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Wind Microgeneration Strategy for Meeting California's Carbon Neutral Grid Goal

Geoffrey Niswander [1] and George Xydis [1,2,*]

1 Energy Policy and Climate Program, Krieger School of Arts and Sciences, Johns Hopkins University, Baltimore, MD 21201, USA; gniswan@jhu.edu
2 Department of Business Development and Technology, Aarhus University, Birk Centerpark 15, 7400 Herning, Denmark
* Correspondence: gxydis@gmail.com or gxydis@btech.au.dk; Tel.: +45-9350-8006

Abstract: As California's Renewables Portfolio Standard continues to phase power production from fossil fuels, carbon neutral sources will need to be implemented. This sets small-scale wind production and battery storage in a position to integrate into current grid infrastructure as means of production. This would be an "E Pluribus Unum" approach where many decentralized small production and storage units would act in combination to provide a stable grid. This is often referred to as distributed generation (DG). By distributing the grid's production in this manner and designating predetermined regional hubs for control (in the event of a fractured grid due to natural disaster), the state and its residents will be able to maintain power for critical infrastructure and basic utilities. This work presents, in detail, a sustainable plan for achieving carbon neutral Californian grid by 2045.

Keywords: microgeneration; Renewables Portfolio Standard; carbon neutral

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1. Introduction

The climate is changing in a negative way because of the actions of humans, who have caused the CO_2 concentration to rise; for the first time, on 9 May 2013, CO_2 levels in the air reached above 400 parts per million (ppm). This milestone is an important reminder that humans continue to shape the world, and our behavior has to change before it is too late. The rising concentration of CO_2 is causing the temperature and the sea level to rise, which was observed in the period 2011–2020, where every year was hotter than the previous one, with 2019 and 2020 being among the top three hottest years ever—the third one was 2016 [1].

Climate changes are also seen in the daily weather as more frequent cloud bursts, increased number of days with strong winds, higher humidity, and many more days with extremely high temperatures [2]. Different countries in the world have started to form coalitions, where participating countries are making different goals about lowering the CO_2 emissions, such as in the Paris Agreement, where the goal is to keep the global temperature rise below 2 °C by the year 2100. According to the Intergovernmental Panel on Climate Change, as a consequence, a major part of the population globally could be exposed to severe heatwaves and other natural disasters as often as once every five years. These goals will be reached by some general changes, but also by individual initiatives in the different countries [3]. The same trend was followed in most countries or states that have set ambitious goals, for example, in California in the US [4].

The California landscape is an amalgamation of geologic uplifting, tilting, folding, and faulting. This has resulted in a unique challenge for the modern era's electric grid. The state can be generalized into eleven geologic regions; The Klamath, Cascade, Coast, Sierra Nevada, Transverse and Peninsular mountain ranges, the Basin and Range, the Modoc Plateau, the Mojave and Colorado deserts, and the Great Valley. The state's electric grid spans all eleven regions and provides power to the residents of each [5].

In 2002, California adopted a Renewables Portfolio Standard (RPS), which phases in an increasing portion of energy generation that comes from carbon-free sources. The current goals are to achieve a 60% carbon-free grid by 2030 and a completely carbon-free grid by 2045 [6]. As the grid shifts to a Carbon neutral grid and as the state will presumably experience intense wildfire seasons, the need to minimize stress on an already aged grid may be necessary to limit the extent of wildfire devastation while maintaining a stable power supply for the state's residents. Since 2018, it has been agreed that the state's grid should be upgraded and modernized due to the fact that, by law, the state must achieve all of its power by 2045 from renewable energy sources. The plan leading the Californian grid to become carbon neutral in the long term, includes operating an energy imbalance market and checking systems' reliability, thus securing high renewable energy penetration. The transmission system operator (TSO) is usually based on historical prices to reach relatively accurate forecasting. The Californian grid often suffers from rather extensive wildfires and other extreme events (natural disasters or other). It seems that due to climate change, historical prices are no longer a good determinant of the future. Three main causes are responsible for this:

- unprecedented heat waves;
- unplanned available storage capacity; and
- unclear overview of actual supply and demand (especially in the evening hours).

