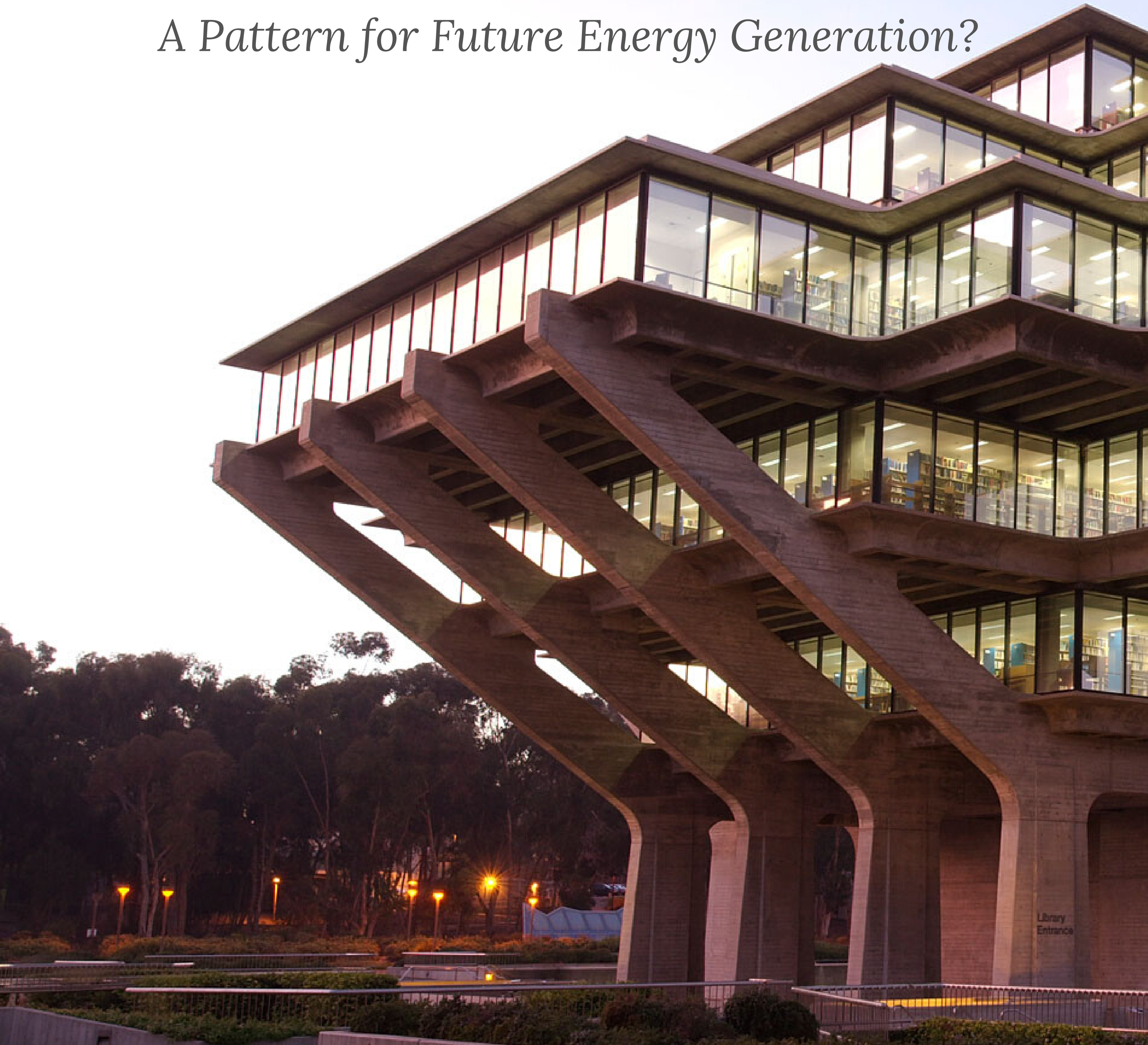
UCSD'S MICROGRID

A Pattern for Future Energy Generation?



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Living Laboratory Report Submitted for *Bending the Curve: Solutions to Climate Change* (Winter 2019)

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Governance | Science | Society | Technology

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Executive Summary

Climate change is an urgent and pressing issue, as temperatures rise due to excessive carbon dioxide emissions, as well as short lived climate pollutants (black carbon, methane, hydrofluorocarbons, and tropospheric ozone) nations are beginning to experience the consequences of climate change. The Bending the Curve Report states that mitigating short- lived climate pollutants (SLCPs) may reduce warming by 0.6 degrees Celsius, allowing the world to implement zero emission technology (Ramanathan et al; pg. 5). According to the report, an 80% reduction in carbon emissions, along with SLCP mitigation action, will maintain global warming below 2 degrees Celsius for the rest of the century (Ramanathan et al; pg. 14). Replacing natural gas with renewable energy will be essential to becoming carbon neutral, this will benefit not only developed cities but reduce the need for SLCPs in rural and developing areas as well. UCSD is taking initiative through development of its microgrid, allowing the ability to produce our own energy and create independence from the main grid.

What is a microgrid?

A microgrid is defined by the US. Department of Energy as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode." (About Microgrids). With the ability to operate autonomously, microgrids strengthen grid resilience and support the integration of distributed energy resources. By facilitating local energy production, energy losses in transmission and distribution are minimized, increasing overall energy efficiency (The Role of Microgrids).

We decided to analyze the microgrid at UCSD as a Living Laboratory to see if it was a model of generation that could be scaled up to help bend the curve of warming. Complete with its own hospital, transportation fleet, laboratories, and residential buildings, UCSD is a great model for implementing interdisciplinary strategies to optimize renewable energy generation. At UCSD, the microgrid provides ~85% of power needs annually (Clean Energy) and as such is a primary instrument for reducing the Universities carbon footprint, in line with the University of California's target of Carbon Neutrality by 2025.

A History of UCSD's Sustainable Practices

As a pioneer in climate change research and education, UCSD has continuously taken action in promoting sustainable practices and carbon emission reduction. To highlight the campus' accomplishments in developing foundations for clean energy and sustainability, we will provide a brief history in UCSD's involvement in climate leadership and development of our microgrid.

In 2001, UCSD installed our 30MW cogeneration plant, producing over 80% of the campus's electricity and heating needs. In 2002, UCSD became one of the first universities to publicly report its greenhouse gas emissions by becoming a member of the California Climate Action registry. In 2006, the university installed the campus's first photovoltaic arrays over a parking structure, providing 1MW of renewable energy to the campus. UCSD developed its 2008 Climate Action Plan, announcing a campus goal of climate neutrality by 2025. The campus installed high efficiency sun tracking solar panels in 2009, add one more megawatt of renewable energy to the campus's solar energy production. In 2011, UCSD constructed a 2.8 MW fuel cell to utilize excess methane gas from the Point Loma Wastewater Treatment Plant for generation of electricity. That year we also installed a 30kW/30kWh energy storage system with a dedicated 30kW PV array. And finally, in 2015 the university installed a 2.5 MW/5 MWh energy storage system. (Carbon Neutrality)

Successes and Accomplishments

UCSD's microgrid is able to provide 85% of our annual 47 MW load (Washom, slide 6), nearly 5 megawatts of which renewable energy generation through our solar PV panels and our fuel cell. The campus has also been making progress in converting our transportation systems to clean energy. Our campus fleet is one of the greenest in the country, 60% of which are alternative fuel vehicles. In addition, our electric vehicle charging infrastructure is one of the largest and most diverse in the country, consisting of a fast fuel compressed natural gas station that dispenses 100% renewably resourced fuel for our fleet.

