The Current State of the Energy Transition in the United States and its Effect on the Grid, the Environment, and Communities

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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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Introduction

There is no avoiding the topic of climate change. It is talked about on the news every time a natural disaster occurs, when temperatures skyrocket, or when the sky is orange in New York City from particulate matter (Lee, 2024; Ebbs, 2023; Cohen, 2023). More Americans today believe climate change is an important issue to be addressed as compared to ten years ago (Tyson, 2023). Links can be seen between Americans living in areas that have felt more effects from climate change and those who express greater concern for taking action (Tyson, 2023). This makes sense as climate change does not just affect the earth and its ecosystems, it directly affects us. We have always been intimately tied to the planet and its systems. The negative effect it is causing, like many other hardships humans face, is not a burden that has been shared equally. Climate injustices can come in the form of worldwide pollution causing certain areas of the planet (many times places that contribute very little of that pollution) taking on more than their share of natural disasters (United Nations Development Programme [UNDP], 2023). Furthermore, it is not just about bad storms, it is about ensuring that we have food to eat, sanitation to keep us healthy, and about protecting our communities that raise, protect, and support us (UNDP, 2023). Ultimately, climate change is not just a keyword to be mentioned in a political debate or a controversial topic to bring up at dinner but a real issue with real consequences.

One of the largest actors contributing to climate change is electricity production. Electricity is a crucial part of many modern societies and not just in the sometimes-superficial ways it is used. It provides heating and cooling, lights, refrigerators, even medical machinery, all things that help to keep a community running and healthy. It is also a sector that has seen and is continuing to see great improvements in creating clean energy technology. Solar panels continue to become more commonplace and wind farms span many miles in many parts of the US (Antonio, 2024; Indiana Office of Energy Development, 2024). President Biden has a goal of reaching 100% carbon free electricity production by 2035, which would require the combination of renewables and batteries (Plumber, 2021). Does this goal make sense with what we know about renewable energy and its effects? Should we push harder and faster for this transition, or should we change our approach or even scrap the idea altogether for something better? This paper seeks to understand to what extent renewable energy has been implemented in the US electricity market and to evaluate the effects it has had on the US grid, the environment, and our communities.

Background and Significance:

Climate change is a contentious phrase that has been used to describe what scientists conclude to be anthropogenic influence on the earth's ecosystem. But one does not need to be a scientist to see and understand the effects climate change has caused so far. Just in recent years, there have been heat waves, storms, wildfires, flooding, and many more with increased severity and frequency (EPA, 2022). This climate change is caused mostly by the burning of fossil fuels releasing greenhouse gases, which is the traditional way of producing energy (Energy System, 2023). Energy production is important for a society to thrive; there are general correlations that can be drawn between the energy that is consumed and the prosperity of a country (Cleveland, 2022). So, if reducing energy consumption is not an option, or at least cannot make a significant enough change to dramatically improve levels of greenhouse gases while not harming our societies, then the answer must be to produce this energy without the release of greenhouse gases.

Luckily, there have been many innovations in renewable energy technologies in recent years, though their implementation has been slow in some cases, especially on a large scale (Energy System, 2023). There are many reasons for this delay, but one is trying to solve the issue of the gap between when renewable energy is produced, such as when wind blows or sun shines, and when that power is demanded, a demand which tends to be much more consistent than the changing weather patterns. To fill this gap, battery storage will be important so that excess power produced at peak times can be used later when less energy is being produced than what is demanded (Energy Storage, 2023).

Renewable energy can come in many different forms including solar, wind, geothermal, hydroelectric, and more (EIA, 2023). Batteries can also come in many types, such as more traditional lithium-ion batteries, or less traditional ones like pumped hydro or compressed air (Energy Storage, 2023). Renewable energy technologies rely upon battery technologies to help balance the highly variable production of energy that renewables often offer. Currently, that variability is generally offset by fossil fuels, but if the US grid wishes to reach 100% renewables, then batteries will need to fill that gap (Plumber, 2021). The National Renewable Energy Laboratory or NREL created a Storage Futures Study that looked at the future of battery technology. In their final publication that summed up their findings, they expressed the importance of batteries for a 100% renewable grid (Blair, 2022). They expect that lithium-ion batteries will be the leader in storage and that many types of storage options will likely continue to improve in efficiency and cost-effectiveness as the technologies improve (Blair, 2022).