Since California has set the 2045 carbon neutral grid, the demand, production, and operation patterns will not be the same. With spanning to multiple states and having efficient communication with the other TSOs, California will be taking advantage of the diversity of the resources on the western side of the country, hopefully avoiding pitfalls. The plan is to follow a similar plan to the target model that prevails in Europe. Serious (and emergency) demand response, such as the Flex Alert or other similar programs, are going to serve and engage end-users more and more in the future. Furthermore, new storage options, new fuels, and investments are going to be the compass for this change.

This could, in part, be accomplished with small-scale wind and grid-tied battery storage [7], but can it be done without storage [8]? In 2018, the California Energy Commission stated that wind production capacity was about 6 GW and accounted for only 7.3% of the state's total power generation for that year, combined with very limited distributed storage facilities [9]. On top of that, California's housing values are notably higher than that of the other 49 states (housing bubble). As of the end of April 2020, the median home price in the state was $578,267, while the nationwide median home price was $248,857 (the question that immediately comes to mind is "should overpriced homes crash"?). This creates an elevated and possibly insurmountable capital cost for any projects that require large swathes of terrestrial land [10,11]. As a result, the use of current infrastructure becomes necessary in order to keep capital costs low. This includes grid-tied households and businesses, as well as transmission hubs, where the supply is consolidated and dispersed to the grid.

Presently, the two major Investor Owned Utilities (IOUs) in the state have instituted mandatory grid shutdowns during weather events (red flag warnings) that cause a high likelihood of wildfire [12]. Power is only restored after line crews have checked the affected infrastructure for damage or contact with vegetation. This can take several additional days after the weather event has passed. Red flag warnings are weather conditions that provide higher than average temperature, low humidity, and high/driving sustained winds. These conditions can persist for days or weeks and have in previous years left whole communities and regions without power for longer. Each of California's eleven geologic regions pose their own challenges and special considerations when it comes to these mandatory shutdowns. The native vegetation alone varies from region to region. The state is home to the Coastal Redwood (*Sequoia Sempervirens*), the Giant Sequoia Redwood (*Sequoiadendron Giganteum*), Manzanita shrub (*Arctostaphylos manzanita*), Lodge Pole Pine (*Pinus Contorta*), Douglas Fir (*Pseudotsuga menziesii*), and several varieties of Oak tree, just to name a few. Each of these species has a range in which they grow in the state and most have ranges where they intermingle and cohabitate. The state's electric grid must traverse all of these regions, landscapes, topographies, and ecosystems in order to provide a stable power supply to the span of California Communities. See Figure 1 for the current transmission network [13]. Note that the dark blue outline denotes the Pacific Gas and Electric service area.