Relation to Clusters

We chose to focus on the clusters governance, society, science, and technology as microgrids have had a significant impact in each of these fields. The Governance cluster is utilized to analyze ways microgrids could potentially assist in electrical infrastructural shortcomings by reducing the burden on the system that which is already in place. Additionally, the regulatory laws governing microgrids will be examined for the purposes of demonstrating how scalable this project is. Lastly, it is worth examining ways in which governance could be used towards the funding of future microgrids and how we might use such funding methods to also further reduced climate-altering emitents.

Society has been impacted by the development of microgrids as they provide an alternative solution to natural gas consumption for energy, reducing the public's need crude oil and mitigating our carbon dioxide emissions. Microgrids have a significant impact on the equal access to energy in rural and developing regions; however cities and developed areas are also tackling how microgrids can be used to provide fair and equitable energy costs to low income areas. As we begin to experience the consequences of climate change, microgrids provide solutions for public safety through restoring energy in the event of an emergency or natural disaster.

Microgrids assist in carrying out the goals given by the Science Solutions cluster in the Bending the curve report by paving the way for grid independence and facilitating the use of new renewable technologies. The implementation of multiple, smaller scale microgrids decreases the load the main grid is expected to supply, allowing for carbon neutral and renewable energy generation to more easily enter the market and decreasing our reliance on fossil fuel utilities. Microgrids also allow the integration of small scale fuel switching projects that can reallocate SLCP emissions for utilization in energy production. These factors contribute to mitigating SLCP emissions and phasing out fossil fuels as our main energy source.

Technology is a key component in Bending the Curve, particularly in shifting generation technologies from those based on combustion of fossil fuels to those based on renewable or low-carbon technologies. As a different approach to electricity generation based on generation in close proximity to consumption and a focus on resilience that is attractive for many communities microgrids are being pushed as a better new way of meeting our energy needs. If they are to be deployed successfully and to the most benefit we need to examine how this should best be done.

Current Issues

A paper written by researchers at UCSD as part of the Deep Decarbonisation Initiative analyses the business case for microgrids. The analysis shows that microgrids face a challenge of economics if they are to become a tool for decarbonizing energy production and distribution. In all scenarios that the paper analyses the lowest cost configuration includes a significant capacity of natural gas based generation. This is primarily due to the low cost of natural gas (the paper even models higher prices than current averages) and the fact that it is a standalone generating system, in comparison to solar that also requires storage due to intermittency and restricted times of generation. The resulting generation would likely still be less polluting than the current grid however that is not guaranteed and would depend on the grid makeup. The main issue is that the investment in generation equipment is generally a long term investment and as such would “lock in” carbon emissions for up to 30 years.

Another issue, apart from economics, is the fact that solar is not a power dense source, so space quickly becomes a constraint. This is a major factor in UCSD’s microgrid where installed solar power is at 95% of capacity and meets under 10% of demands. UCSD is particularly dense in terms of energy demands through the constraint is still a limiting factor for many applications. The constraint is highly context-dependent however, the lower the energy demands of the organization and the more space is available the more viable solar power is and conversely the lower the solar irradiance the less viable it is.

Another serious constraint is the capacity of biogas, a potential solution to both of the above issues by using fuel switching. Unfortunately for California to switch to biogas would consume over twice the entire US capacity of biogas, in addition, it is much more expensive than natural gas is, due to these two factors it is not really scalable.

Due to the limitations on expanding low carbon generation on site, an area of focus is increasing the use of electric vehicles. UCSD’s microgrid provides electric vehicle charging stations to consumers, and has greatly incentivised students, staff, and faculty to buy into electric vehicles. UCSD created incentive programs with BMW, Volkswagen, Honda, Hyundai, Mercedes-Benz, and Nissan to offer special promotions for the UCSD community to purchase electric vehicles. (UCSD Resource Management and Planning, 2019) However electric vehicle charging stations are predominantly located on UCSD’s campus and with in the La Jolla Colony region. This creates disproportionate access to charging stations and disincentivizes community participation in buying electric vehicles. As UCSD expands their microgrid and energy initiatives we will have to consider consumer participation and how to provide equitable access to renewable energy sources.

Conclusion

The main conclusion is that microgrids have many benefits over the traditional grid infrastructure and it seems likely that more will be implemented over the coming years. In order to maximise the environmental benefits of this it is important that potential operators consider the context of their microgrid and place minimising carbon emissions as a key target for the potential microgrid, rather than simply minimising costs. There are some specific policies that governments could implement to help align these two goals. One is carbon taxes and subsidy reapportionment that increase the cost of natural gas installations reducing the additional cost of low carbon generation technologies while simultaneously driving the main grid to lower carbon sources of energy that microgrids are likely to import instead of generating themselves. Other policies are those of subsidies on low carbon generation and investment in enabling technologies for zero-carbon hydrogen.

Science Solutions Cluster

Author: Jamie Mascarina

An innovator in energy management and sustainable practices, UCSD is well aware of the urgency of climate change, implementing groundbreaking technologies and emission reduction strategies since 2001. As a leader in combating climate change, the university continues to execute critical action against the issue in attempts to bend the curve both immediately and sustainably. These efforts actualize the strategies described by the science solutions cluster in the Bending the Curve Report, which highlights the necessity to reduce short-lived climate pollutants and phase out fossil fuels. The development of our campus's microgrid facilitated our independence from the main power grid, granting us the freedom to explore alternative energy technologies without risk of affecting San Diego County as a whole. Through the isolation of our power, we are capable of conducting an array of innovative projects and research that aid in our campus's ability to bend the curve.

UCSD's Emission History

Since 2002, UCSD has committed to reporting our greenhouse gas (GHG) emissions to third party sources for verification and transparency. As a member of the California Climate Action Registry and the University Climate Change Coalition, we have been able to track our emissions history, as displayed in Figure 1. We can see that UCSD's GHG emissions have remained relatively stable, which is an impressive feat given the steady growth in campus population and a 50% increase in gross square footage since 2004. The slight upward trajectory of our emissions beginning 2015 is mainly due to the construction of Tata Hall and the Jacob's Medical Center. Through the maximization of energy efficiency, investment in renewable energy generation, and transition to low emission vehicles, the campus has been able to reduce its emissions in spite of rapid growth (UCSD 2019 CAP, pg. 14).

