CONFRONTING THE CHALLENGES FOR PEROVSKITE SOLAR CELLS

THE SOCIAL AND TECHNICAL ASPECTS OF SOLUTIONS TO ENERGY POVERTY

A Thesis Prospectus
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Bachelor of Science in Electrical and Computer Engineering

By
Robert Adam McGill

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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.

Signed Robert Adam McGill Date: 7/22/2020

Approved: Date:
Catherine D. Baritaud, Department of Engineering and Society

Approved: Date:
Patricia C. Click, Department of Engineering and Society

Better electricity access and sustainable sources of energy are two important targets for any society. A technology that has the potential to satisfy both goals is solar power, which is being transformed by the exciting new prospect of perovskite solar cells. Perovskite cells offer potential in both “higher energy conversion rates… [or] significantly lower processing costs” (Green et al., 2014, p. 1). Lower processing costs would contribute to the growing economic viability of solar, potentially leading to cleaner power options in the future, while higher energy conversion rates would make systems more profitable long-term. I plan to conduct an overview of the technical prospects and challenges of perovskite cells with the hope of understanding the intriguing potentials of the new technology.

Solar energy offers not only promise for forming a cleaner grid system, but also an option to combat energy poverty. Despite investments in grid power, around 600 million people in Sub-Saharan Africa live without electricity (Lee et al., 2002), with similar issues are being tackled in India and South Asia. The potential for perovskite solar cells to offer a cheaper solar power is strongly coupled with the topic of solutions for energy poverty due to the off-grid nature of solar energy. Regardless of the location and means, solutions to electrification in new areas will depend “at least as much on the social and economic organization of such systems as on their technical configuration” (Ulsrud et al., 2011, p. 293). With this in mind, an STS analysis will be applied to case studies of bringing electricity access to new areas, with the goal of establishing best practices for a successful project across the social and cultural level in addition to the technical.

The timeline for the research and writing on my technical and STS topics is shown in Figure 1 below. First, my STS research on recommendations for projects alleviating energy

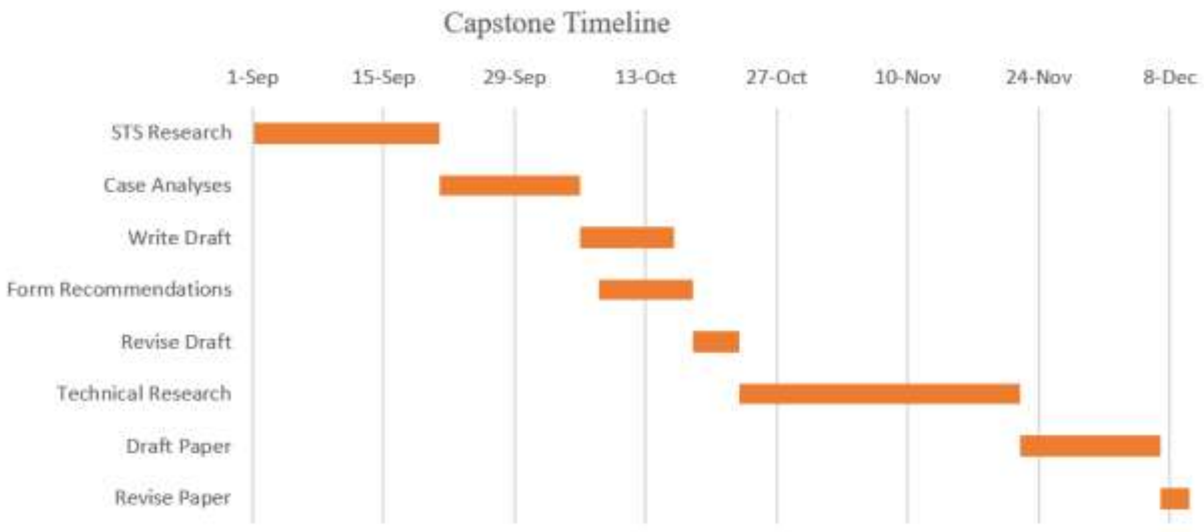


Figure 1: Gantt Chart for Research Project. The main body of STS analysis will be conducted first, followed by technical work throughout the school year. (McGill, 2020).

poverty will be conducted, followed by research into perovskite solar cells. The total research will culminate in a state-of-the-art report on perovskite solar cells and a scholarly article on running successful electrification projects.