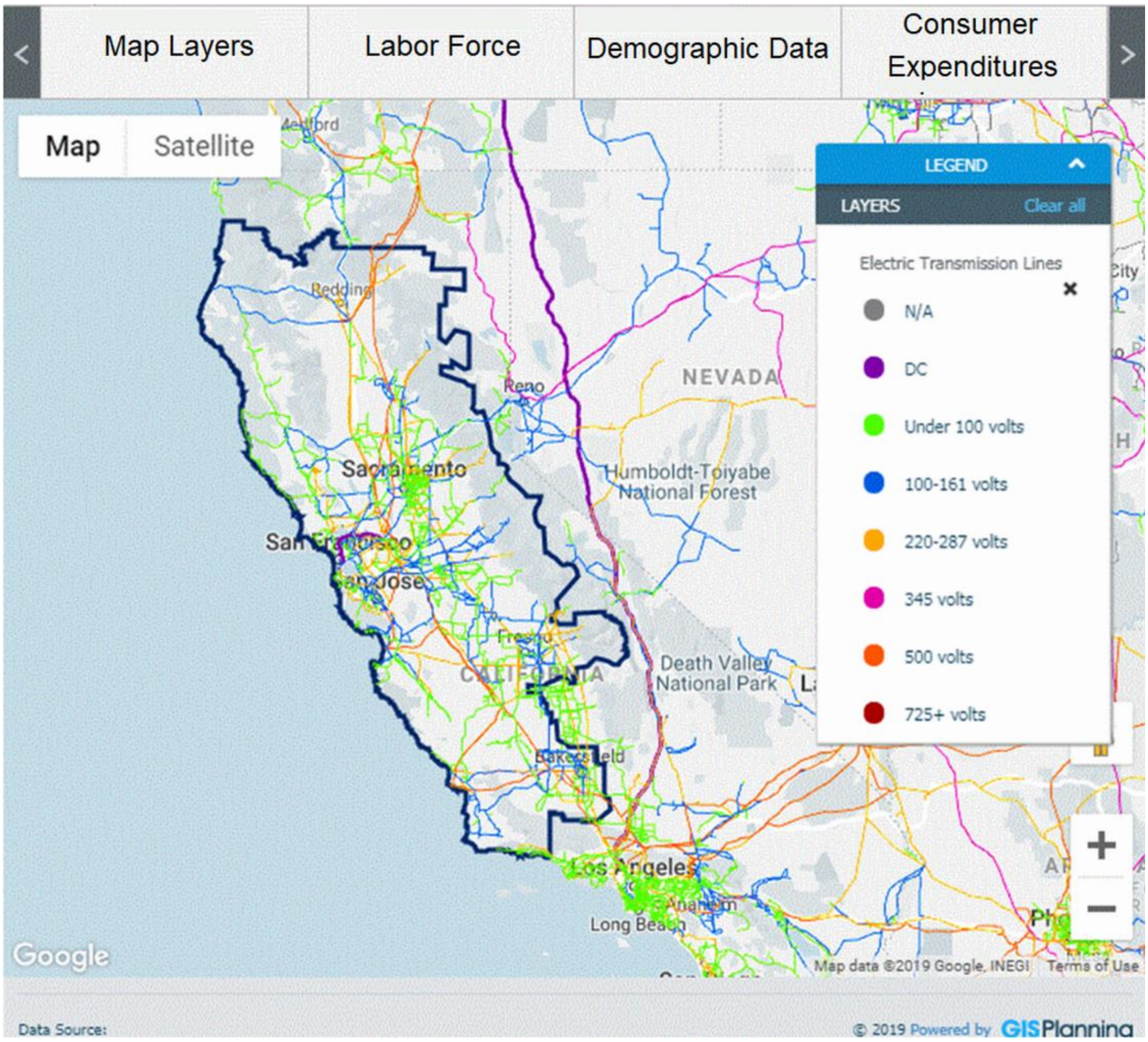

Figure 1. The current transmission network in California [14].

2. Literature Review

A number of published works have focused on the required infrastructure upgrade in California State, as the number of wind and solar energy projects, EVs, and hydrogen storage applications are increasing. Based on a technical report from the National Renewable Energy Laboratory (NREL), US Department of Energy, released in July 2009, attention is particularly given to the use of wide-scale disbursement of wind energy production across large balancing areas. Because of wind energy's production variability, the integration of wind energy into larger balancing areas would mean that the variation in production could be minimized more easily when coupled with more sources of generation [15]. This reasoning for regional-scale control, however, did not take into account the use of battery storage to meet demand response. Nevertheless, it does make the case for a large distributed network of production for wind, so that when wind production decreases due to unfavorable weather conditions or maintenance, the remaining balance can be met by the other production means within the region. If battery storage is incorporated to capture excess production and then be remotely regulated for demand response, then the issue of wide disbursement due to production variability becomes less necessary and the area of disbursement can be proportionally decreased to the quantity of available battery capacity [16].

The known report from the state of California's Department of Housing and Community Development discusses some of the housing issues facing the state. The recommendation made in the report was the construction of 180,000 homes annually through to 2025. At the time the report was written, the state was constructing less than 80,000 new homes, with the decreasing supply and increasing sprawl are two of the root causes of increasing land values. However, this further emphasizes the need to use current infrastructure as the cost of dedicated land will progressively increase when assuming a continued sprawl and short housing supply in populated regions (where most of the demand will be located). The report also notes a single-family housing stock of approximately 9 million statewide. This leads to the assumption that there are homes in the state that could be retrofitted to produce wind energy at the small or micro-scale and that production would not necessarily be restricted to new construction [17].