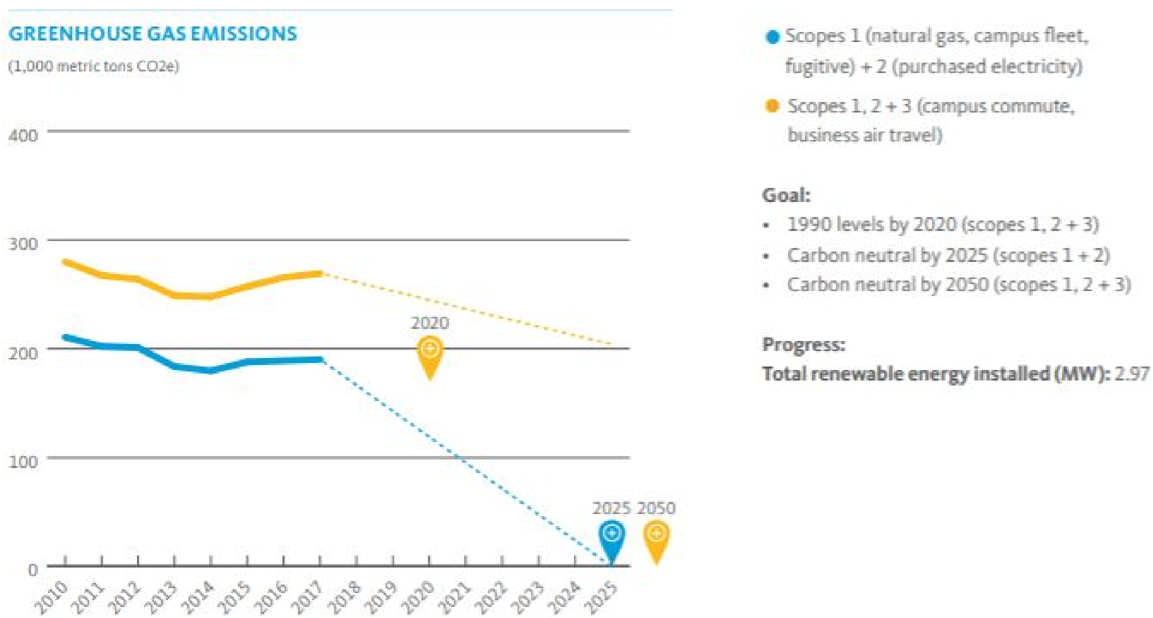
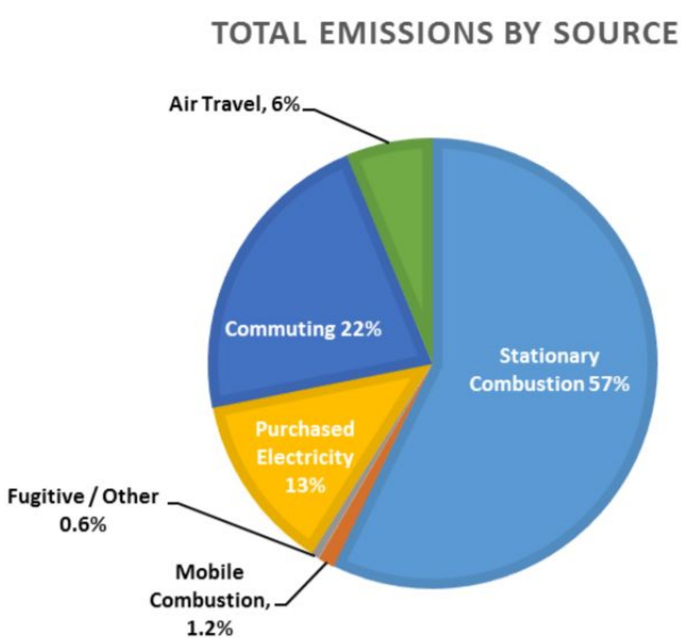


Figure 2 quantifies the university's emissions by source, revealing that a majority of our emissions emanate from stationary combustion, 44% of which is through our natural gas cogeneration plant (UCSD 2008 CAP;pg. 3-3). In the sections below, I will further discuss how we make efficient use of this facility, but also how our heavy reliance on it can prove to be an issue on our path towards carbon neutrality



Efficiency in Energy Generation

Now that we have the context for which UCSD has been successful in reducing GHG emissions, let's further elaborate into how this feat was accomplished. One significant strategy in emission reduction for the campus is promoting efficient energy generation. Our microgrid promotes this strategy through utilizing waste methane and heat for energy production in our fuel cell and cogeneration facility.

The Bending the Curve report emphasizes immediate emission reduction through the minimization of short-lived climate pollutants. UCSD's microgrid undertakes this objective directly through the development of its fuel cell and a partnership with the Point Loma Wastewater Treatment Plant. The plant developed an environmental project, called the Beneficial Use of Digester Gas (BUDG) Project, to reallocate their daily production of 1.1 million cubic feet of digester gas. Instead of flaring this renewable gas into the atmosphere, it is transported to UCSD where our 2.8 megawatt fuel cell utilizes this waste methane to provide 8% of the campus's energy needs (Clean Energy). UCSD installed a 350 ton absorption chiller attachment to the fuel cell, capturing waste heat and boosting efficiency to 66% (Washom slides). Through the BUDG Project, 780,000 cubic feet of methane emissions per day is prevented from polluting our atmosphere and instead utilized for renewable, clean energy (BUDG Project; pg. 1).

Another component of UCSD's microgrid that provides efficient energy generation is our cogeneration facility, which supplies our campus with 85% of our electricity and 95% of our heating and cooling needs. The facility is 70% efficient, consisting of 2 natural gas turbines and a steam chiller that utilizes the turbines' waste heat. The gas turbines themselves are equipped with pollution controls, making them 45-50% more efficient and produce 75% less emissions than conventional natural gas plants (Washom slides). As seen in Figure 2 above, the emissions produced by cogeneration facility take up a majority of the university's overall GHG emissions. However through expanding the efficiency of this system, we ensure that the fossil fuels we do consume are being utilized to their maximum potential. In other words the same amount of natural gas consumed will provide relatively more megawatts for our campus than less efficient technologies, thus reducing our fossil fuel consumption.

By investing in efficient energy generation, our university is able to effectively reduce our fossil fuel consumption. UCSD's microgrid saves the university $10 million per year in energy costs and sets our GHG emissions 27% below California Energy standards (Washom slides).

Replacing Fossil Fuel Energy

Another solution highlighted by the Science Solutions Cluster in the Bending the Curve report is to phase out fossil fuel energy. UCSD has been taking great strides to do so by increasing photovoltaic (PV) arrays on campus and investing in advanced energy storage systems. UCSD currently possesses a 3 MW solar network, paired with a 2.5 MW/5MWh advanced energy storage system to provide stable and efficient solar energy for the university (Washom Slides).

In addition to the construction of PV panels, the university has also been conducting research in intra-hour solar forecasting and heat transfer between buildings and the environment. Utilizing satellite remote sensing models, ground sensors, and numerical weather prediction, the Kleissel Solar Resource Assessment and Forecasting Lab provides solar forecasts ranging from 10minutes to 72 hours. This project hopes to incorporate the forecasts into our microgrid by sending the data to a microgrid optimizer that will enact supply, storage, and load adjustments, increasing the reliability of our solar energy systems. Further research is being conducted in the Kleissl Urban Energy Efficiency Lab, which discovered a connection between rooftop PV panels and decreased roof cooling load. The lab hopes to reduce urban energy consumption by minimizing heat transfer between commercial buildings and the environment. (Kleissl)

Although the campus has made notable progress in establishing solar infrastructure, we have limited solar capacity and opportunities for expansion as we have utilized most of our available rooftop space. As a research university, UCSD possesses an abundance of energy exhausting laboratories that require a complete change of air every 10 minutes. Labs utilize their rooftop space for these HVAC systems, creating issue as they both consume relatively more energy and cannot facilitate renewable energy generation.

Case Study: University of Hawaii at Maui

To see how we can improve upon UCSD's renewable energy capacity, I decided to analyze the University of Hawaii at Maui's microgrid, which has been able to generate 100% renewable energy for the campus. Through this analysis, we can see how UCSD can improve upon its transition into renewable and carbon neutral energy generation and discuss potential issues associated with this shift.

The microgrid at the Maui campus of the University of Hawaii's is mainly reliant on solar energy, consisting of 2.8 MW of solar PV panels paired with 13.2 MWh of energy storage batteries (Digital Trends).

