A Feasibility Study on Building a Stand-Alone Community Microgrid in the United States

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***Abstract*—Switching from fossil fuels to renewable energy is an essential step towards reducing emissions of greenhouse gases. On a local level, microgrids could be the solution to further renewable energy penetration. This study develops and makes use of an analysis tool for calculating the cost and benefits of developing a self-sufficient community microgrid in several locations throughout the United States. The novelty of the study includes the analysis of costs and benefits of developing a residential neighborhood of 1000 households powered by 4 to 8 MW of renewable energy as well as powering this stand-alone community microgrid with 100% renewable energy. The study investigates using energy savings to sell houses at a discounted price to attract customers and aims to boost the usage of renewable energy through the popularization of this model. Because of the variable nature of renewable energy, storage systems play an essential role in designing a stand-alone microgrid. The study uses the National Renewable Energy Laboratory's (NREL) System Advisor Model (SAM) to calculate available resources in various locations and model the electric load. This data is then used to estimate the amount of energy needed for storage purposes. Detailed calculations of costs and benefits can prove the viability of such a system in various locations across the United States. The results show that this model would be viable in locations such as southern California where wind and solar energy resources are highly available.**

Keywords—microgrid, community, renewable energy, photovoltaic, wind energy

I. Introduction

Microgrids have been implemented for over half a century [1] in many different contexts and have facilitated the penetration of renewable energy in the power-grid. Different types of renewable energy, such as wind turbines and photovoltaic panels have been used to power these microgrids. Because of the intermittency of renewable energy, energy storage plays an essential role in bridging gaps between energy production and energy load. In recent years, models for stand-alone microgrids have been developed using hydrogen battery storage [2], yielding promising results for solving the issue of intermittency. A report given by the National Renewable Energy Laboratory (NREL) [3] showed the various scales and types of microgrids and their respective cost. Microgrids operating with larger wind turbines have a lower relative cost than smaller scale ones. Research and development in energy storage technologies has increased the capacity of energy storage to much larger scales able to support large loads during power outages. Studies such as Colbertaldo et al. 2020 [4] analyze the impact of hydrogen storage on a larger scale and propose a model for powering California on 100% renewable electricity, by analyzing different combinations of wind, solar and battery storage combinations. However, the costs of hydrogen storage remain an obstacle to its implementation.

With increased potential of energy storage, a stand-alone community microgrid relying solely on renewable energy is a conceivable concept. Usage of renewable energy can significantly reduce greenhouse gas (GHG) emissions from energy consumption and lower the energy generation costs in specific regions. Profit from reduced energy generation costs could be used to incentivize people to live in such a community by offering a subsidy to the house sale price or the electricity bill. This would help lead to a boost in usage of renewable energy. This study aims to show through a cost benefit analysis that developing a new residential neighborhood powered by a stand-alone community microgrid would be advantageous in the long run in certain locations where renewable energy resources are highly available.

II. Methodology

An analysis tool was developed using Excel to evaluate the costs and benefits of building a stand-alone community microgrid. This software enables automation of the calculation of the many components factoring into the analysis. The tool is composed of a spreadsheet which takes a set of inputs including costs such as neighborhood development, renewable energy capital expenditures (capex) and operational expenditures (opex), energy storage costs, and benefits such as renewable energy retail value, tax credits and house sales. The tool models a community of 1000 houses of area 1500 square feet, with an average of 5 houses per acre. The community is powered by wind and solar power and relies on energy storage to compensate for renewable energy variability. The wind and solar power facilities are located close to the community so that the expensive long-distance power transmission infrastructure is avoided. The values for wind turbine capex were estimated from the price of several wind turbines [5]-[7] and the opex values were estimated to be around $4.60 per kW per year [8]. The values for solar panel construction were taken from the U.S. Energy Information Administration [9] and the values for maintenance were estimated to be around $10 for a