Research on microgeneration has started occupying more and more space in mature urban solutions over the last decade [18,19]. Kakran and Chanana [20] discussed the simulated use of energy management and balancing systems in individual homes alongside a small-scale wind generation unit. In their study, the researchers placed constraints on the system that required a stable power supply to the simulated homes, a sustained level of comfort in the form of a sustained power supply sufficient to maintain a set of predetermined modern household appliances. During the simulation, the wind energy source was able to produce a sufficient amount of power to provide a net negative use for the simulated homes. This excess power would be sent to the grid to provide additional power where it may be needed. Further restrictions were placed on the simulated homes in the form of rationed energy use during low-priced times. This effectively kept the demand load from spiking during times of excess supply, making look-ahead forecasting more predictable [21].

Drawing a parallel to microgeneration, the importance of off-grid wind energy systems, as well the parameter of the grid structure uniformity, are discussed in Lu et al. [22]. This article discusses the practicality of how to effectively analyze the efficiency of an off-grid wind system and the importance of examining the individual components of the whole system for analysis. By emphasizing each individual component in an efficiency analysis, the study showed the importance of a near-uniform structure when it comes to grid components. The use of uniform components within a region will be important for grid reliability, especially when trying to balance a demand load within a regional network. Component turbines will need to be either uniform or listed and known so that a forecast can be made for production and estimated downtime for maintenance and failure. The best analogy for this would be the efficiency of a house or building constructed from multiple material types, none of which is identical. If the parts of the system are not, at a minimum, compatible and reliable, then the system itself becomes unpredictable and unreliable.

Borunda et al. [23] give an example of small-scale wind turbines (SSWT) and their process behind site selection based on a case in Mexico. These are defined in the article as ranging from 5–10 kW in generation capacity and are intended to cover the demand load of residential power usage in Mexico. The authors of this article utilize a Bayesian Network as a means of determining the probability of a successful project site for the SSWT [24]. The variables used in the decision-making model included the sustained wind speeds of a given site, the capacity, class, and power curve of the turbine to be used, and the residential tariff to be assessed in a given city or area [25]. The tariffs considered were based on monthly use and were used to assess the probability of successfully lowering energy costs if the SSWTs were constructed. This approach would need to alter slightly if applied to the California grid, as utility ratepayers are charged for both monthly total consumption and usage during low and high demand periods, commonly referred to as "off-peak" and "on-peak" periods, respectively. However, this analysis could show a path forward for how to determine the viability of small and micro-scale wind energy projects in California by using the readily available Meteorological Aerodrome Reports (METARs), National Oceanic and Atmospheric Administration (NOAA) ground/buoy monitoring stations, National Climatic Data Center observations from the satellite constellation of the Joint Polar Satellite System (JPSS), Geostationary Operational Environmental Satellite Program (GOES), and the Polar Operational Environmental Satellite Program (POES). This plethora of current and archived data could be used to carry out a similar Bayesian analysis of the state to determine an ideal site location. Other factors that would need to be included would be proximity to end-users, nearest available infrastructure, compatibility with nearby transmission networks, and a common microsite analysis estimating wind energy yield potential [26]. Some of the issues and solutions to overproduction and curtailment of wind energy are also important. Examples provided were issues relating to transmission congestion, which resulted in curtailments. A solution provided was to use thermal or cold storage as secondary use [27]. This would lead to a unified electric grid and heating and cooling network that minimizes the amount of energy wasted after generation. By using the excess energy generated for secondary uses that serve the local population, the overall efficiency of the project and generation points can be drastically increased. This would be an important consideration when planning a statewide small scale power generation network [28,29].

3. Proposal and Analysis

If California's growth, with respect to supply and demand for power, continues at their current rates, what quantity of small and micro-scale wind energy with combined battery storage would be needed to meet the needs of a carbon neutral grid in 2045? This will treat wind energy production and battery storage as combined units, so that the energy produced will be either used immediately on the grid or later stored for demand response. Figure 2 (below), shows the dispersion of generation sources across the state.

