The New Bridge to Renewable Energy: Relative Advantage and Compatibility

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

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Spring 2022

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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The Problem

Once a topic of focus for only scientists, engineers and a small fringe of the world's population, climate change has become an omnipresent issue for everyone. All over the world, weather changes resulting from global warming have become increasingly undeniable. July of 2021 was the hottest month in history and natural disasters such as hurricanes have become more extreme and more prominent (NOAA, 2021). The most critical consequence of climate change is global warming -- the actual measurable rise in average global temperature. The main source of global warming is when the heat generated by energy from the sun, infrared radiation, cannot properly leave the atmosphere at the rate it did in the preindustrial era, because it's trapped by an increased amount of greenhouse gases (GHG) generated during the industrial era. In other words, "the global radiation and energy balances are 'off,'" according to Scott Doney, a UVA professor who specializes in the science, impacts, and solutions of climate change (Doney, 2021).

Recently, the public debate has shifted away from arguments about whether climate change is real, thanks to complete and undeniable scientific proof (including the most recent Intergovernmental Panel on Climate Change report (IPCC, 2021)) that the world we live in is changing due to our behavior. The "Keeling Curve" measures the rate of increase of atmospheric carbon dioxide not because of natural processes, but because of human activities, see Figure 1.

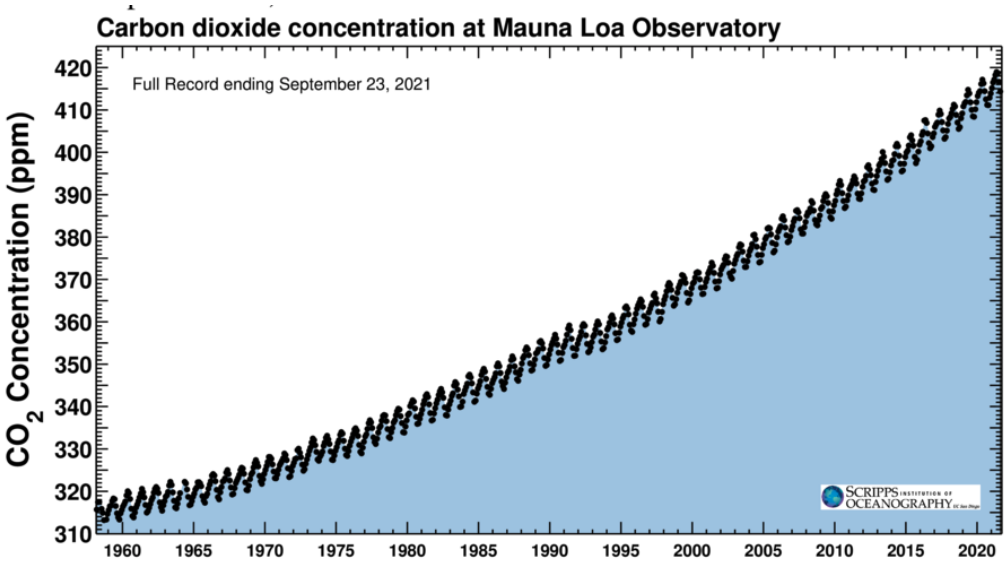

Figure 1. The Keeling Curve (Monroe, 2021)

Instead, the debate has shifted to the question of what to do about climate change, with a meaningful segment of the population appearing to embrace "doomism" – the view that the impacts of climate change cannot be effectively mitigated. According to one of the world's most influential climate scientists, Michael E. Mann, "Inactivists know that if people believe there is nothing you can do, they are led down a path of disengagement. They unwittingly do the bidding of fossil fuel interests by giving up" (Mann, 2021).

Large scale regulatory action has largely proven ineffective for a variety of reasons, leading to efforts at the local governmental and individual levels. Increasingly, innovators, engineers, political activists, and constituents have taken the lead in the form of changes in current practices, investments in more clean energy, electrification, building new and cleaner buildings (also known as green urban renewal), and more. For example, large companies have reacted to pressure from shareholders and have started to consider more heavily their environmental, social, and governance (ESG) footprint, including focusing on GHG emission reduction. Smaller governmental organizations have established net zero goals, but have thus far

failed to specify how exactly they plan to achieve these goals. Why is this the case? How can we encourage people, organizations, and governments to adopt renewable energy technologies and agree on a common path to net zero? It would take takes roughly 22,000 square miles to power the entire United States on solar energy, according to the National Renewable Energy Laboratory, which is only about the size of one-fifth of Nevada (NREL, 2013). So, why have we not made that change? My hypothesis is that through a sociotechnical analysis of the integration of solar technology into society, we can better understand the necessary tools to improve the success of clean energy and pave the path to net zero.

