An Analysis of the Viability of Adoption of Renewable Energy Sources

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The Electric Grid and Greenhouse Gases

The production of electricity accounted for 27.5 percent of America's greenhouse gas emissions in 2017 according to the Environmental Protection Agency. The EPA also reports that 62.9 percent of American electricity is generated from the burning of fossil fuels (US EPA, 2015). Existing renewable energy technologies could allow for the reduction of carbon emissions in the production of electricity, making it an ideal candidate for immediate action. These technologies could eliminate over 1/8 of the United States' greenhouse gas emissions by leveraging them either on their own or in conjunction with new technologies to replace the burning of fossil fuels. To best analyze the viability of renewable energy sources as a replacement for burning of fossil fuels, the framework of the technological determinism may be employed.

Research Question and Methods

The primary questions to be investigated are: Are solar, wind, and nuclear power production feasible replacements for the burning of fossil fuels? If so, what factors limit their widespread adoption? The feasibility of each mode of power production is determined by its capacity to be scaled up to service large regions and communities. Factors limiting implementation can be categorized as either technical or non-technical. Technical factors include the inherent properties of each technology and explore whether technological advances could possibly curtail problems with the technology currently. Non-technical factors include social and political reasons why technology has not been adopted. These non-technical factors could be compounded with the technical factors in certain cases. Documentary research methods and historical case studies are the primary methods of research being employed. Historical case studies will be particularly useful in the case of nuclear energy, as historical events such as the Chernobyl disaster of 1986 and the Fukushima Daiichi disaster of 2011 have greatly impacted public perception of nuclear energy. Documentary research methods outline the technical hurdles associated with each of the chosen forms of renewable energy, such as issues of efficiency and waste byproducts.

Background Information

According to the National Resources Defense Council, "Renewable energy, often referred to as clean energy, comes from natural sources or processes that are constantly replenished" (Shinn, 2018). For the purposes of this paper, renewable and clean energy will be used interchangeably according to this definition. Although nuclear energy does not technically fall under this definition due to uranium not being a renewable resource, nuclear energy will be included in this paper's definition of renewable energy sources in order to create a clear and concise contrast between the forms of energy production being investigated and the fossil fuels they aim to replace.

The Nuclear Energy Institute describes the production of nuclear energy as the splitting of atoms through nuclear fission to produce heat, which is then harnessed to boil water into steam to power a traditional turbine generator (*What Is Nuclear Energy?*, n.d.). Wind energy similarly makes use of a traditional turbine, whose rotation comes from the spinning of the blades of a windmill (*The Basics of Wind Energy | AWEA*, n.d.). Solar energy is created using solar panels to convert the energy contained in sunlight into other more useful sources of energy such as chemical or thermal (*About Solar Energy*, n.d.).

One of the burgeoning technologies that could potentially allow for the large-scale use of renewable energy sources on the electric grid is that of the liquid metal battery. Originally developed at MIT, liquid metal batteries have a much larger electric storage capacity than comparably sized batteries currently on the market. If further research allows liquid metal batteries to be scaled up, they could be used in conjunction with renewable energy sources to provide viable replacements for the burning of fossil fuels (*A battery made of molten metals*, n.d.).

Another technology that could be used to bridge the gap between renewable energy sources and the needs of the electric grid comes from the inventor of the lithium-ion battery, John Goodenough. This new technology of solid state batteries promises to yield batteries that charge faster, operate more safely, and store more power than current battery technologies. These batteries consist of solid electrolytes rather than the liquid electrolytes that comprise the lithium ion variety. The issue of combustion and explosion that have appeared in lithium ion batteries is caused by the formation of metal dendrites short circuiting the battery cell. The solid composition of the electrolytes in solid cell batteries prevent dendrites from being able to form. The solid composition also allows for new combinations of electrolyte chemistries previously not possible. This will theoretically result in more durable batteries with greater capacities ("Lithium-Ion Battery Inventor Introduces New Technology for Fast-Charging, Noncombustible Batteries," 2017).

