Grid Modernization: Infrastructure for the Future

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Abstract:

In order to meet modern energy demands and combat environmental issues, the United States' energy grid must transition to a clean model that is smart, flexible, efficient, and sustainable. A sustainable design will allow the grid to function for a long period of time while having the smallest possible adverse effect on the environment in which it is built. Economic incentives and changes to the political structure can make a sustainable clean energy grid achievable. Combining the use of multiple renewable energy sources and effective transmission methods can ensure inherent flexibility in the grid. Doing this will enable the grid to adjust more quickly to varying levels of energy demand and therefore avoid both shortages and waste of excess energy. Energy storage and transmission from the primary production source should be prioritized to ensure that renewables can easily be integrated and relied upon to power the grid. Currently, the United States wastes billions of dollars worth of energy annually, by investing in more efficient infrastructure the United States will be better off economically and environmentally. Finally, as the modern United States energy grid digitizes, it must become smarter by utilizing data, machine learning, and stronger cybersecurity tools and in order to interact with the energy production and consumption process to assess potential problems, needs, and threats in real-time.

Introduction:

The United States is split into three energy grids: Easter, Western, and Texas. (**epa**) Each section is composed of various sub-grids, hundreds of power plants, and millions of miles of transmission lines. The grids run on Alternating Current (AC) power (**notes**), which relies on large power plants to produce mass amounts of energy for the public. The power plants produce energy and then send it through transmission lines. Along the transmission line there are various transformers which lowers the voltage so that it can be used to power houses and appliances without shorting out circuits.

When the energy grid was first created, it was built off of the idea "bigger is better," and large power plants would be built to supply large portions of the public. This design, while allowing for integration of electricity into many people's lives, created a variety of problems and inefficiencies. Firstly, this setup allowed for a natural monopoly in the energy sector, where one company could control virtually all the energy for a large area. This decreases the competition in the marketplace and subsequently leads to stagnation in this sector. In addition, the U.S. relies on base load power plants, and uses peaker plants in order to meet demand when it rises. Peaker plants are fossil fuel powered plants, which are expensive and produce large amounts of pollution. Lastly, the U.S. government is still providing the fossil fuel industry with large amounts in subsidies, money that could easily be more beneficial for transitioning to renewable energy. Along with other issues, such as the public perspective of renewable energy, mismanagement of energy, and a focus on supply over demand, the U.S. is far from where it needs to be in terms of modernizing the grid.

While the U.S. was once a leader in renewable innovation, it is far behind much of the developed world. Countries such as Germany, Denmark, and even China are now increasing this investment and commitment into renewable energy—and it is benefitting their economy as well as the environment. As the rest of the world begins to modernize their energy grids, the U.S. must realize the transition to renewable energy is inevitable. Although much of the United State's infrastructure, regulations, and funding benefits fossil fuels, there are plenty of ways in which the U.S. can increase its reliance on renewable energy and promote clean technology. Over the next few decades, the United States must begin to shift their focus from fossil fuels to creating a grid that is sustainable, consistent, efficient, and smart.

Argument 1: Sustainability

An imperative facet of the modern clean energy grid is sustainability, meaning the grid will be able to operate far into the future with minimal harm to the environment and population. Although the U.S. faces many economic and political barriers to this goal, through economic incentives and changes to the political and physical structure, a sustainable clean power grid is achievable. A sustainable power grid seeks to include microgrids, connects the existing electric grids present within the continental U.S., and removes fossil fuel subsidies.

