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Economic feasibility study of standalone community microgrid in 37 cities of the USA

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ABSTRACT

Community microgrids are applicable universally because they can decentralise grid-connected areas and electrify remote areas. Moreover, they can provide energy security by improving the reliability and resiliency of electric distribution while diminishing the infrastructure costs of preserving or constructing electric power generation, transmission, and distribution assets. Using renewable energy sources (RESs) maybe incentivised through the government and utilities, which can help make such projects economically viable. A model has been developed to calculate the costs and benefits of building a standalone community microgrid in various cities in the United States, powered by wind turbines and photovoltaic (*PV*) panels where the battery is the backup. Using the System Advisor Model, the sizing of the microgrid system was optimised. This microgrid community's capital, operation, and maintenance costs were calculated using various per unit costs obtained from previous research. Real-estate data were collected from websites to calculate the average price of land and houses. An automated tool was created to calculate the developer's profit and house price subsidy for building such communities. The result demonstrated that several states in the USA could be profitable for developers to build and homebuyers to be a member of this microgrid community. Additionally, this microgrid community has the objective of real/near power supply during disaster and emergency events (e.g., coastal/riverine flooding, tsunamis, earthquakes, wildfires, possible damage, and terrorist attacks). The benefit is not only the direct power generation cost but also the advantage of keeping some critical services operational during catastrophic events that cause electricity blackouts.

KEYWORDS Community microgrid; cost-benefit analysis; remote electricity; system advisor model; renewable energy
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1. Introduction

Microgrids are not a new form of technology, and they are often interconnected to the electric utility's grid. Many states in the United States have pledged to use 100% carbon-free electricity, 100% renewable energy, and 100% zero-emissions electricity, plus other clean energy goals by the next 30-50 years (Clean Energy States Alliance, 2022). Community microgrids will play an essential role in seamlessly integrating and managing RESs into the grid as well as enhancing community resilience. In a microgrid system, there are two operational modes: one is the grid connected mode and the other is islanded mode in which the microgrid is disconnected from the main grid. The present manuscript focuses on standalone community microgrids (Hu et al., 2014). A standalone microgrid operates disconnected from the main grid, while the community microgrid is a coordinated local grid area served by one or more distribution substations and supported by high penetrations of local renewables and other distributed energy resources (DER), such as diesel generators and energy storage systems. Standalone community microgrids have been utilised successfully in many countries. In Huatacondo-Chile, a community of 150 residents in the Andes mountains who were isolated from the grid were being powered by diesel generators. The Energy Center (EC) of the University of Chile implemented a standalone community microgrid project in 2010 which consisted of a diesel generator, tracking solar *v*system, a wind turbine, and a battery providing electricity 24 hours a day whereas the diesel generator was previously providing electricity 10 hours a day (Montedonico et al., 2018; International Microgrid Symposiums, no date). There is a similar project in Ollagüe named Advanced Hybrid Microgrid in the Chilean Desert a microgrid solar *PV* system, wind turbine and battery storage were installed which can provide continuous electricity to 50-100 families (The Guardian, 2015). This project was able to improve the lifestyle of the inhabitants as the diesel generator was not operating from 1:00am to 8:00am and it also demonstrated economic benefits (Rodriguez, 2016). A feasibility study using HOMER (Hybrid Optimization Model for Electric Renewable) software was utilised to find a hybrid system to meet the electric load of a remote village in Bangladesh. The optimum system consisted of a solar *PV* system, diesel generator, and battery storage and it was shown how this can provide socio-economic benefits to the residents of a remote village which is not connected to the grid (Mandal et al., 2018). Various other studies have demonstrated that a solar *PV* and wind turbine system combined with batteries to replace diesel generators can provide a remote island/ village adequate power in a practical and cost-effective manner (Ma et al., 2014; Nnadi et al., 2017).

The goal of this research is to examine the economic feasibility of building a new community with standalone microgrids in different cities of the United States. This community needs to be in such a place which has a need for a new community development, potential for renewable energy, and profitable real estate market. For the standalone microgrid, a solar *PV* and wind turbine system is used as the source of energy with a battery as the energy storage. Solar *PV* and wind power is chosen as it is widely recognised as a viable alternative to the traditional fuel-based (diesel) generators supplying power to remote areas. Also, it is more reliable than systems with just one source of generation as solar power and wind power can complement each other (Zhou et al., 2010). Depending on the locally available resources of wind and solar, the size can be optimised for a geographical area (Belmili et al., 2014). To build such a community, firstly, land is purchased and then houses are built along with roads and public utility infrastructure. Then the size of the solar *PV* system and wind turbine needs be determined by using the electric load data of such community. After that, the energy storage size is selected based on the microgrid size. From all the obtained data, a model is utilised to analyse the cost and benefits of building such a community with a standalone microgrid to determine its feasibility in different cities of the United States.