Technological and Rhetorical Theory Behind the Success of Technologies

I will be analyzing why some types of renewable energy technologies have been successful despite ethical setbacks on sociotechnical systems, why others have not, and whether we can learn from prior experience in ethically moving forward with the path to net zero emissions. Climate action is difficult to address because of the many layers of the technologies themselves and the societies they are integrated into. Governments around the world have tried to act against climate change but have faced many barriers in politics and ethics. The Paris Agreement, the only widely-agreed-upon set of principles for climate action, still has many inconsistencies because of an inability to agree on necessary steps to reduce global warming.

According to Johan Rockstrom with the American Association for the Advancement of Science, the Paris Agreement's goals are "aligned with science," and can, in theory, be "technically and economically achieved," but there are still inconsistencies between science-based targets and national commitments (Rockstrom, 2017). Thus, it is necessary to understand on a more technical level reservations about certain engineered solutions as well as the stated and

unstated reasons for those reservations. For example, some technologies such as solar power have been successfully implemented on smaller scales, but there is often a lack of international commitment to those same technologies. This begs the questions: *why* have some technologies been accepted while others have not, and are there ways to address this reluctance? If the goal of climate action is to achieve "efficiency without sacrifice" (ISECOECO, 2016), which sacrifices are deemed substantial enough to prevent the integration of these technologies?

First, I plan to analyze a framework called *diffusion of innovation* (Rogers, 2003) that looks at the five main factors that influence the adoption of a technology into society:

- Relative Advantage – Is it better than other options?
- Compatibility – Is it consistent with values?
- Complexity – Is it easy to understand and use?
- Triability – Can it be tested or experienced before a commitment is made?
- Observability – Does it show tangible results?

Further, it looks briefly at inputs such as communication channels, the nature of social systems, and the extent of change agents' promotion efforts. The goal of analyzing a technology through this lens is to understand the social systems it inhabits and influences. A critic of this framework explains that it needs to better include resources and social support as a factor in the success of a technology (Lamorte, 2019). I believe that an expansion on this framework that dives farther into the first two pillars, relative advantage and compatibility, to consider together both economic resources and social support, would be helpful to analyze the current state and future possibilities for the integration of clean energy technologies into society.

Most public documents and proposals regarding climate change tend to face one of two sides: science or social ethics. The Paris Agreement and other international climate change

discussions are backed in science, but not backed in specific and realistic monetary steps or any kind of ethical framework upon which people can act. John Rawls outlines what is called *ideal theory* for climate change – principles that would apply if every nation complied with international goals for emission mitigation and adaptation (Leif, 2021). However, we unfortunately live in a non-ideal world. Caney outlines strategies to approach international climate action, which he calls *nonideal theory*. He points out that often, not everyone will be pleased, so we must understand which sacrifices are worth the benefits received from mitigating global warming. "The extra (unjust) disadvantage that compliers bear is less than the extra (unjust) disadvantage that would be borne by many victims of climate change … Dangerous climate change will lead to the death of many and for this reason, as well as for others, imposes irreversible harm." (Caney, 2016). Beyond that, there are economic implications for why we need to act against climate change. Innovation in clean technologies will reduce the cost of mitigation of global warming by as much as 50 percent (Brant, 2014). So, to address the integration of these technologies into society, we need to further understand the relative advantage of *each* technology when it comes to economics, rather than the necessity of clean energy.

The second aspect of the Diffusion of Innovation framework addresses social compatibility. To understand that we need to consider the conversations we have around climate change. Jonathan Pickering introduced a concept called *moral language*, which "may be used to generate and communicate prescriptions for action on climate change, namely through: (i) characterizing the problem of climate change and identifying solutions to the problem; and (ii) motivating people to take action in response to climate change" (Pickering, 2016). He discusses the difference between the analytical role and motivational role of words. He implies that moral

language can trigger emotions in people that can overcome feelings like doomism and strong political determinism. A concept like this could further supplement the Diffusion of Innovation framework to analyze these technologies and the futures they face in society.

Action needs to be taken to combat climate change in a timeline that fits with the IPCC's goals, but it is currently unclear how technologies can be integrated to take this action. There are a lot of hurdles that society faces in acting and reaching net zero emissions and reducing the effects of climate change. Next, I intend to analyze how we can understand these hurdles and how to overcome the tradeoffs and integrate renewable energy technologies into our lives in the most ethical way possible.