Microgrid technology, also known as Distributed Energy Resources (DER) encapsulates renewables powering the community in which they are located, ranging from solar panels on rooftops to wind turbines to energy storage[25]. Generally, DER systems are operated either by a single consumer or a group of invested community members. According to the NRECA, electric cooperatives already provide power to 56% of the nation's landmass, with the dropping price of solar being a major factor in increasing numbers of low-income communities turning to community co-ops for electricity[23]. Microgrids are transforming the rural electricity economy and increasingly serve to lower electricity bills for low-income families. Additionally, as climate change intensifies natural disasters such as hurricanes, microgrids often act as a self-contained generator of electricity for communities affected by severe weather events[4]. Microgrids are an essential part of the sustainable electric grid by making renewables possible by providing a larger range of energy-generating sources than traditional power plants, allowing for the flexibility an electric grid powered by renewables requires. Additionally, the sustainable electric grid needs scalable technology, and microgrids are low-hanging fruit the U.S. can seize as an opportunity to incorporate renewables into the electric grid while large, systemic change slowly manifests.

While microgrids are an essential component to the electric grid, they must take place in a larger grid interconnected across the entire nation. The U.S. is currently serviced by three major grids, one in the East, one in the West, and one in Texas. These grids lack interconnections, meaning each is entirely self-contained, crippling the U.S.'s ability to exchange electricity between regions. This is a major issue because it hampers domestic trade of electricity between regions, thus hindering the flexibility required of a sustainable electric grid powered by renewable energy[4]. By connecting these three power grids, the National Renewable Energy Laboratory calculated production costs could be reduced by up to 4 percent[3]. Interconnecting the three US domestic power grids would not only benefit the national economy but would lead to a more sustainable electric grid. Larger electric grids are able to integrate more renewable energy sources as they have more flexibility in choosing which sources to draw from, thus mitigating the inconstant nature of renewable energy sources[3]. Using high-voltage direct current (HVDC)

technology to replace existing outdated connection points would not only make long-distance electricity transportation between the three grids within the US viable, it would make it efficient and affordable[47].

Lastly, the sustainable electric grid must remove subsidies given to the fossil fuel industry. These subsidies meant to protect fledgling industries have ballooned to over $649 billion in 2015—ten times more than was spent on education that year[1]. These subsidies artificially and unsustainably allow fossil fuels to stay viable in the current electricity market, despite the fact removal of these subsidies would lower global carbon emissions, reduce pollution, and increase government revenue[10]. Removing subsidies would also allow the money to flow to other areas of public spending, such as investments in infrastructure, public health, and education. Additionally, it would allow the market to move towards green energy as prices on renewables such as solar and wind drop[9]. A sustainable electric grid requires the removal of fossil fuel subsidies to stop the unsustainable contortion of the electricity market and allow natural market forces to return and renewables to prosper.

A barrier facing the removal of fossil fuel subsidies in the US remains the role of money in politics. The 2010 Supreme Court ruling in Citizens United v. FEC determined spending was speech and protected it as free speech. This opened the way for corporations to begin pouring money into the US political system, influence public opinion, and threaten politicians to follow their agenda[8]. Before the Citizens United ruling, Republicans were often more likely to co-sponsor bipartisan bills regarding climate change activity, white after the ruling, such Republican activity largely ceased due to fears of reprisal from the powerful fossil fuel industry[41]. However, there is hope for change in the future as increasingly public opinion pressures Republicans to take action on climate change[41]. Many Republicans hear from constituents who have been harmed by climate change, such as farmers and fishermen, and many represent states who have much to gain economically from renewable energy as jobs in wind and solar outpace jobs in traditional sources of energy such as coal[12]. Lastly, removing subsidies on fossil fuels is estimated to increase government revenue by 3.8% of GDP, thus creating an economic incentive[10].

Systemic barriers to change also stand in the face of connecting the three major electric grids of the US. Projects often take a decade in planning, complicated further by the overlap in legislative jurisdiction ranging from independent system operators to regional transmission organizations to independent electric utilities companies[36]. Additionally, as long-distance electricity transportation crosses state lines, cost-benefit calculations grow more complicated and permits harder to secure. If the process was streamlined, it is estimated long-distance electricity trading infrastructure requiring fifteen years of construction could be instead completed within two[3]. Solutions to these problems are being examined, ranging from clarification of legislative oversight to use of scenario-based planning to calculate beyond simple direct cost savings to even a complete redesign of the electric grid[3, 36]. The electric grid in the US has functioned on the same model for several decades while technology has rapidly progressed, and the old model may no longer be sustainable for the present day. As information and communication technology continues to become more and more accessible, modernizing and connecting the electric grids in the US becomes more and more possible[36].

