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Centralized Versus Decentralized Solar Grids for San Francisco

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ABSTRACT

Climate change requires a transition to renewable energy sources, but different cities have different contextual needs that require place-specific solutions. Renewable energy sources like solar power reduce greenhouse gas emissions and are becoming more efficient. This makes solar energy an up-and-coming source of power for the city. By 2045, San Francisco wants to have 100% renewable energy. Given their urban environment, they must account for the city's population energy density relating to energy consumption, trying to discuss whether solar energy can be seen as a viable source for this. Two possible ways to harness solar energy would be a centralized solar grid and a decentralized solar grid. A decentralized solar generation system would be more effective in San Francisco because it is efficient in electricity use, it takes up less natural resources, and it is economically more favorable cost-wise. Incorporating this form of solar energy in San Francisco will be beneficial for addressing climate change and supporting energy demand in the city and wider region.

Introduction

Climate change requires a transition to renewable energy sources, but different cities have different contextual needs that require place-specific solutions. For example, in India, they are located near the equator and want to capitalize on the plethora of sunlight, and attempt to implement solar panels. In Sweden, they use wind power, solar power, and hydropower, taking advantage geographically of the excess wind, water, and sunlight they get (18). The world faces a rising carbon dioxide concentration in the atmosphere, leading to changing weather patterns in global warming.

Currently, fossil fuel production in the United States emits a large amount of these greenhouse gasses. The US has passed many policies to combat and reduce GHG (carbon) emissions [1]. For example, Assembly Bill 32 addresses emissions by setting a goal for California to reach a reduction of emission levels from 1990 to 2020. To combat the rising problem of global warming and its inherent effects on industries in agriculture, lumber, and land preservation, AB32 sets goals and plans for the state to reduce emission levels (10). Such legislative measures help prevent the imminent threat of global warming, as cities are starting to regulate their emissions, with some cities opting for renewable energy sources.

At present, a centralized electrical grid has been the main source of power for San Francisco. The Pacific Gas and Power Company (PG&E) has been the primary supplier of San Francisco's power (16). Its power is mostly composed of renewable energy and nuclear energy. PG&E's sources of energy include outside sources from other states that are bought and transmitted to PG&E, as well as local energy generation sites that produce electricity via means such as hydropower and nuclear energy (16).

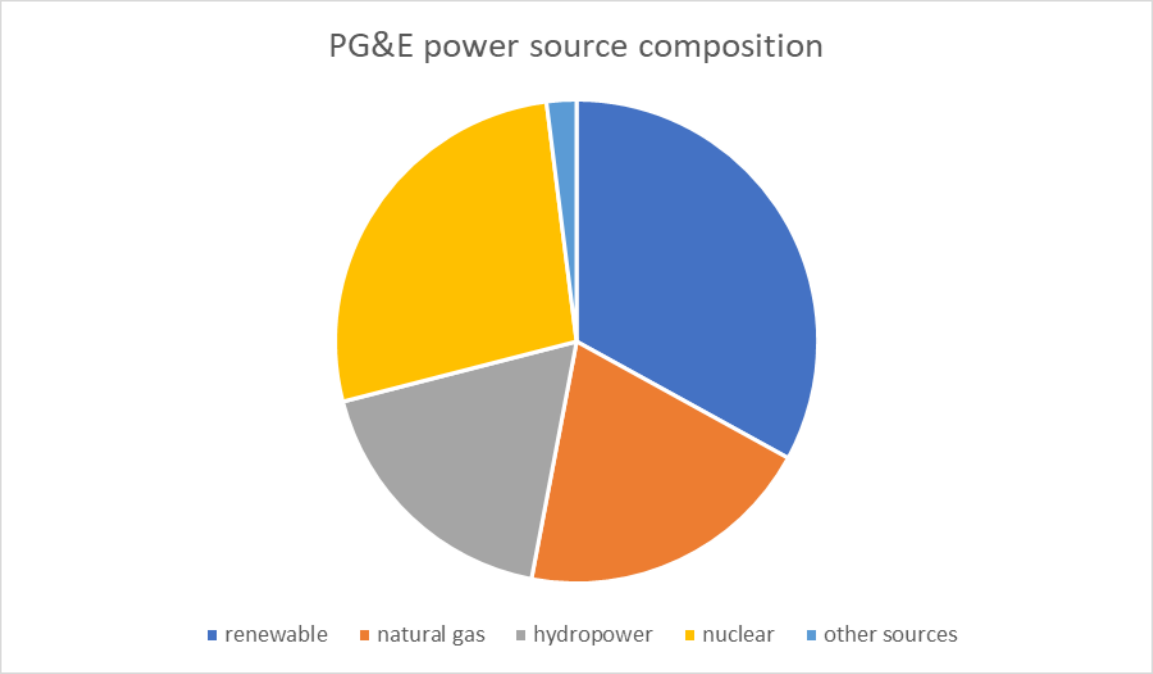

Figure 1. Shows the composition of PG&E's power source. PG&E is the main energy supplier for San Francisco. This shows the reliance on certain energy sources that may produce high levels of emissions. Numbers from [16].