2. Motivations and objectives

The construction of standalone microgrid systems has several benefits for the end consumer as well as the electricity operators and power grid system stability. In fact, remote areas isolated from the grid are more considered for the deployment of a standalone microgrid systems. The end consumer can produce the electricity locally, thereby minimising the use of other pollution sources such as diesel generators (Martinez-Cid and O'Neill-Carrillo, 2010). In some cases, the installation of RESs is the only practical solution for supply power to isolated areas without considering the cost benefits. In the past decades, investments and projects have been created to improve the microgrid community, especially in the United States (Feng et al., 2018; Warneryd et al., 2020). This microgrid community is not only for remote areas but also for urban areas. The objective is the development of standalone power systems that can produce, consume, and store electricity locally in case of catastrophic events such as coastal flooding, hurricanes, ice storms, strong winds, earthquakes, and much more. During such events, the electrical system can undergo a global blackout affecting emergency services and individuals' lives. The cost benefits are not only calculated based on the global investment cost and maintenance cost; the huge economic losses that can be caused by electricity outages should be considered (Shuai et al., 2018). There is extensive research reported in the literature about the direct economic losses caused by electricity blackouts (Falama et al., 2022; Kim et al., 2014). The deployment of microgrid communities can help to mitigate such economic losses. On the other hand, the use of local sources in microgrid communities reduces the effect of peak electricity demand which is a key cause of power outages. During heat waves and cold waves, the power grid lines can reach their maximum capacity due to the usage of heating, ventilation, and air conditioning (HVAC) systems causing cascading outages in the grid. The use of local sources reduces the effect of such events, and consequently, the microgrid community can reduce the peak load of the main grid. This work studies the economic feasibility of a microgrid community in the United States. Since the various society components (e.g., government, researchers, and companies) are involved to encourage people to achieve this objective, a simplified cost-and-benefit analysis model is studied in a way that can be useful for both the research community as well as individual consumers. An analysis of the literature shows that generally the previous works focus more on specific case studies of microgrid system deployment for a specific geographical area and under certain weather conditions (Holdmann et al., 2019; Shamsi et al., 2015). In contrast, this work studies the technical and economic feasibility of deploying hybrid RESs for a microgrid community considering the various investment costs from building construction to RES deployment. The data are collected from reliable and up-to-date sources in the United States.

3. Methodology

A software cost-benefit-analysis tool is developed which can assist the interested parties to decide whether to build a standalone microgrid community in a particular city of the United States and to buy a house in the considered cities especially in relation to developers and home buyers. An automated tool is developed which has various cost and benefit inputs. These inputs consist of real estate building cost (e.g., capital, operation and maintenance (O&M) cost of renewable energy, electric load profile and energy production data, electricity rate per *kwh*, and available tax credits). There are formulas in the analysis tool which automates the process of calculating the benefits over cost for the related parties. There are essentially two main components of this project in terms of construction. In fact, building the community houses, space for wind turbine/solar panels, roads, and public utilities are the main components considered in this project. For this project, building a community with 1,000 houses is considered. Each house occupies an area of 1,500 square feet with an average of five houses per acre. To maximise the profit from renewable energy production and tax credits while lowering the per unit cost of building renewable infrastructure and its operation, such number of houses is chosen. The land needed for a wind farm is considered as well as for the streets and public utilities.