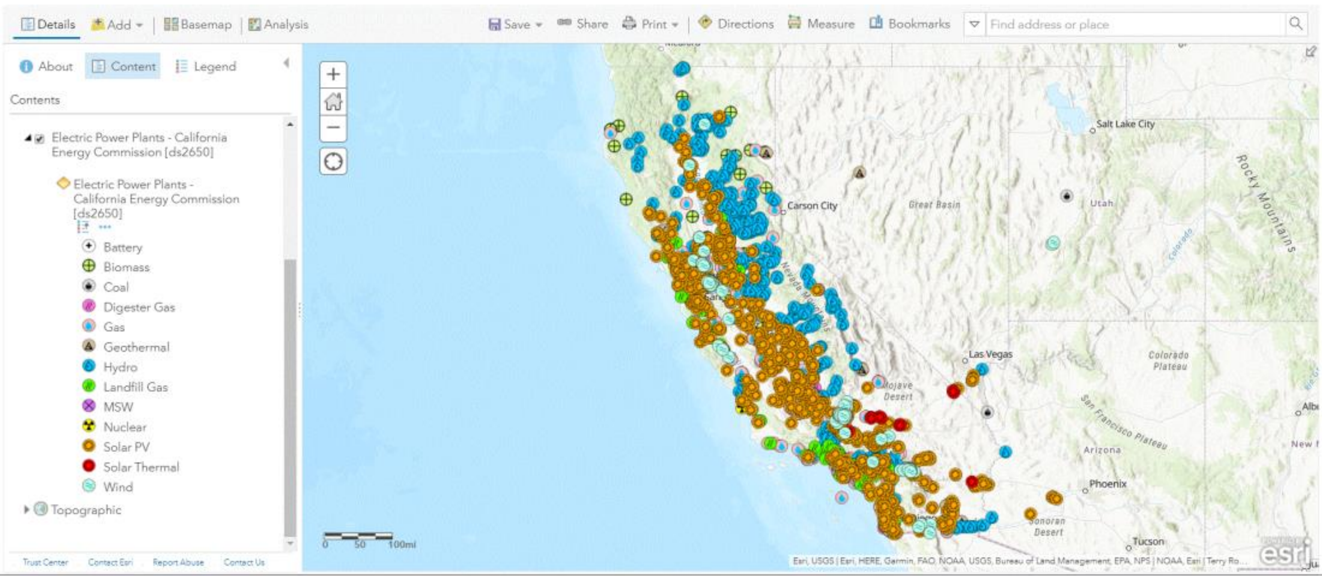

Figure 2. California Energy Commission Layer displayed via the JHU ARCGIS online application [29–31].

From 2014 to 2018, the California instate supply grew on average 0.63% year to year. As of 2018, wind energy accounted for 7.48% of total capacity. If the state intends to keep on track with the RPS, and achieve a carbon neutral grid by 2045, then the construction (on public infrastructure) and incentivizing the purchase of (on private infrastructure) small and micro-scale (<1 kW) wind turbines and point-source grid-tied battery storage need to occur.

For this proposal, a 400-Watt turbine with 46″ rotor diameter (based on the Primus Wind Power Air Silent X Wind Generator) and a battery bank of 4 kW continuous capacity and at least 13 kWh charge capacity (based on Absorbent Glass Mat Battery banks assembled by wholesalesolar.com (assessed: 1 November 2021) and the lithium battery based Tesla Wall) will be used [32,33]. Approximate costs for each are estimated at $1600 and $10,000, respectively, representing a minimalistic starting array that could be scaled up as needed for residential, commercial, and utility structures. These aforementioned consumer products were selected as standards because, at the time this paper was written, they were the most readily available. This is not intended to be an endorsement of any given product or company, merely an analysis of readily available products that could be placed into grid service immediately. The technical specifications are likely to change for both components as both technologies improve and gain more market penetration. This analysis will strictly use these.

In the event of a fractured grid, a system such as this would be used to meet the demand of individual homes and businesses in the interim until the grid could restabilize. The emphasis on micro-scale wind turbines is used in this proposal as it allows for much lower capital costs at the point of entry into the energy market and therefore potentially encourages private citizens to use their own capital to improve the grid's reliability by implementing their own turbine systems. This would not necessarily be the case if the emphasis was initially placed on small-scale turbines that may require too large of a footprint to be viable for the average resident and ratepayer to access and utilize.