Renewable energy sources like solar power reduce greenhouse gas emissions and are becoming more efficient. This makes solar energy a very promising source of power for the city. Because of an endless supply of sunlight, solar energy won't run out and it doesn't release emissions to generate energy. The common unit for measuring electricity and quantifying the energy transferred is the SI unit watt, equivalent to a joule per second. The sun can provide over 2500 terawatts (TW) of solar energy over large areas on Earth. The sun is certainly an abundant and easily accessible source of energy for California. California's energy consumption was 295.5 TW in 2012 (17).

San Francisco has passed bills and has been trying to move towards solar energy. Examples of such are Proposition B (2001) and Proposition H (2001). These bills were passed to generate a revenue bond of 100 million dollars for solar production and renewable energy. However, local government policies made it unrealistic to build solar stations in the city, as issues occurred for licensing, property use, and land (3). Although this is the case, rooftop solar grids aren't out of the question, and are, in fact, supported by local policies. By 2045, San Francisco wants to have 100% renewable energy. Given their urban environment, they must account for the city's population energy density relating to energy consumption, trying to discuss whether solar energy can be seen as a viable source for this.

Centralized and decentralized forms of solar energy have different costs and benefits associated with them. Solar energy can be turned into electricity through photovoltaic (PV) methods or concentrated solar power (CSP) methods. Both have similar costs and energy yields. CSP uses the sun's thermal energy to generate electricity. It uses turbines from the heat to do so (7). PV just converts direct sunlight into electricity. This is the more popular version of solar generation as it uses semiconductor solar cells that harness sunlight and generate electricity (6). These solar generation methods make functionally unlimited electricity relative to the highest potential energy demand of Earth as the nearly everlasting sun provides light and heat. It also will require little to no emissions to generate electricity, compared to other forms of energy generation.

Solar energy is a viable energy source to power San Francisco in a sustainable way, but there are multiple types of solar energy, each with its own costs and benefits. Centralized (also called utility-scale) and decentralized solar generation each have different levels of efficiency. Centralized solar generation would involve a bigger central

solar energy plant dispersing energy throughout multiple areas, requiring other pieces of equipment. Decentralized solar generation would need multiple smaller solar plants dispersing energy throughout areas (9).

Compared to a centralized solar grid, a decentralized solar generating grid would be more effective in San Francisco because of three main reasons. Its favorable efficiency of electricity generation, based on its Kilowatt hours (KwH) generated, compared to utility-scale within a controlled session, makes a decentralized system more optimal in terms of energy yield and cost. Additionally, it takes up less natural resources in a local area, based on the surface area required for each system and the extra amount of land. Lastly, based on the costs of making the materials for electricity generation, and the maintenance required, decentralized systems are more favorable economically.

Due to these problems, this research paper will examine the following question: What are the environmental and technical costs and benefits of implementing centralized versus decentralized solar energy in San Francisco?

Proposal/Solution

A decentralized solar generation system would be more effective in San Francisco because it is efficient in electricity use, it takes up less natural resources, and it is economically more favorable cost-wise.

Efficiency in Electricity Use

A decentralized system would be more efficient with electricity use. In general, smaller scattered solar panels would generate more electricity than larger grouped solar panels (9). More solar panel setups for a decentralized system would be more costly compared to a central grid of solar panels. However, if costs were budgeted for each, there would still be a higher KwPH generated with more solar panel systems (12).

A decentralized system would also be less likely to have grid failure. In a utility-scale solar grid, solar panels are impacted by other panels. If there was a grid failure in one section of the solar grid, the whole system would likely be hindered, with less production happening over duration. Utility-scale also relies on power lines to transmit energy to a city. If those power lines are damaged or aren't working, then the solar grid's electricity can't be transmitted towards the city. These risks make centralized solar systems an uneasy prospect. The power lines used in centralized systems also lose a bit of electricity through transmission over time (11).