Within the larger electric grids, microgrids, although promising technology, also face their own host of challenges. For example, microgrids are not always the most sustainable, cost-effective solution, so judicious choices must be made regarding their implementation in

certain communities[32]. Additionally, construction of microgrid infrastructure can be prohibitively expensive for individuals and communities, a constriction only exacerbated by rampant wealth inequality in the US. These same low-income communities are often the communities most at risk from extreme weather events magnified by climate change[48]. Climate justice activists have responded to this by launching community-owned cooperatives in vulnerable neighborhoods and reaching out to local businesses[16]. These community collectives not only serve as a resilience plan to severe weather, but also generate a consistent cash flow for members. This community collective system is easily scalable and when implemented correctly can provide a viable path to microgrid integration in a modern sustainable electric grid.

Through microgrid inclusion, increased interconnectedness between existing US electric grids, and removal of subsidies on fossil fuels, the US can move towards a sustainable electric grid. This facet of the modern clean energy grid requires the grid to be able to function for long periods of time while minimizing negative externalities, and although systemic barriers remain, with forces such as community collectives, grid architecture redesign, and increasing political pressure, the US may yet be able to reap the benefits from a future sustainable clean electric grid.

Argument 2: Enhancing Transmission Networks

One of the most significant drawbacks to using renewable energy sources like solar and wind is their unreliability due to variance in weather and geographical conditions. Cloud cover, nightfall, and lack of steady wind are all examples of conditions under which solar and wind would fail to supply the grid with the energy that it needs. These sources of variance make it more difficult to predict aggregate supply levels and therefore makes it harder to match energy supply to demand, increasing the probability of both shortages in periods of high demand and wasted production in periods of low demand. Studies of grid integration in the United States have shown that the need for system flexibility increases significantly when variable sources of energy (like wind, solar, etc) make up more than 30% of total energy production[30]. Considering that an ideal clean energy grid would consist of much higher than 30% variable production, it is evident that increased flexibility is essential for the United States' energy grid moving forward. One of the most effective ways to improve the flexibility of an energy grid is through improved transmission systems, which could supply the grid with multiple renewable sources of energy production and therefore lessen the unpredictability of aggregate supply.

The idea behind extending transmission networks is simple: by extending transmission lines and connecting with neighboring grids, each area of the grid will have access to a wider range of balancing resources[2]. For example, if cloud cover is heavy in California and solar production lessens, wind energy from Wyoming can be transmitted over state lines and can meet the unfulfilled demand. For solar and wind energy production, much of the fluctuation in output is localized because of weather and geographic conditions[18]. Therefore, it makes sense that a grid with access to a wide range of resources is less prone to heavy variability. In a study comparing the variability of two different grids, one smaller grid consisting of 15 wind turbines and one larger grid consisting of 215 turbines, it was found that the smaller grid had a variance level 47.2% higher than the larger grid[18]. This illustrates the impact that a wider, more interconnected grid can have on solving the issue with increased variability from renewable resources. If one area is experiencing problems with generating energy, the grid can tap into excess energy from another area to fill in the gap. Other countries are ahead of the United States in terms of

expanding transmission networks to overcome geographic and weather-related limitations. Germany has experienced large imbalances between locations of wind energy production versus energy demand, so they planned three major north-south transmission lines to extend the reach of their grid and supply energy from distant wind farms to locations of high demand[28]. In addition, China and Denmark both proactively plan and implement transmission capacity to accommodate growing wind energy production[28]. If energy production from a wide range of locations can be consolidated onto a single grid in the United States, net variability is lessened and one of the major problems with using renewable energy sources is mitigated by this increased flexibility.