CONFRONTING THE CHALLENGES FOR PEROVSKITE SOLAR CELLS

Concern for the vast emissions of modern society is driving a push towards cleaner forms of energy, with solar power foremost among them. Solar technology has the potential to fill the world’s energy needs and lower emissions, yet it is still peripheral to modern energy supply infrastructure (Kabir et al., 2018, p. 1). The wider adoption of conventional solar cells has been hindered by large installation costs and issues with durability (Kabir et al., 2018, pp. 4-5) as well as production costs due to the high rate of flaws in manufacturing (Green et al., 2014, p. 1). Recently, new materials have been used to develop perovskite solar cells of relatively high efficiency, with the prospect of cheaper fabrication and thin film applications (Green et al., 2014, p. 1). A slim, versatile, and competitive solar cell could be the push the solar industry needs, but challenges still remain in the use perovskite cells, such as the use of lead and chemical instability (Elseman et al., 2018, p. 1). The potential of perovskites demands unified effort towards resolving such challenges. Therefore, my research objective is to conglomerate work into a state-of-the-art report on the issues of toxicity and durability in perovskite solar cells. My hope is to provide a stepping stone for further research, and provide a focused base for people seeking information about the field.

The basic functionality of perovskite solar cells is analogous to that of traditional photovoltaic (PV) cells. Multiple sources exist on the physical understanding of solar cells, such as *The Physics of Solar Cells* by Juan Bisquert, which lends knowledge to the following simplified explanation (2018). Conventional solar cells work by taking a base material such as silicon and binding it with elements containing slightly more or less valence electrons in a process called ‘doping.’ Two primary types of materials are formed with the doping process: materials with an excess of electrons, or n-type materials, and materials with a lack of electrons, or p-type materials. When n-type and p-type materials are placed adjacently, they excess electrons in the n-type material fill the holes lacking electrons in the p-type material, creating an electric field at the boundary of the materials. When exposed to the sun, the photoelectric effect causes photons to ‘dislodge’ electrons in the material. With an electric field and excess electrons to flow across it, electrodes can be connected to the material to harness the current for usable power. Figure 2 shows the basic layers of a perovskite solar cell, with arrows indicating the flow of electrons and holes out of the perovskite and into the contacts on the cell.