Case Context – The Positives of Solar Energy

To put this into context, we will consider the current state of solar energy in the lens of the diffusion of innovation framework. There are good reasons for this investigation beyond simply addressing climate change. The solar industry is not only becoming increasingly affordable as an energy source, but it also provides jobs for 3.4 million people in the United States (Tierney and Bird, 2020). Helping to scale this technology may help to address one well-known tradeoff to a move away from carbon-based energy sources – job loss. Solar is successful in part because it can be easily adapted and scaled for different energy systems, from residential use to an entire town based on a solar system. In America, its ease of integration on a small scale gives the technology relative advantage in terms of its accessibility. It is currently installed on a building or network basis, so it is compatible based on its severability. Panels can be installed by professionals and integrated into regular home usage, so it passes complexity, as well. In terms of trialability, it is usually sourced from solar companies and is therefore tested thoroughly

before use. For observability, people can use metrics like their energy usage and costs. At a basic level, it seems like every home and every building should be based on solar energy by this point in time. However, with a deeper dive into the first two pillars, we can see why that is not currently the case.

Energy Tradeoffs and Investigation Intentions

Every type of energy production has some sort of tradeoff. Consider the following: Hydroelectric energy, one of the US's most prominent sources of renewable energy, can displace people from their land and homes due to the large swaths of land needed (Kumar, 2019). Solar fields could have a similar impact. Hydraulic fracturing (also known as fracking) can cause health problems in surrounding communities. Biofuels, an alternative to fossil fuels, have been socially opposed because of religious and moral concerns about genetic modification, and ethically opposed because of the magnitude of water consumption that may deprive others of clean drinking water. Nuclear energy can have catastrophic failures, which introduces significant compliance costs and societal concerns for safety to provide an adequate amount of energy for a completely clean energy grid. Wind power causes concerns in violations of natural beauty and proper use of space (Caney, 2016).

These all demonstrate that there will always be tradeoffs in introducing new technologies to an area, and I believe that an understudied area is the ethical tradeoffs in renewable energy technologies. So, the question I hope to tackle throughout this analysis is the following: *what are the sociotechnical implications of renewable energy technology that tie into whether a particular technology, with a focus on solar, is successful as a large-scale solution on the path to net zero, and can we learn from this to make technologies more likely to be adopted?*

Methods and Data Gathering Tools

A question like this will never be answered by only one type of evidence, one group of people, or even one technology. My methodology of investigation began with a rhetorical analysis of public speeches, essays, and press releases to understand the connection between scientific analysis and public opinion. I selected a few successful speeches that highlight this relationship and provide examples of this consideration of both the technical integration of clean energy and the ethical implications of its integration. I use solar energy as a base case for the success of a technology by investigating its history and nuances. I take a deeper dive and interview an engineer and coordinator heavily involved in renewable energy. The interview (Participant 1) provides insight into the growth of the solar industry and the current trajectory of renewable energy, especially on the technical side. Overall, this interview helps tie together my independent technical and rhetorical analyses (through the ethical frameworks of Diffusion of Innovation and Moral Language) by adding a holistic view from real people directly involved in the success of renewable technologies.

Diffusion of Innovation, as a theory, is crucial to this analysis because it analyzes the technical side of my research question through five structured pillars: relative advantage, compatibility (with existing systems), complexity, trialability, and observability (of different metrics of success) (Lamorte, 2019). Insight gained from Participant 1 provides context on the first pillar, relative advantage, and the moral language theory will allow me to take a deeper dive into the compatibility aspect of this framework (Pickering, 2016). These two pillars are essential to social and economic support of clean energy technologies. This combination allows me to

address, in addition to the technical side, the ethics and social responsibility of a technology and how public figures influence constituents to be more likely to accept new technologies.

Results and Sociotechnical Analysis

This adaptation of the Diffusion of Innovation framework in the analysis of the solar energy industry will provide a deeper understanding of the integration of clean energy into society and how this can be applied to other technologies. Table 1, shown below, gives a summary of the framework pillars applied to an ideal integration of solar energy. It depicts what would constitute a successful integration of solar energy into society according to each aspect of Diffusion of Innovation.