Improving transmission systems not only helps mitigate the variance of renewable energy sources, it is also proven to be an effective way to reduce costs. Some have raised concerns over the time it would take to construct and implement an enhanced transmission network, since in the short term the grid would be significantly less flexible and would be quite costly[21]. However, if the United States is to move towards a modern clean energy grid with high renewable energy penetration, enhanced transmission systems are one of the best long-term options for saving costs. A study conducted at Stanford University explored the expected cost savings behind various methods of improving grid flexibility under the assumption of high renewable energy penetration. The study found that geographic aggregation through an enhanced transmission network had the best level of cost savings relative to the norm, or what would have occurred if no flexibility improvement measures had been taken, surpassing other methods like renewable overgeneration and storage methods[15]. The cost savings of enhanced transmission networks became more pronounced as renewable penetration increased, proving that as more and more renewables are used on the grid it would be more economical to enhance transmission networks to access a wider diversity of resources rather than leaving the grid segmented as it currently is[15]. The effectiveness of enhanced transmission networks was illustrated in Texas between 2009 and 2014. In 2009, the Electric Reliability Council of Texas (ERCOT) suffered wind curtailment levels of 17%, meaning there was a 17% reduction in energy output below what could have optimally been produced, and a major contributing factor was how limited their transmission network was[21]. In the next five years, ERCOT restructured the regulatory framework surrounding transmission and made significant investments in their networks, and by 2014 wind curtailment levels had fallen to just 0.5%[21]. This displays the effectiveness of an enhanced transmission network and the impact it can have on a modern energy grid.

There are some problems that come with extending transmission lines to different geographic areas, and perhaps chief among them is the amount of land required. Land consumption is already a cause for concern with increased solar and wind energy production. A study compared two hypothetical grids, one which would reduce greenhouse gas emissions by 80% below 2018 levels and the other by 100%. They found that the grid that reduces emissions by 100% would require almost three times as much land for solar and wind energy alone, with specific land requirements ranging from three to fourteen million acres[31]. While land is limited, allocating land for extended transmission networks might be made simpler by taking advantage of the infrastructure already in place for the coal industry. Coal is an industry on the decline, so establishing renewable energy resources in locations in which coal is currently retiring and utilizing existing transmission infrastructure could reduce the need to sacrifice additional land and build transmission lines from scratch, which in turn lessens financial and regulatory burdens[18]. This might be more difficult in the short term as current federal policies favor the

dying coal industry over the emerging solar and wind industries, but this represents a possible solution to one of the main hurdles with improving transmission systems.

Enhancing transmission networks to widen the resources available to energy grids is proven to be an effective method of modernizing a grid with high renewable energy penetration. This is not the only effective option, however, and the most likely scenario is a combination of multiple methods that together will improve the flexibility of the energy grid more than any one method would by itself. For example, interconnecting different neighboring sectors allows these sectors to share generator capacity, thereby reducing the total required generator capacity for the entire connected region[30]. The use of generators and storage methods is one of the other more intriguing methods of improving grid flexibility, and will be explored further in the next section.

Argument 3: Energy Storage

Renewable energy is expertly presented as the sovereign solution to the planet's dire need for a cut in carbon emissions. Therefore, the rise in demand of solar, hydroelectric, wind, and various other renewable sources of energy has resulted in an increase of jobs and a decrease of carbon emissions. In order for the grid to successfully transition from carbon-based energy to renewables, diverse applications of renewable sources will directly result in reduced energy costs. The inconsistencies that come with the wind and solar energy will allow for the two energy sources to complement each other. For example, during the sunny season —when UV production is at its peak— the primary energy source is solar and vice versa during the windy season[20]. Although this is an idealistic solution which would allow for the U.S.' energy grid to run on renewables while economically benefiting, it is essential that the energy grid's technology and systems of storage are refined in order to properly retain the immense amount of valuable energy the country produces.