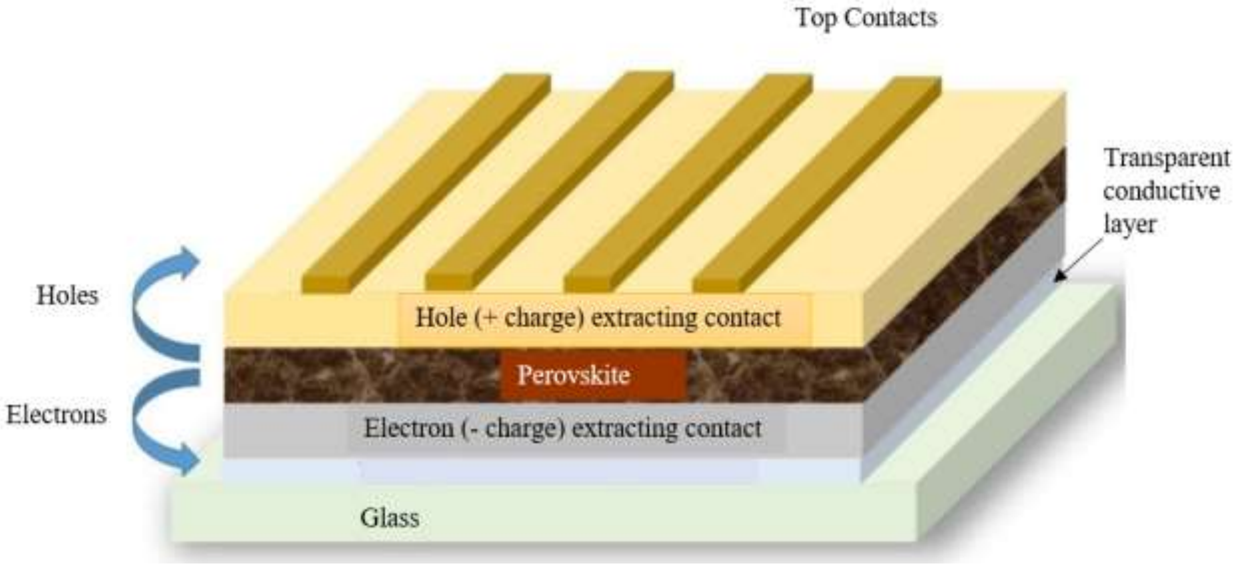


Figure 2: A cross-section of a perovskite solar cell. The perovskite material is shown sandwiched between metal contacts. (Clean Energy Institute, 2020)

The figure demonstrates the similarity in concept between conventional solar cells and perovskites. Perovskites are just a new material, with a different crystal structure than silicon, but with fresh potential for use. They offer exciting potential for thin film solar applications, with films on the order of nanometers (Sutherland et al., 2014). Technical interest also lies in the challenges of increasing the durability of perovskite cells, improving their efficiency, and eliminating toxic materials used in them. Rapid advances have been shown in increasing perovskite efficiency, now comparable to conventional solar cells at up to 25%, in the span of just eleven years of research (National Renewable Energy Laboratory, 2020). These advances are why I have chosen instead to target the challenges facing perovskite cells. My objective is to construct a state-of-the-art report that will review the less glamorous issues of perovskite development so that I can learn more about the field and help others do the same.