Hawaii has higher solar energy potential, reduced energy consumption, market incentives to convert to renewables, and strong foundations in renewable energy generation, all factors advantageous for the state in its shift towards 100% clean energy. With multiple plants utilizing solar, wind, ocean thermal energy, hydropower, bioenergy, and geothermal energy, the state is able to produce 2,525.8 GWhs of completely renewable energy for its islands (Hawaii Energy Facts & Figures ;pg. 18). These plants provide a strong backing of alternative renewable energy sources to account for the intermittency of solar energy. In the event of low PV production, the state can switch to alternate renewable energy sources, increasing its reliability and easing the transition off of fossil fuels. In addition the state mandated 100% clean energy by 2045, which included statewide reduction in electricity use by 4300 GW/hr by 2030, significantly reducing energy consumption. Another advantage for renewable energy is the fact that gas and oil prices are much more expensive in Hawaii. The state has to import these fossil fuels from the mainland, driving up costs. In fact, according to the Hawaii State Energy Office's Energy Facts and Figures report, energy prices in Hawaii more than double the national average (Hawaii Energy Facts & Figures; pg. 2). This provides a market incentive for firms to purchase renewable energy over fossil fuel energy, vastly contributing to the ease in the state's phasing out of fossil fuels.

UCSD does not have the same opportunities for renewable energy as the University of Hawaii, creating difficulties in direct application of their strategies. For instance, UCSD is very reliant on fossil fuels as our natural gas cogeneration facility produces about 80% of the campus's energy needs. The university has extremely limited potential to build the necessary amount of PV panels to replace the energy generated by our natural gas turbines. In addition, solar PV panels are relatively inefficient and have much higher initial investment costs, eliminating the possibility of market incentives in lieu of political policies for them. Furthermore, the University of Hawaii at Manoa is one tenth the scale of UCSD, so the relatively inefficiency of solar power does not make a huge impact as the university needs much less energy to sustain their population size. Also, the importation cost of fossil fuels does not apply to UCSD, so renewable energy sources are much more expensive and much less cost effective.

Promoting Energy Efficiency

In order to account for the issues in renewable energy production, we should concentrate on significantly decreasing our energy consumption through the adoption of energy efficient practices. Our campus has implemented an array of projects and programs to promote energy efficiency on campus.

UCSD has invested over $100 million dollars to improve the energy efficiency of existing campus buildings. These projects included the installment of energy efficient HVAC systems, transition to LED lighting, and the replacement of appliances to energy efficient ones. In addition to fine tuning our existing buildings, UCSD has taken action in ensuring our future buildings are energy efficient through compliance with the Leadership in Energy and Efficient Design (LEED) building rating system. This internationally recognized system provides 3rd party verification that a building is designed and built to improve energy and water efficiency. UCSD currently has 32 LEED certified buildings and plans for every newly constructed building to comply with LEED standards. UCSD has also taken action in making our labs more efficient through the Green Lab Certification problem, which implements strategies to reduce resource consumption. Green Labs saves the university 1.3 million gallons of water and thousands of kilowatt/hours of energy per year.

In increasing energy efficiency throughout the campus, we are significantly reducing our energy consumption, thus decreasing our GHG emissions. Building retrofits and green building will provide better insulation so there is less need for air conditioning, reducing our use of HFCs.

Issues to Consider Going Forward

By taking early action aggressively and seriously, we have been able to cut our emissions in spite of major campus growth. However, we will eventually reach a standstill in which maximizing our energy will not be sufficient enough to lower our emissions. In addition, we have invested in relatively cheaper methods for emission reduction, so the university is nearing the point where technologies and strategies will be too expensive and it won't be cost effective to take further action. Although energy efficiency did a lot to combat increased emissions with campus growth, its effectiveness can only go so far as it will not be able to sustain our rapidly growing population and expansion. However, investment in new technologies can provide innovative methods for decreasing our reliance on fossil fuels and improving the reliability and efficiency of renewable energy generation.

Technology Solutions Cluster

Author: Roger Milroy

A True Living Laboratory

One of the great things about the microgrid at UCSD is the fact that from the start, one of the main goals was to demonstrate the possible and trial new technologies. That commitment means that when we look at UCSD we can see all of the key technologies that a potential microgrid could use, analyze their costs and benefits and ultimately decide the best technologies for potential microgrids of the future.

The key generation technologies are cogeneration facilities, also known as Combined Heat and Power (CHP) plants with natural gas turbines and waste heat recovery. Solar power, both photovoltaic (PV) and concentrated solar (CSP) installations. Hydrogen fuel cells (Paulos, 2014). And finally diesel generators for backup purposes.

There are two main storage technologies, thermal storage, at UCSD there is ~10 million gallons (Washom slides) which is enough for approximately 2 days of cooling loads. And battery storage, there are a number of different battery storage technologies but the core of UCSD's storage is a 2.5MW/5MWh battery energy storage system (Energy Storage, 2019).

UCSD also has distribution and demand control technologies. This consists of a master controller and sensors to

That covers all of the generation technologies used by UCSD but the microgrid also controls demand to some extent. The main technology for that is the Energy Management System (EMS). This is a central system that monitors and controls the HVAC which is one of the main energy demands of the campus. This is extremely important because one of, if not the key challenge to a microgrid operator is matching supply with demand so having some control over demand gives you more flexibility and reduces the chances of shortages or other issues.

Technologies that are not used in the microgrid at UCSD include most notably wind power. The main reason for UCSD is that the wind patterns on campus (speed, direction, duration) mean that wind power is not viable.

Issues for Carbon Neutral Microgrids

A key finding in researching the area was a paper by Ryan Hanna et al. that analysed the business case for microgrids. The paper analysed three categories of microgrid applications, a large commercial building such as a supermarket or warehouse. A critical asset, such as a hospital, or potentially research facility. And finally a campus, such as a university, military base or commercial headquarters/office. The headline finding was that for all of them natural gas CHPs were likely to be the least cost option for the core of generation with varying amounts of solar power (Hanna, 2017). This is a challenge when examining the case for encouraging microgrids as a scalable solution as without the right policy environment currently we would lock in emissions for around 30 years with microgrids investing in natural gas generation.

The paper also shows that low carbon microgrids could be incentivised with carbon taxes for example but it is also important to consider the context of the potential microgrid. Areas where natural gas supplies are expensive available for example on many islands, natural gas based microgrids are less attractive and low-carbon microgrids are more economic. Then the main challenges are the capacity constraints on low carbon generation.

Another key issue highlighted by the paper was that because the power density of solar panels is so low, space is a key constraint on the total capacity of installable solar power. In fact, for the campus and critical asset categories of microgrid the cost was not the only issue preventing them from having a zero-carbon grid, they quickly run up against this capacity constraint when modeling the effect of increased natural gas prices. UCSD is a perfect example of that, the reason why the microgrid only has 3MW of solar capacity is that it has installed solar in all the places that it can, not because it is too expensive. This constraint has the largest impact on urban microgrids, which is unfortunately the area where most energy demands occur and where most organisations thinking of adopting microgrids are located. There are additional issues that the paper did not directly address, for example the assumption of clear weather days and amounts of solar irradiance that vary widely. This makes solar an even weaker proposition in quite large areas of the world.

An alternative then to solar which has such hard constraints could be to switch to using biogas, either in fuel cells or in turbines. Unfortunately biogas is also constrained by the available quantity. The total biogas potential of the US is estimated at 420 billion cubic feet per year (Biogas Potential in the United States) to put that in context, California's annual consumption of natural gas was estimated to be around 2.1 trillion cubic feet in 2017. (California Natural Gas Total Consumption (Million Cubic Feet), 2019). This is a key limit on the viability of biogas based generation. In addition to this hard capacity constraint, biogas is consistently more expensive than natural gas and so is not economically desirable.

Wind might be another potential solution to the capacity constraint problem as it has a higher power density to solar and could be used in conjunction with it. Unfortunately costs rise very rapidly for smaller turbines making it uneconomic for small microgrid applications (Distributed Generation Renewable Energy Estimate of Costs, 2019). In addition to the economic case there is often public resistance to new wind turbines.

