Climate Change as a Driving Force for Social and Technical Innovation

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

Jackson Sompayrac
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

Signature _____ Date _____
Jackson Sompayrac

Approved _____ Date _____
Joshua Earle, Department of Engineering and Society

Introduction

An enormous amount of global progress has been made in the recent decades to combat climate change and develop more sustainable methods of producing and distributing electricity, virtually a core necessity for every American. However, many scientists and climate change experts are concerned these efforts will not matriculate fast enough to keep overall global warming below 2 °C by the end of the century. An increase in temperature greater than 2 °C could cost the future Earth up to 20 percent of global GDP, economists predict (Maslin, 2014, p. 23). And while these are some of the most highly-regarded predictions of our time, history has repeatedly proved many of the best predictions of their day wildly inaccurate. This is the case because the global climate, and its response to the introduction of conventional man-made pollutants, is an incredibly intricate and massive system to attempt to model and predict. Even so, in order to avoid massive consequences for future generations, it is of utmost importance to make the best effort possible and try to innovate solutions to counteract the damage that human consumption has already had. Solutions to climate change prove to be quite difficult to identify and implement, however the logical conclusion is that humans must find ways to dramatically lower their overall impact on the global climate. A general increase in attention to climate change-inducing activities in our society is a reason for cautious optimism.

Since the 2020s it is commonly understood that climate change is one of the defining of the 21st century. The consequences of climate change not only deeply impact the environment, they can have massive effects on economic, sociological, and geopolitical wellbeing. The United States is a huge emitter of greenhouse gases (GHGs), with electricity generation creating a quarter of its overall emissions (EIA, 2019). The electric grid in the United States is a particularly interesting and complex subject of analysis, because it is composed of dynamic and

interconnected components such as technological innovation, governmental policy, and economic interests. Improving our electric grid and implementing innovative sustainability measures is the United States' path to lowering its overall contribution to climate change, as almost every developed country is already doing and must continue to do if serious global consequence is to be avoided. Innovation on this level must be deeply studied and analyzed as the effects reach virtually every member of the population.

The decision-making processes responsible for ushering in these changes, however, are the opposite of inclusive. Giant corporations and bureaucratic governmental organizations will be dictating the general pathway for the future of our electric grid and the emissions it produces. With such a discrepancy in power and consequence, it is paramount to evaluate the current landscape of the US electric grid and its sustainability measures, and the combined effect they will have on our population and culture. This paper summarizes these relationships and applies the STS frameworks Actor Network Theory and Paradigm Shift Theory to construct a holistic prediction for the future of the United States electric grid and assess its overall performance with special attention to the equity of benefit provided.

Background

Thanks to advancements in scientific curiosity over the past several decades, there has been increased concern for the impact humans and our technology have on the planet. The first measurements of carbon dioxide concentrations in the atmosphere began in the late 1950s on Mauna Loa Mountain in Hawaii. The results are impossible to misinterpret; the measured carbon intensity level has risen every year since it began to be recorded, from 280ppmv in 1958 to over 400ppmv in 2014. To put this increase into perspective, in another carbon concentration measuring technique where ice cores from Antarctica are sample and analyzed, scientists were

able to determine that, in 800,000 years leading up to the late 1980s, the carbon concentration only increased by the same amount, 180ppmv to 300ppmv (Maslin, 2014, p. 35).

Carbon dioxide, CO_2, the product of burning fossil fuels, as well as other man-made pollutant gases like methane, CH_4, nitrous oxide, NO, and various other gases are classified as greenhouse gases because of their ability to warm the Earth's atmosphere by absorbing radiative heat from the sun's UV rays. Since the industrial revolution, developed areas of the world have been emitting these gases at an accelerating rate, increasing the overall global temperature with it (Sundback, 2020). Because of the deeply complex and interconnected components and systems that make up the Earth's climates, such increases in global temperatures have a wide breadth of impact such as melting sea ice, raising global sea levels, causing unexpected droughts and flooding, as well as producing natural disasters more frequently. The deeper one investigates into each impact of climate change, they will find a growing list of the economic, cultural, and political damages that accompany it, along with the obvious ecological degradation. For example, when examining the relationship with the Earth's oceans, rising GHG levels cause a continued rise in sea level which threaten certain populations of both humans and animals in island and coastal areas, concurrently, GHG concentrations are so high in our atmosphere that they have started to absorb into the oceans, removing oxygen from the water and actually destroying aquatic ecosystems (Maslin, 2014, p. 27). Outcomes like these can uproot entire communities and force them to relocate or drastically change their way of life. Given that nearly 40% of the Earth's population lives within 100km of the coast (United Nations, 2017), the continuing incrementation of Earth's global temperature begins to become a real threat to our future.

