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Macroproblems Require Microsolutions: The Case for Microgrids in the U.S. Energy Infrastructure

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Abstract

This paper explores the shortcomings of the modern United States Power Grid in the face of climate change and worsening climate conditions, and seeks to explore how alternative styles of power grids could be viable replacements for current designs. The power grid is one of the most fundamental aspects of modern life, without it there would be no reliable energy supply to power devices and machinery. Oftentimes when energy generation is discussed in the United States, it only focuses on the source of generation for the energy, not the transmission of the energy. The lack of complete discussion around this topic means that some of the roots of the problem are left unresolved when discussing how to properly tackle climate change. Chapter one discusses the shortcomings of the United States power grid, along with some quantitative data and IPCC climate recommendations and guidelines to meet regarding climate change. Chapter two is largely focused on the development of the United States power grid from a series of smaller microgrids, to the now massive and interconnected connected power grid. Chapter three focuses on the economics of the current power grid, and how a wide implementation of microgrids in array with renewable energy could be economically beneficial. Chapter four focuses on the activity surrounding microgrids, whether it is bill, law, or some other form of funding for microgrid developments, or if it is a new microgrid project that is either completed or in development. Chapter five focuses on policy recommendations to meet IPCC guidelines and to begin the process of implementing microgrids nationwide.

Keywords: microgrid, power grid, energy generation, renewable energy, climate change

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Introduction: Blown Away by a Hot Breeze

Hurricane Irma swept through Florida back in September of 2017, destroying homes, wildlife, and infrastructure as it ravaged through the state. For some, it was a minor inconvenience. Maybe their power went out, maybe their home sustained a small amount of damage. For some, it was deadly.

Approximately 28,000 elderly Florida residents that reside in nursing homes were left without power during the hot and humid months of September (Alvim, 2022). Due to this lack of power, many elderly residents passed away. There was a notable increase of 25% in mortality rates for the first week after Hurricane Irma made landfall, dropping down to 10% for the month after Irma made landfall (Alvim, 2022). When the generators were not enough to power both the machinery of the residents and the Air Conditioning system, power had to be rationed, the lack of power led to dangerous and fatal overheating by the residents of the care facilities. Due to how the modern U.S. power grid is set up, it’s easy to have large systemic failures during extreme weather events such as a hurricane. Being completely interwoven and codependent on every part of the grid means that one instance of damage can cause cascading and catastrophic failures down the line. Lindsay Peterson, an assistant professor at the University of South Florida School of Aging Studies says that the most important thing is getting the power back on to actually run the air conditioning. Generators can be useful in the short term; but usually aren’t enough. Peterson said that “They help a great deal in the days after a storm, but if the power loss is extensive, you're going to need a lot of fuel, and that might be difficult. So there are continuing concerns around ensuring that there is enough power when a power loss is as massive as it was during Hurricane Irma. (Alvim, 2022).” But in a scenario such as Hurricane Irma where there is extensive damage to the power grid, the situation can look bleak.

This lack of energy security highlights the benefits of microgrids. By not being completely reliant on the grid, there’s a chance that even in an extreme weather event such as a hurricane your power will stay on. Even if the infrastructure of the microgrid gets damaged, by not relying on the central power grid for energy, there is a chance of less down time than a house hooked up to a traditional power grid due to a reduction in the scale of damage.

The energy needs and demands of the American citizen is drastically different than what it was a century ago, so why is the current U.S. power grid still fundamentally the same in design?

Chapter one will quantify data on climate change and the U.S. Power grid, chapters 2-4 will discuss the historical, economic, and political activities and data of the traditional power grid compared to the microgrid. Chapter five will focus on a variety of policy recommendations for the United States to fully modernize and strengthen their energy grid while also meeting climate change mitigation goals.

Chapter 1: The U.S. Power Grid and its Shortcomings

The United States Power Grid is a large nationwide network of power grids working in tandem with each other to provide over 145 million users with energy. The Energy Information Administration, or EIA, is a federal agency that is largely responsible for the collection, analysis, and dissemination of the United States’ energy information. According to the EIA, the grid is made up of over 7,300 power plants, over 160,000 miles of high voltage power lines, along with millions of miles of low voltage distribution lines and transformers (U.S. Electricity Grid &

Markets, 2022). The current workings of the United States power grid are environmentally unsustainable and must be changed. The International Panel on Climate Change, or the IPCC, released in their sixth assessment report that current United States power generation infrastructure in inadequate in the face of increasing climate change, the report states:

> Within energy system transitions, the most feasible adaptation options support infrastructure resilience, reliable power systems and efficient water use for existing and new energy generation systems (very high confidence). Energy generation diversification, including with renewable energy resources and generation that can be decentralized depending on context (e.g., wind, solar, small scale hydroelectric) and demand side management (e.g., storage, and energy efficiency improvements) can reduce vulnerabilities to climate change, especially in rural populations (high confidence). Adaptations for hydropower and thermo-electric power generation are effective in most regions up to 1.5°C to 2°C, with decreasing effectiveness at higher levels of warming (medium confidence). Climate responsive energy markets, updated design standards on energy assets according to current and projected climate change, smart-grid technologies, robust transmission systems and improved capacity to respond to supply deficits have high feasibility in the medium- to long-term, with mitigation co-benefits (very high confidence) (Summary for Policy Makers, 2022).

As climate change continues to worsen, there is an increased need to update the power transmission infrastructure of the United States. Decentralized power transmission systems, or microgrids, are an optimal solution to improve the security and resilience of the United States power grid.

Electrical Energy and Ecosystem Services

The United States Power Grid is reliant on ecosystem services. Ecosystem services are any benefits provided by animals and ecosystems to people (National Wildlife Federation, n.d.). There are four different types of ecosystem services, provisioning, regulating, supporting, and cultural.

Provisioning services are ones that focus on the material output of an ecosystem. These materials are primarily things like food, raw materials, fresh water, and medicinal resources. The power industry is reliant on the fossil fuels extracted from the environment to generate energy.

Regulating services are responsible for maintaining the functionality of ecosystems. These services include processes vital for human survival, such as climate and air quality regulation, carbon sequestration, moderation of extreme weather events, waste-water treatment, erosion prevention, maintenance of soil fertility and health, pollination, along with pest and disease control. The power generating industry relies mostly on access to clean and running water to operate at optimal capacity (An overview of ecosystem services, n.d.). Energy production relies on water for cooling, cleaning gas exhausts, running turbines, and disposing of waste. There is also reliance on other ecosystem services such as carbon sequestration to mitigate Carbon Dioxide (CO_2) emissions, air purification to mitigate air emissions, and water purification to mitigate pollution runoff (An overview of ecosystem services, n.d.). The EPA has guidelines regarding different types of aerosolized emissions and the acceptable limits that energy generation stations must follow. These are categorized as primary and secondary standards. Primary standards focus on public health, accounting for sensitive and weak populations such as asthmatics, children, and the elderly. Secondary standards are more focused on public welfare, such as decreased visibility and damage to crops, animals, vegetation, and buildings. The EPA tracks the atmospheric concentrations of Carbon Monoxide (CO), Lead (Pb), Ozone (O_3), Particle Pollution (PM), and Sulfur Dioxide (SO_2) (Environmental Protection Agency, 2023). The standards for these emissions were set under the Clean Air Act of 1963 along with further amendments to the law (Environmental Protection Agency, 2022d). The tracking of these pollutants helps ensure that ecosystem service losses are minimized. The generation of energy via fossil fuels interrupts and degrades these important processes, with the pollution they create destroying many of the factors that are vital to a functioning ecosystem.