The future of the microgrid at UCSD

UCSD has major expansion plans that is projected to increase the headcount by 16,750 and to accommodate this increase the University is planning to increase the amount of building floor space by 8.9 million gross square feet, an increase of almost 50% over 2018 levels (LRDP, 2018). These expansions come with a serious impact on energy demands, in the context of the constraints we identified we wanted to know how the microgrid is planning to accommodate these new energy demands. The answer is that the current plans are to import more energy from the main grid with the stipulation that it is renewably generated. Currently it is 92% renewably generated and is expected to be 100% by 2020 (Washom, 2019).This reinforces our earlier conclusions on the limitations of microgrids and we see that despite the increase in projected floor space this does not come with a comparable increase in roof space available for solar power.

Due to the limitations for increasing low carbon generation on campus the focus of the microgrid has shifted to trialling new storage systems and increasing capacity. As with previous stages of the microgrid this has tied in well with the research being done at UCSD. One project for example is using EV battery packs that are life expired and no longer useable in EVs and using them for storage of solar power, extending the usable lifetime of the batteries as well as providing data to researchers exploring the reasons for cell failure (Paulos, 2014). Another technology in testing is that of vehicle to grid, that is using EVs that are plugged into chargers on campus as a potential source of power in grid emergencies, of course leaving them with a pre-agreed minimum charge level (Electric Vehicle Charging Infrastructure, 2019). This would allow a more flexible use of storage resources and potentially minimise the amount of static battery storage required.

The other main thrust of improvement is a drive to increase EV uptake by installing more chargers and fast chargers. A future area to tackle is that of shifting charging times to later in the day to line up better with solar power output.

What are the potential technological solutions?

Looking more generally at the future for low carbon microgrids in the context of the identified constraints, I wanted to explore some of the technological possibilities that could enable low carbon microgrids to be the desired configuration of new microgrid.

As one of the key constraints for low carbon microgrids is the power density of solar cells I explored whether this could be solved by improvements in the efficiency of solar panels. Current PV panels on the market generally have efficiencies of around 20%

(Solar News, 2019) and the highest efficiency currently demonstrated is ~45% (DOE, 2019). Looking longer term we find that the maximum calculated efficiency is ~68% (Wikipedia, 2019) indicating that the current record is not far from the achievable maximum. With those parameters in mind, we can examine whether increasing PV efficiency and reducing the cost is a possible solution to our space constraint issues.

If the current record efficiency was available at the same cost as current PV systems it would increase capacity and drop the cost per kwh far enough to enable some microgrids to be low-carbon. The key factor that would decide whether this is possible is the demand density of the potential microgrid. For example UCSD wouldn't benefit much from this hypothetical scenario as we only produce 3MW of solar power currently and have demands of up to 47MW (Washom slides). Even with a doubling we can see that solar power will not be sufficient. Applications that could benefit are large warehouses and low and flat commercial buildings. This does suggest however that dense urban environments are poor environments for potential microgrids which is unfortunate given their disproportionate energy demands.

Does it need to be a microgrid?

One of the defining characteristics of a microgrid is the ability to "island" or isolate itself from the macro-grid this allows the microgrid to continue operation even when the main grid fails. While this is one of the key advantages to implementing a microgrid it also brings certain requirements upon the microgrid. It must be able to cover its peak load entirely and reliably, for example a fully solar based microgrid would require quite significant battery storage to weather anything but minor grid outages. It also requires relatively sophisticated control and sensing to react in time to grid outages. These bring not insignificant costs. Relaxing this constraint would allow a model similar to the installation of residential solar panels where excess power is supplied back to the grid and power is demanded from the grid as and when local generation fails to meet local demands. This approach is not without challenges, this approach would complicate the challenge of matching demand and supply. In addition, one of the key seling points of microgrids is the reliability benefits so removing it weakens the case.

UCSD is a model we could emulate to some extent, operating in concert with the grid as one of the largest demand response customers. With control over consumption as well as generation microgrids can be flexible customers and support grid stability.

Long term solutions.

In the long term the only technology that could make zero-carbon microgrids feasible is hydrogen fuel cells. They don't have the power density constraints that prevent solar cells from being the right solution, the 2.8MW unit at UCSD takes up the same area as a tennis court (Washom slides) and in a true hydrogen fuel cell you would not need the equipment for converting natural gas to hydrogen so size would be smaller still. The efficiency would also be higher that the unit at UCSD, the current best fuel cells have efficiencies of 60% (DOE, 2019) but require high purity hydrogen. Fuel cells can also ramp up and down depending on demand and are significantly more predictable than solar power so in a primarily fuel cell based microgrid the storage needs would be minimal and mainly to bridge the ramping times.

The main challenge that will need to be overcome in order to realise this scenario is the cost of the infrastructure. For fuel cells to be low carbon they must be supplied by either biogas or hydrogen generated by electrolysis where the electricity is low carbon, if they are fuelled with natural gas they are no better than gas turbines. Unfortunately both fuel cells and electrolysis units are prohibitively expensive currently so this is an area that requires investment and research to bring these down. Another factor will be the distribution infrastructure for hydrogen as fuel cells will most likely be located away from the sources.

Conclusion

In conclusion, the main technology available for low carbon microgrids is solar power and battery storage. This is not possible in some contexts, due mainly to space constraints and high power demands and in others is not the cheapest option. As it stands policies are required to encourage low carbon microgrids over natural gas based solutions. In the future technological progress will lessen those needs with a fully developed hydrogen economy potentially removing the need for any supporting policies.

Societal Transformations Cluster

Author: Mary Sellers

The course Bending the Curve introduces six clusters and ten solutions to tackle climate disruption. The cluster, societal transformations, calls for "Attitudinal and behavior change. Foster a global culture of climate action through coordinated public communication and education" (Ramanathan et al; pg. 6). Microgrids are interconnected loads that act as a single controllable entity with respect to the main grid. (Asmus et al; pg. 1) Microgrids fall within the cluster of societal transformations by increasing public education of energy use and climate mitigation strategies such as renewable resources. Developing microgrids stimulate behavioral change through reducing consumer costs and enhancing public safety, while also creating a culture of climate action through reducing carbon dioxide emissions and providing clean energy to rural areas. This paper will address how microgrids fulfill these expectations to be considered a solution.

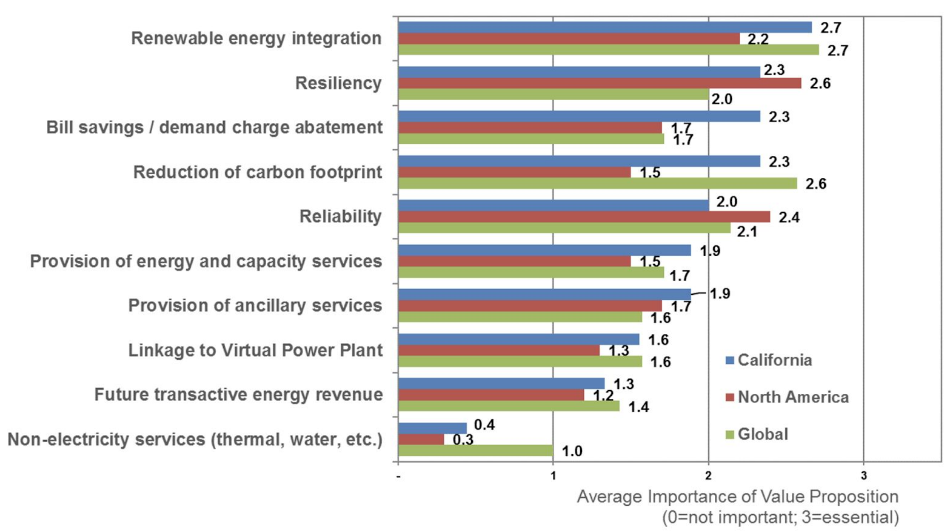
Consumer Costs

Prices for energy have increased as the demand for natural gas has also increased, renewable energy has been a solution in combating the costs associated with providing energy to consumers. Consumers pay for the generation, transmission, and distribution of energy. Generation costs are derived from an increase in demand for natural gas, maintenance, or extreme weather conditions. Power plant to power lines is not the most energy efficient process, at about 33% efficiency, energy is wasted through heat as it travels long distances to consumers. Energy is generated with fossil fuels, coal, and oil releasing CO_2, which in 2017 the U.S Electric Sector contributed 1,744 million metric tons of CO_2 to the atmosphere (U.S Energy Information Administration, 2018). Microgrids are able to reduce these costs through using renewable energy sources for generation, and using technology that captures waste heat and recycles it. Microgrids increase connections to the main grid which provides stronger and more efficient connections to consumers, reducing waste. The average Californian in the greater Los