Technological Determinism and Renewable Energy

The subject of renewable energy has long been viewed as a social issue, not a technical one. Due to the technologies behind renewable energy sources still being in their relative infancy, fossil fuels have yet to be made obsolete. The framework of technological determinism allows for an analysis of the drivers behind the adoption of technologies. The wide scale adoption renewable energy is best investigated through the use of technological determinism due to the concept's deep roots in the underlying technologies. According to technological determinism, social changes are driven by the development of superior technologies.

Successfully scaling up energy sources such as solar, wind, or nuclear in conjunction with advanced battery technology will provide the same benefits found in fossil fuels while adding the benefits of domestic job creation, reduced carbon emissions, and reduced costs in the long term. Ensuring that the implementation of renewable energy sources fits into the context of American society will provide the best chance for successful adoption.

Rarely does the world operate in absolutes, and the same is true for the debate between technological determinism and the social construction of technology. Due to past tragedies such as the Fukushima-Daiichi accident of 2011 and the Chernobyl incident of 1986, public perception of nuclear energy is bleak (*Fukushima Daiichi Accident—World Nuclear Association*, n.d.) (*Chernobyl | Chernobyl Accident | Chernobyl Disaster—World Nuclear Association*, n.d.). Additionally, unless the issue of nuclear waste management is resolved, nuclear power might prove to be worse for the environment than fossil fuels. Currently no suitable policies are in place to ensure the safe disposal and storage of nuclear waste (*Nuclear Waste: Last Week Tonight with John Oliver (HBO)—YouTube*, n.d.).

The term technological determinism was coined by Thorstein Veblen, also famous for the phrase “conspicuous consumption.” Another prominent contributor to the theory of technological determinism is Merritt Roe Smith. These two agreed that technological advancements were causal to most social changes throughout history, though Veblen more largely emphasized the role of determinism on the interpersonal scale, noting the relation between social status and physical possessions. The social construction of technology was developed by Trevor Pinch and Wiebe Bijker. As collaborators it can be assumed they agreed on the role that social constructs, their embedded meanings, and their influence on the development of technologies.

Analysis of Renewable Energy Sources

The future role of renewable energy sources' role in powering the electric grid hinges directly on the advancement of battery technology to such a state that large-scale power storage is possible and not economically prohibitive. The likelihood of successful integration would be increased should solar and wind power technologies improve their efficiencies, and if nuclear power's shortcomings can be reversed enough to turn the tide of public opinion back in its favor. Given the right combination of technological advances, an economic and cultural context will arise such that the adoption of renewable energy sources will become a logical choice and not a measure to be pushed for.

Historical Examples

For many years, nuclear energy seemed like a viable source of clean energy. However, multiple disasters at nuclear power plants and growing concerns over the management of radioactive waste byproducts have left nuclear power's benefits not being viewed as worth the risks associated with them. The oldest, and arguably most notable disaster at a nuclear power plant occurred at the Chernobyl power plant in Ukraine (then part of the Soviet Union). Due to human error and design flaws, the Chernobyl 4 reactor exploded on April 26, 1986. These explosions were a direct result of unsafe actions performed by the operator such as deactivating a mechanism that would shut down the reactor automatically in case of disaster. These actions allowed an anomaly of the reactor's design to then cause an uninhibited buildup of pressure from steam generation, ultimately leading to a pressure induced explosion. While two workers died in the explosion itself, the resulting leaking of radioactive material into the surrounding environment caused damage that is more difficult to judge in magnitude. 30 workers and first responders from the accident died in the months following the explosion due to their exposure to radiation. Onsite there were 237 diagnoses of Acute Radiation Syndrome, to be later confirmed in 134 of those patients. Initially over 100,000 people had to relocate outside of the region around Chernobyl, and access to that land is still either restricted or prohibited due to the persisting damage to that environment (*Chernobyl | Chernobyl Accident | Chernobyl Disaster—World Nuclear Association*, n.d.). Ultimately, the outdated technology behind the Chernobyl plant led to its failure, and updated safety mechanisms could have prevented the disaster.