THE SOCIAL AND TECHNICAL ASPECTS OF SOLUTIONS TO ENERGY POVERTY

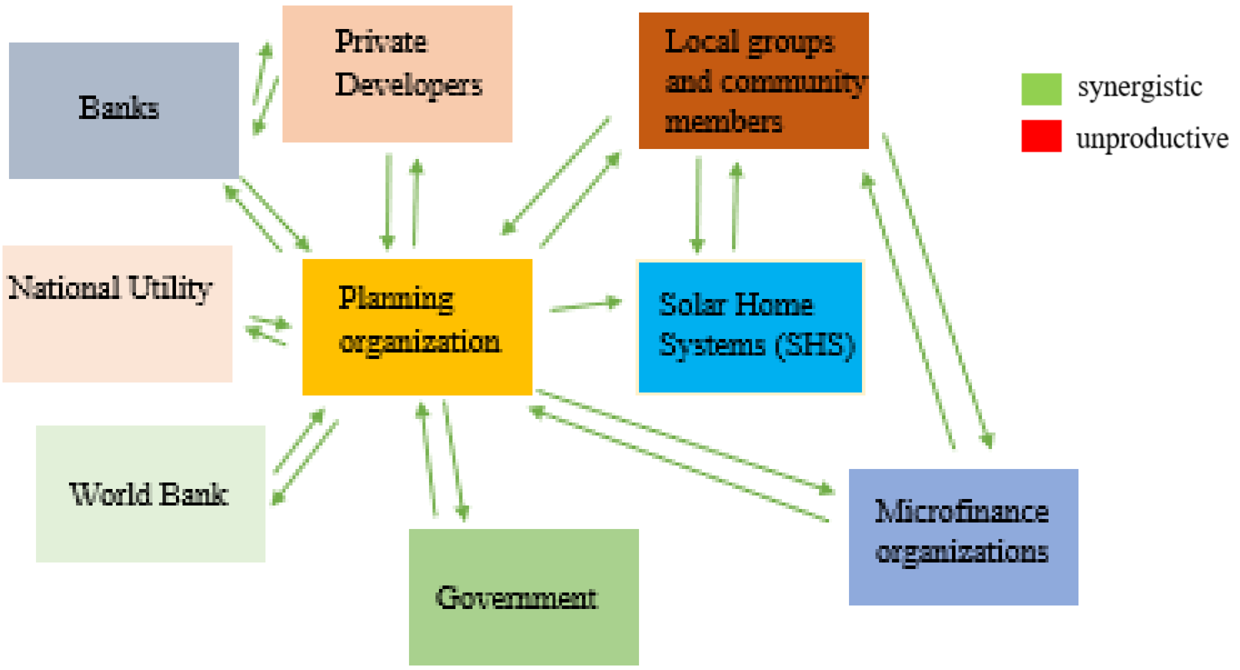
Every year, the houses and streets of the United States are kept lit by the brilliance of 216 billion kilowatt-hours of electricity (U.S. Energy Information Administration, 2020). Yet throughout the world, hundreds of millions of people are still without electricity, prompting the United Nations to make "access to affordable, reliable, sustainable, and modern energy" a Sustainable Development Goal (United Nations Programme for Development, 2015). The central role of electricity in modern standard of living and economic activity is evident, with access considered "central to the everyday lives of people" (Nussbaumer et al., 2011, p. 1) and key for economic growth (Acharya & Sadath, 2018, p.1). The solutions to alleviating energy poverty will bring new opportunities for development and education to the millions of people. Understandably, much research and multiple case studies have therefore been devoted to addressing the potential benefits of electrification and offering prospective energy solutions (Molyneaux et al., 2016; Chaurey et al., 2004; Ulsrud et al., 2011; Lee et al., 2016). To support the vision of electricity access for all, many projects have been undertaken, yet for every success, there is a failed project (Sovacool, 2018; Barnes, 2011). What obstacles are complicating electrification efforts? Different outcomes for the same technical strategies suggest the need for more multidimensional solutions. In order to understand the components of a successful electrification program, the social, institutional, and cultural aspects of the implementation must be understood in addition to the technical. My objective is to use Actor-Network Theory (ANT) (Rhodes, 2009) to analyze case studies of electrification projects and distill my findings into a framework for planning future work.

ANALYZING PROJECTS USING ACTOR-NETWORK THEORY

Each community attempting to scale up to electricity access must craft their own solution to the problem of implementing a source. The various groups at play in the development process bring their own set of priorities to the project and in turn have their roles altered by the degree of success of the electrification effort. Identifying these groups, their motivations, and how previous work has utilized or neglected their interests could be a helpful lens with which to study the structure of successful projects. As a result, Actor-Network Theory (ANT) will be the conceptual strategy of choice. In ANT, actors are animate or inanimate objects that attempt to impose their view on a project, while networks are the connected bodies of actors which share a perspective (Rhodes, 2009, p. 4). The core of actor-network theory is to “follow actors and see how they try to impose worlds upon one another” (Rhodes, 2009, p.4). Figure 3 demonstrates how an ANT analysis might begin, with nodes representing groups at play in the electrification effort. The graphic juxtaposes two solar electrification projects from Sri Lanka and Indonesia studied by Sovacool in 2018. The relationships between each network in the figure are demonstrated via arrows indicating communication, with the width of the arrow directly related to the strength of the dialogue between the groups and the color indicating a synergistic or oppositional relationship.