Angeles area pays ~0.15¢/kwh (Bureau of Labor Statistics, 2019) Where as UCSD has reduced our energy costs to ~0.7¢/kwh of self generated energy, 85% of UCSD's annual supply, and ~0.17¢/kwh for imported energy, 15% of UCSD's annual supply (Mozaffarian, 2019). UCSDs microgrid use gas turbines with pollution controls that are 45-50% more efficient than natural gas power plants and release up to 75% fewer emissions. (UCSD Sustainability, 2019)

Consumers may be concerned with the initial costs of microgrids, as the technology is very expensive. Some microgrids can cost as low as $250,000 or up to $100 million. (Wood, 2016) The cost analysis comes from implementing renewable generation technology, and can be dependent on the region as efficiency correlates with some generation technology such as solar or wind power. Certain regions also may choose to implement different types of microgrid structure based on their preference for efficiency or resiliency and reliability. A case study of California, North America, and Global microgrids shows the rankings of each regions value of different aspects of

Figure ES-6: Value Proposition Rankings, by Region



microgrids. (Fg. 1)

The graph shows that California places value on "Renewable energy" and "carbon reduction" which is in-line with state policy and future goals. These goals also correspond with California's high energy prices and initiatives to reduce these prices for consumers. "This is a driver microgrids share with energy storage systems for commercial customers in California, where electricity rates and demand charges are quite high" (Asmus et al; 2018) While in comparison microgrids in other North American regions place a higher value on reliability and resilience which likely because of the extreme weather events that threaten energy stability. (Asmus et. al; 2018) Depending on the need for generation technology, based on value, and natural resource efficiency, the cost for microgrids can vary. Although initially cost intensive, microgrids also have ability to store and sell generated energy. If too much energy is generated after supplying the demand, it can be stored, or resold back to the main grid. This will offset the cost of the microgrid and eventually "pay back" the grid. An example of this is the University of Hawaii Maui, with a microgrid that offsets 30% of their annual energy consumption UHM saves $37,000 annually. At a scale that affects the public more directly, new California residential homes with microgrids may add $9,500 to the cost of a home but will save ~$80 per month on a residents energy bill. (Cohn, 2018) From these case studies we can conclude that cost is dependent on value of need. Some microgrids still use natural gas for partial generation, which is a cheaper option if the need for microgrids is valued for reliability and resilience. While renewable generation technology is initially more expensive, California's goal is to reduce our carbon footprint and save on consumer costs, which is evident in the long term, however other regions may implement microgrids to protect the public.

Public Impact and Safety

Microgrids will be essential in the event of natural disasters. As global temperatures rise the frequency of extreme weather events such as hurricanes, wildfires, heat waves, and extreme cold temperatures have begun to threaten modern life. Due to these natural disasters the electric grid can suffer impacts that lead to grid disruptions or total grid shut down. Microgrids have the ability to provide relief in these instances by "islanding" from the main grid and providing power to essential community resources such as first responders, emergency sites, and healthcare facilities. Borrego Springs, California experienced a community wide power outage in 2013 when a severe storm knocked out their only power transmission, and 3,000 residents were without power. The Borrego Springs microgrid using local and stored energy was able to restore power to 1,200 residents until crews from SDG&E were able to go out and service the community. Although California is not prone to extreme weather events such as hurricanes, flooding, or snow storms, deaths have increased due to extreme heat, causing drought and wildfires. Microgrids may have the ability to prevent wildfires. As the weather gets hot and dry utility lines can sometimes be responsible for sparking wildfires, to prevent this major utilities such as Pacific Gas and Electric may shut off power in advance to fire prone areas. With the instillation of microgrids, instead of areas being without power, microgrids can supply power to these communities without the risk of potential fires. "Take the Camp fire, which killed at least 85 people and decimated the town of Paradise. In the days leading up to the fire's ignition in November, PG&E warned 70,000 customers it might shut off power in areas including Paradise. But the utility kept the power on, and it now says its infrastructure probably sparked the blaze." (Roth, 2019) Microgrids could reduce the risk of fires by allowing utilities to shut down power lines without completely shutting of power to critical infrastructure.

East Coast Examples

The East Coast has also experienced severe weather events that have incentivized states and companies to build microgrids. After hurricane Sandy 8.1 million residents lost power and 1.3 million were still without power a week after the storm. This has incentivised states to invest in microgrids as a safety and security measures. New York created the NY Prize, which is a statewide competition providing funding for projects that improve or create grid technology. Successful microgrids have also been seen at Princeton, New Jersey; which during hurricane Sandy was able to maintain power at the University while surrounding areas were out of power. When certain areas are able to maintain power in emergencies they are able to act as a place of refuge for those in serious crisis. As the nation became aware of the devastating effects of hurricanes it opened up the conversations for how climate change is amplifying hurricanes and their storm surges. This encourages consumers to understand their environment and their individual impact which will inturn support implementing microgrid and environmentally friendly technology. Developing microgrids also brings to light the relationship of common resources and social justice.

Microgrids for Social Justice - MIT Case Study

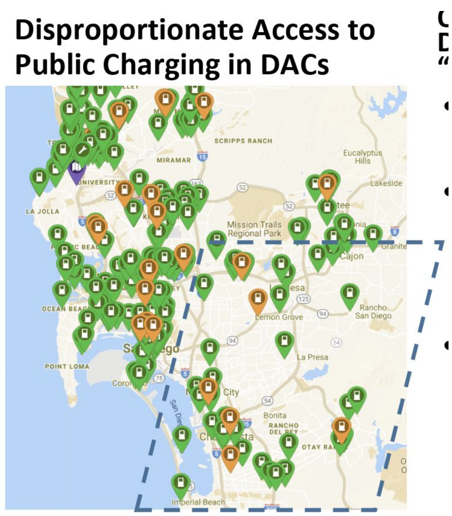
As climate disruption most drastically affects the poor it is essential to help implement mitigation and adaptation technology and techniques to reduce short lived climate pollutants. The world's bottom three billion do not have access to the technology that can help reduce short lived climate pollutants like black carbon and methane. However microgrids have been crucial in bringing clean energy to rural areas. MIT brought solar technology to village in India by developing a system for homeowners who could afford solar panels to share their energy with rural homes. The system uses Direct Current (DC) instead of Alternating Current (AC) which is much safer and will reduce the need for complicated installation or rewiring. The researchers at MIT approached implementing microgrids as a "bottom-up approach", the locals who interact with the technology are able to decide what is installed and where. This approach allows community members to learn about and build the grid themselves. This method fully optimizes the energy from solar panels already installed, reducing the monthly cost of electricity because neighbors won't have to pay for new generation costs. Researchers at MIT believe their system is scalable because it can provide many opportunities at different stages "— for companies that provide components, local workers who do the installations, solar panel owners who get revenue from the power, and end users who get power that not only facilitates reading and working after dark but can also power water pumps for irrigation and other uses." (Chandler, 2015)