Supporting services are the most essential to life on earth, providing habitats for humans and animals to live in, along with maintaining genetic diversity in species. These are the foundation of which life on earth is built on, with the extraction and burning of fossil fuels threatening to destroy these services.

Cultural services are the most unique of the ecosystem services, holding a more anthropocentric importance. Cultural services are ones that are important for the maintenance of human health, tourism, and human spirituality. These are the services most enjoyed by everyone, being nebulous concepts such as appreciation of nature, in the spiritual, aesthetic, and recreational sense. The degradation of these services would be a major loss not easily reflected in the market, although there have been attempts.

In 1997, it was estimated that the total global ecosystem services had a valuation of approximately US$16-54 trillion (Conservation tools, n.d.). These values play into our global economy through a combination of maintaining public health, damage mitigation, and allowing industry to operate to their current levels. These valuations are not completely reflected in the market, savings that might be brought on via ecosystem services can be unrealized savings, with the loss of these services possibly requiring alternative methods of operation for market forces. At the time of this study in 1997, the global GNP was approximately US$18 trillion.

The United States Macro-grid and its Energy Sources

The United States national power grid works by generating electricity at large central power stations along with decentralized units, which is then fed through a series of substations, transformers, transmission lines and distribution lines (U.S. Electricity Grid & Markets, 2022). The process of power generation is through a series of centralized and decentralized power plants, which are then fed through a maze of substations, transformers, transmission lines and distribution lines to be used by consumers (U.S. Electricity Grid & Markets, 2022).

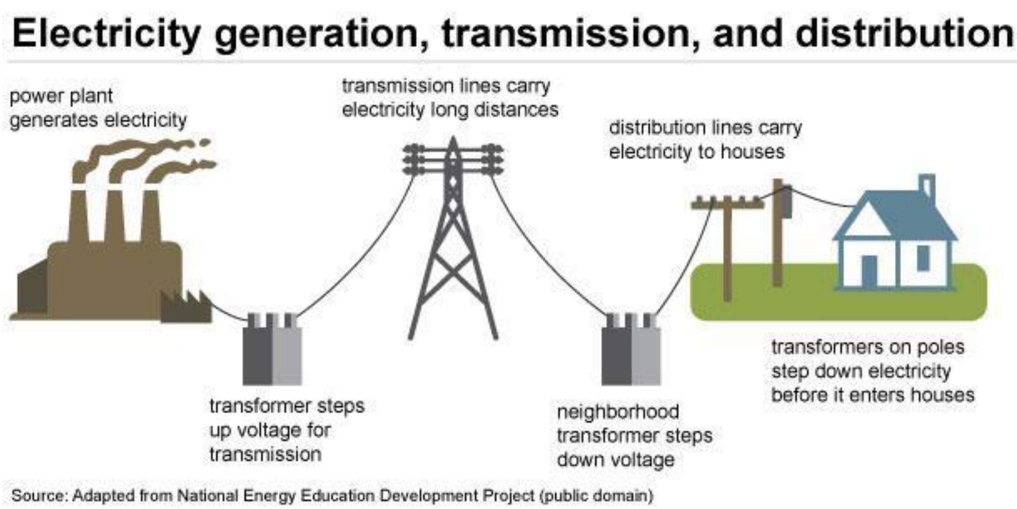

Figure 1: A simple diagram visualizing the process of electricity generation and transmission from generator to consumer (U.S. Energy Information Administration - EIA - independent statistics and analysis, n.d.).

The current North American grid infrastructure is divided into two primary grids, the eastern interconnection, and the western interconnection. There are also three secondary grids, the Alaska, the Texas, and the Quebec interconnections. These grids all operate independently of each other but provide nearly all the power to North America.

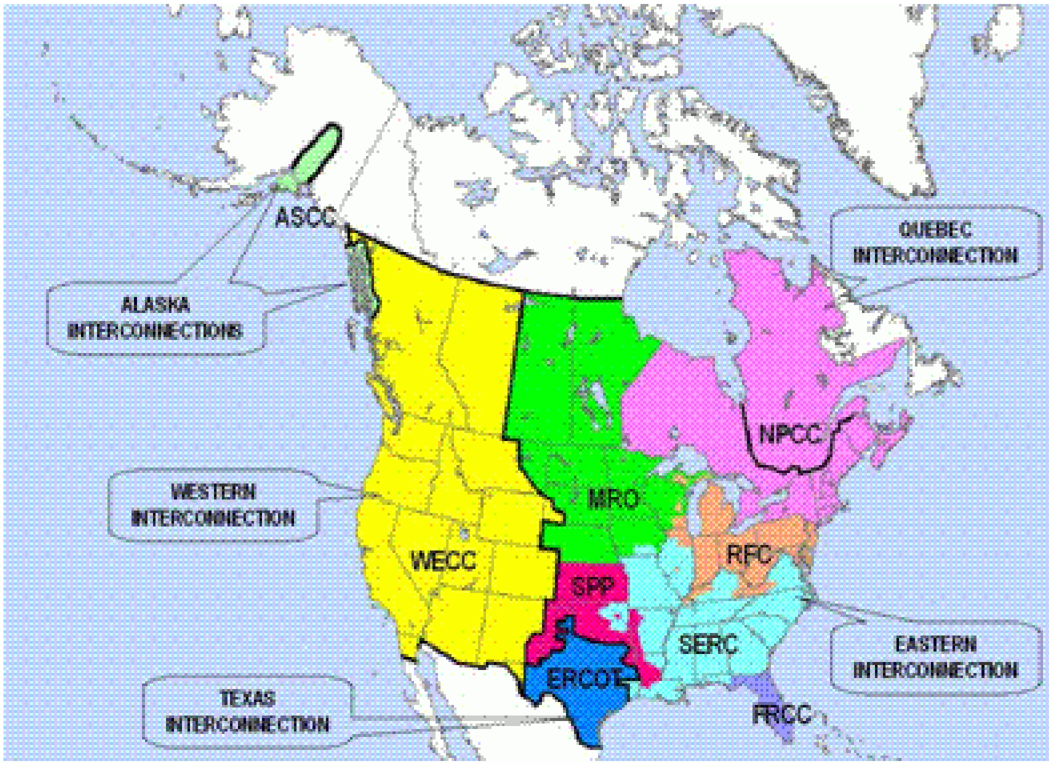

Figure 2: The various macro grids that power North America (Learn more about interconnections, n.d.).

One of the main drawbacks of the current U.S. system is that energy is produced as it is desired, there must always be a constant supply of energy generation. The primary fuel source employed by the United States is natural gas, making up approximately 40% of American energy generation sources in 2020, with approximately another 20% coming from coal. The remaining 40% is split relatively evenly, with 20% coming from nuclear, and the other 20% coming from renewable energies sources such as wind, solar, or hydroelectric power (U.S. Electricity Grid & Markets, 2022). Due to the historic ease and cost efficiency of energy generation via fossil fuels, this distribution of energy production sources that largely favored fossil fuels was seen as optimal and viable for the country's needs at the time, which was not a completely incorrect assertion.