More recently, three Japan's Fukushima Daiichi nuclear reactors experienced meltdown following a 9.0 magnitude earthquake on March 11, 2011. Reactors shutdown operation at the time of the earthquake, but continued cooling of the reactors required power from either the electric grid or backup diesel generators. Though initially resisting the effects of the earthquake itself, the resulting tsunami left the reactors without any power with which to remove heat from the reactor cores. While no deaths occurred from the nuclear meltdown itself, the accident revealed design flaws such as leaving the reactors in a vulnerable state in case of a total loss of power, and locating the source of backup power in a place where it might easily face conditions leading to its malfunction (*Fukushima Daiichi Accident—World Nuclear Association*, n.d.). According to the theory of technological determinism, better designed nuclear plants that prevent the possibility of events similar to the accident at Fukushima will fortify public opinion of nuclear power.

<u>Nuclear Storage</u>

Even when disasters such as Fukushima and Chernobyl do not occur, nuclear power generation still incur a monetary cost. The spent fuel rods America currently has possession of would occupy the area of a football field, stacked 20 feet high. These spent fuel rods consist of the byproduct of nuclear power generation, and are still both toxic and radioactive. Currently no effective means exists to store this nuclear waste, meaning that the waste is not sufficiently secured against the elements, natural disaster, or even theft. If large-scale increases to nuclear power are made, first the existing nuclear waste we house must be secured, along with room for the influx of new waste following said increase (*Nuclear Waste: Last Week Tonight with John Oliver (HBO)—YouTube*, n.d.).

Previous methods of nuclear waste disposal were recklessly dangerous. For many years, nuclear waste was covered in concrete and stored in barrels which were dropped in the ocean off the coast of New Jersey. In one case during July of 1957, a pair of the drums failed to sink. The solution for this was that "Naval aircraft were summoned to strafe them with machine-gun fire until they sank" (The U.S., Too, Has Dumped Waste at Sea—The New York Times, n.d.). Even when nuclear waste is stored rather than disposed of, current methods lack the robust safety protocols needed to keep the material secure. A facility in South Carolina called the Savannah River Site leaked radioactive material into the groundwater, causing so much ecological damage that the radiation has travelled up the food chain and alligators in the area are in fact radioactive (*Nuclear Waste: Last Week Tonight with John Oliver (HBO)—YouTube*, n.d.). Plans have been created for safe storage of harmful waste in secured locations deep underground, and facilities have been created for low level waste. However, no facility has yet been created to house the most dangerous of high level wastes.

Nuclear Innovation and the Travelling Wave Reactor

Bill Gates, founder of Microsoft, is heading a venture to create a new generation of nuclear power plants which will mitigate the problems of past nuclear plants. The company, TerraPower, promises a new model of nuclear plants with the goal of that radioactive byproducts are not able to escape, and a disaster such as Chernobyl or Fukushima can never occur again. Lowell Wood originally conceived of the idea for this new Travelling Wave Reactor (TWR) along with Edward Teller, inventor of the Hydrogen bomb, during their tenure at the Lawrence Livermore National Laboratory. Says Wood of current nuclear plants, “Almost all nuclear power plants currently in existence were not designed with computers at all. They were literally slide-rule designed plants.” This lack of innovation inspired Wood, as he said “Most modern nuclear power plants in existence in the US at the present time represent 1960’s designs and 1970’s implementation,” meaning that about half a decade’s worth of technological advances are not being taken into account in the United States’ nuclear power plants (Inside Bill’s Brain: Decoding Bill Gates, n.d.).

The TWR’s design focuses on minimizing the opportunity for human error in operation by leveraging modern automation and controls systems, requiring less input from operators. Another benefit is that instead of using enriched uranium, the TWR is powered by depleted uranium, which cannot be used to make nuclear weapons, and is part of what current nuclear waste consists of. The TWR will theoretically only require refueling once per decade, meaning that the fuel can remain securely housed in the reactor for that entire time period. Further safety measures include operating pressures remaining at atmospheric levels to prevent the risk of Chernobyl-like explosions, and existence in a safe state when power is off to prevent disasters such as Fukushima. The facility housing the reactors will also be built to withstand natural disasters (Inside Bill’s Brain: Decoding Bill Gates, n.d.).