320 W panel [10][11]. Additional costs such as controls, soft costs and additional infrastructure were also considered [3]. However, it is important to note that these additional costs might vary on the case-to-case basis. Because of the large size (4 to 8 MW) of the modeled stand-alone microgrid, energy storage was essential to the development of the model. Li-ion battery storage was chosen because of its lower costs compared to other types of energy storage. Capex and opex of Li-ion storage were taken into consideration for the analysis tool [2][12]. Tax credits were factored into the benefits and included a 10% tax credits for wind turbines larger than 100 kW, a 26% for solar energy and fuel cells, a production tax credit (PTC) and $2000 for energy efficient homes [13]. The study employs NREL's System Advisor Model (SAM 2020.11.29) to optimize the capacity of renewable energy needed for each location depending on available resources. Optimization was implemented by using the Commercial Wind case for wind and energy and the PVWatts, TPO Host/Developer case for solar energy. The wind turbine used for modeling is the 1000 kW Vergnet GEV HP turbine. For each location, a simulation was run using the corresponding wind resource file and local solar output data. Specific wind resource files and zip codes used for photovoltaic (PV) data can be found in Table 1. The electric load was adjusted using a scale factor of 14.6638 to match the electric load of 1000 households, approximated at 10,649 MWh per year [14]. Monthly energy and load data was exported to Excel spreadsheet for analysis. Separate cases were used for wind and PV and added together in Excel. Once in the spreadsheet analysis tool, the data automatically update the inputs for the cost and benefit analysis. Data from the SAM simulation results are also used to estimate energy storage needs. The proportion of energy storage needed varies for different PV/wind resource ratios and can be calculated from the renewable energy capacity of the system [15]. Accounting for efficiency compensations, a stand-alone microgrid would need its energy storage system to be approximately .42 times the size of the renewable energy system capacity.

III. Feasibility Study

The primary objective of the feasibility study was to compare the cost and benefits of building a stand-alone community microgrid in various locations throughout the U.S. The locations were selected on the basis of population density and wind and solar resource availability. Places with a population high enough to warrant the construction of a new neighborhood were favored. The minimum population density required was a population of 1500 per square mile. Exact locations were chosen in the suburbs when a residential construction project was not feasible inside the city. Places with varying capacity factors of solar and wind resources were selected for the purpose of comparison. The capacity factor, defined as "the ratio of average power generation of a turbine to its rated generation" [15] is the ratio of the net electricity generated to the energy that could have been generated at continuous full-power operation. The overall capacity factor of each system was calculated using (1), where CF_{system} is the overall capacity factor of the system, p_W is the proportion of wind energy capacity (kW) in the system, CF_W is the capacity factor of wind energy in the corresponding location, p_{PV} is the proportion of solar energy capacity (kW) in the system, and CF_{PV} is the capacity factor of solar energy in the corresponding location.

$$CF_{system} = p_W \times CF_W + p_{PV} \times CF_{PV} \tag{1}$$

TABLE I. Locations Selected for Feasibility Study along with Population Density, SAM Wind Resource file, Zip Code, Wind and PV Capacity and Capacity Factor

City	Population Density	Wind resource	Zip code	Wind (kW)	Capacity Factor	PV (kW)	Capacity Factor
Los Angeles	8500/mile^2	Southern CA, Rolling Hills	93062	3000	34.40%	1800	19.60%
San Diego	4400/mile^2	Southwestern CA, Mountainous	91901	4000	35.20%	1750	19.80%
Phoenix	3400/mile^2	Eastern AZ, Rolling Hills	85326	6000	18.50%	4400	19.90%
Houston	3600/mile^2	Southeastern TX, Flat lands	77469	5000	28.70%	1900	16.70%
Dallas	3700/mile^2	Southeastern TX, Flat lands	76028	5000	28.70%	1800	17.50%
Denver	4900/mile^2	Northeastern CO, Flatlands	80137	5000	32.20%	2700	18.20%
Portland	4800/mile^2	Northern OR, Flatlands	97036	5000	27.00%	900	13.00%
Orlando	2600/mile^2	Southern FL, Flatlands	34741	6000	14.70%	6250	17.50%
Miami	13200/mile^2	Southern FL, Flatlands	33401	6000	14.70%	5800	17.90%
Detroit	4800/mile^2	Eastern MI, Flatlands	48174	6000	23.30%	3650	14.70%
Spokane	3300/mile^2	Central WA, Rolling Hills	99201	4000	26.80%	2100	14.30%
Boise	2800/mile^2	Southern ID, Mountainous	83701	5000	22.40%	2800	16.70%
South Bend	2400/mile^2	Northwestern IN, Flatlands	46556	5000	28.20%	3350	14.80%
Roswell	1600/mile^2	Eastern NM, Flatlands	88202	5000	30.70%	2950	20.00%
Kansas City	1600/mile^2	Central KS, Flatlands	64030	4000	36.80%	2250	16.30%

Only places with capacity factors of solar over 13% and wind resources over 14% were considered (Table 1). For each location, SAM was used to optimize the amount of wind and solar energy depending on different optimization factors. These factors include minimizing the capacity of energy storage needed by keeping the PV/wind capacity ratio between .3 and .7, which allows for each resource to compensate for the other's intermittent power output [4] to a certain extent. Another factor is the maximizing of the amount of solar energy because of higher tax incentives [13] and working with larger wind turbines which have a lower relative cost [6].