The effects of climate change on the power grid

With the increases in the severity of climate change and global warming, this assertion is losing its economic and ecological support. It is estimated that the emissions from energy generation in the U.S. is around 1600 million tons of CO_2 in 2022, a slight decrease of a little over 1% from the previous year, but a significant amount nonetheless (Rivera, 2023). Since the average energy loss from power plant to end user is approximately 22.5% (Kumar, 2022), approximately 360 million tons of CO_2 generated from energy production was pure waste. Of the predicted 4,027 billion kilowatt-hours (kWh) used by the U.S. in 2022, only 4,605 megawatts (MW) of that power demand could be met via battery stored energy (DiSavino, 2022). Due to the large power demands of the U.S. along with the limited power storage capacity, the U.S. seems to be largely forced into meeting its power demands with fossil fuels. The 2022 Intergovernmental Panel on Climate Change, or IPCC, report has once again concluded that climate change is not only anthropogenic in nature, but its pace is increasing rapidly (Summary for Policy Makers, 2022). The IPCC reported its predictions on how climate change will begin to have increased consequences on American energy infrastructure, stating:

> Due to the connectivity of infrastructure systems, climate impacts, such as with thawing permafrost or severe storms affecting energy and transport networks, can propagate outside the reach of the hazard footprint and cause larger impacts and widespread regional disruption (high confidence). Interdependencies between infrastructure systems have created new pathways for compounding climate risk, which has been accelerated by

trends in information and communication technologies, increased reliance on energy, and complex (often global) supply chains (high confidence) (Summary for Policy Makers, 2022).

The report also includes how even with a complete and drastic overhauling of the global economy including complete decarbonization of U.S. energy grids, climate change will continue to increase and worsen until at least 2050. If the global community were to continue down the path that it is currently on, then "there is at least a greater than 50% likelihood that global warming will reach or exceed 1.5°C in the near-term, even for the very low greenhouse gas emissions scenario (Summary for Policy Makers, 2022)."

As climate change worsens, disasters such extreme weather events begin occurring more frequently and violently. With the increase in extreme weather events and natural disasters, the U.S. power grid becomes more vulnerable to disruptions from these events. The IPCC lists extreme heat and windstorms as very high-risk factors for North American energy transmission systems (Fact Sheet North America, 2022). These vulnerabilities to weather in the energy transmission systems has led to their recommendations for policy makers including an overhaul of North American energy transmission systems to limit the damage that can be wrought on communities by long range power transmission lines being damaged or destroyed due to extreme weather events.

The burning of fossil fuels also leads to a degradation of ecosystem services. The emission of greenhouse gasses from the burning and use of fossil fuels releases large amounts of Nitrogen Oxides and Ammonia into the atmosphere. The presence of Nitrogen Oxides and Ammonia in the atmosphere leads to the formation of smog and acid rain, a detriment to public health and the United States economy as both primary and secondary pollutants. These compounds will then eventually make their way into local water systems, leading to harmful algal blooms, pollution, and anaerobic regions in the ecosystem (The Sources and Solutions: Fossil Fuels, n.d.). These factors will severely degrade the supporting and regulating ecosystem services, leading to decreased survival odds for organisms present in the ecosystem along with economic damage. The extraction of fossil fuels is also linked to a degradation of ecosystem services. Events such as oil spills will lead to large scale contamination of the ecosystem, impacting supporting, regulating, supporting, and cultural services. The burning of fossil fuels and subsequent release of greenhouse gasses into the atmosphere also leads to ocean acidification. As more CO_2 is emitted into the atmosphere and is dissolved into the ocean, leading to a reduction in calcium carbonate. The reduction of calcium carbonate in the ocean and subsequent lowering of the Ph leads to the disintegration of coral reefs, a vital species for preventing coastal property damage, erosion, and loss of life (How do coral reefs protect lives and property?, 2014). The loss of these coral reefs means a loss in regulating and cultural ecosystem services, as these previous barriers acted as buffers against extreme coastal weather events in addition to being frequent tourist areas.

As climate change increases and global temperatures rise, there is also an increase in the duration of the wildfire season, leading to an increase in the occurrence and severity of wildfires (Climate Change Indicators: Wildfires, n.d.). As wildfires become more frequent and severe, there is a loss in provisioning, regulating, supporting, and cultural ecosystem services. The reduction in forest ecosystems leads to a decrease in productivity in the air purification and carbon sequestration sections of forests, along with a decrease in harvestable material from the ecosystem due to destruction caused by wildfires.

The Decentralization of the Power Grid

To combat climate change, the IPCC report recommends a conversion of our current centralized power grid to a more decentralized microgrid. A microgrid is a smaller scale energy grid that typically services a smaller area or community, they can operate in “island mode” or as an integrated part of the greater macro-grid, they can provide up to 10 Megawatts (MW) of energy to its users. Island mode is when the grid supplies and consumes all necessary energy to keep the grid running, when running in island mode a microgrid can operate at full capacity for all customers consuming energy from it. Island mode is not always necessary or required, microgrids can also connect to the greater macro-grid, supplementing and providing energy to areas of the grid that may have peak loads greater than what they can provide.

According to Duke Energy, a large North American electric and natural gas holding company and self-reported leader in renewable and sustainable energy, there are three main types of microgrids: Remote, grid-connected, and networked, the company defines them as:

> Remote Microgrids, or off-grid microgrids, are physically isolated from the utility grid and operate in island mode at all times due to the lack of available and affordable transmission or distribution (T&D) infrastructure nearby. For these remote scenarios, renewables, such as wind and solar, typically provide a more economic and environmentally sustainable DER solution for the microgrid operator. Additionally, many remote microgrids are considering battery energy storage systems for backup power in lieu of conventional generators. Grid-connected Microgrids are microgrids that have a physical connection to the utility grid via a switching mechanism at the point of common coupling (PCC), but they also can disconnect into island mode and reconnect back to the main grid as needed. In grid-connected scenarios, a microgrid that is effectively

integrated with the utility service provider can provide grid services (e.g., frequency and voltage regulation, real and reactive power support, demand response, etc.) to help address potential capacity, power quality and reliability, and voltage issues on the utility grid. In islanded scenarios, local voltage and frequency controls are required within the microgrid and can be provided by energy storage (e.g., battery, flywheel) or a synchronous generator (e.g., CHP, natural gas, fuel cell diesel). Due to its ability to perform multiple functions for grid services and emergency backup power, battery energy storage systems have been gaining popularity for microgrids that need to operate in both grid-connected and island modes. When serving a relatively small geographic area, grid-connected microgrids demonstrate economic viability for educational campuses, medical complexes, public safety, military bases, agricultural farms, commercial buildings and industrial facilities. Networked Microgrids, also known as nested microgrids, consist of several separate DERs and/or microgrids connected to the same utility grid circuit segment and serve a wide geographic area. Networked microgrids are typically managed and optimized by a supervisory control system to operate and coordinate each grid-connected or island mode at different tiers of hierarchy along the utility grid circuit segment. Community microgrids, smart cities and new utility adaptive protection schemes (e.g., closed-loop self-healing) are examples of networked microgrids. (3 types of microgrids transforming the industry: Blog, 2021).