Table 1. Breakdown of the Diffusion of Innovation Framework on Solar Energy

Diffusion of Innovation Pillar	Summary of Ideal Scenario for Solar Energy
1. Relative Advantage	A. Cheaper and more accessible than other energy sources it replaces* B. Cheaper and more accessible than alternative clean energies
2. Compatibility	A. Consistent with values and needs of users* B. Easy transition (gradual or immediate) from existing systems
3. Complexity	A. Easy to use and understand
4. Triability	A. Can be easily tested or experimented before a commitment is made B. Is a valid and trustworthy source of energy
5. Observability	A. Provides tangible results in decarbonization and ease of use

The two subpoints 1A and 2B are starred because they both, as the figure stands, very general and don't provide enough insight as to why this technology has not been as successful as it could be thus far. Points 3-5, as addressed in "Section III. Case Context – The Positives of Solar Energy" of this paper, are very successful components of the solar energy industry, thus for purposes of this analysis, I will focus on the starred subpoints.

Lately, there has been an increasing amount of investment in renewable energy based on social pressures in the form of ESG requirements and goodwill, but the first step to ensure the longevity of a technology is to increase its economic viability, also known as its relative advantage (See Table 2.1). According to Participant 1, who worked in the solar industry from 2013-2016 and now works as a solutions architect at [a large software company],

> "In the past, solar energy was simply not a profitable investment. Companies, much less residential homes, had to rely on government subsidies to provide these products at a reasonable price, and even then, there was an unnecessarily large payback period that made people reluctant to invest. Solar companies had to be innovative. They had to be creative. They had to go through trial and error. Eventually, they found a solution that worked by creating financial instruments out of these solar panels through power purchase agreements to take advantage of the culture shift going on" (Participant 1).

These agreements, or PPAs, are typically fifteen-year contracts where a solar company will provide energy at a constant price. They explained that solar companies had to be "nimble and adaptable. They had to become real estate companies" (Participant 1). Solar power is already beginning to become profitable for large companies. In terms of residential areas, it's slower to adapt. In India, for example, solar panels can be installed on a home for roughly $10-15,000, translated into U.S. dollars. In the United States, however, it's around $100,000, mostly due to

installation and materials costs, which can lead to a payback period of nearly 20 years, any many Americans don't even plan to own a house for that long (Participant 1). So, either the labor and material costs need to change, or the technology itself. If this happens, solar can achieve this relative advantage (and improve observability through payback period and a reduction I energy costs) that the Diffusion of Innovation framework lays out and have the technical grounds to be integrated into society.

Nonrenewable energy sources are "facing increased competition from wind and solar, with battery storage, but that doesn't mean utilities are feeling the financial pressure," because we need to focus on the attitudes of and compatibility with the *people* adopting the technologies (Hitt, 2020). Moral language, generally, is the idea of combining science, politics, risk, and raw emotion to spur people to action, to show them not only how urgent a problem is, but how possible it is. Right now, people are told that clean energy solutions are ineffective and expensive (Hayhoe, 2018), so they don't have any sort of urgency. Those without a scientific background don't fully understand how necessary clean energy is becoming in *every* part of life, not just in Corporate America, much less why it costs as much as it does. Right now, according to Akshat Rathi's article in Bloomberg News, "Climate scientists see their role as informing policy, which makes it okay to not try and model policy outcomes" (Rathi, 2022). Engineers, scientists, and economists are failing to work together with public figures to "see beyond the confines of … inherent bias and to overcome hierarchical, reductionist, and compartmentalized thinking to see the holistic patterns" which may allow these technologies to succeed, and to communicate that to everyday people (Mitchell, 2018). The IPCC report, for example, gained a lot of attention, but didn't necessarily garner much action beyond these general "net zero goals" (IPCC, 2021). The Green New Deal is a climate proposal to the federal government championed

by Representative Alexandria Ocasio-Cortez of New York and Senator Edward J. Market of Massachusetts. This proposal gained much more momentum than the IPCC report, both at the grassroots and the government level because of its hopeful yet specific nature that connects science and reason and tells people what needs to be done and how to do it. Naomi Klein, in her essay "On Fire," explains,

> "If the IPCC report was the clanging fire alarm that grabbed the attention of the world, the Green New Deal is the beginning of a fire-safety and prevention plan, not a piecemeal approach that merely trains a water gun on a blazing fire, as we have seen so many times in the past, but a comprehensive and holistic plan to actually put out the fire" (Klein, 2019).