Yet, the energy transition is about much more than just getting solar panels on as many roofs as possible; we need to look at the economics, the reliability of the grid, cradle to grave analytics, environmental impacts, and social justice and community impacts locally and nationally. This research is important to get a holistic view of the benefits and costs of the energy transition as of where it is now. This research can help to inform us as to whether, based on how renewable energy has been doing so far in the US, we should continue with the energy transition.

Methodology:

The methods used in this paper include a literature review of primary sources and secondary sources of data describing the scientific and numerical findings associated with the transition to renewable energy and its impact. The paper also includes a literature review of sources describing human experience with the transition and an analysis of the qualitative data that is available. I will express my informed opinion about how well renewables have done so far in the US and their impact on the grid, the environment, and communities and whether the benefits weighed against the costs support continuing the transition to renewable energy.

Literature Review:

Renewable energy is beginning to make up a sizable share of the electricity production in the US. As of 2022, the combined electricity production from all renewable sources was just over 20%, making it the first year in history that renewable energy sources produced more electricity in the US than coal (U.S Department of Energy [DOE], n.d.). Within this 20%, wind energy makes up roughly half of the power production at 10.3% of total US energy production, followed by hydropower at 6%, solar at 3.4%, biomass at 1.2%, and geothermal at 0.4% (DOE, n.d.). In the US, the National Renewable Energy Laboratory (NREL) constructed a map highlighting the best places in the US for each type of renewable (see fig 1, DOE "Assessment", n.d.). Compare this with current technologies already in use in a map made by Synapse using information from the U.S. Energy Information Administration and U.S. Environmental Protection Agency that is accurate as of 2020 (See figure 2; Knight, 2020). When compared, it can be seen that technology has been placed in areas slated for their best production but there is still significant room for expansion.

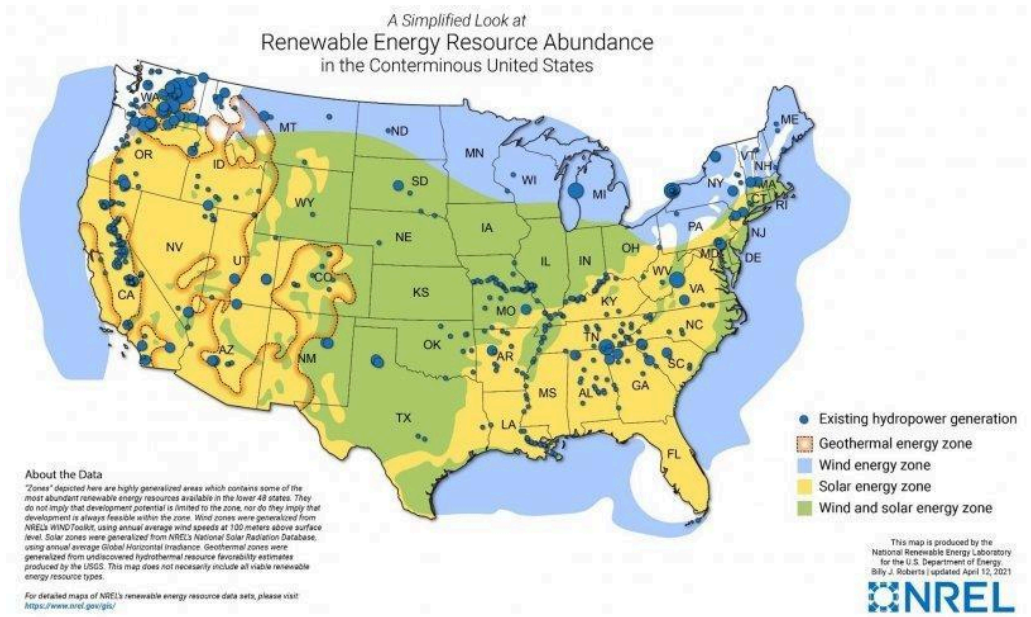

Figure 1: Optimal power plant locations in the US (DOE "Assessment", n.d.)

