of the generator, and the electrical design.

Materials selection is particularly important as the field has not yet come to a consensus on the fundamental mechanisms behind the triboelectric effect and how to accurately predict triboelectric generation performance. Even though the field has not settled on an explanation and model for predicting triboelectric performance, a qualitative comparison of different materials' triboelectric characteristics can be compiled into a triboelectric series that has been generated by numerous studies (Zou et al., 2020). There is a potential, beyond choosing two materials to use for our triboelectric generator design, to conduct research on triboelectric materials. To this end, we will utilize a sinusoidal contact-separation testing apparatus to develop a triboelectric series for materials that we will obtain. We will utilize this series to determine the optimum materials for our design and conduct further testing as is determined appropriate to design the optimum triboelectric generator for low-speed winds.

The physical design of the system plans to use biomimicry by designing a "blades of grass" or "leaves" like structure of dissimilar triboelectric materials so that the different materials will hit each other frequently in low wind speeds, optimized for wind speeds of 5-10 mph. Preliminary calculations and computer modeling will be conducted to determine a starting point for prototype wind tunnel testing. Through prototype testing the final spacing, orientation, and shape of the blades will be determined.

The electric system has been constructed by Professor Sun before who has offered to help us design it for this project. The system will be able to take the high voltage impulses generated by the triboelectric generator and transform this electric signal into a constant DC voltage able to power electronics.

We Don't Want It: Resistance to Solar in the Rural Charlottesville, Va Region

What causes resistance to large scale solar projects in the Charlottesville region?

Background

Solar projects are an important part of the energy transition in the US. Solar is expected to make up a majority, about 58%, of new electric-generating capacity in the US in 2024 (U.S. Energy Information Administration (EIA), 2024). National surveys report high public support for the added solar projects, but there has been significant resistance and criticisms at the local level including concerns about the intermittency, excessive noise, and risks to wildlife, productive farmland, biodiversity, and human health caused by solar projects (Crawford et al., 2022). The projects are perceived to have a negative impact on the local environment, even though they are meant to have a positive impact on the global environment through mitigating GHGs (Jones, 2024). A "not-in-my-backyard", or NIMBY, mentality is often adopted for these projects locally despite their widespread national support. Nationally, this has led to more solar and wind projects being blocked by local governments than approved for the first time in 2023 (Crable, 2024).

Virginia has committed to 100% clean electricity by 2050 in the 2020 Clean Economy Act (Virginia Clean Economy Act, 2020). Hampering this legal commitment, the NIMBY movement in Virginia has led to solar projects such as a 80 megawatt facility in Culpeper County withdrawing their application (Brugger, 2019). A current project in Prince George is also facing local opposition with one resident saying “nobody wants to live next to a solar farm” (Dantzler, 2023). In addition to local grassroots opposition, consulting firms such as Citizens for Responsible Solar in Culpeper advise and promote the opposition of solar farms (*There Is a Place for Solar, but Not on Agricultural-Rural Land.*, n.d.). In Virginia, an increasing amount of county ordinances and restrictions are threatening solar farms’ approval (Noah Sachs, 2024) leading to at least eight renewable energy projects being contested statewide (Aidun et al., 2022).

Communities hold the key to approving large scale solar projects needed to advance the energy transition and meet Virginia’s legal obligations. Local cooperation and strong laws have been found to be vital to successful solar development (Gross, 2020). Misinformation (Padyk, 2023), aesthetics (Roddis et al., 2018), and beliefs about the environment and renewable energy (Scovell et al., 2024) have been found to impact the local community’s response to large-scale renewable energy projects worldwide. In Appalachia, anti-solar local ordinances have been adopted in some communities because of opposing understandings of solar projects (Gamper-Rabindran & Ash, 2024). While these are potentially impactful in Virginia, each locality responds to solar projects differently as the opposition “does not typically originate from only one source” (Susskind et al., 2022). Therefore, it is proposed that a study be conducted in the region around Charlottesville, Va to determine the causes for resistance to large scale solar projects. This study aims to inform stakeholders in building new solar farms about common complaints so that solar farms can be built more quickly, fueling the energy transition needed to mitigate the harmful effects of climate change.

Research Methods

To answer the question of the causes for resistance to large scale solar projects in the Charlottesville, Va region, a literature review of scholarly resources analyzing social perspectives of solar, news articles about solar projects in the region, and surveys in Virginia already completed such as the Virginia Solar Survey will be conducted to evaluate the stakeholders in the establishment of new large scale solar farms in Virginia (Weldon Cooper Center for Public Service, 2022). In addition, primary sources such as news articles and press releases from electric utilities will be gathered. Projects in various stages of development will be analyzed to determine common causes for resistance and strategies employed by advocates of solar farms to attempt to alleviate these concerns. Projects that are completed, in the approval process, and that have withdrawn their application will be considered.

This study will focus on the Woodbridge solar development in Albemarle County breaking ground next year, the Cricket solar proposal in Culpepper County that was withdrawn, the Bakers Pond Solar Farm proposed in Prince George County, and the operational Black Bear Solar Farm in Buckingham County.

Conclusion

The energy transition is a vital mitigation strategy to stave off the detrimental effects of climate change. While lauded by climate scientists, renewable energy projects face both legitimate and misinformed opposition from local NIMBY activists despite high levels of public support nationally. A literature review studying the causes for this opposition will be conducted with particular focus on the Charlottesville, Va region. In addition, small-scale renewable energy that can be deployed at the site scale, particularly within cities, will mitigate the need for these controversial large scale solar farms. Triboelectric energy generation technologies offer the opportunity for these small-scale renewable energy projects to be realized. Through these studies, the understanding of renewable energy will be furthered and used to assist with the adoption of more renewable energy generation. This will support the energy transition which mitigates the harmful effects of climate change.

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