In order to mitigate the risks and uncertainties associated with climate change, action must be taken, and in this paper, special attention and emphasis will be placed on activities in the US electricity generation and distribution system—a system that will continue to change the way energy is produced and consumed, especially with the introduction of new technologies like electric cars, electric heat pumps, and a multitude of other innovations. Obtaining a full understanding of the operations and intricacies of the US electric system is a complicated effort in itself, and when you incorporate the necessity for decarbonizing and promoting sustainability and resiliency within the network, it becomes a seemingly unsurmountable objective. However, the Paradigm Shift Theory will prove to be a vital tool for understanding how our current position became, and provide insight into some of the developments to come in the future.

In the late 20th century, the US government introduced policies and legislation that promoted the availability of electricity to virtually all Americans, even in rural communities. They created regulations, such as natural monopolies, for the electricity production and distribution industry so that electricity could be made affordable to all (Sundback, 2021). While this is an applaudable goal, it incentivized cost-cutting by large electricity producers which likely institutionalized the capitalistic incentives we see today with large scale utility companies. Another unforeseen consequence of such a wide infrastructure campaign, is it perpetualized infrastructure across the entire nation, that more adaptive and sustainable technology have made and will continue to make obsolete in the coming decades. Since this campaign, the US government has continued to take an active role in the oversight and regulation of the entire grid structure. Government organizations such as the Federal Energy Regulatory Commission (FERC), the Department of Energy (DOE), the Environmental Protection Agency (EPA), and a multitude of other agencies and organizations regulate and monitor activities in the US electric

system at the federal level. These organizations also have the power to make markets in energy. For example, in the previous Presidential administration, in response to perceived threats in grid reliability due to "premature" coal-fired power plants decommissions, the federal energy commissions supported legislation that bolstered and strengthened the fossil fuel industry while going as far as to create barriers to entry for renewable power plants (Sundback, 2020). Since the new administration, many federal energy standards were rescinded and updated to create more room for energy savings and decarbonization efforts (Ross & Middlemass, 2022).

At the state level, in semblance to the objectives of their administrations, more aggressive carbon reduction efforts can take place including the creations of Renewable Portfolio Standards (RPSs) that dictate the proportion of energy generation that must be produced from renewable resources such as solar, wind, hydroelectric, and nuclear power stations. Currently 29 states and counting have created RPSs, however they have yet to be mandated at the federal level (Sundback, 2020). According to the US Energy Information Administration (EIA), in 2020 fossil fuels accounted for 67% of overall electricity generation, while nuclear and renewables only accounted for 19% and 17% of electricity generation, respectively (EIA, 2019). Some states, with more aggressive decarbonization campaigns than others, have created timelines for net zero emissions in an attempt to expedite the investment and development of more renewable resources and decarbonization methods. It is likely that we will continue to see these restrictions appear in the future across the nation as well as other paths to incentivize sustainability such as a carbon tax on corporations. While this appears beneficial at surface level, large corporations would likely pass those costs onto the consumer and actually create negative economic effects.

STS Frameworks

Technological Determinism is a theory that a society's technology advances according to its own internal logic; while society, in parallel, adapts certain cultural and societal values according to developments in that same technology (Caldwell, 2001). The theory is thought to have originated from American economist Thorstein Veblen, but was made more famous by German philosopher Karl Marx, who further elaborated that such technological innovation is the driving force in manipulating human social relations and organizational structures. In the case of the US electric system, this theory provides a helpful explanation for the enormous reliance on electricity we currently see in the US. As the benefits of electricity were made more apparent and available in the 20th century, the population had to evolve with the technology they were given, and this trend only accelerated into the 21st century as the digital age started to take form. Today, the US consumes more electricity than it ever has and the deeply imbedded reliance on the technology within reinforces reasonings such as those supporting fossil fuel resources, as the previous Presidential administration thought were necessary.