The areas most likely to be the most vulnerable to forced power outages will be outlying communities with few transmission routes that are connected to the grid. Should the state move forward with this proposal, the implementation process should focus on those areas as they tend to have more isolated communities, rugged terrain, and a greater likelihood of being susceptible to wildfire events, which would fracture the grid.

4. Results and Discussion

Using Equation (1) (below), the total amount of instate production can be estimated, assuming that the growth rate of 0.63% remains constant year to year. The starting year used will be 2018, as it is the latest data available from the California Independent Service Operator [33–36]. The initial capacity used will therefore be 80,304 MW (80.304 GW). The growth rate is applied once per year, and the number of years assessed will cover the span from the start of 2018 to the end of 2045 (28 years). The average rate used (0.63%) is calculated from the previous five years and will represent a conservative growth of instate supply capacity. This leads to an estimated instate supply capacity of 95,742 MW (95.742 GW) in 2045. In terms of the growth of infrastructure, the state would need to bring approximately 551 MW of capacity online each year until 2045.

$$A = P\left(1 + \frac{r}{n}\right)^{nt} \tag{1}$$

where

- A = principal amount at time t;
- P = initial amount;
- r = rate of change (growth);
- n = number of times r is applied per unit t;
- t = number of years assessed.

In 2018, wind energy accounted for 7.48% (6004 MW) of the total instate capacity (80,304 MW). If wind is to keep its market share moving forward, then capacity will need to increase by 41.24 MW each year until 2045. In terms of small and micro-scale wind energy for residential and small business applications, this means 3683 turbines at 400 W and 369 4 kW grid-tied battery banks will need to be brought online each year. The cost of hardware alone would be $165 and $103 Million (respectively) over 28 years. Only in 2020, it was announced that Sidewalk Infrastructure Partners (SIP) would invest (once) $100 Million in order for the Californian Grid to be upgraded [37].

If micro-scale wind energy were to account for the entire net difference between 2018 and estimated 2045 capacities (15.44 GW), then the instate generation would need to construct and install 49,232 wind turbines at 400W and 4924 4 kW batteries in order to meet the future demand. These costs would amount to $2.2 and $1.4 Billion, respectively, over the 28-year period.

If the 17-year average rate of growth for generation capacity is used (2.23% for the years 2002 to 2018), then the net production capacity difference between 2018 and 2045 becomes 68.61 GW. This would require a much larger and drastic implementation of over 16,000 turbines at 400 W and 1600 4 kW batteries per year in order to keep the 7.48% market share. If required to fulfill the entire difference of the 28-year gain, micro-scale wind energy would need to increase by 218,778 turbines at 400 W and 21,878 kW batteries per year for 28 consecutive years.

On the other hand, NREL has estimated only for "greening" 100% Los Angeles the costs somewhere between $57 billion and $87 billion [38], excluding practically micro-scale wind energy [38]. The various studies focus on greening the cities and not and the accompanying demand without focusing on the independent end-user needs to meet their demand. Therefore, supporting a whole grid and all the infrastructure is, of course, much more costly and expensive.

The 2.23% increase includes 5 years where Solar PV increased at yearly rates between 114 and 680% (See Figures 3 and 4). Solar PV's growth over the 17-year timespan was an outlier of 107.43%. This calculation was not carried out and used with the 17-year average growth rate due to the Solar PV rate over the same period of time. When Solar PV is excluded from the growth rate calculation, the 17-year growth rate is 0.11%.