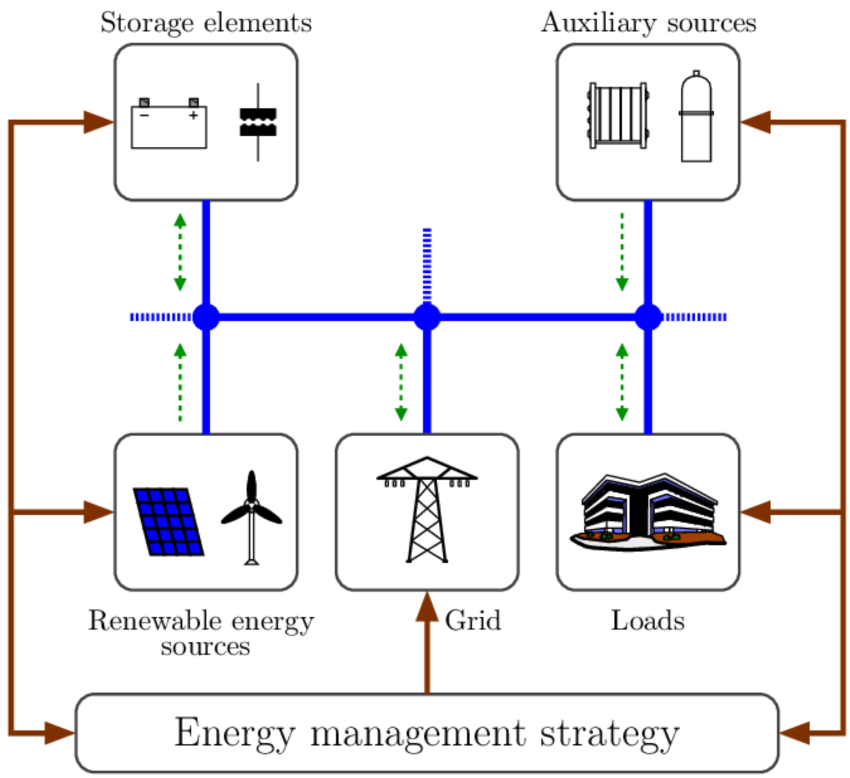

Figure 3: A simple diagram of how a microgrid would work in tandem with centralized energy transmission services (A simple schema of the microgrid used for validation, n.d.)

The Environmental Injustice of the Power Grid

The current arrangement of the United States macro-grid is inequitable and a hard propagator of environmental injustice. Environmental justice is defined by the Department of Energy as:

> Environmental justice is the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. Fair treatment means that no population bears a disproportionate share of negative environmental consequences resulting from industrial, municipal, and commercial

operations or from the execution of federal, state, and local laws; regulations; and policies. Meaningful involvement requires effective access to decision makers for all, and the ability in all communities to make informed decisions and take positive actions to produce environmental justice for themselves. (What is environmental justice?, n.d.).

As the grid currently is, a disproportionate amount of the burden and effects of pollution are allocated to communities that are either poor, primarily constituted by ethnic minorities, or indigenous populations. According to mapping tools provided by the EPA, of the nation's 3,477 fossil fuel burning power plants, 1,599 are located in communities where at least 50% of the residents are people of color, 582 of them are located in communities where at minimum 75% of the residents are people of color. 2,204 of these power plants are located in communities where at least 50% of residents are considered low-income (Power Plants and Neighboring Communities Mapping Tool, n.d.). These communities have historically had the injustice of shouldering the health problems that are associated with habitation near power plants. The health impacts of such close proximity to fossil fuel burning power plants will be explored further in chapter 3.

According to a study done by Home Power Magazine, nearly 180,000 families in the United States are voluntarily not connected to the power grid as of 2013 (Wood, 2017), a number that has undoubtedly grown in the last few years with the reduction in price of renewable energy generation. Additionally, there is a further minimum of 15,000 families not having any access to electricity at all (15,000 Native American Families live without electricity. How can solar power help?, 2021). While those who are voluntarily disconnected from the power grid may have their own means of energy production, it is the 15,000 families with no history of electricity that are the bigger concern. Many of these families are in rural areas, isolated from any primary infrastructure, and deemed too sparsely populated to be an economically viable customer base. Many utility companies will not put in the effort to connect these households to the main grid due to the prohibitive costs that are associated with running new transmission lines out into rural or isolated areas. These communities are instead forced to turn to inefficient, loud, and dirty diesel generators if they wish to have any access to power at all. These unideal circumstances have led to many smaller microgrid projects popping up around the U.S. in recent years, which will be expanded upon further in chapter 4.

Chapter 2: A Historical Upscaling and Downscaling of the U.S. Power Grid

When electricity was first "harnessed," it was an incredibly expensive resource and a far cry from the electrical infrastructure we enjoy today. Due to the difficulties and costs associated with energy production and distribution, the first Energy Production Facilities, or "power stations," were rather small and covered only a small geographical range with its services.

The First Power Stations

When Thomas Edison opened his Pearl Street Station, the first U.S. power station, in New York City in 1882, it only served a few blocks in the metropolitan area (Ethw, 2017). The customer's of Edison's service were typically wealthy or important, oftentimes both, with services being provided largely to hotels, hospitals, or wealthy households in the area (Ethw, 2017). A large part of the costs associated with these initial power stations was the use of Direct Current (DC) by Edison. This form of energy transportation is largely inefficient, resulting in significant energy loss over distances (Ethw, 2017). The costs of this inefficient form of energy transportation were exacerbated by the use of coal as the primary fuel source. Having to ship in large amounts of coal to Manhattan to power the station was not a cheap endeavor (Powermag, 2010).

This was fixed by the introduction of Alternating Currents (AC) by Nikola Tesla, which was more efficient at transporting electricity over long distances (Laplante, 2018). As AC was established as the standard of use for energy transportation, energy prices did fall for consumers. Although it was becoming less expensive to transport energy to customers, it was still cost prohibitive to create. These prohibitive costs meant that most power stations were privately owned and operated, typically on a smaller scale. These could be considered some of the earliest microgrids, being totally isolated from other power grids and self-sufficient.

The Power of Economies of Scale

In 1892, Samuel Insull arrived in Chicago and assumed control of Edison’s power generating company for him in the city, throughout his tenure he would go on to form and innovate many practices of the power generation industry. Given the intense competition provided by the services of at least 20 other companies, Insull realized he had to innovate to gain larger profits and portions of the market. He soon realized that the best way to go about this is to increase his “load factor”, or the consumption of power during off peak hours compared to peak energy usage hours. Doing this would lessen the waste of generating excess energy during off peak hours and increase profits (Emergence of Electrical Utilities in America, n.d.).

Insull and Edison would also be quick to also capitalize on new technologies. Realizing that the steam engines at the time were too weak and inefficient to produce the required energy demanded, they turned their attention towards steam turbines (Smil, V, 61-62, 2005). The steam turbine provided many benefits over the traditional steam engine, utilizing a rotary motion instead of the up and down one of the traditional steam engine, steam turbines could provide higher energy generation efficiency, decreased noise, and cheaper maintenance costs. Despite the high initial capital investment, the introduction of steam turbines and their efficiencies drove down power production costs dramatically. The steam turbine also boasted one incredibly important aspect of its design: It was very easily scalable to bigger sizes capable of much higher power production (Emergence of Electrical Utilities in America, n.d.).

The Dangers of the Consolidation of Power

The economies of scale were still impossible to fully utilize and exploit with competition being so fierce in the early days of the power generation market, so the consolidation of power companies began. Edison's company recognized this and began to buy out the other firms, turning their sites into backup substations and providing power to large areas with the massive primary steam turbines and eventually becoming a monopoly for the city of Chicago. His strategies and models for consolidation would be copied by other companies in other cities across the nation (Emergence of Electrical Utilities in America, n.d). As they grew and consolidated more customers, they also attracted the attention of wealthy investors. Eventually these power stations were taken over by holding companies, companies which had no purpose but investing in other companies, eventually these holding companies began expanding rapidly. The expanding power companies were seen as a growing threat by progressive politicians of the time. As private grids moved away from the micro and moved to macro through consolidation of smaller power companies, they also forayed into the territories of monopolies. Worried at the growing power wielded by these holding companies, President Franklin Delano Roosevelt took action, addressing congress on March 12, 1935, stating:

> I have been watching with great interest the fight being waged against public utility holding-company legislation. I have watched the use of investors' money to make the investor believe that the efforts of Government to protect him are designed to defraud him. I have seen much of the propaganda prepared against such legislation—even down to mimeographed sheets of instructions for propaganda to exploit the most far-fetched and fallacious fears. (Roosevelt, 1935).