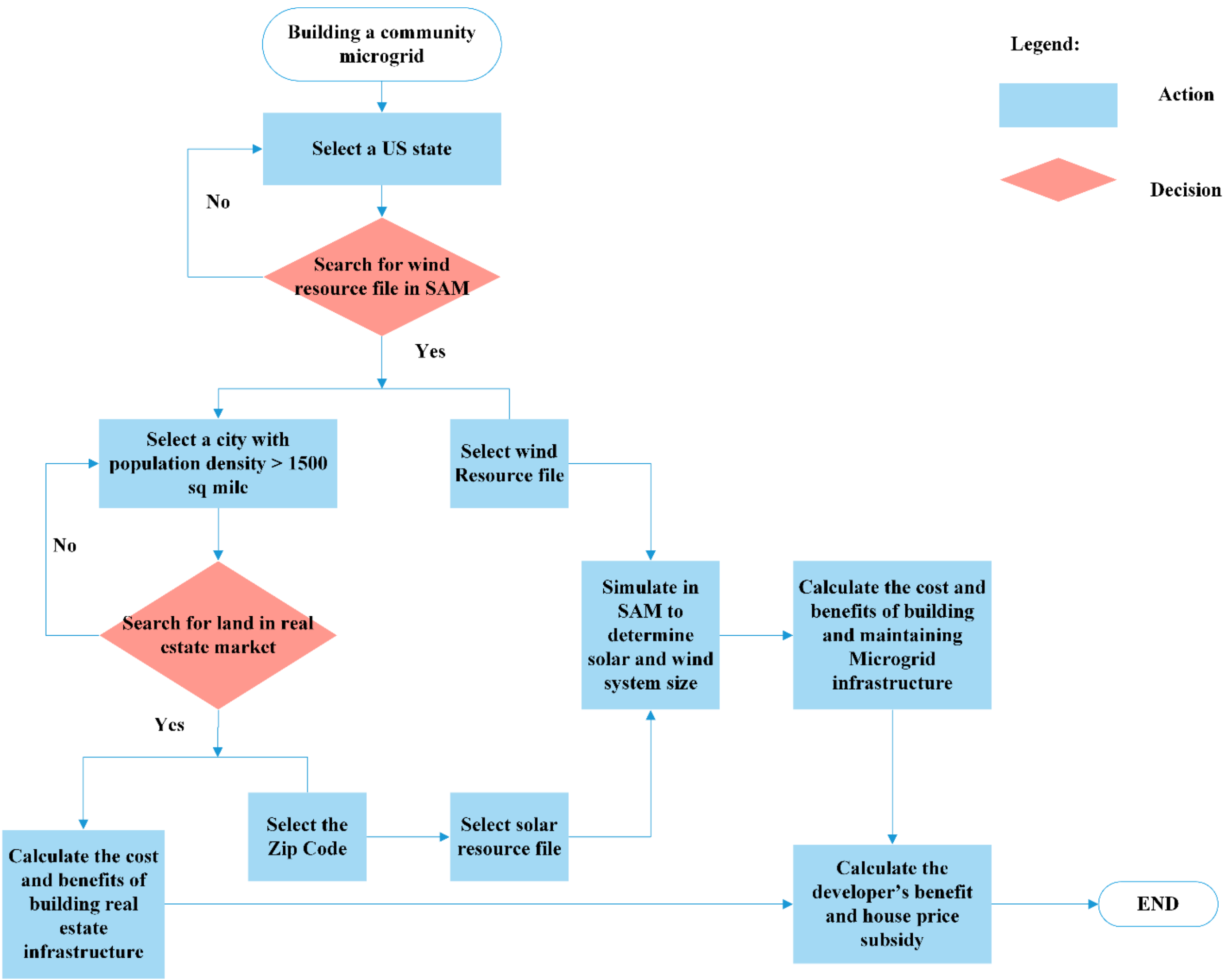

Figure 1. Overview of the workflow of the cost-benefit analysis.

One of the key elements of this process is to obtain real estate data. House market price is important to know as the developers have to offer a subsidy based on that price. House market price for a specific zip code is obtained from real estate websites. Single family houses with three bedrooms and two bathrooms are considered and the price is normalised to a per unit cost of 1,500 square foot interior area. The land for the development is also searched on real estate websites and the average price per acre of different residential zoned land is used. For the land needed to build the wind turbine, the farmland cost per acre of individual states is used (United States Department of Agriculture, 2021). Overall, a substantial amount of real estate research is carried out in all the cities and their neighbouring areas to find suitable places to build this community. The workflow of the cost-benefit analysis is shown in Figure 1.

Moreover, the solar *PV* and wind turbine system sizes are selected depending on the workflow presented in Figure 2. A wind turbine system's rated power is x in kW, while a solar *PV* system's rated power is y in kW, and n is the number of wind turbines. x starts from 1,000 kW and y must satisfy $0.3x \leq y \leq 0.7x$. R is the difference between monthly energy production of a renewable system and the monthly load demand.