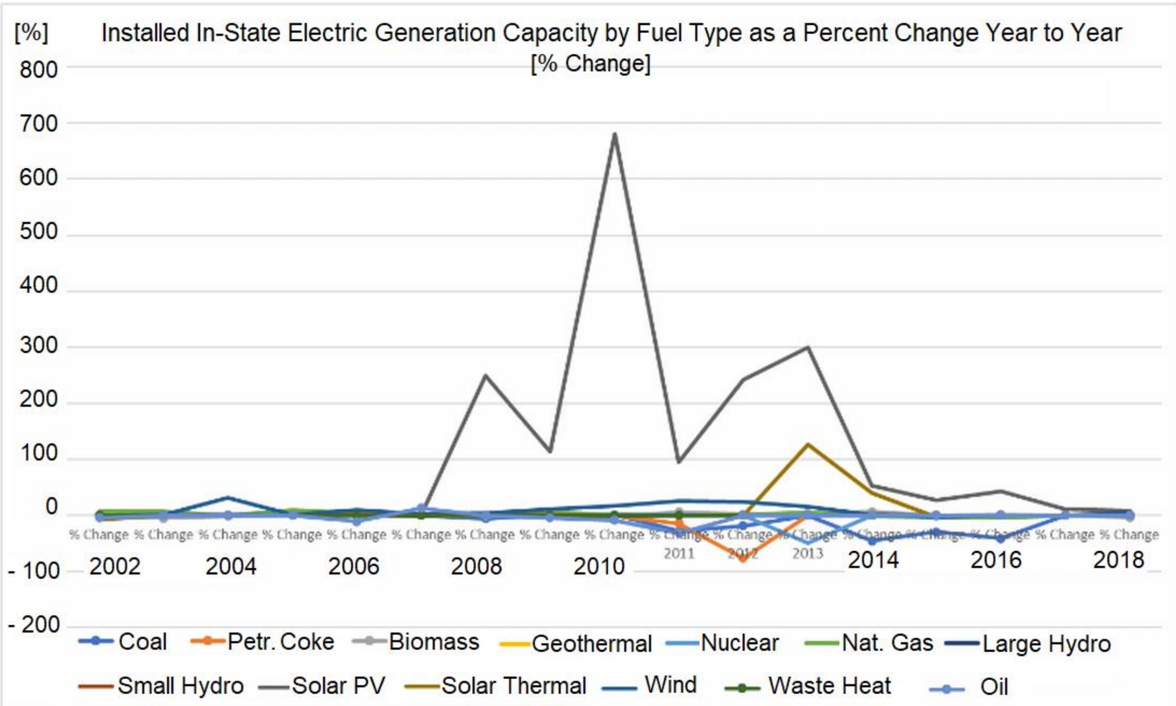

Figure 3. California's capacity by yearly percentage change.