Actor-Network Theory presents reality as a network of interoperating human and nonhuman drivers, or actors. It describes the complexity of technological developments as they introduce both new tools and new gaps within the network. Critics of the theory have trouble with the idea that nonhuman entities should be actors with the actor-network, as a human actor implies a level of intentionality, while a nonhuman entity only acts according to the will of its human operator(s). The enormity and wide-scale human reliance on the electric system seems to side with the Actor-Network Theory, however, as certain innovations resulting from electricity institutionalization, now control human interaction in a lot of ways. Especially if environmental elements are considered in the network, the Actor-Network Theory is an incredibly useful tool in understanding the complex interactions between humans and their environment. In the US

electric system, this network has created the need for new decarbonization and renewable energy campaigns, which are taking especially long to fully develop given they are constantly in conflict with the magnitude of energy demand (from human actors).

Paradigm Shift Theory describes the way society accepts developments in scientific theory and technology. Old technology is made obsolete because of paradigm shifts, in which new technological developments are introduced and become normalized and eventually institutionalized. An American philosopher, Thomas Kuhn, introduced the theory in 1962 in his book, *The Structure of Scientific Revolutions*, and he argues that the new paradigm is always new and it is always better than the previous, or else it would not be adopted on a large scale (Bird, 2021). This theory encapsulates the paramount role that innovation plays and will continue to play in the adoption of new electric system technology to improve efficiency and sustainability capabilities. Climate change created the necessity for innovation and scientific discovery in renewable technology and alternative power to burning fossil fuels, and the paradigm shifts can be seen in their adoption by governmental organizations at both the state and federal level. New and even more innovative processes for generating electricity and reorganizing its distribution structure are on the edge of making disruptive updates to the US electric system, and it is very likely that we will see much of our legacy electricity distribution systems become obsolete in the coming decades. The US governments response to new developments in the science and technology surrounding climate change and decarbonization will drive the entirety of the nation's advancement to a net-zero emissions future, and it will incredibly important to monitor the impacts such forces will have on the society at large.

Methods

In order to get a holistic picture of the complexity of climate change and the levers driving development in areas of sustainability, several reports published by government organizations such as the EIA, EPA and DOE were synthesized with summaries of their probable causes and effects in several academic papers and scientific articles. Several pieces speculated on possible pathways for global decarbonization with developed countries making massive decarbonization commitments and aiding developing countries in the construction of their own sustainable infrastructure. STS themes are brought in to aid in the understanding of how such developments in our understanding of technology control the way humans interact with each other and with their world, as well as how the developments perpetuate, always creating opportunities for new understandings and further advances.

Results

By applying STS Frameworks to the US electric system, in its present state and through the history of its regulation and implementation, one can track developments in the contemporary understandings of the time with the technology innovations that coupled them. By extrapolating on these theories and their application to the US electric system in its response to the threat of climate change, predictions can begin to be made about where it could be headed. The predictions follow four major response triggers.

1. Demonstration of need for innovation due to climate change.
2. Adoption of concern by regulatory commissions.
3. Continued conflict between vast reliance and decarbonization goals.
4. Opportunity for innovation in technologies and business models.

Demonstration for the need to combat climate change will continue to grow. As scientists continue to formulate their full understandings and predictions of the possible extents of climate

change, their warnings will continue be manifested in damaging climate anomalies like natural disasters and destroyed ecosystems. Such impacts will cripple not only the communities most proximal; they will have profound effects on the cultural, sociological, geopolitical, and most importantly, the economic wellbeing of the world. As Technological Determinism has historically and continues to predict, human advances have created new challenges and opportunity for discovery. These challenges, while frightening, have to and will be overcome by adaptations to the way our society functions.

As scientific discovery and innovation accelerate in the area of combatting climate change, those entities in charge of overseeing the United States' energy future, will adopt new understandings of the situation and investigate new solutions for decarbonizing the overall US energy system. As Actor-Network Theory suggests, the introduction of new nonhuman actors, such as innovations in electricity generation, will simultaneously provide gaps in the actor-network that will quickly be filled. For example, if an incredible innovation enables the US to produce all of its necessary electricity demand completely carbon-free, developments would follow such that infrastructure would all be updated in accordance; electric transportation, infrastructure, more efficient organizational structures and consumption practices, etc.