The long disputed inconsistency of renewable energy's production has remained an incessant impediment in the future of the U.S.' energy future. However, avoiding the transition to renewables has inhibited the grid's energy storage technologies as well. The vast decrease in the prices of wind, solar, and more recently, lithium-ion batteries, the energy grid can optimistically look forward to efficiently storing renewable energy. However, the reformation that is required of the country's current energy grid may present this optimal storage preposition as unattainable. The U.S. currently holds 22 gigawatts of stored energy, therefore the country needs to accelerate its current rate of energy storage growth from 1.4 gigawatts, in order to achieve the goal of 120 gigawatts by 2050 [33]. With the current trajectory of our energy grid technology growing at such a slow rate, the necessity for the U.S. government to prioritize new technology is becoming vastly more urgent, due to the antiquated and inefficient storage systems that are in place presently.

As the world advances towards more intuitive energy grid technology, it is imperative that the U.S. begins to implement change in the current technology being utilized. Due to the unreliability of certain renewable energy sources, such as solar and wind, energy plants are discovering more consistent forms of energy to store, in order to increase the volume of energy that the U.S. grid can sustain. Biomethane and solid lithium batteries have risen as the most effective forms of energy storage systems, due to their reliability and lack of dependency on weather and location. Biomethane forms its energy by breaking down organic material and generates electricity through heat, which allows its energy to be stored for a longer time. With this technology being implemented worldwide, the U.S. is beginning to recognize the urgent need for "e-fuels," such as biomethane and lithium batteries, which store their energy as fuel as

opposed to electricity. The use of gaseous fuels can allow the grid storage systems to decentralize, in order to allow for energy to become more accessible throughout the country, instead of being based on the isolated grids that the U.S. currently has in place. The introduction of hybrid-source energy to the U.S. grid will allow a multi-faceted system to sustain large quantities of energy, while reducing the percent of error of energy lost when transferring energy[11].

The reliance on the fossil fuel industry has resulted in the U.S. to fall behind in the globe's progression of energy grid technology. A centralized system of technology will only perpetuate this delay in advancing our grid storage systems, therefore the implementation of a hybrid grid storage system will project the U.S. towards reaching a more renewably sourced storage system, by optimizing multiple sources of energy, as opposed to drawing energy from fossil fuels and electricity-centric sources.With the incentive of decreasing prices, the probability of the U.S. transitioning to a renewably sourced energy grid by 2050 is increasing, as each local grid is prioritizing gas and heat based energy sources, as opposed to the less efficient electric sources that are currently being utilized in the grid system. Improving the efficiency and maximizing the storage systems capacity is becoming the most cost efficient solution to altering the grid storage systems, which has resulted in a 93% increase in optimal storage systems as of 2019, therefore the U.S. is beginning to deploy a widespread adaptation to a multi-faceted, renewably sourced grid system[14]. However, this transition is not occurring at the pace that is required in order to reach the country's current trajectory for the renewable electricity storage system.

The misconception that the country faces, is the belief that the electrochemical or battery storage technology fails to supply enough energy to meet the country's demand; however, the issue lies in the U.S.' reliance on seasonal storage, which results in an inconsistent production of energy that isolates energy systems from being able to consistently produce and store energy efficiently[5]. As solar and wind power are heavily reliant on the consistency of weather, the production of renewable energy is not meeting the country's demand of energy, therefore, the nation's grid technicians are experimenting with technology that will overcome the dilemma of seasonal storage shortages. For example, in Southern California, the NREL has installed a power-to-gas bioreactor, which will utilize multi-faceted, renewably sourced power a pipeline that stores natural gas in order to avoid energy shortages that typically occur during seasons where energy is not being produced at the rate that energy is being utilized [6]. With the country experimenting in the installation of advanced grid technology, the emphasis on multiple sources of sustainable energy requires the careful consideration of optimal energy storage and will project the U.S. towards achieving a larger capacity of energy storage by 2050.