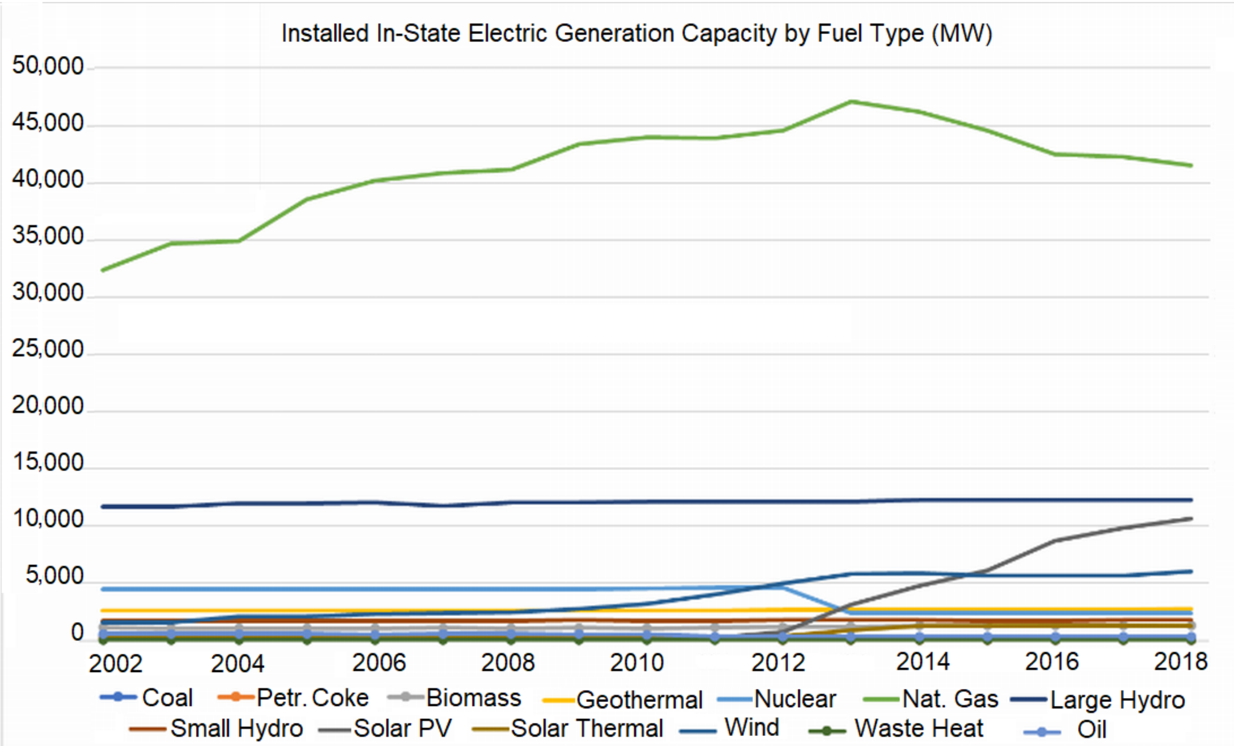

Figure 4. California's capacity by fuel type.

As of 2018, over 50% of the state's generation capacity came from natural gas (See Figures 3 and 4, above). This presents a significant challenge when it comes to pushing the grid towards carbon and greenhouse gas neutrality. Natural gas generation is primarily used to meet peak load as combined cycle plants are easily ramped up and down to meet the demand curve during peak hours. An ideal replacement would be excess production during off-peak hours that is stored to meet demand response later in the day. This could be accomplished, to varying degrees, at utility and small-scale operations. However, when dealing with demand response storage, capable infrastructure will need to be taken into account and potentially constructed or improved so that transmission congestion is minimized.

There are various plans that are focusing on greening various US states, however, it is the Californian state that is prioritized to turn the Golden State green since, in a number of studies, California is often referred as an environmental savior towards a greener future. California's ambitious climate policy operation has cast the state as a global leader on climate change in the USA. Therefore, an alternative approach to achieving California's environmental goals in various ways, such as for instance, importing fewer carbon-intensive products, is giving a signal as well to the rest of the country. Therefore, a wind microgeneration proposal could ignite an alternative way of thinking to all the other US states.

5. Conclusions

The use of micro and, possibly, small-scale wind generation coupled with battery storage for meeting the State of California RPS goal of a carbon neutral grid by 2045 is possible. By distributing the power generation infrastructure, the risk associated with natural disasters can be minimized as said natural disasters are typically confined to small geographic segments of the state. If small portions of the distributed network are affected, then the remainder can be used to meet demand, or usage can be constrained to essential infrastructure by regional balancing hubs [39]. This will be important moving forward as California's wildfire seasons and overall activity increase in severity and frequency as a result of climate change [40]. The most vulnerable communities may very well be the most viable as they reside on or around the wildland–urban interface. Further analysis will be needed to determine specific locations for ideal generation and energy storage [41].

This proposal focuses on wind generation with grid-tied battery storage on-site or nearby to the site of generation. Calculations are based on current costs for micro-scale wind turbines and battery storage systems that are currently available to the residents and small businesses of California. It assumes that the costs of these components will not change over the course of the time assessed (28 years) and that more efficient means of energy production or storage will not come online during that period of time.

At this time, the best example of how a transition from natural gas to utility-scale batteries at the Moss Landing Natural Gas power plant in Moss Landing, California. This is currently a joint venture between Pacific Gas and Electric (PG&E) and the Tesla Motor company and will result in the construction and installation of a Tesla MegaPack at the PG&E plant. When coupled with carbon neutral power production, these systems can become the next generation of "peaker plants" that are used to quickly ramp up and down to meet on-peak demand [42].

Moving forward, a few additional analyses could be undertaken to help see this proposal (or one similar) come to fruition. The first and foremost would be an analysis that quantifies the characteristics of ideal locations for storage and generation. These characteristics may include local topography (to assess issues with maintaining associated transmission lines), weather patterns (to quantify potential productivity and the likelihood of red flag warnings), proximity to established grid infrastructure (to quantify capital costs needed to connect to major segments of the grid), nearby population density (to assess whether a future demand load may or may not overwhelm a future supply of a given region or site), and proximity to major highways (to quantify possible costs of construction and maintenance).

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