His goal was to sway congress into supporting the recently introduced Public Utility Holding Company Act of 1935 (PUHCA), a bill that would grant the Securities and Exchange Commission (SEC) the authority to regulate electric holding companies as they see fit. The SEC defined a holding company as:

> (A) any company which directly or indirectly owns, controls, or holds with power to vote, 10 per centum or more of the outstanding voting securities of a public-utility company or of a company which is a holding company by virtue of this clause or clause (B), unless the Commission, as hereinafter provided, by order declares such company not to be a holding company; and Sec. 2 P.U.H.C.A. of 1935 6 (B) any person which the Commission determines, after notice and opportunity for hearing, directly or indirectly to exercise (either alone or pursuant to an arrangement or understanding with one or more other persons) such a controlling influence over the management or policies of any public-utility or holding company as to make it necessary or appropriate in the public interest or for the protection of investors or consumers that such person be subject to the obligations, duties, and liabilities imposed in this title upon holding companies. (PUHCA, 2004)

A necessary specificity, since by 1932, nearly 73% of the investor traded owned electric industry was controlled by eight of the largest holding companies (Hyman, 1988), so the SEC was eager to make sure no company can be reckless when investing in utilities. A large driving force behind FDR wanting to go after the utility holding companies was the failure of the Middle West Utility holding company, one of the largest utility holding companies in the nation in June of 1932. Their operations extended to 39 states, and their bankruptcy led to hundreds of thousands of investors losing their savings while also providing FDR his winning presidential campaign of reforming the electric industry (Samuel Insull Trial, 2018).

Federal Regulation of the Grid

Once the major problem of the unchecked power of the utility holding companies was finally checked, the grid started to become more cohesive and connected. The Federal Government was content with letting companies operate independently, with governing bodies only assuming more control during wartime. Examples of this occurred in World War I with President Wilson establishing the United States Fuel Administration to try and ration energy to promote wartime efforts (Executive order 2690, 1917). The abundance of fuel sources gave the Federal Government little reason to intervene and set energy policies, private companies were more than capable of fulfilling national demand for energy. This changed with the oil crisis of 1973. During the Arab-Israeli war, members of the Organization of Petroleum Exporting Countries (OPEC) enacted an embargo on the United States for supporting Israel (U.S. Department of State, n.d.). The embargo started by OPEC highlighted the danger of the hands-off approach by the United States towards energy generation, which led to the eventual creation of the Department of Energy in 1977 (A brief history of the Department of Energy, n.d.). The

Department of Energy's main goals were to oversee atomic energy, along with enact policy to help secure other sources of energy.

With a steadier hand on the wheel now for energy security, the main goal now was to open the grid to more avenues of power generation and to increase competition, a healthy goal for consumers. With the passage of the Public Utility Regulatory Policies Act (PURPA) of 1978, the Federal Government encouraged a more open and competitive market, conservation of energy and resources, more renewable energy, and an increase of efficiency in power production. One of the most notable policies to come out of this was now utilities were required to open their lines for non-utility power generation (Bureau of Reclamation, 1978). This was the death knell of the government sanctioned monopolization of power that these utilities previously enjoyed, with any facility capable of generating power now being able to enter the market and potentially undercut the utilities and subvert some of the control they had over the energy supply chain.

With fuel security and grid competition now in a healthy state, the government has a new goal: Increase energy security. The introduction of microgrids would allow for a much more secure energy grid with minimal downtimes in the face of exacerbating issues from climate change. Chapter 4 will discuss the various movements across the United States to try and promote microgrids.

Chapter 3: The Economics of the Grid

The economic costs of the United States Power Grid

While historically, fossil fuels and the current grid set up were seen as economically advantageous due to its relative stability, the current state of the United States power grid is woefully outdated and ill prepared for the coming hardships of climate change. All the infrastructure for the U.S. power grid was centered around the usage of nonrenewable fossil fuels. As of 2009, the U.S. was projected to spend approximately $700 billion to $1 trillion on fossil fuels annually (The high cost of fossil fuels, 2022). A transition to a renewable energy based decentralized power grid could cut a large amount of these costs.

A large amount of urban microgrids would rely largely on solar energy for their power generation, which would lead to a massive increase in jobs. During the year 2021, there has been a 9% increase in solar energy related jobs, adding in 21,563 new jobs, bringing the nationwide total up to 255,037 jobs in the solar industry (Palmer, 2022). The job numbers are not only impressive, but when only about 3% of the nation's energy is solar during 2021 (U.S. Electricity Grid & Markets, 2022), there is clear room for growth. According to the World economic forum, there will be an estimated 2.7 million jobs lost in the coal and oil industries by 2030 (World Economic Forum, n.d.). While this may be a worrying number initially, there will be a massive increase in jobs in the fields of bioenergy, renewables, and technological research, predicted to be in the neighborhood of 3.1 million jobs added by 2030 (World Economic Forum, n.d.).

The implementation of microgrids also invites the need for smarter grids. Unlike the current “dumb” grid, a smart grid would study trends in power usage for its network to be able to more efficiently supply energy to areas as their demand rises. This is accomplished by adding in a lot more electronic and computer software based monitoring, along with an army of energy storage batteries to pick up the slack when grids fail. With large scale utility energy storage batteries still being in its infancy, there is also large employment potential to be found in this industry. As of 2021 there are approximately 70,000 people employed in the battery storage industry, with an additional 3,000 jobs added in 2021 alone (Colthorpe, 2022). With the use of battery technology still being in its infancy of implementation due to the relatively weak battery technology, there have been great strides in the economic feasibility of microgrids as improvements in battery technology are constantly being made. In 2021 the price of a 60MW battery installation fell to US$379/usable kWh, which is a 13% drop from 2020 (Colthorpe, 2021). Although there are current limitations in battery technology, these can be circumvented by using a different type of battery: Gravity Batteries. The concept of a gravity battery is rather simple, use excess energy produced to push a heavy object to an elevated location while connected to a turbine, and when energy demands increase, the heavy object attached to the turbine is lowered, and the energy produced is sent into the grid to be used. These types of batteries are much cheaper than lithium ion batteries, and can be implemented in a wide array of situations. The company Renewell Energy has invented a new method of gravity battery that they dub “gravity wells.” Gravity wells convert the infrastructure of inactive upstream oil and gas wells into gravity batteries, a way to repurpose approximately $4 trillion in existing oil and gas well infrastructure as well as a method to plug up the inactive oil and gas wells that could potentially leak methane into the atmosphere (Repurposing infrastructure for Gravity Storage using underground potential energy, 2021).