The Sri Lanka project succeeded, while the Indonesian project failed, though both were funded by the world bank and focused on solar power. The Sri Lankan project involved more groups and had stronger net communication, as indicated by the additional nodes and strong green arrows. The addition of microfinance organizations supplemented bank loans by filling the

Sri Lankan Electrification Project



Indonesian Electrification Project

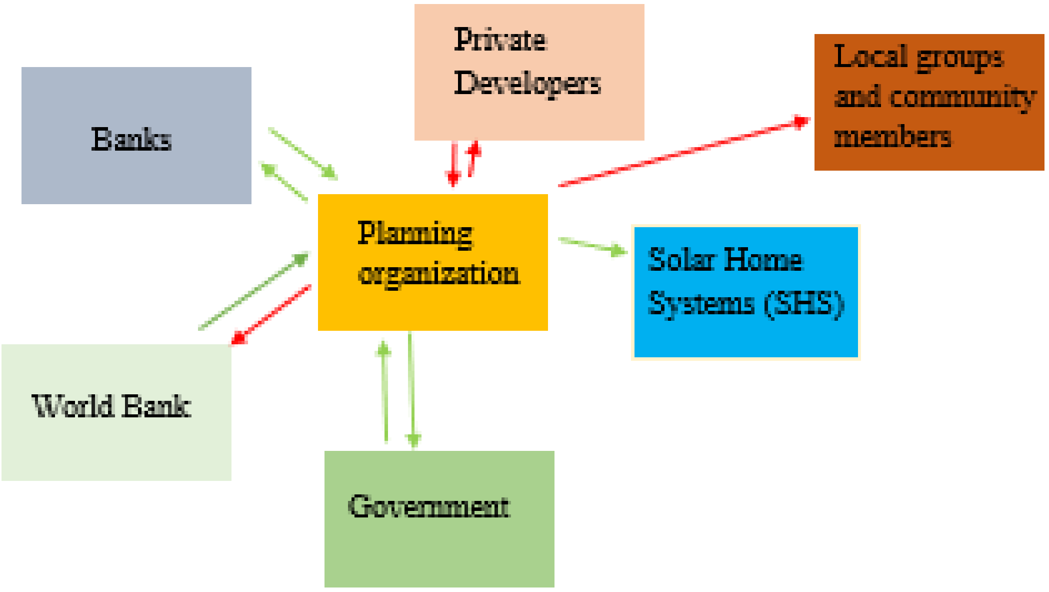


Figure 3: An ANT Analysis of Electrification Projects in Sri Lanka and Indonesia. In the successful program in Sri Lanka shows stronger roles of non-governmental organizations (NGOs) and the community in the dialogue of project development, and has more artifacts available for use. (Adam McGill, 2020)

need for smaller household loans (Sovacool, 2018, p. 29). Private developers were more strongly involved, contributing to the survival of a market for renewable energy after the project had concluded, while the planning organization for the project was both active in engaging the community and responsive to community feedback. In contrast, the Indonesian project was characterized by pressures from organizations more distanced from the actual community and their needs. The planning organization was less responsive to the community, leading some members to feel the electrification attempt was simply pushed on them by the World Bank (Sovacool, 2018, p. 32). While Figure 1 does not encapsulate all of the complexities of the situation, such as the choice of reliable banks or the diversity of different solar options offered, it is useful in identifying some qualitative differences between the projects. For instance, the numerous green connections indicate that the successful effort focused more on responsive communication with the community and reliance on private organizations that would be held accountable by their business model, whereas the failed project was controlled more strongly by actors who were distanced from the community feedback and needs. This type of analysis, provided in tandem with deeper looks into the structure of participating organizations, will provide the basis for my policy and planning recommendations.

CONCLUSION

The longer unsustainable methods are used to produce power, and the fewer people who have access to that power, the more people are locked out of a modern standard of living and faced with increasing emissions. The goal of my work will be to address these issues. A review of perovskite technology will provide a resource for researchers eager to learn more about the state of the technology, while recommendations for electrification projects could help more plans to increase access succeed. It is my goal to use the analysis of multiple projects to inform my recommendations for planning future electrification efforts. I plan to deliver an STS analysis of what makes a successful project in a scholarly article, seeking to establish how societal and cultural differences can be harnessed to create more lasting solutions that serve the community they function in. My hope is that this analysis will be used to increase the probability of successful electrification efforts in the future.

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