A speech by Abigail Dillen titled "Litigating in a Time of Crisis" embodies a similar methodology. In the beginning of the speech, she starts off by explaining how humanity is failing as a unit to act adequately against the climate crisis, and explains, "driving fast on a highway, I get spooked by the proximity of sudden death to life as usual. The first few years of the twenty-first century felt like that" (Dillen, 2020). She then states, "that said, the struggle is welcoming to latecomers. Living in this time of crisis, for our democracy as well as the climate, is breaking my heart open and creating space for new understanding. The weight of history is on our shoulders, but this moment is alive with possibility" (Dillen, 2020). This is a powerful combination of images because it communicates not only how serious the problem is by showing her own raw emotion, but she also welcomes people into her own struggle to show them the possibilities of hope. After this display of passion, she spends the rest of her speech covering more technical ways that people can get involved, pressure governments and companies, and make changes in

their own everyday lives. This takes climate change at a high level and breaks it down to make action compatible with people's values and needs.

In another example, Katharine Hayhoe's speech at the Successful Canadian Women's Dinner connects climate change to individuals by reframing it not as something that needs to *start* mattering to people, but as something that already does matter and is integrated into every part of their lives. She explains, "I don't start by talking science, I first identify something we have in common" (Hayhoe, 2020). After her speech, several sponsors approached her and commended her for how many people she was able to inspire in a mere twenty-minute delivery. Her ability to take a scientific subject and relate it to everyday people and their lives allows these people to be more open-minded to climate action.

Examples like these show the power that focus on the constituents and actual users of these technologies can have, but what lacks is the specificity on a single technology. The ability of these change agents to make science feel personal, to inspire people to act, makes climate action much more realistic for people -- in residential homes, larger-scale renewables, changes in everyday lifestyles, litigation, and more. However, if solar energy had some sort of change agent taking the lead on this integration, as electric vehicles do in Elon Musk, it would be able to better conquer the compatibility pillar of the Diffusion of Innovation.

Reflection: Broader theories

There is still a long way to go before we are on the right track to tackle the climate crisis. Mary Anne Hitt explains, "Already more than three million Americans work in the clean energy industry, outnumbering fossil fuel workers three to one. There is so much more work to do: retrofit our buildings, create transportation alternatives, expand regenerative agriculture, and

restore the land and water that have been ravaged by mining, fracking, and drilling" (Hitt, 2020). All possible minds and hands need to be involved in the technical and cultural integration of clean energy into society. Engineers and corporations can work on the technical integration, but it is crucial that they work hand in hand with politicians, public figures, and those affected at lower levels by these technologies to address the cultural acceptance.

Much of this analysis is based around solar energy as a base case but can be applied to many forms of renewable energy that are ready of system integration. I have identified two crucial areas of improvement for solar as relative advantage and social compatibility, which can be at least somewhat addressed by the influence of change agents. Some technologies, such as geoengineering battery storage, and renewable natural gas may also need focus on elements like complexity, triability, and observability. The first two pillars of diffusion of innovation, however, are crucial for all forms of renewable energy. If we are to slash global emissions at the rate needed to avoid climate disaster, these technologies need to be sought after both economically and socially by people at all levels of power.

An important next step to this research would be applying it to newer technologies to hopefully frame its development and implementation in the research stage, rather than at such a late stage as solar. Solar energy has existed since the photovoltaic effect was discovered in 1839, and I write this analysis in 2022 – if we were to determine a way to take this research and create a framework for emerging technologies, society could make a much smoother transition to clean energy and a carbon-free future.

Conclusion

While there will always be the possibility to expand this analysis with further research, time, and resources, I have determined that success of a renewable energy technology ultimately comes down to two things: money/economic viability and social acceptance. These concepts both depend on getting people involved, both in research and in public relations, to tackle the hurdles in front of us, find ways to make clean energy cheaper and more efficient, and involve people on their *own* terms in this fight against the climate crisis.

Climate future is an ever-changing study because of its inherent nature; its name includes the word *future*. There will likely never be a tell-all textbook, so research, as well as the public relations I discussed throughout this paper, must be done by everyone from students to government officials to CEOs. My research consisted of conversations, news and literature review, public opinions, and a general awareness of the past, present, and future events that will continue to shape the course of renewable energy and the path to net zero.

My main hope is that this research can be used to emphasize the significance of all working together for the climate crisis. I believe that not a single person is exempt from action. Most people believe that reducing their plastic use, traveling less, and "going digital" is enough action, but I have shown why they need to be aware of what's happening in the world around them and how they can get involved on a larger scale (like investing in renewable energy). Public figures have a major role in getting them involved and can use methods like moral language to not only pull the "fire alarm," but provide the "fire-safety and prevention plan" that Naomi Klein spoke about.

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