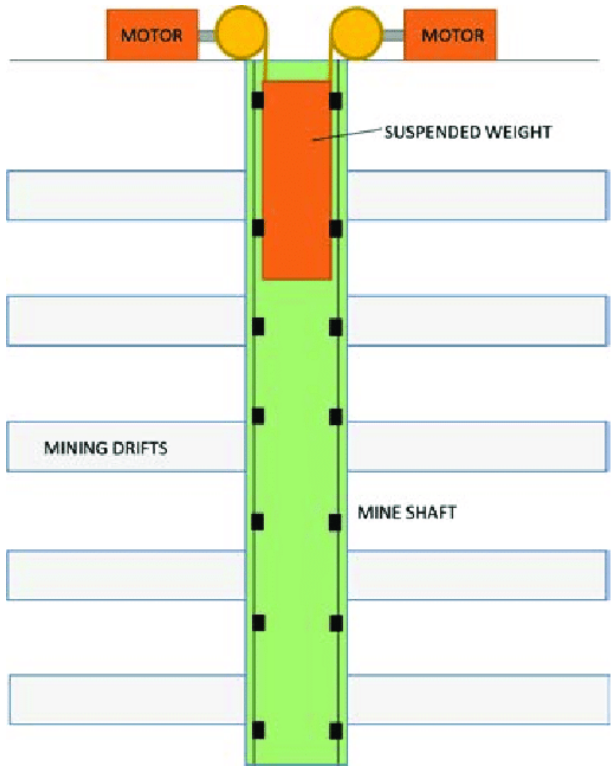

Figure 3: Simple diagram of a gravity battery using a repurposed old mine shaft (Schematic diagram of the gravity energy storage system with suspended ... 2020).

The World economic forum predicts that there will be a net gain of 5.5 million jobs in the power generation industry. The majority of these jobs will be found in the form of upgrading the grid to be more efficient, and to utilize renewable energies for power production (How many jobs could the clean energy transition create?, n.d.). These figures are predicted on the following international climate agreements such as the Paris Climate agreement, a full decarbonization of the grid would lead to significantly more jobs created by more than double the previous numbers, despite the predicted losses in the fossil fuel industry. The Department of Energy estimates that by 2035, the solar industry itself will employ anywhere from 500,000 to 1.5 million people as the United States begins to do a more systematic decarbonization of the grid (Doe releases Solar Futures Study providing the blueprint for a zero-carbon grid, 2021)

The decentralization and decarbonization of the power grid can also lead to direct economic benefits. The DoE estimates that power outages cost the U.S. around $150 billion annually in loss of productivity and damages (Hussein, 2019). Microgrids can save over $140 billion of that through the simple act of not going down when the rest of the grid does. Microgrids can achieve these savings due to the 98% average reduction in downtime that they experience when compared to a normal power grid configuration (Ton et al. 2012). It is difficult to truly factor all the economic benefits that microgrids can bring to the U.S. economy, since while there are the tangible benefits such as an increase in productivity, an increase in employment and jobs, or a reduction in energy costs, there is also the value of human lives that will be saved by this. Situations such as blackouts during heatwaves will be severely reduced, meaning that people who are depending on electricity to keep them alive during a severe climate event can actually depend on it. There are approximately 1,300 deaths a year due to extreme heat (Climate Change Indicators: Heat-Related Deaths, 2022), many could be prevented by a more secure and reliable energy grid.

The indirect costs of the United States Power Grid

With the increasing severity of climate change that also brings about an increase in the frequency and intensity of natural disasters, the current grid system is highly vulnerable to environmental damages when accidents occur, and things go wrong. The California Campfire of 2018, the deadliest wildfire in California history, was found to have been caused by negligence in the current grid set up by Pacific Gas & Electric, one of California's primary utility companies. This fire caused a total of 85 deaths and destroyed upwards of 19,000 structures, including homes and businesses (Eavis, et al. 2019). Currently, the company is liable for approximately $10.5 Billion in damages.

In the years of 2016-2020, it was estimated that the United States has sustained approximately $606.9 billion in damages caused by extreme weather events (Environmental and Energy Study Institute (EESI), 2021). These damages will become increasingly more expensive as climate change and severe weather events increase. The worsening of climate change will also lead to a rise in sea levels, and it is predicted that over the next 20 years, the United States will spend approximately $400 billion in defending coastal communities from rising sea levels (Environmental and Energy Study Institute (EESI), 2021). Since 1980, the United States has sustained 355 weather or climate disasters where the damages exceeded $1 billion in costs adjusted for inflation (Billion-dollar weather and climate disasters, n.d.). The average amount of disasters from 1980-2022 is 8.1 annually. In the period of 2018 through 2022, the amount of extreme weather events and disasters exceeding $1 billion in costs through damage and cleanup is averaged at 18 events annually, a massive increase from previous years (Billion-dollar weather and climate disasters, n.d.). As of May 2023, the United States has seen 7 extreme weather events that have totaled over $1 billion in damages, adding up to a current total of $19 billion in damages (Billion-dollar weather and climate disasters, n.d.). These events and damages are before some of the more dangerous seasons of the year, with hurricane and wildfire season not yet beginning in the United States.

The harvesting of fossil fuels also leads to a large increase in negative externalities. The 2010 BP Deepwater Horizon oil spill, the largest one in history, ravaged the environment along the Gulf of Mexico. The damage caused by BP’s negligence cost the company $8.8 billion in environmental damage and cleanup, and the company was fined a further $5.5 for being in violation of the Clean Water Act (Deepwater Horizon, n.d.). The transportation of fossil fuels can bring about severe negative externalities, the Keystone pipeline, a large oil pipeline spanning from Alberta, Canada to the U.S. Gulf Coast, had an oil spill in Washington County, Kansas in December of 2022. The pipeline spilled over 500,000 gallons into local waterways, and cleanup costs have been reported at $480 million (Llopis-Jepsen, 2023). The pipeline had already spilled over 700,000 gallons total in North Dakota in previous years, causing extensive environmental damage and degradation to ecosystem services (Cohen, 2019).

Due to the world's continued use of fossil fuels, a study by The Environmental and Energy Study Institute (Eesi) found in a 2019 study that we are on track currently to sustain damages of up to $300 billion a year, split evenly between labor, extreme temperature mortality, and property damage due to climate change (How climate change affects the United States, 2019). These could be negated by up to 48%, 58%, and 23% respectively by changing ourselves to a low emissions track to combat climate change (How climate change affects the United States, 2019).

The costs of environmental injustice in the United States Power Grid

The average annual cost per person for air pollution in the United States is about $2,500 in the form of medical bills (Air pollution costs each American $2,500 a year in healthcare - study finds, 2021). The annual total damages in the form of healthcare costs are approximately $820 billion dollars, with air pollution contributing to an estimated 107,000 premature deaths annually (Air pollution costs each American $2,500 a year in healthcare - study finds, 2021). A large portion of these costs are burdened by the taxpayer, as these healthcare burdens are disproportionately placed on more vulnerable poor communities with higher-than-average

Medicare and Medicaid coverage (Air pollution costs each American $2,500 a year in healthcare - study finds, 2021). The historic practices of redlining in neighborhoods to exclude ethnic minority populations from wealthier white neighborhoods had a lasting impact on the placement of power plants (Cushing et al, 2022). The correlation between being a poor and ethnic minority neighborhood and having a power plant sited upwind are strong (Cushing et al, 2022).

Despite the extensive damages wrought by the production of power via fossil fuels, there are still plans for new gas fired power plants to be built. About 88 Gigawatts worth of new natural gas fired power plants were proposed across the United States by the end of 2021 (Mills, 2022). Legislators have pushed back on some of these plants, citing health concerns for communities already disproportionately harmed with environmental injustice, but many of them will still go through.