The wind and solar energy capacity of each system was calculated by selecting the month where the least amount of energy was generated and calculating a capacity that would ensure that the system would generate enough energy to cover that month. For the purpose of simplifying calculations, the assumption was made that energy storage does not carry over to the next month.

The capacity of each system varied depending on location and was factored into the calculation of total costs. The assumption was made that solar panels would be evenly distributed on the roof of each house. The storage capacity was adjusted for each location depending on PV/wind ratios. The value of wind and solar power production were included as benefits and vary by state [16]. The net present value (NPV) of electricity for each location was calculated using (2), where *Profit* is the difference between investment and maintenance costs for the microgrid and renewable energy and tax credits revenue, *discount rate = .0138* [17] and *i = 25 years*.

$$NPV = \sum_{i=1}^{n} \frac{Profit}{(1+Discount\ Rate)^{i}} \quad (2)$$

Other costs such as the costs of neighborhood development were estimated by calculating land prices from tax collector-assessor services and online realtors as well as estimating the average house construction cost in each state for different locations [18]. Because of the high amount of variability in land costs, the price/acre for each location is only a rough estimate for each location and could vary significantly across the area. Street improvements and public utilities were also taken into consideration [19]. Land prices for the wind farm were based on farmland costs by state rather than residential land costs because of the lower cost and different use of the land [20]. The market value of houses in different locations was estimated from a number of online listings. The profit to the developer was calculated using (3), where DVP_{costs} are the development costs including land costs, house construction costs, street improvements and public utility installation and *HR* is the revenue from house sales.

$$Profit_{D} = DVP_{costs} - HR \quad (3)$$

The maximum discount percentage offered on house sale price was calculated based on the profit for an electricity company from the NPV of electricity using (4):

$$Discount_{H} = \frac{NPV}{HR} \quad (4)$$

To provide an alternative viewpoint, in lieu of house price subsidy, the maximum discount percentage offered on electricity bills was calculated using (5), where RE_{VAL} is the value of renewable energy calculated from retail rates and RE_{COST} is the cost of producing energy with the microgrid including tax credits.

$$Discount_{E} = \frac{RE_{VAL} - RE_{COST}}{RE_{VAL}} \quad (5)$$

IV. Results And Discussion

Results from the analysis were summarized in several different ways, including overall monetary benefits over costs, sum of expenditures subtracted from the income for the developer, net present value of electricity for different locations and monetary benefits to the homeowner. Fig. 1. shows the ratio of overall costs and benefits which are listed in section II. The places in green are places where the overall benefits of building a self-sufficient community microgrid are greater than the costs.

The costs and benefits are however split between three parties: the developer, the electricity company owning the rights to the wind turbines and solar panels, and the homeowner. A breakdown of these costs and benefits between all three parties will help gain awareness of what factors into successful locations. Fig. 2. shows the difference between the developer's expenditures and income for all 15 locations. Expenditures include house construction, land costs, street improvements and public utilities. Income includes total house sale revenue. The five locations in red have a negative difference, meaning the expenditures outweigh the income. For most places, this is caused by a poor housing market in that location. In these locations, building a new community of 1000 households would not be profitable. The locations in green have a positive difference, meaning the developer's profit would be positive. In general, locations with the highest housing market rates were the most successful. A larger gap between land costs and house prices was also of influence to determine the most profitable locations for a developer to build.

To reflect the profits of an electricity company who would purchase the rights to the renewable energy-generating infrastructure, the net present value of electricity was calculated for the 15 locations. Fig. 3 shows the NPV of electricity over the next 25 years for a 1000 household stand-alone community microgrid. The locations in green have a positive NPV, meaning that if the rights to the renewable energy resources were to be sold to a company, the company would be able to make a profit. Locations with the highest energy retail rates as well as high availability of renewable energy are the most profitable. The surplus income from electricity generation profits is used to offer a discount on the sale price of the houses.