Takes Up Less Natural Resources

A larger space is required for a centralized solar system as it would require an increased surface area, requiring permits and funding for the system to be made. It also needs power lines to connect the system to urban cities as it would be positioned outside the city. A decentralized system wouldn't need as much space as they can be placed on smaller roofs, which would be more likely in San Francisco, an urban environment with a plethora of buildings.

A decentralized system is favorable environmentally as well. It uses less water compared to centralized systems, which would use water for cooling systems. The dry land beneath solar panels would also cause erosion in the ground (13). The large amount of space used would cause a disturbance within biodiversity in the site of the solar grid, hindering the growth of plants and causing animals to relocate. Decentralized solar grids would capitalize on the space already occupied by humans, not impacting biodiversity (1). Decentralized solar grids would be most favorable if they were planted on top of building roofs, providing little to no risk to the environment.

Economic Cost

With the implementation of either solar generation system, the local government or organization funding the project would have to take into consideration the costs and profits from these solar grids. When comparing material costs, a

decentralized smaller solar would likely cost more for materials such as converters and panels. However, centralized would require more money for more continual maintenance as it would be harder to maintain a larger system, compared to the amount of maintenance for a system of smaller solar panels (12). It is also reasonable to assume a budget would be put in place; hence, if the money spent on getting the solar panels and assembling them in these systems was the same, the decentralized systems would still produce more energy compared to the centralized systems throughout the majority of the day.

In the face of natural disasters or power outages, the chance of needing reparations and implementations of a centralized solar grid would be more likely, meaning there would be more risk of paying extra costs with a centralized grid.

Background

San Francisco is located on the coast of California, with the San Francisco Bay being known to host various marine life and support connected terrestrial ecosystems. Marine life in the local area could be impacted by climate change and non-renewable energy sources through problems such as oil drainage and ocean acidification. Runoff oil from fossil fuel sites can end up in sewers and onto the ocean's surface. This can lead to problems with marine life near the surface, such as contamination and food poisoning, as well as suffocation due to oil's density compared to water. Carbon emissions from non-renewable energy sources can diffuse in ocean water, forming carbonic acid, and causing ocean acidification. In light of the need to transition away from fossil fuels, renewable sources like solar energy are seen as viable alternatives. However, certain implementations of the different solar grid systems have their own setbacks.

San Francisco is a coastal city in California that has varied in weather. It is best described as having a Mediterranean climate in the city. It is noted that a more moderate climate occurs nearer towards the coast. The Bay Area tends to also have the same pattern, with cities farther from the bay, having a warmer climate. The hotter temperatures in the Bay Area occur during July or August, and the colder, rainier weather occurs during November or December (8). Average temperatures over the past few years have tended to vary between 50-60 Fahrenheit during the winter and 80-90 Fahrenheit during the summer. During most mornings, the bay tends to have a thin layer of fog till the sun heats up. However, due to recent increases in carbon dioxide concentration in the atmosphere, and global warming, the sea level has risen over time, the fog has been thinner lately, and the average temperature has increased by 1.7 degrees Fahrenheit from 1950-2005 (19). The environmental risks that current energy sources have require a change to a renewable energy source like solar power that will reduce the increase in carbon dioxide in the atmosphere, prompting severe weather pattern changes for the worse.

San Francisco currently is run through electricity, mainly supplied by PG&E. PG&E's energy sources are made of natural gas, nuclear energy hydropower, renewable energy, and a small percentage of other sources, according to figure 1, with renewable and nuclear energy being the bigger contributors to PG&E's electricity source.

Warmer summers mean a higher energy demand because of air conditioning, as well as increased energy demands inland San Francisco based on the sea level rise posing a threat to the coastal regions of San Francisco (21). The imminent threat of global warming stems from emissions, so San Francisco has been trying to avoid generating emissions, which includes referring to a new energy source. However, San Francisco has 6500 PV systems on buildings, but only 1% of them actually work in the face of natural disasters such as earthquakes, which cause power outages. The growing energy demand as well as the need to reduce contributions to global warming mean that San Francisco needs a renewable energy source like solar power that operates in the most efficient way possible in order to be cost effective and satisfactory to its high population's energy consumption

Solar panels on the ground create a dry surrounding on the earth, causing soil erosion. Solar panels can also dry up groundwater along with soil erosion, leading to possible droughts in nearby farmland. Solar panel equipment involves cables and wires, which can also generate risks of fire hazards.