According to research by the Rocky Mountain Institute, or RMI, approximately 80% of these proposed plants could be avoided by a combination of cleaner renewable energies, higher energy efficiency, and increased battery storage. These alternatives would provide the same services, while also saving over $22 billion dollars throughout the course of their lifetimes (Mills, 2022). Not implementing these gas plants in favor of cleaner energies could also save anywhere from $23-$74 billion dollars over their proposed 20-year lifespans in health impacts alone (Mills, 2022). Fossil fuel based power generation is responsible for a various pollutants such as including Sulfur Dioxide (SO_2), particulate matter, CO_2, Nitrous Oxides (NO_x), Mercury (Hg), and other hazardous pollutants (Power Plants and Neighboring Communities, 2022). The presence of NO_x and SO_2 leads to the formation of smog and other fine particle pollutions (Power Plants and Neighboring Communities, 2022). These pollutants are responsible for an increased rate of cardiac and respiratory diseases development, while also increasing susceptibility to respiratory and cardiac symptoms, these in turn lead to a higher rate of hospitalizations and premature deaths for those who live in close proximity to the power plants (Air Pollution and Cardiovascular Disease Basics, n.d.).

Chapter 4: United States "Current" Policies

The Microgrid scene has seen a recent surge of activity in the United States political landscape, with initiatives on the federal, state, business, and grassroots level. Technological innovations might make microgrids possible, but it takes the actions of governments and people to get them in place.

Federal initiatives for microgrids

On the federal level, legislation is the primary way forward for the implementation of microgrids. H.R. 2482, or The Making Imperiled Communities Resistant to Outages with Generation that is Resilient, Islandable, and Distributed (MICROGRID) Act on April 13, 2021 was introduced by Jimmy Panetta, a democrat from California's 20th congressional district (H.R. 2482, 2021) during the 117th Congress (2021-2022). Its main goal as summarized by the Congressional Research Service is:

> This bill allows a new tax credit for investment in qualified microgrid property.
> The bill defines qualified microgrid as an electrical system that incorporates a microgrid controller, includes equipment that is capable of generating not less that 4 kilowatts and not greater than 50 megawatts of electricity, is capable of operating in connection with the electrical grid and as a single controllable entity

> with respect to such grid, and is capable of operating independently (and disconnected) from such grid. (H.R. 2482, 2021).

This bill passed in the Senate and House as of August 2022, riding along with the much larger H.R.5376 - Inflation Reduction Act of 2022, what is partly a huge investment by the Federal Government into the energy infrastructure of the United States (H.R.5376, 2021). The Investment Tax Credits (ITC) of solar and other renewable energies was slated to go from 30% in 2019 to bottoming out at 10% for projects that were started before the end of 2023. Not only does this extend the ITC of these renewables, it also adds a large ITC specifically for microgrids, up to 50%, and extends this ITC as far as 2028.

The MICROGRID Act isn't the only federal initiative to incentivize microgrid implementation. H.R.3684, the Infrastructure Investment and Jobs Act, is another law that was signed into place in 2021 that introduced new avenues of funding for microgrids (H.R. 3684, 2021). It has over $100 billion earmarked for different microgrid projects, with $50 billion for programs and technologies that will improve power grid resilience, and $65 billion for power grid improvements (H.R. 3684, 2021). The bill highlights its desire for increased energy security and grid resilience, with a large focus on an increased implementation of smart grid technology. Increased federal support for microgrids will dramatically hasten the implementation timeline for a fully decentralized power grid and will lead to improved energy security for the United States.

State initiatives for microgrids

While the Federal Government is a powerful driving force for the decentralization of the power grid and implementation of microgrid technology, it is not the only avenue to decentralize the power grid and improve its resilience. There are many states that are introducing their own legislation to facilitate microgrid implementation into their power grids. In Maine, LD 1053 was passed by the state legislature. This bill is intended to help fund microgrids for small and isolated communities that would otherwise be unable to afford upgrading their power systems. The state is taking precautions to avoid giving taxpayer funds to groups that are not the intended beneficiaries of this law, defining the power load parameters for a microgrid as:

> The proposed new microgrid will serve a total load of no more than 10 megawatts, except that the commission may approve no more than 2 new microgrids that each serve a load greater than 10 megawatts but no more than 25 megawatts; (L.D. 1053, 2016).

A necessary step to not sour the opinion of the public by fraudulently funding projects for a technology and concept that is new to the public.

In the aftermath of Hurricane Sandy in 2012, many states in the Northeastern part of the United States introduced funding opportunities for microgrids to repair and attempt to improve the resilience of their power grids in the face of worsening extreme weather events. The Connecticut General Assembly passed a statute that authorized the state to give grants to municipalities to help fund the construction of new microgrid projects (Parks, n.d.). The statute helped develop a swath of new microgrids, with the pilot program awarding $18 million in funding to nine different projects. The program was responsible for creating Connecticut's first microgrid at Wesleyan University in 2014 (Microgrid Grant and Loan Program, 2020). New York passed similar legislature in the wake of Sandy. Governor Cuomo introduced "Reimagining New York for a New Reality," a program focused primarily on ensuring that the power grids have improved extreme weather resiliency and response, making available $40 million in grant aid to help fund these projects (Parks, n.d.).

These efforts weren't isolated to just the Northeastern United States, Oregon also passed their own legislature concerning microgrids. The goal of HB2021, the legislation passed, was primarily to decarbonize the power grid in Oregon, but there are specific provisions made for microgrid funding. It specifies funding for "community renewable energy projects," defining these as:

> one or more renewable energy systems, storage systems, microgrids or energy-related infrastructures that promote energy resilience, increase renewable energy generation or renewable energy storage capacity and provide a direct benefit to a particular community in the form of increased community energy resilience, local jobs, economic development or direct energy costs savings to families and small businesses. (Enrolled house bill 2021 - Oregon Legislative Assembly 2021).

The future importance of microgrids is not lost on the Oregon legislature, as they see the importance it will carry in the future, as well as the economic benefits that microgrids can bring.

Microgrids in the wild

Many companies, grassroot organizations, and municipalities are working towards implementing more microgrids into the system across the U.S.. On the business side, one of the most notable examples of this is Google's plans to build an array of microgrids throughout their Californian campuses (Wood, 2020). What makes this notable is that unlike a large amount of current microgrids in the U.S. which aim to be active in the events of an outage, Google plans on having their microgrid be functional at all times to supply power to their campuses, although the security that it brings in a state rife with power outages due to forest fires is also a considerable boon and smart investment on Google's part.

Another notable example of microgrids emerging in the market is the adoption of microgrids for healthcare facilities. In the state of California, the Kaiser Permanente medical center achieved carbon neutrality in 2020, and is set to be carbon net positive by 2025 (Kaiser Permanente pioneers California's first Medical Center Microgrid, n.d.). The medical center was among the first to connect its already existing diesel generators to a new network of renewable energy and battery storage, the increases in energy efficiency and the ability to sell energy back to the state results in potentially $400,000 a year in savings (Kaiser Permanente pioneers California's first Medical Center Microgrid, n.d.).

While the main benefits for those microgrids may have profit-based incentives, there are also great benefits for isolated communities when considering microgrids. Off the Coast of Massachusetts, the town of Gosnold, which resides in a small chain of islands near Cape Cod, explored and implemented their own microgrid for the island community. Before, the town with a population of around 75 relied on diesel generators for its year-round supply of electricity. With such a small population in such an isolated area, it was not economically viable to pay for an underwater cable to transport power from the mainland to the majority of the town's residents who lived on the island of Cuttyhunk, so the islanders had to consider alternative options (Solar plus storage microgrid for Cuttyhunk Island, 2020).