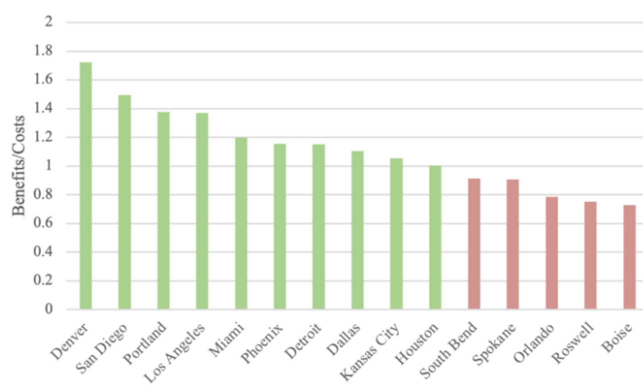

Fig. 1. Overall benefits/costs of building a self-sufficient community microgrid and neighborhood in 15 different locations.

The availability of renewable energy can be expressed as a capacity factor. Fig. 4. shows the relation between NPV of electricity for the next 25 years and the capacity factor for wind and solar power at each location. A strong correlation can be seen between NPV and capacity factor, meaning that the greater the capacity factor, the greater the NPV of electricity will be. Because the electricity retail rates (which were factored into the NPV of electricity calculation) do not correlate with the renewable energy capacity factor, the correlation is not as strong as it could be.

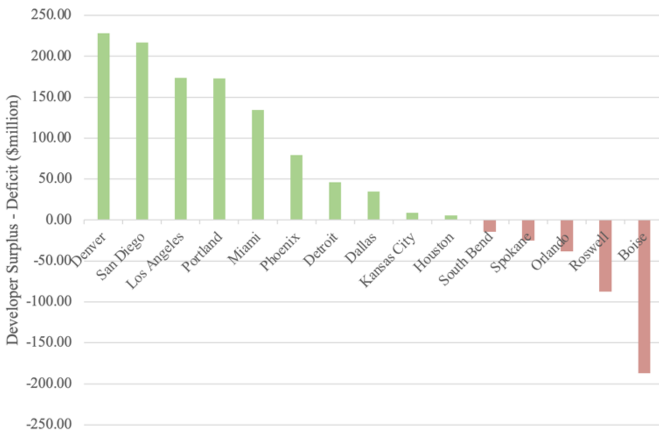

Fig. 2. Surplus - deficit of the developer calculated by subtracting the expenditure of building the community from the income of selling the houses for 15 different locations.

Fig. 5. shows the maximum possible house sale price discount offered at each location. Locations with a greater difference between expenditures and income were allotted a greater house sale price discount. Locations with a negative difference were not allotted a subsidy. These locations include Spokane, WA, Orlando, FL, Miami, FL and Boise, ID and are absent from Fig. 5, 6 and 7 for this reason. In Fig. 5, Roswell, NM shows an exceedingly high house price subsidy. This is caused by the fact that the market price of houses in that area is very low, making the discount a larger percentage of the total. However, as shown in Fig. 2, the expenditures for the developer are greater than the income, mainly because of the low market price of houses, meaning that building a residential community is not actually feasible. Therefore, locations in grey represent locations where building a residential community would not be profitable for a developer. However, implementing a self-sustainable microgrid in an already existing community could still be considered an option.

To provide an alternative perspective, the same approach to calculating a benefit to homeowners as in Fig. 5. is taken in Fig. 6., but instead applies the discount to the electricity bill of households. This approach is more representative of the value of energy at different locations, and is not affected by the housing market. Locations with higher NPV of electricity have higher discount rates.

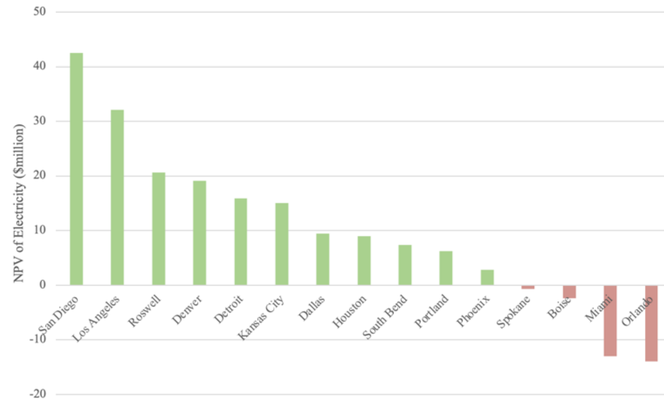

Fig. 3. Net present value of electricity over the next 25 years for 15 different locations.