Currently, in the face of natural disasters, power sources are likely to face problems and outages because of such disasters. Earthquakes and fires may destroy power grids on the ground. Centralized solar grids on a dry land mass are prone to damage via local fires and earthquakes that damage the surrounding bases of solar panels. The power lines that transmit collected solar energy to energy sites for a city are at risk of falling down due to extreme weather conditions such as hurricanes. Power outages due to these natural disasters affect electricity revenue (4). Thunderstorms, snowstorms, hurricanes, and forest fires all correlate to an increase in revenue lost for electricity in the United States. Data shows that 50% of power outages are due to bad weather, which will largely be exacerbated by climate change (4).

Many of these risks are avoidable with a decentralized solar grid. Since centralized solar grids are ground-based, they are more susceptible to disfunction from natural disasters causing a power outage. However, because decentralized systems are spread out and mounted, or raised above the ground on steel bases to a height of about 10 feet, they are less prone to risks on the ground, such as fires or earthquakes. Even if a system were to fail, decentralized solar grids are tolerant enough to continue working if a system fails, due to the numerous plants stationed in different locations across a service area. Decentralized solar grids would be as sturdy as the structure they are mounted on in the face of natural disasters.

The two main types of solar panels are photovoltaic and concentrated solar power. Photovoltaic (PV) solar panels convert sunlight into electricity using PV cells, each generating around 1-2 watts of power. When the sun shines, its energy is absorbed and transferred into electrons that start to flow, generating an electrical current. To enhance the amount of energy produced, each of these cells is all connected to form a grid system. To utilize the energy produced by the PV grid, materials convert direct electricity (DC) produced from the system into alternating-current electricity (AC), which is more usable (6). Concentrated solar power (CSP) uses mirrors, and heliostats to reflect the sunlight into converters that generate a heat transfer fluid, such as steam. This fluid is used to activate a turbine generator to produce electricity (7). PV panels are more popular than CSP panels because they are cheaper and easier to construct and maintain.

Solar panels use semiconductors to capture sunlight and turn it into electricity. Silicon is the most commonly used semiconductor in solar cells. It's the second most common element on earth, after oxygen (6). Silicon used in solar panels is commonly found along the earth's crust in mineral rocks and sand, usually in silica. After being processed in electrode arc furnaces or hydrogen in a furnace, pure silicon is produced and is crystallized to form structures, proving useful for converting sunlight into electricity. The second most common semiconductors used in solar panels are cadmium telluride (CdTe) and copper indium gallium selenide (CIGS), which are used in thin-film solar panels. Thin film solar cells have a thin layer of semiconductor, encapsulated by protective materials such as glass or plastic (6).

Solar cells that use silicon are proven to be highly efficient at a low cost over the long term. CdTe and CIGS semiconductors are cost-effective yet challenging to manufacture due to their structure. In factories, processing silicon semiconductors releases chemicals and gasses like perfluorocarbons and uses water and energy to help produce it (14). Workers in these factories, varying in countries, have insufficient wages for the exhausting work shifts and poor working conditions, producing silicon for solar panels and other silicon products (15).

People who mine for silicon-containing materials may inhale tiny pieces of silica in dust, which could lead to a severe lung disease called silicosis. There is no cure, and it can be very damaging to the lungs, but it is preventable with precautions (5). Mining also has negative environmental impacts. Mining may remove groundwater, causing erosion or dryness of soil in that area. Despite the environmental drawbacks in the production of solar panel materials, it is minimal compared to the potential environmental drawbacks in non-renewable energy sources.

Methods

In this section, to explain key findings from prior research on these topics, I will describe three studies and how their results apply to this case in San Francisco.

Analysis of Solar Canopies in Connecticut

In a study entitled "The potential for community Solar in Connecticut: A geospatial analysis of solar canopy siting on parking lots" (11), researchers selected sites in random cities within Connecticut and analyzed energy generated from solar canopies (for example, in parking lots) and compared it to the current energy usage in the cities and the state of Connecticut. The decentralized system of solar canopies proved viable and more efficient than current energy standards, and along with other sorts of systems within a decentralized fashion, it proved beneficial. They also were analyzed across different classes and income areas within the towns. The solar "canopies" used were meant to prove the usefulness of a decentralized energy system within an urban city. The study reflects on the technical and community benefits of this said system.

This magnifies how decentralized systems in the study are helpful, compared to centralized systems discussed prior in the paper as being inferior compared to decentralized systems of solar generation in many contexts. Decentralized systems have proven to be optimal as they produce energy consistently, even in the failure of one component of the system, such as a transformer or centralized plant. It also proves that mounted solar panels are often more useful than grounded solar panels because roofed solar panels leave space for other structure sites while grounded panels do not. San Francisco shares many urban characteristics with the cities studied in Connecticut, making the implementation of a decentralized system of roofed solar panels there promising.