Argument 4: Grid Efficiency

As the United States begins to create a more sustainable energy grid, efficiency is a necessary part of reaching that goal. More efficient handling of energy reduces waste, decreases its cost, and helps the energy sector become more sustainable long term. Currently, the United States wastes around ⅔ of the energy it produces[30], which is roughly 200 billion kilowatts of electricity and costs over $20 billion dollars[44] annually. By investing in better storage, policies, and more efficient infrastructure, the United States will be better off economically and environmentally.

An efficient energy grid requires creating a system in which very little energy is wasted, and less energy may even be needed. There are large-scale and small-scale changes in efficiency[24]. Large-scale efficiency is in regards to improving energy producers, infrastructure, and energy policy. Small-scale efficiency regards the changes made on a personal level, such as in buildings and houses. Both levels need to experience a shift in their usage of energy in order to create a more environmentally friendly energy grid.

In terms of large-scale changes, one of the largest issues with efficiency is the lack of storage and transmission of energy [27,24]**.** In plants that produce more energy than they consume at a time, insufficient storage leads to a large amount of waste. However in some areas, when there is not enough energy produced, the grid lacks the ability to import from areas which produce a surplus. The latter allows for the prevalence of fossil fuels in the United States, since increases in energy demand are most easily managed through the use of natural gasses with "peak plants". The United States has three grids, and connecting these grids is a crucial aspect of increasing efficiency, since it would decrease the need for "peak plants". Instead, energy could be transported from energy plants in one area to another during peak hours. However, connecting the grid in a sustainable way requires better transmission infrastructure and monitoring.

Transmission lines already have many leaks, thus the implementation of intragrid sensors is a paramount step in increasing efficiency[44]. Intragrid sensors monitor the voltage from one transformer to the next. They can be retrofitted onto existing transformers in the grid, and therefore are a simple addition to increase efficiency. If a significant amount of voltage were being lost in between two sensors, maintenance can locate and fix the energy leak. This has the ability to save the U.S. over $10 billion dollars annually and nearly 100 billion megawatts of electricity[30]. This technology would not only help conserve energy, but has the ability to produce a variety of maintenance and installation jobs.

Another large scale change is to increase funding in methods of storage. Currently, lithium ion batteries are used to store excess energy; however, lithium ion batteries are expensive, and store a few hours worth of energy at a time[24]**.** Promising new storage technologies, such as Solid-state Lithium Batteries, lead acid batteries[27], and phase-change methods of storage, are beginning to increase (**Ron Defelice**). In addition, many companies are looking into multi-use EVs, or other forms or multi-use technology. This type of storage works by using something that is already a part of the grid to store energy when possible. For example, Dominion Energy has developed electric school buses, which would store energy when not transporting kids—cutting down on GHG emissions and increasing stability in the grid[7]. Similarly, the placement of storage is important. Rather than simply putting energy storage near the plant, storage can be installed along the transmission route in places which conveniently store energy for quick transmission and use. (**Ron Defelice**) While changes such as these are expensive and laborious initially, they make up for it in the long run. According to Dominion, electric buses are 60% cheaper to maintain[7]. Additionally, by increasing the efficiency of the energy grid, the U.S. will save billions of dollars, making it a worthwhile investment.

Lastly, the United States government must create more regulations that advocate for renewable energy sources and energy efficiency. California implemented a law that requires 3% of all new parking lots to be designated EV charging stations. Regulations such as these increase the public's commitment to transitioning. In addition, local governments can include energy efficiency standards in all new and old buildings in the area[22]. This could include standards that require a certain efficiency use, installations of smart/sustainable devices, and other energy

codes. Similarly, policies could favor regionally designed architecture, which would fit the geography and cause buildings to require less energy. This is important in the creation of zero net energy and net positive energy buildings[24].