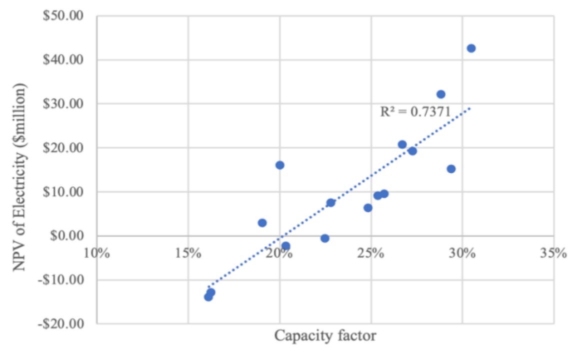

Fig. 4. Net present value of electricity for systems of different overall capacity factors.

The benefit to the homeowners is shown in Fig. 7. The total benefits are calculated from the surplus income from renewable energy generation. This graph mirrors the NPV of electricity graph, which is the source of the benefits, but gives the amount of savings in dollars for each household. The benefits are independent of whether the discount is applied to the house sale price or the electricity bill.

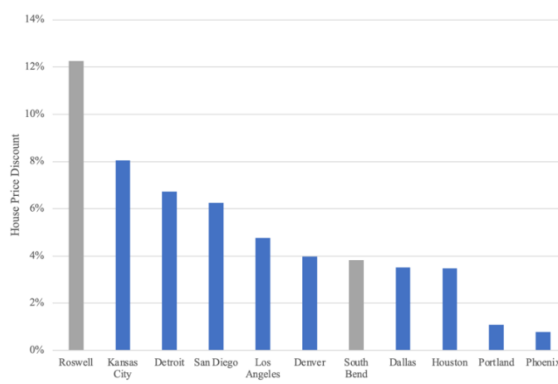

Fig. 5. House price subsidy for 11 different locations.

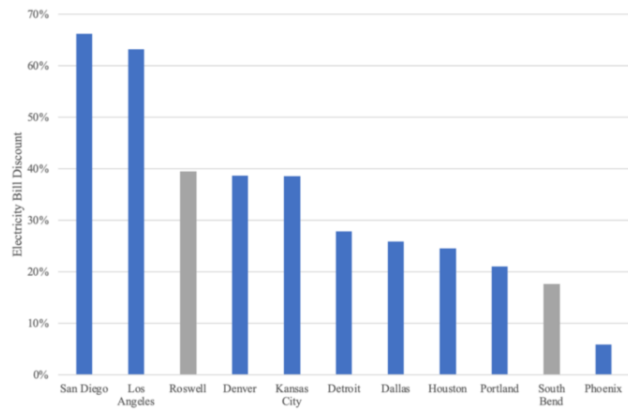

Fig. 6. Electricity bill discount for 11 different locations.

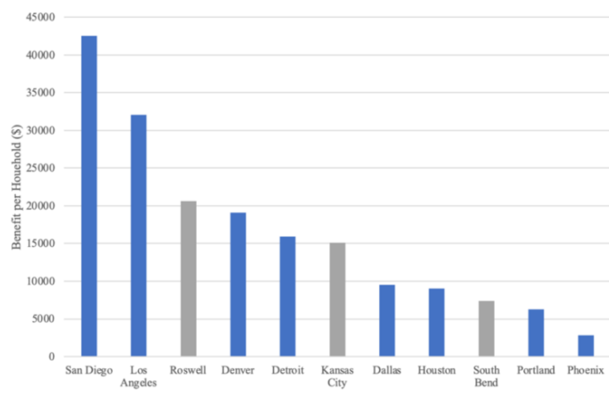

Fig. 7. Benefit per household for 11 different locations.

The strong correlation between NPV and capacity factor shows that the results from the analysis tool are coherent. Successful locations are thus places with incentive to build, which have a positive difference between developer expenditures and income, allowing the developer to build the community. Additionally, places with a high capacity factor and high energy retail rates, which leads to a high NPV of electricity, incentivize electricity companies to purchase the rights to the renewable energy resources. This in turn allows for a higher house price subsidy (or higher electricity bill discount), attracting more customers to buy a home in the community.

V. Conclusion

An analysis tool was developed to assess the feasibility of building a stand-alone microgrid for a community of 1000 residents. The aim of this study is to boost the usage of renewable energy by highlighting the benefits of switching to a 100% renewable energy model. The sale price of houses (or electricity bill) would receive a discount factored in from energy savings, incentivizing customers to purchase and live in such a community. The results show that such a project would present benefits in locations with high renewable energy capacity factors and high energy retail rates, such as Simi Valley, CA and Alpine, CA. The project can be a model to be duplicated over these locations to achieve net zero carbon emissions in the United States.

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