The first pilot reactor was planned to be built in China, following an extensive period of negotiation. Following the recent trade war with China, the United States government exercised its right to terminate the contract allowing TerraPower to build the first TWR. No arrangements have yet been made to get the plan back on track (Inside Bill’s Brain: Decoding Bill Gates, n.d.). The fact that no real performance data for Travelling Wave Reactors yet exists is additionally problematic for the purposes of this paper, as no quantitative analysis may be conducted on the new reactor style's economics.

Energy Output Analysis

According to the Energy Information Administration, one nuclear power plant, the R.E. Ginna reports that of the United States generated 4.7 million megawatt hours in 2018 (How much electricity does a nuclear power plant generate? - FAQ - U.S. Energy Information Administration (EIA), n.d.). Overall, the US produces 4.2 billion megawatt hours of power in 2018 (U.S. nuclear industry—U.S. Energy Information Administration (EIA), n.d.). Thus, it would require 894 power plants operating at the same rate of production as the R.E. Ginna plant.

Similarly, a solar power farm generates 357 megawatt hours of power annually per acre (Solar Farm Land Requirements: How Much Land Do You Need?, n.d.). In order to generate the 4.2 billion megawatts required to power the entirety of the nation, 11.8 million acres of solar panels at their current efficiency would be required. This is an area larger than the state of Maryland (*Ranking Of States By Total Acres—Beef2Live | Eat Beef * Live Better*, n.d.). It must be then, that in order to act as a feasible replacement for fossil fuels, the efficiency of solar panels must be increased. The American Wind Energy Association estimates a maximum annual output of 17,520 megawatt hours for a two-megawatt wind turbine, with capacity factors of roughly 40 percent to account for wind not always blowing (The Basics of Wind Energy | AWEA, n.d.). Therefore, each turbine can produce roughly 7000 megawatt hours per year. This would mean in order to replace fossil fuels to power the electric grid, 600,000 current wind turbines would be required.

Battery Technology as a Supplement to Renewable Energy

Various new forms of battery technology could bridge the gap between the electric grid and renewable energy sources. Solar farms cannot be setup in urban areas, not every location has enough wind to be suitable for wind turbines, and nuclear plants require large amounts of water nearby to cool the reactors. Therefore, in order to effectively deploy these energy sources, large scale batteries capable of containing enough power for extended periods can theoretically be leveraged to transport power to where it is needed from where it is produced. Deploying large batteries as intermediaries between generation and use also handles the other drawback of solar and wind power: that they currently only provide power at the time of its generation, and not as needed in the way fossil fuels do. The success of such a plan is dependent on the further development of the battery technology and the implementation of infrastructure to support this new system.

Limitations and Future Work

This research is limited in its scope by several factors. Delays in the deployment of a prototype facility for the TWR prevents research on its feasibility for mainstream integration. Further research into solid state batteries is also needed before a plan of action can be created to deliver renewably produced energy to locations not suitable for renewable energy development. Future research would more specifically detail the infrastructure requirements needed to be met in order to fully power the United States via renewable energy sources and battery deployment.

Looking Forward with Renewable Energy

Should the technologies behind solar power, wind power, nuclear power, and battery technologies be advanced enough, the electric power grid could feasibly be powered by a combination of various forms of renewable energy sources. Adopting renewable energy sources to power the electric grid will allow the United States to no longer burn fossil fuels to provide power, eliminating 12.5% of its annual carbon emissions. Reversing climate change is a lofty goal that must first begin by stopping the damage currently being done to the environment. The measures discussed in this research are surely not an extensive list end global warming, but reducing the carbon emissions of the nation with the third most (the United States) by over 1/8 is a useful first step on a journey to a more sustainable way of living.

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