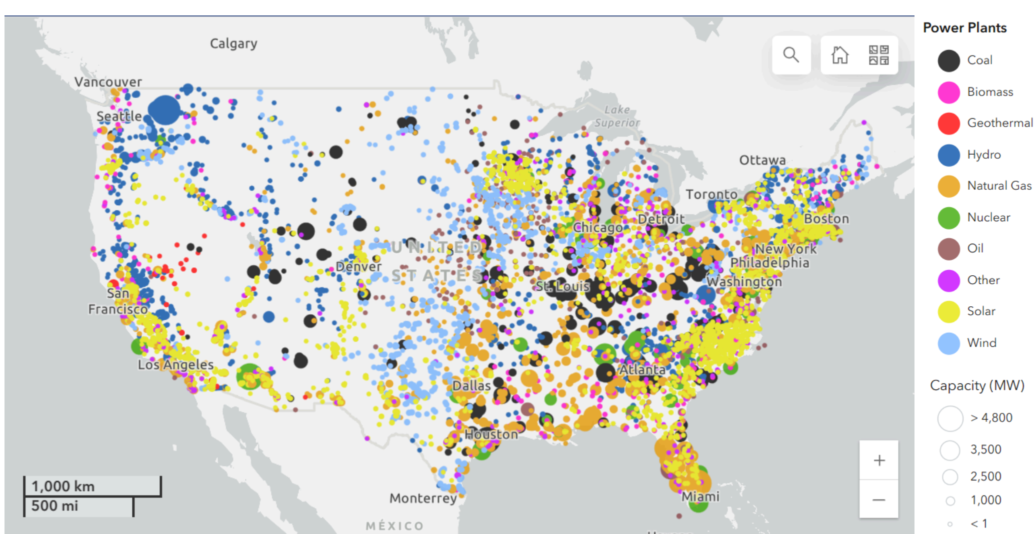

Figure 2: Power plant locations in the US and their relative size (Knight, 2020)

So far, the unreliability of renewable power technologies has not affected the reliability of the grid, as non-renewables still fill that gap, but as more renewable energy sources replace these sources, the grid will need batteries to bridge the gap. Pumped hydro currently fulfills most of the battery capacity in the US for electricity production and the DOE cites battery power expansion as being vital for the transition, even investing in research for its development (DOE "Reliability", n.d.).

When it comes to the reliability of the prices of renewable sources and the price itself, the US is reaching a tipping point in how its energy economics works. Solar and wind prices have come down significantly in the last 10 years and renewable energy is now competitive with its nonrenewable counterparts (Murray, 2019). The reasons vary from lowered manufacturing costs to utility scale projects picking up, meaning bulk pricing (Murray, 2019). However, current electricity production is very centralized and consistent while renewable energy is spread out, often not directly near areas that demand electricity, and inconsistent (Murray, 2019). Higher costs can be attributed to issues such as increased transmission costs from longer distances from production to use and the need for ramping facilities or battery resources to bridge these inconsistency gaps (Murray, 2019).

On the other hand, fossil fuels require consistent supply, meaning they can be more affected by supply chain issues and global conflicts (Jaeger, 2022). Renewable energy, such as wind and solar, once in place, just need wind and sun but no more fuel supply. There is also the issue of battery storage technologies being expensive even though the energy generating technology prices have become competitive (Moseman, 2023). Yet, looking at straight cost vs long-term, all-inclusive cost, which would include issues caused by CO2 released by fossil fuels, renewables would be cheaper in the long run (Moseman, 2023). Not all sources are totally sold on renewables being affordable but even an author from Columbia University, who writes an article pointing to much higher costs for renewable energy, agrees that this higher cost is still better than the costs incurred if fossil fuels persist (Toh, 2021). Overall, a Forbes article from 2019 referenced earlier sums up the economics well,

> "If private capital is to fuel the renewables wave, it seems likely the sector will need to move from a more commoditized market where revenues are determined by a price per kilowatt hour to one in which revenue is generated by providing guaranteed delivery of electricity when it is needed from sources either desired by the customer or required by regulation. This is much like the way phone and internet service is delivered today,"(Murray, 2019).