The most imminent threat to decarbonization and sustainability objectives is the magnitude of electricity dependence and demand exhibited by the US population. Scientific discovery and innovation take time to fully mature, and until it can produce an incredibly excessive amount of energy, such as the amount Americans consume, it is unlikely that such a perceived necessity would be sacrificed for sustainability purposes. STS Frameworks clarify this tradeoff by demonstrating society's perceived need for the technology they develop, permanently altering the interactions and structures within. Further, once developed and fully

institutionalized, such innovation as electricity becomes an absolutely essential actor in society's operation. Therefore, until fully developed to provide a new and *improved* alternative to the current operation, this conflict will continue to hinder the full adoption of renewables and decarbonization projects.

As inferred in the previous response triggers, technological advancement will have to drive the path to climate change neutralization and reversal. Given that fact, there will be an enormous opportunity for investment and development of sustainable and decarbonization processes. Driven by scientific discovery, government incentivization, and an ever-approaching deadline for improvement, it is certain that there will come a much needed Paradigm Shift. As the theory suggests, there will come a development or event that will completely change our understanding of reality and how society operates, while simultaneously making vast amounts of legacy technologies obsolete. What such an event would look like is impossible to foresee and it is that uncertainty that makes modeling and predicting the future of the electric system so incredibly difficult. While this is an optimistic view of the future of the US electric system, this framework also provides reason for concern. In assessing historic applications of Paradigm Shift Theory, it often is followed by an initial inequity in the distribution of a seemingly necessary resource. It is likely that this trend will continue with developments associated with decarbonization, and marginalized groups will be affected most by new developments in the realm of climate change. Therefore, while climate change threatens every human, the physical, cultural and economic impacts are all felt most harshly by already marginalized populations, and it is very likely, that whatever the solution, it would be slowest to arrive to those already disparaged.

Conclusion

Using STS Frameworks as vital tools for discovering trends in human interaction with technology and society, several predictions can be made about future developments in both innovation as well as human behavior. While it would be nearly impossible (as demonstrated by previous attempts) to accurately predict the future of the US electric system and its response to climate change, framing historical and contemporary understandings in this way serve to produce more holistic interpretations of human interaction with both our technology and our environment. In an assessment of the possible future of the US electric system, several response triggers will act as innovation catalysts to ensure that a solution is discovered, adopted, and eventually institutionalized, radically changing the way society is structured.

In this necessary promotion of innovation and societal development, there will still be populations unfortunately facing the most severe effects from all aspects of climate change and its possible solutions. Therefore, it is paramount to the creation of a utilitarian solution to climate change, that an equitable approach to the problem be taken. If such a belief can be incorporated within the Paradigm Shift that must occur, it is entirely possible that a global effort unlike anything conceivable could save our world from disaster.

References

Bird, Alexander. "Thomas Kuhn." *Stanford Encyclopedia of Philosophy*, Stanford University, 31 Oct. 2018, https://plato.stanford.edu/entries/thomas-kuhn/#DeveScie.

Caldwell, Stephanine. *Technological Determinism Theory- Mass Communication Context*, 19 Feb. 2001, http://www.uky.edu/~drlane/capstone/mass/determinism.htm.

Maslin, Mark. *Climate Change: A Very Short Introduction*. Oxford University Press, 2014.

Morgan, Granger, et al. *Future of Electric Power in the United States*. The National Academies Press, 2021.

"The Paris Agreement." *United Nations*, United Nations, https://www.un.org/en/climatechange/paris-agreement.

Ross, Lynn C., and Keesha Middlemass. "Tracking Regulatory Changes in the Biden Era." *Brookings*, Brookings, 11 Apr. 2022, https://www.brookings.edu/interactives/tracking-regulatory-changes-in-the-biden-era/.

Sundback, Mark, et al. "Electricity Regulation in the United States: Overview." *WestLaw*, 1 July 2020.

Sustainable Development Goals Fact Sheet - United Nations. https://www.un.org/sustainabledevelopment/wp-content/uploads/2015/08/Factsheet_Summit.pdf.

"What Is Climate Change?" *United Nations*, United Nations, https://www.un.org/en/climatechange/what-is-climate-change.

"U.S. Energy Consumption by Source and Sector, 2020." *EIA, U.S. Energy Information Administration*, https://www.eia.gov/totalenergy/data/monthly/pdf/flow/total_energy_2020.pdf.