Ethical Public Impact

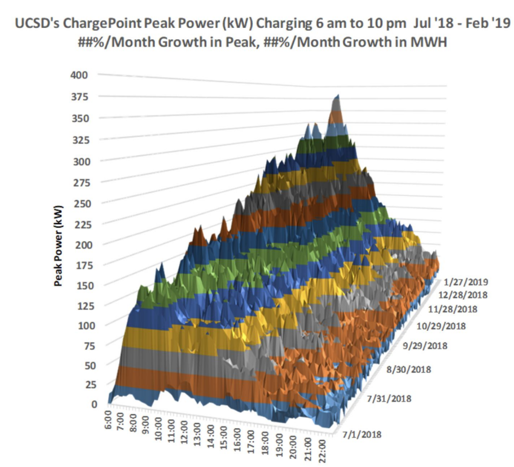
As microgrid technology advances its critical that we understand how to share the wealth. Wolsink, a researcher at the University of Amsterdam states "The development of smart grids also suffers from a focus on mere ‘technology’, continuing the neglect of social determinants” (Wolsink, pg. 117) Wolsink describes microgrid technology as a collective action problem which calls for a Common Pool Resource management approach (CPR). The CPR approach requires “good governance” which calls for governments to work in partnership and sustain “co-operation between users and different levels of regulation” (pg. 117). Wolsink determines in order for socio-technology to benefit society it must be monitored so that resources can optimize long term benefits and that exploitation by one user does not reduce the resources available to all other users, this is specifically important as not every region has the space to implement renewable energy generation technology and infrastructure (Wolsink, pg. 117) Wolsink discusses consumers relationship with electric vehicles. He explains that as electric vehicles are becoming more available to consumers they should be considered “co-producers” of energy. Because consumers have the ability to balance supply and demand of electricity through the microgrid, and also have the potential to recharge the microgrid and therefore the relationship between consumers and the grid needs to rely on self governance and regulation. Establishing where microgrids are located needs to be relevant to residence so they will be able to take part in clean energy initiatives. “Besides this essential space, the secondary relevant ‘institutional’ issue relates to whether establishing microgrids based on high involvement of end-users creating power supply meets certain standards of equity and fairness.” (Wolsink, pg. 118) To illustrate the success of microgrids and fairness the Blue Lake Rancheria tribe of Humboldt County, California implemented a microgrid for self sustainability, resilience, reducing costs. “Many tribes in California_and across the country_don't have access to the electrical grid, and never have. Where tribes are connected to the grid, a lot of them are at the end of the distribution line. So when things happen, their infrastructure is prioritized below more populous areas' and other needs of the electrical grid. It's a chronic problem for tribes.” (The Sierra Club, 2019) After implementing a micro grid the Blue Lake Rancheria tribe has saved $150,000 and

$200,000 a year in electric bills and although they still purchase some energy from PG&E, 20 to 40 percent of their own energy.

UCSD has experienced this potential problem of socio-technological injustice as 2,000 UCSD employees do not have access to electric vehicle charging stations. This disincentives customers from buying into EV as they would also have to commute to charge the vehicles. UCSD has a goal to install 250,000 EV charging stations by 2025 to meet consumer demand and create a more equal opportunity to use microgrid technology. (Washom, slide 20)This will also benefit microgrids as optimal energy use will be spread out throughout the day. Currently the majority of EV users charge between six and ten in the morning using most of the grid's stored energy early on in the day. UCSD would like to change this behavior and asks consumers to charge later in the evening to reduce energy consumption all at once. By increasing the amount of charging stations this may allow consumers to charge after the end of their day, closer to their homes.



Fg. 2



Fg. 3

The first chart (Fg. 2) shows the Disproportionate Access to Public Charging (Washom, slide 20) this illustrates how coastal areas have more access to public charging stations than those in more inland regions. The second graph (Fg. 3) showcases how EV consumers have increased the amount of charging (the peak power) however the time of charging has stayed in the time period 6 a.m to 10 a.m. (Washom, 2019)

Microgrids have, and will continue to have, a significant impact on societal transformations. Microgrids will be key in reducing costs for consumers over time. Through renewable technology and increasing the amount of microgrids electricity transmission and distribution will become more efficient. Market demand as microgrids become more popular will reduce prices for renewable technology making it more accessible to implement microgrids at state levels and residential levels. As global warming increases the likelihood of severe weather events resulting in power outages leaving communities vulnerable, microgrids will be able to island from the main grid supplying power to critical infrastructure or in some cases entire communities. Microgrids can be used as an essential tool to reach rural areas and provide them with technology to reduce their consumption of natural gas, and safer and cheaper methods of energy use. As microgrids become more popular governments will need to analyze how the consumer plays a role as co-producers and what regulations will determine the benefits from acting as such, as well as how to structure social behaviors to create optimal energy use.

Governance Cluster

Author: Jacob Garfinkel

Over the course of discussing several different types of solutions, it became clear that each and every one of the solution clusters featured in the Bending The Curve report is necessary for the combatting of climate change and reduction of carbon emissions. In the governance cluster, there is a stressed importance of utilizing the successes made in California and bringing these successes to the rest of the United States. It also discusses "[scaling]-up subnational models of governance and collaboration around the world to embolden and energize national and international action" (Ramanathan, 2016). What this means is that while California can serve as a model in other states, international ideas and efforts are also required if any serious government level changes can come into fruition. Thus, while California may serve as a national model, it is also important to note areas where it is lacking. Although a microgrid that reduces greenhouse gas emission levels may very well not be worth the immense financial costs at today's current price point, it is possible that there are reasons outside the scope of emissions reduction that would benefit society in such a way that makes the implementation of an expensive microgrid worth the cost. Additionally, this section will be examining ways in which to utilize governmental programs and ideas already in existence as a method for lessening the gap between cost and affordability.

Regulations/California As A Model

California is often regarded as a national leader on environmental and technological issues, and microgrids do not pose as an exception to the rule. While the list of laws regarding the rules and regulations of microgrids is fairly barren, this is to be expected as microgrids are not considered to be a utility. They, therefore, lack the same types of regulatory restrictions that one might find on a utility and have not been around for very long, so special regulations created for them are in the few. Most of the current regulations have to do with interconnection, which refers to connecting a microgrid to either the main grid system or to another microgrid. California currently does have a standard already in place. SB-1339 Electricity: microgrids: tariffs is a State bill that was passed in 2018 that requires the governing board of local publicly owned electric utility to create and allow public access to a uniform standard set of rules for interconnection which include credits/payments/reimbursements. Additionally, all metering is based on the customer-side meter, so long as said customer is connecting a microgrid system that is compatible with all other local and state laws involving home electricity (LegInfo, 2018). Previous to SB 1339, microgrid interconnection was not addressed by any state laws (Villarreal, Erickson, & Zafar, 2014). It is predicted that other States may attempt to pass similar laws for the purposes of allowing microgrid projects in their own States.

Potential Grid Replacement?

The United States did not have a national power transmission electrical grid in the sense that we know it today until the passage of the Public Utility Holding Company Act of 1935. This bill required utility companies to attach grid systems together and share electrical burdens, as well as further regulating them as a public good (Public Utility Holding Company Act (PUHCA), n.d.). However, the United States power grid is now old and outdated, ill equipped to handle the massive energy burden placed on it by our ever-advancing technological country. The 20th-century grid was designed for 20th-century level power outputs. In fact, many now believe that due to the way our grid system was designed, “failure in one place will lead to failure in another place, which cascades into collapse” (Tollefson, 2013). There has been little effort to try and restructure our grid system to prevent the collapse of this major energy infrastructure, all the while our countries energy demand grows more and more with each passing year.