Decentralized Panels Vs Centralized Panels Around Different Cities in India

Another study, "Centralized vs decentralized solar: A comparison study (India)" (12), set up a utility-scale solar grid and a decentralized solar grid, in order to compare which system would benefit India as a more favorable system for energy generation. They set these two different types of grids up in multiple cities for more accurate results. The researchers compared the technical and environmental differences between the two systems. The decentralized system had a better ratio of kWh per capita compared to the utility-scale, taking into account the cost of materials, maintenance, and electricity harnessed. In fact, solar generation systems, with more solar plants, produced more energy over a longer period of time, showing how numerous solar grid systems are more optimizing. Decentralized systems were also much more convenient as decentralization involved smaller systems on rooftops, while centralized had to be based on a remote location with enough land mass. It is noted that centralized systems require more money for maintenance than decentralized systems do. The environmental and financial necessities of a centralized solar grid are greater than those of decentralized solar grids.

These advantages make decentralized solar generation more appealing to San Francisco than centralized because the city is urban with a plethora of rooftops, whose space can be utilized for planting these solar grid systems. San Francisco, during peak daytime with maximum sunlight, is comparable to the sunny climate of India. The optimizing use of decentralized solar generation grids has proven to be more useful than centralized solar generation grids, given the urban and climate situation of San Francisco.

Decentralized Vs Centralized Solar Collection In Uttar Pradesh, India

In the study, "Performance Analysis and Comparative Study of a 467.2 kWp Grid-Interactive SPV System: A Case Study" (2) , the researchers set up 2 solar panel systems on multiple roofs and another solar panel system on one roof to represent decentralized and centralized power, in India. They did so in order to compare the outputs of both systems in order to determine which solar grid system would be best suitable for Indian cities. In this case, decentralized was better cost-wise if they had multiple cheaper panels. If there are multiple that are the same cost as the centralized solar panels, the costs outweigh the power generated. The study found that the centralized solar grid cost less money, yet the decentralized solar grid generated more power from all the panels collectively. The centralized system measured

at 230.4 kWp, while collectively the decentralized system measured at 236.8 kWp. Decentralized solar panels provide quicker currents, meaning more energy generation compared to a centralized grid being transmitted.

Given that the city of San Francisco would likely present a budget for a solar grid, a decentralized plant would still generate more power with cheaper panels than a centralized grid would. The study showed that a decentralized system over the course of a year would produce more power than a centralized system would most of the time.

Conclusion

To address the search for a viable renewable energy resource, solar power has proven to be excellent given that it has an unlimited power source and it doesn't contribute to pollution. Given the rising energy demand all over the bay area, as its population increases, the maintenance for current electricity generation is too costly for what it is worth. Solar power allows for a more local, reliable power source.

A decentralized solar generation system would be more effective in San Francisco because it is efficient in electricity use, it takes up less natural resources, and it is economically more favorable cost-wise. San Francisco would be better off working with a system that requires less maintenance over a longer period of time, less risk of damage or danger, and larger generation of power. While a centralized system would require the extra space that San Francisco will need to authorize, a decentralized system is also much more convenient. Given the high population density and large number of buildings already in place, the solar grid systems can take advantage, and build on top of these buildings, if licensed. The decentralized system has also proven that it generates more power during most of the day, compared to a centralized system. Even at the risk of damage, a decentralized plant would be able to continue generating power because of its build.

While a decentralized plant is proven to be more efficient and sustainable compared to a centralized system, some questions about utilizing the system still pose. Given that San Francisco is a very urban place, the solar panels would have to be placed in areas where sunlight can be accessed. In other words, it needs to be placed where energy production will not be disturbed. Solar canopies on parking roofs seem to be a good option but rooftop solar grids may be more practical given that they are less susceptible to disturbances. The city of San Francisco would also need to license certain buildings to allow solar panels to be built on top of them, and some buildings may not be keen on having that.

While solar production seems endless, some companies won't rely on solar energy in the case of damage to the system, causing a disturbance to the electricity generator. PG&E will have to navigate through these possible errors in order to advertise solar power as a generational power source. Given San Francisco's situation, how would a decentralized system be implemented throughout the city? In living areas, most people live in apartment complexes. Landlords don't see it necessary to build a solar grid system, as their tenants are paying for their own electricity bills.

Despite questions still lingering when discussing the possibility of switching to solar energy to power the city of San Francisco, it remains a promising option for the city due to its convenience and sustainability. In order to maximize electricity production while being cost-effective and weary to the environment, a decentralized system of solar panel groups positioned on rooftops throughout San Francisco would be found to be very sustainable for the future.

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