In an effort to move away from the noisy and dirty diesel generators that solely supplied Cuttyhunk's supply, the town received a grant worth $2.15 million from the U.S. Department of Agriculture in 2012, with the microgrid being put to use in early 2017 (Solar plus storage microgrid for Cuttyhunk Island, 2020). The project is one of the first community scale microgrids in the United States, with the plan includes a 351-kilowatt solar array that supplies the power with up to half of its energy requirements in the summer and up to 80% of the town's electricity during the less popular winter months. All of the town's excess power generated from the solar array charges a backup 1.25-megawatt-hour lithium-ion battery, with their power needs not being met by the solar panels instead being supplied by diesel generators when necessary (Gosnold: Solar + storage microgrid, 2019). While still not completely independent of fossil fuels, the town can now save on paying for 30,000 gallons of diesel along with the shipping costs every year. For a small community such as the town of Gosnold, this is a historic advancement, and can pave the way forward for many other communities who might benefit from a microgrid to supply their power.

Yet microgrids are not just for the isolated, or the rich, they can also help secure the energy of average people. The Holcim Foundation is a foundation that strives towards more sustainable living. One of their most notable projects in the U.S. is The Seebaldt Pilot (TSP) is a microgrid being developed in the suburbs of Detroit, Michigan. The Holcim Foundation was rewarded with funding by the Department of Energy to produce 100kw for the 25 households by the end of 2018 with a mixture of solar and geothermal power, goals which have already been met. The project says that it could eventually expand to other sections of the city and fulfill up to 6MW of energy to sustain up to 1400 households in all sectors of the city (Holcim Foundation, 2018). This project creates a microgrid for the neighborhood, but also turns it into a Net Zero Energy Zone (NZE), a fantastic step forward in decarbonizing the power grid and creating more sustainable power. TSP is fully capable of supplying its own residents with power, but is still connected to the grid. In peak times when power might go out, TSP is also capable of autonomously operating, going into what is known as "island mode." The island mode capabilities of TSP highlight the benefits of microgrids not only being more environmentally sustainable by utilizing mostly renewable energies, but also being more secure and ensuring that energy demands can always be met.

Chapter 5: Policy Discussion and Recommendations

As climate change continues to worsen and increase across the globe, it is imperative that the security, sustainability, and resilience of the United States power grid is improved.

Decentralization Discussion

As discussed in chapter 1, the current state of the United States power grid is extremely detrimental to the environment and ecosystem services. Although the fuel sourcing for power generation has been trending towards more sustainable methods via renewable energies in recent years, the progress made has not been enough. The losses incurred by the continued use of fossil fuels that will also contribute to an increase in climate change and greenhouse gas emissions will begin to quickly outstrip the historic reliability and cost effectiveness of fossil fuels in power generation. The insistence on a historically cheap and reliable fuel source for power generation will have far reaching impacts to every industry in society. As ecosystem services degrade, the losses sustained will reach into the trillions of USD, as manmade processes will have to step in to supplement the failing natural regulating and supporting ecosystem services. A focus on transforming the power grid to be more renewable energy focused will help preserve these ecosystem services by reducing pollution released into both the atmosphere and local ecosystems.

The massive scale that the United States power grid operates on means that fundamental changes made to it will have tremendous impacts on reaching any goals that will lead to the mitigation of climate change and averting the incoming climate disaster. The conversion of the power grid to a series of microgrid arrays is vital to meeting these goals.

As seen in chapter 2, the origins of the power grid were decentralized. The rampant growth of the power grid was first attributed to the free and unregulated market at the time. Centralization was brought on by a consolidation in power by the utility companies. The laissez faire capitalist environment for power generation was proven to be unreliable with the introduction and creation of the Department of Energy after the oil crisis of the 1970's, with the Federal Government choosing to take a more active role in national energy policy. Afterwards, the government slowly transitioned away from the monopoly that utility companies held, introducing legislation like PURPA, which would give more access to the power market and increase competition. The move to check the power of utility companies by introducing more competition to the market was a good initial step, although an increase in decentralization and implementation of microgrids would further check the power of utility companies.

As discussed in chapter three, the combined grid downtime alone costs the U.S. economy upwards of hundreds of billions of dollars in lost productivity. Then adding in the increased damages that the loss of services can cause in terms of human life, it becomes clear that something must be done. Simply adding in more power generation points will not suffice, at its core the grid is vulnerable to massive losses of service from a multitude of sources due to the design of the grid in the U.S. With increased natural disasters from climate change, this problem will only worsen. Despite a push both globally and in the U.S. for a transition away from fossil fuels, much of the energy production and transportation in the United States is still largely focused on the potential and applications of fossil fuels, and not renewable energies.

As it stands, the government is making good strides in promoting a decentralization of the grid, although progress is slow. Chapter 4 showed that support for microgrids and power grid decentralization is slowly spreading and building as different entities see the benefits and value that a smarter and decentralized power grid can bring.

Policy Recommendations

The most important and often difficult step in decentralizing the power grid is getting support for projects to undertake such a task. While legislation from the Federal Government such as the MICROGRID Act and the Infrastructure Investment and Jobs Act are great avenues to start with incentivizing decentralization of the power grid, they can go further. Tax breaks and grant opportunities are great tools for those looking to build and implement a microgrid, but there should be provisions made to incentivize the average consumer to be in favor of microgrids. Options such as federally subsidized energy costs for a certain number of years after installation of the microgrid would sway public opinion heavily in favor of microgrids.

While an increase in grant and funding opportunities is a great method of encouraging the implementation of microgrids, there needs to be improvements in various technologies to make the mass implementation of microgrids to be economically feasible. Legislation such as the Inflation Reduction Act gave investment tax credits to those investing in solar and battery technologies (*H.R.5376,* 2022*).* In addition to tax credits, there are technological research grants included, which includes funding to a multitude of battery manufacturers and researchers across a multitude of states, which is a step in the right direction. While there is a large potential market for improved battery technology that the U.S. is primed to take advantage of, the environmental benefits that this bill brings is no small matter. While it does focus largely on the production of lithium-ion batteries for the intention of electric vehicles, this research and funding will bleed over and benefit other areas of battery research. We are in the space race of the 21st century, except instead of building rockets to the moon, we are focusing on building batteries to capture the sun.

In addition to tax incentives for renewable energy sources and microgrid implementation, there needs to be tax penalties for fossil fuel-based power plants. As discussed in chapter 3, the simple existence of fossil fuel-based power plants is a detriment to public health. Currently, their existence is tolerated due to their historic economic feasibility and their already existing infrastructure. A potential way to disincentivize current and future fossil fuel-based power plants is to impose additional taxes on these power plants which would pay into a superfund to help fund medical costs and damages caused by the emissions of the power plant. This would help make the United States power grid more equitable and help alleviate instances of environmental injustice.

A massive increase in funding for microgrid projects, tax incentives for microgrid implementation, tax penalties for fossil fuel based power plants, and increased funding for battery technology research are all realistic goals and policies that must be adopted on a federal scale in order to address the dangers of climate change towards our national power grid. Chapter one explained how the continued use of fossil fuels are degrading our ecosystem services at risk to human life, and how the United States power grid relies on fossil fuels. Chapter two explained how the United States power grid became the massive infrastructure it is today, as well as the government regulation that acts on it. Chapter three went into detail about the inefficiencies of the grid, its costs, and the economic benefits that would come from a decentralization of the power grid. Chapter four highlighted the strides that governments and grassroots organizations are taking to secure and increase the resilience of the power grid through legislation and microgrid projects. Finally, chapter five offered policy recommendations that would attempt to decentralize the grid through legislation and economic incentives.

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