Individuals also have the ability to increase their energy efficiency. Certain people have the ability to install solar panels, co-own renewable energy sources, install "smart" devices to monitor and decrease energy usage, and invest in energy efficiency appliances, and the cost of these energy efficient changes is becoming more affordable[47]. Homes and businesses use around ¾ of the energy produced and are responsible for ⅔ of greenhouse gas emissions[22]. The installation of personal energy producers and renewable energy sources has been shown to save money long term, especially in low income households, which spend on average 16.3% of their total income on energy—over 4.5 times as much as higher income households[47]. Additionally, the price of photovoltaic cells has decreased substantially in the past three decades, leading to an increase in installment. In addition, installation of personal or co-owner renewable energy sources helps decrease the need for "peak" plants, as people both with and without storage are able to decrease the United State's reliance on fossil fuels.

Another small scale change is the addition of smart devices and energy efficient appliances [28,47]. Smart devices allow for easy monitorization of energy use, and helps individuals decrease their usage where they can. Similarly, energy efficient appliances, such as LED lights, smart thermostats, and energy timer controls. The installation of more energy efficient appliances and smart devices could halve U.S. energy demand[47]. Similarly, individuals can unplug devices that are left plugged in when not in use.

Lastly, the rise of electric vehicles (EVs) can help to decrease carbon emissions and advocate for large scale installation of more renewable energy plants. EVs are overall more efficient in their use of energy and help decrease Greenhouse Gas Emissions (GGE). However, in places where natural gas or coal is the main source of energy, EVs are only around 4% more efficient than gas powered vehicles[30]. Despite that, the transition to EVs is a necessary step in creating a more sustainable energy grid, since they have the ability to rely entirely on renewable energy.

In conclusion, grid efficiency is a necessary part of modernization. Using energy as efficiently as possible, and minimizing the amount of energy necessary, decreases the demand on energy plants and fossil fuels. In addition, small changes in efficiency have large effects on the overall use of energy, both in industries and an individual. Changes such as increasing available storage, monitoring voltage transmission, and monitoring personal energy usage help lead the way to a more energy efficient future, which is more economical as well as sustainable.

Argument 5: Smart Grids

As the modern United States energy grid integrates more renewable sources of power, it must become smarter by utilizing artificial intelligence, machine learning, and stronger cybersecurity tools in order to interact with the energy production and consumption process to assess potential problems, needs, and threats as they arise. In 2007 President Bush signed the Energy Independence and Security Act which outlined the major aspects of a smart grid model which the United States should move towards [46]. A top priority of the smart grid is to be resilient to cyber-security attacks made by malicious parties. As cyber threats to the energy grid grow more frequent and sophisticated they have been labeled as a national security issue; the future smart grid should be able to effectively predict, prevent, and recover from these security

breaches [17]. Another key feature of the smart grid is allowing real-time interaction between energy producers and consumers to allow for proper allocation of resources[36]. Demand response, promoting users to make energy efficient and conscious choices, will better balance the supply and demand of energy resources at any given time [40]. The smart grid will also need more sophisticated electric load forecasting tools to better predict short, medium, and long term demands on the United States grid[36]. This involved predicting users' needs, estimating the amount of energy generated by different sources, anticipating grid failures before and as they arise, and working dynamically to address all aspects of the energy production and consumption process [36,39,34]. In order to make this vision for a smarter grid a reality, machine learning tools will need to be integrated into every aspect of energy production, management, distribution, and consumption to appropriately analyze historical and real-time data, and adapt accordingly [36].