As for personal and residential uses, solar installations still generally cost anywhere from $15,000 - $30,000 but this cost can be offset with incentives, financing, and saved money from not buying from a power generator (DOE, n.d.). For context, an average household in the US pays just under $2,200 a year for electricity (EnergySage, 2024). But large-scale implementation of renewable energy will be important for the scale of change the US is looking for rather than house to house implementation. That should not discount that this type of change is also beneficial to the grid, especially considering transmission cost no longer becomes an issue when you produce energy right where you use it.

When it comes to the environment, renewable energy sources seem to be holding up to their promises. NREL did a "harmonization" project in which they tried to take many Life Cycle Assessments (LCAs) done over the years on photovoltaics and harmonize them into one finding (NREL, 2012). They found that over the lifecycle of solar panels 1) they release comparable amounts of CO_2 equivalent as other renewable sources and nuclear energy and 2) their grams of

CO2 eq/kWh as compared to coal is significantly lower (40g as compared to 1,000g for coal) (NREL, 2012).

As for the sourcing of these materials, there are a few things to take into account. Let's consider solar panels; one of the largest producers of solar panels is in China where worker conditions and forced labor are issues (Hoffs, 2022). The area where some materials are mined, such as silver in Guatemala, has caused water contamination and community issues (Hoffs, 2022). The same sort of scenarios are seen for aluminum and copper, mined in locations with human rights issues or on protected land (such as indigenous areas)(Hoffs, 2022). There are virtually no domestically made parts for these panels and most of the pieces are made in countries with questionable working conditions (Hoffs, 2022). This is all due to significantly cheaper costs in buying from foreign manufacturers, meaning we could produce all of our own panels but we choose not to almost exclusively for lower prices (Hoffs, 2022).

On a larger scale, our US community as a whole could benefit from the energy independence that renewables would bring if we produced our own technologies. The US also does a lot to try and combat human rights issues and advocate for good working conditions, such as fair living wages, which raise costs of products, albeit for a very good reason (US Department of Labor, n.d.). These problems can be helped with more emphasis on guaranteeing an ethical supply chain and increasing efficiency in the panel making process, though making sure rules are followed has its own challenges (Hoffs, 2022). Lastly, cradle to grave analytics, in which the true cost of a technology is evaluated not just in its operational state but from its resource gathering to disposal, lack on the later side as so many panels have now been installed but few have been retired. If materials from retired panels could be used in a closed-loop recycling approach, this would also significantly decrease the amount of raw materials needed to be mined and less land to be disturbed (Hoffs, 2022).

As for our communities, the energy transition has a net positive impact on the wellbeing of Americans. Energy employs over 8 million Americans as of 2022 and for the past few years, jobs in the sector have grown at a faster rate than the overall employment rate in the US (U.S Department of Energy [DOE] “Clean”, n.d.). The EERE, Energy Efficiency & Renewable Energy, a subset of the DOE, states that in its effort to, “increase diversity in DOE and the U.S. clean energy research community, business, and industry, EERE is expanding outreach at minority-serving institutions and minority professional organizations to raise awareness of research and job opportunities.” (DOE “Clean”, n.d.). The EERE also has a Clean Energy to Communities (C2C) program that works to help communities in the clean energy transition based on their goals and what is best for them (DOE “Clean”, n.d.). The NREL also has an, “Advanced Research on Integrated Energy Systems platform, on which local leaders can see how a virtual model of their community interacts with actual and emulated clean energy infrastructure and devices, such as wind turbines, controllers, and electric charging stations—helping de-risk future investments,” (DOE “Clean”, n.d.).