The community is solely fed by wind and solar *PV* power; therefore, their individual capital and operation and management (O&M) costs are considered. The capital cost of a wind turbine is estimated from the previous research (European Wind Energy Association, 2009; ICF International, 2010; Renewables First, 2012; Stehly et al., 2020; The Renewable Energy Hub USA, 2016) while the O&M cost was estimated to be US$4.60 per kW per year operated (Reuters Events, 2007). The capital cost of solar *PV* is found in U.S. Energy Information Administration (U.S. Energy Information Administration, 2020) and the O&M cost is estimated to be US$31.25 per kW per year operated (Sunrun, 2019a; Sunrun, 2019b). Controls, soft costs and additional microgrid infrastructure costs are also considered (Giraldez et al., 2018). As this is a standalone microgrid system, having an energy storage system to provide backup is a main factor that should be considered. A Li-ion battery is used as the energy storage and its capital and O&M costs are also used in the total cost calculation (Cole et al., 2016; Dawood et al., 2020). For the benefits estimation, tax credits and power generation are the main source of income for such project. Production tax credits are available for 10 years as follows: residential wind tax credit is 10% for using wind turbines generating more than 100 kW, solar & fuel cell tax credit is 26%, and energy home tax credits of US$2,000 per house are applied (N.C. Clean Energy Technology Center, 2020).

Algorithm 1

x→ $NameplateCapacityOfWindPowerSystem$
y→ $NameplateCapacityOfPVSolarPowerSystem$
n→ $NumberOfTurbine$
R→ $EnergySurplus$

```
procedure OPTIMIZATION(x,y,n,R)
while y>0.7*x do
    n← n + 1
    x← 1000 * n
    y← 0.3 * x
    R← GenerationAndLoadFunction(x, y)
end
end procedure
procedure MAIN
Set n=0
n← n + 1
x← 1000 * n
y← 0.3 * x
R← GenerationAndLoadFunction(x, y)
OPTIMIZATION(x,y,n,R)
while R<0 do
    y← 0.3 * x + 50
    R← GenerationAndLoadFunction(x, y)
    OPTIMIZATION(x,y,n,R)
end
print(x,y)
```

Figure 2. The process of selecting the solar *PV* and wind turbine system size.

The other step of this work is to determine the size of the microgrid system. National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) version 2020.11.29 is used to simulate and determine the size of the wind and solar *PV* system. For the solar *PV* system, Photovoltaic *PV*-Watts program's Distributed Third-Party Owner-Host model is used and for the wind power system, the Distributed Commercial Owner model was used. SAM contains a large database of solar generation data and can be obtained by the zip code of different locations in the United States whereas there are wind resource files available for different regions of a state to simulate the wind power generation. Renewable power generation must match the electric load in real time. For this research, we match the monthly energy usage of the community to the monthly energy production of the renewable system. An average household in the US consumes approximately 887 *kW*h per month (Choose Energy, 2020). By applying a sample load model to that average consumption, monthly consumption for 1,000 houses for each month of the year is approximated (Burges et al., 2022). The criterion for the sizing of the microgrid's solar *PV* system and wind power system is being able to satisfy the monthly consumption. Using SAM, monthly and yearly energy production from solar *PV* and wind power are simulated for each city. The algorithm in Figure 2 shows the steps to find the optimal size of the solar and wind energy systems. In the flowchart, *x* and *y* are the solar and wind system's rated power. The number of wind turbines is represented by *n*, and the rating of each turbine is 1,000 *kW*. Different values of *x* and *y* are inputted into SAM to obtain monthly figures for energy production which are then exported into Excel to be compared with the monthly electricity consumption of 1,000 houses. For each month, the energy produced must be greater or equal to the electricity consumed, and by using the automated tool it is ensured that there is a surplus of energy every month. As a 1,000 *kW* turbine is used, the wind energy capacity is increased by 1,000 *kW* per step while the solar *PV* system is increased by 50 kW. In order to size the energy storage, SAM is utilised. It is found that the nameplate capacity of the Li-ion battery needs to be 42% of the microgrid size given that the solar *PV* to wind ratio stays between a set interval of 0.3 to 0.7 (Burges et al., 2022).

The feasibility of building a standalone microgrid community for 37 cities across the United Sates is considered in this study. Those 37 cities are scattered over 27 different states of the US. The study utilised all the available wind resource files for different states in SAM. Depending on the geographic location of the wind resource file data, an optimum city must be chosen where such new development is needed. For that purpose, real estate research is essential. There are two main factors involved in the selection. The city must have enough population density which is set as 1,500 per square mile and there must be available residential land in the market. Solar resource files are different for each zip code; hence, the real estate search must be limited to a certain zip code where there is land available. From the available residential land, an average cost per acre is calculated after collecting all the data on price and area. After that, the market price of a house in that zip code is obtained by setting a filter of three-bedroom and two-bathroom single family houses in that zip code. Using these data, the average price of 1,500 square feet is calculated.

It is essential to differentiate between the parties involved in this kind of project. The first party is the developer who will develop such a community to make a profit by selling it. An intended resident of this community will have to buy a house, but it will be offered at a subsidised price. There is a third party involved who maintains and manages the microgrid. This third party itself

Table 1. List of cities with their renewable energy data.