The current American energy grid consists of over 1,800 independent entities who own and operate portions of the system[13]. Resultantly, malicious third parties have lots of entry points and opportunities to interfere with the grid. A Global Information Security Survey of 2013 indicated that 80% of power and utility companies have reported an increase in mobile computing, incidents of malware, and phishing[45]. However, a 2013 congressional report only outlined minimal cyber security measures organizations are taking in response to this growing concern; several investor-owned utilities had up to a 300% increase in the number of cyber security employees over the course of five years, however, federal agencies had hired none to very few cyber security personnel[41]. This report highlighted the inconsistent and inadequate measures the United States electric grid, as one entity, has taken thus far to address the growing cyber security threats. In response to this concern, much research has successfully generated softwares that rely on machine learning to detect real-time cyber threats in smart grids[34]. Robust infrastructure can greatly mitigate the risk of cyber threats; implementing secure softwares and retraining personnel with cyber security conscious practices will be time consuming and expensive, but necessary to ensure the reliability of the electric grid in years to come [17].

In addition to hyper-responsiveness to cyber threats, the modern smart grid must be responsive to consumers. Interaction between producers and consumers should be fostered in real time to increase the efficiency of energy generation. A key piece in this is demand response (DR) which entails a change in energy consumption behaviour to better match energy generation [40]. This significantly reduces the need for peaker plants which are one of the most inefficient components of the current grid.

While DR can help streamline the process of estimating energy usage due to a change in energy consumption behaviors, historical data can still be utilized to predict the short, medium, and long term needs that will be placed upon the electric grid. Statistical Machine learning has been successfully utilized in the New York area to 1) prioritize the urgency of different types of failures across the grid, 2) assess the physical state of different grid components, 3) estimate time between failures, and 4) predict risk involved in physical maintenance[38]. This type of software greatly streamlines the energy generation/transmission and grid maintenance process. In the long term, a proactive grid software can save utilities a lot of unnecessary costs. This style of software should be regionally created based on relevant data and expanded to the rest of the United States grid.

The modern grid must also be able to forecast the output of renewables effectively - only then can decisions be made about how to best generate, balance, and transmit and the electric load at any given time. As we move towards a model that relies on a growing diverse sources of

renewable energies, having tools to precisely predict energy generation based on weather patterns and other factors is a top priority. Researchers have already developed a machine learning algorithm to utilize data from the National Weather Service that are 27% more accurate at predicting solar power generation than existing forecast models[39]. Accurate predictions of energy production save significant time and money and help determine which sources should be relied on to satisfy different types of energy demand patterns. Locale specific prediction models are being developed and should be deployed and integrated into renewable energy generation sites across the United States.

Conclusion:

The United States, while an early leader in renewable energy development in the 20th century, has fallen behind foreign counterparts like China, Germany, and Denmark. A big factor in the United States lagging behind is the slow rate of renewable energy penetration into the energy grid. While the current political climate makes it difficult to spark major change, the United States can modernize its energy grid and incorporate higher levels of renewable energy by making the grid more sustainable, flexible, efficient, and smart. A sustainable grid will function efficiently for long periods of time with minimal harm to the environment or society. Through economic incentives and changes in political structure the United States' grid could become more sustainable, with possible solutions being the implementation of microgrids, connecting the existing electric grids present within the continental U.S., and the removal of fossil fuel subsidies. Considering the variability issues that come with most forms of renewable energy production, a modern energy grid will also have to be flexible and ensure energy supply is able to consistently match demand. Grid flexibility in the United States can be greatly improved through enhanced transmission networks that enable energy sharing between grid sectors as well as developing storage methods to take advantage of more of the energy we produce. The United States currently wastes a large portion of the energy it produces, emphasizing the need for a more efficient grid that is able to cut down on waste and general costs. Possible paths to a more efficient grid include better storage, monitorization, and large and small scale changes in efficiency. Lastly, a modern energy grid should take advantage of the rapidly advancing technology in the United States to become smarter, namely by utilizing things like artificial intelligence, machine learning, and stronger cybersecurity tools to continually update and adapt to new circumstances as they arise. All of these components will be essential in the implementation of a modern energy grid in the United States if we hope to implement higher levels of renewable energy in the coming decades and transition to a sustainable, flexible, efficient, and smart electric grid.

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