However, the varying costs mentioned earlier that have already started to occur and likely will continue to occur as the market figures out how to value these new energy sources could cause financial burdens to those who have lower incomes and have a larger energy burden.

Discussion and Results:

Based on the above research, renewable energy is at a turning point as the energy transition continues to gain momentum. The grid has been able to absorb the inconsistencies of renewables such as wind and solar, but this will get more difficult as these technologies grow and the fossil fuel sources that provide backup for renewables decrease. Batteries will need to fill this spot, but these technologies are more pricy than the renewable, market-competitive power generators themselves. Increases in renewables in the market might be causing some of the hikes in prices but other costs, such as aging transmission lines, are likely contributing as well. Despite some varied perspectives on how much price variability and increases have been caused by renewable energy sources integrating into the grid, most agree that the cost is worth avoiding the costs associated with climate change if nothing changes in the grid. Renewable energy does release less carbon dioxide and other greenhouse gases than fossil fuels based on LCAs. However, all the natural resources needed for the energy transition can negatively affect our communities if workers and/or land is exploited. Domestic production of panels is beginning to ramp up but raw material extraction could still continue to cause human rights issues. These could possibly be mitigated with recycling of panels as they retire. Domestically, the DOE is working to educate and hire workers for the renewable energy field. Overall, the energy transition, though it may have difficulties that could be avoided without a switch to renewable sources, will be worth the saved climate change issues and costs that would occur without intervention.

The US is currently making strides in new renewable energy installations. In 2023 alone, solar installations increased by 55% compared to the year before and renewables as a whole accounted for over three-fourths of all new capacity built in the same year (Bird, 2024). These are great numbers but the Biden administration has a goal to be 100% carbon-free in the energy sector by 2035. This would require doubling the 2023 rate of installation, which is not impossible but also a large task. There is hope this is possible as more states make goals towards carbon-free or reduced technologies and as incentives and economic gains make them better investments (Bird, 2024). On the flip side, there are also downsides as companies deal with supply chain issues and slow progress sometimes caused by red tape (Bird, 2024).

This being said, there is important context for the scale of the analysis in this paper. The energy sector only accounts for 25% of all greenhouse gas emissions in the US, which is second highest behind transportation at 29% (U.S. Environmental Protection Agency [EPA], 2024). This paper focused on the energy sector exclusively; however, the other 4 sectors of greenhouse emissions in the US, namely, transportation (29%), industry (24%), Commercial and residential (13%), and agriculture (10%), also have ways of reducing greenhouse gas emissions (EPA, 2024). It would be important to compare the scale of these changes on greenhouse gas reduction in comparison to the energy transition on the grid for perspective. Also, even within the energy sector, renewable energy is only 1 of 5 ways that we could reduce emissions from electric energy (EPA, 2024). The other 4 include increased efficiency of power plants, increased efficiency of end use technologies, nuclear energy, and carbon capture and sequestration (EPA, 2024).

Conclusion:

The purpose of this paper was to explore the effect the energy transition has had on the grid, the environment, and our communities in the US. In sum, the energy transition is progressing and beginning to ramp up in just the last year or two. Predictions for the future are hard to assess and there are many challenges that could arise but the outlook is bright. Having a global look at energy production would allow countries to make better informed decisions on clean energy production. It is also important to remember that the global system is connected and just the US changing likely does not make a large difference. Conversely, what we do here by releasing gases affects other places that may not contribute as much to global warming but bear its consequences.

Further research would hope to expand this question into other countries and ultimately the whole world. This full picture approach would allow us to better understand how much impact renewable energy could have on climate change on a global scale and what technologies we would need to accomplish that. Time is also important to examine as practical timelines for technology implementation may not agree with theoretical timeframes needed to make notable change. Considerations also need to be made as to how this might change energy grids across the world. Some could be more unstable, while others would be providing energy more reliably or for the first time to places that have historically struggled. Lastly, we must consider how it would hurt or benefit our communities and the way of life that people value.

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