To try an mitigate the inaction and inefficiencies of Congress attempting to pass a bill through both of its chambers, which many believe refuses to act on a problem until the worst has already happened, some have floated the idea of utilizing private and more localized governmental level microgrids to try and reduce their reliance on the main grid. An additional added benefit of this is that it would reduce the total reliance on the grid as well, as the number of people who draw power from it would decrease, rather than increase as is happening currently. This is referred to as “load-shedding.” In such a system, if interconnection between the main grid and microgrids, and between microgrids themselves, has taken place, there is an increase in the total reliability of the system (Villarreal, Erickson, & Zafar, 2014). In the event that the main grid fails, or is damaged due to unforeseen circumstances, such as an extreme weather event, islanding would still allow for the power to remain active for much of the communities still reliant on the main grid for their energy needs. Islanding refers to a scenario where no power is being supplied to the main grid via utilities, but microgrids which are interconnected are still actively giving it some amount of power (Villarreal, Erickson, & Zafar, 2014). In a possible distant future where microgrids are commonplace, it is not a stretch

Government Subsidization

Even though microgrids are not yet a cost-effectively model for reducing emissions on their own, it is entirely possible that with state and federal level subsidies that it could become inexpensive enough for some early technology adopters to deem starting a project worth investing in. If enough of them do so, this would continue to bring down the total costs of both starting and maintaining a microgrid project. While any type of government spending increase can be a non-starter in American politics, it is entirely possible to achieve a sizeable amount of government subsidization without increasing spending. Currently, the United States federal government subsidizes the fossil fuel industry by $14.9 billion per year. If you also include the $5.8 billion that fossil fuels receive from States, that number jumps to a grand total of $20.7 billion annually (Redman, 2017). To give a better understanding of what this actually means, it is currently more costly to maintain a coal-burning plant open than it is to build and maintain a large-scale solar or wind facility/farm, so coal subsidies are heavy in an attempt to keep coal competitive (Ivanova, 2018). If this money was instead taken away from these expensive-to-keep-open, non-renewable, and outdated forms of energy production and relocated to green technology and energy initiative projects, we would more than likely see an improvement in both the costs (they would become cheaper) and in levels of efficiency (they would become more efficient) of said projects, especially given that the subsidization would be annual. This does pose a fairly great challenge though, as the Oil and Gas Industry spent $46.9 million in direct Congressional election donations in 2018, and spent an additional $35.5 million in outside spending donations. The industries lobbying expenses from that same year total at $124.49 million (OpenSecrets, n.d.). Considering that without first putting an end or limiting the over $200 million per year that is spent with the intention of keeping their subsidies, shifting federal subsidization at this time seems unlikely.

It is also worth examining state-level funding as a possible avenue. So far, state subsidization of microgrid projects seems to be reasonably limited. The best current example of a state-funded microgrid project would be the state of New York's previously mentioned NY Prize. Currently, the NY Prize has awarded funding to a total of 83 microgrid projects across the entirety of the state using a three-tiered funding method. Those who reach the initial stage are granted $100 thousand each of state funds (Wood, 2018). This number increases to $1 million at the second and $7 to those who make it to the final stage (Wood, 2015). Since the end goal is a reduction in emissions, taxation of emissions for non-microgrid facilities could be used to balance or cut emissions while simultaneously encourage the adaptation by private businesses to incorporate microgrids at a faster rate than they would otherwise. Additionally, New Jersey also has a state-funded program focused on community-based microgrids. This is funded through the state's investment using public funds toward green technologies

(Burger, 2018). Other states that also have programs like this are Connecticut, New York, and California. Unfortunately, these programs are all still fairly new, and while these states have made claims that the investment is worth the money, there is no long-term record of profits that would be able to convince more moderate states that this is something worth placing their State public assets into (Burger, 2018). The only solution to this problem is time. If the programs are successful long term, I see no reason why a State would not also want to take advantage of their own.

Carbon Taxes

In California, we have opted for the use of a Cap-and-Trade system in an attempt to limit carbon dioxide emissions. Cap-and-Trade refers to a type of policy meant to reduce emissions by setting a firm cap on the amount of pollution corporations are allotted per year; this limit shrinks over time, steadily reducing emissions. There is also an open market allowing for corporations to purchase and sell emissions amounts (Environmental Defense Fund, n.d.). Additionally, California's Cap-and-Trade system has successfully reduced carbon-dioxide emissions by 8.8% from 2013-2016, all while continuing to grow its economy (Environmental Defense Fund, n.d.). This may seem like an attractive way to reduce emissions without posing any harm on the State's economy, in fact, several other States have followed California's lead and enacted their own similar Cap-and-Trade plans. Unfortunately though, this plan reduces corporate emissions at a rate that is far too slow. According to a Carbon Majors Report, a "relatively small set of fossil fuel producers may hold the key to systematic change on emissions" (Riley, 2017). The same report continues by saying that 71% of global emissions are caused by just 100 companies (Riley, 2017). There need to be harsher and swifter actions taken against these top polluters as forcing them to curb their emissions is a far faster way to bend the curve. One way in which you could do this is with a carbon tax.

A carbon tax is a fair bit easier to explain, it's just a tax on the amount of emissions produced; it also leaves quite a bit of room for creative law writing. An example of that would be making a bracketed taxation system where the more you emmit, the more expensive each unit representing a predetermined designated amount of carbon would become. Over time, each one of these brackets would become more expensive, encouraging continued reductions. However, none of this matters if the emissions price is not high. Many argue against a high carbon tax, claiming it will negatively impact the economy, all while suggesting Cap-and-Trade as a more market-friendly approach. Currently, the nation with the world's highest carbon tax is Sweden, at USD$139/tCO2, while the average of nations with carbon taxes is less than one-tenth of that. Since 1991, when the tax was implemented, Sweden has seen 60% economic growth and a near 30% reduction in emissions (Our World In Data, n.d.). This proves that even with the strictest emission standards in the world, an economy is able to grow and reduce pollutants. From this, one could gather that an even higher standard would also be feasible.

The taxes collected could then be used either for the purposes of helping people and businesses who cannot afford to change to a carbon-neutral lifestyle be able to do so, or they can be used for the purposes of investing and subsidizing green research and technologies that will allow us to more efficiently reduce future emissions and bring down the costs of new and existing green technology. Microgrids fit into both of these uses. For the first, take a statistically poorer city that cannot afford to retrofit itself to become Carbon Neutral: profits could be used to establish carbon-neutral microgrids to provide power to that city, all while lowering their energy costs, giving the people of that said city the potential for increased economic opportunity. For the second: in the technology cluster, it was referenced that renewable technologies need to become both better and cheaper before zero-emissions microgrids can really be recommended. Well, by setting up a public fund that invests directly in these technologies and their research, one could gather that this would be an effective way to fund research and development of these zero-emissions technologies. Once that is done, the cost of funding a microgrid would become dramatically reduced to the point where communities and businesses could implement them in a way that would be financially beneficial.

Which Solution Is Best? What works?

In reality, not all of the potential solutions presented in this section are entirely feasible in the immediate. Our country is far too market-friendly to risk pushing for high carbon taxes. While green technology investment plans have had promising results in the immediate, it will most likely take both time and hard profits before additional States are willing to jump on board. Congress is still far too reliant on Oil and Gas campaign funding to do something like rerouting their subsidies. Before any of this happens, microgrids as a short-term solution to power grid failure does not seem likely. However, as long-term goals, each of these potential solutions when utilized in conjunction with one another has a high probability of being able to bend the curve.

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