City	Population density	Wind resource file (SAM)	Installed wind (*KW*)	Wind capacity factor	Installed solar (*KW*)	Solar capacity factor
Albany, NY	4,455	Northern NY - flat lands	6,000	24.55%	4,050	14.24%
Albuquerque, NM	3,003	Eastern NM - flat lands	5,000	30.69%	3,000	19.96%
Amarillo, TX	1,963	Northwestern TX - flat lands	4,000	36.43%	2,050	19.58%
Atlantic City, NJ	3,535	Southeastern NJ - offshore	5,000	34.43%	2,200	15.77%
Beaver, UT	480	Southwestern UT - flat lands	6,000	21.39%	3,700	18.32%
Boise, ID	2,749	Southern ID - mountainous	5,000	22.59%	2,850	16.43%
Boston, MA	13,841	Southeastern MA - offshore	5,000	40.70%	1,500	15.09%
Cheyenne, WY	2,024	Southern WY- flat lands	4,000	43.75%	2,650	17.58%
Cleveland, OH	4,847	Northern OH - offshore	6,000	34.12%	2,750	14.28%
Colorado Springs, CO	2,510	Southeastern CO - flat lands	4,000	33.27%	2,400	18.24%
Corpus Christi, TX	2,048	Southern TX - offshore	4,000	38.92%	1,950	17.52%
Dallas, TX	3,700	Southeastern TX - flat lands	4,000	28.71%	2,800	17.62%
Denver, CO	4,900	Northeastern CO - flat lands	5,000	32.39%	2,700	18.24%
Detroit, MI	4,788	Eastern MI - flat lands	6,000	23.43%	3,650	14.69%
Fayetteville, AR	1,657	Northwestern AR - flat lands	6,000	22.22%	4,000	15.98%
Fresno, CA	4,682	Southern CA - mountainous	3,000	43.62%	1,550	19.01%
Grand Rapids, MI	4,530	Western MI - offshore	5,000	38.24%	2,150	14.36%
Great Falls, MT	2,516	Northwestern MT	5,000	30.18%	2900	15.09%
Houston, TX	3,600	Southeastern TX - offshore	5,000	30.04%	3450	16.48%
Indianapolis, IN	2,454	Northwestern IN - flat lands	6,000	28.22%	2,700	15.17%
Los Angeles, CA	7,009	Southern CA - rolling hills	3,000	34.41%	1,750	19.64%
Miami, FL	13,286	Southern FL - flat lands	8,000	14.76%	5,300	17.75%
Minneapolis, MN	8,130	Southwestern MN - flat lands	4,000	35.80%	2,400	15.33%
Minot, ND	1,733	Northern ND - flat lands	4,000	35.06%	2,500	15.04%
Morgantown, WV	3,020	Northeastern WV - Rolling hills	7,000	23.15%	4,400	13.80%
Portland, ME	3,052	Northern ME - flat lands	6,000	22.20%	3,450	14.94%
Portland, OR	4,966	Northern OR - flat lands	4,000	27.06%	2,700	12.67%
Raleigh, NC	3,315	Eastern NC - offshore	4,000	38.93%	2,250	15.93%
Sacramento, CA	4,660	Northern CA - offshore	4,000	33.04%	1,800	18.44%
Salem, OR	3,652	Northwestern OR - offshore	4,000	35.50%	2,000	13.76%
San Antonio, TX	3,261	Southwestern TX - flat lands	4,000	33.43%	2,650	16.95%
San Francisco, CA	6,266	Southwestern CA - mountainous	4,000	35.25%	1,800	18.14%
Seattle, WA	9,260	Central WA - rolling hills	4,000	26.90%	2,650	11.39%
Tucson, AZ	2,330	Eastern AZ - rolling hills	7,000	18.49%	4,550	20.08%
Valdosta, GA	1,571	Eastern GA - offshore	5,000	29.34%	2,750	16.76%
Virginia Beach, VA	1,840	Eastern VA - offshore	5,000	33.38%	3,150	16.12%
Wichita, KS	2,421	Central KS - flat	4,000	37.05%	2,100	17.17%

does not make any profit for simplicity of the calculation. It is just a variable to calculate the house price subsidy using the income from renewable energy.

$$House\ price\ subsidy = \left(\frac{3rd\ Party's\ benefits - O\&M\ costs}{House\ market\ price}\right). \quad (1)$$

A detailed breakdown is given in the table below:

Table 2. Breakdown of cost-benefits for all involved parties.

Developer's cost	Developer's benefits	Homeowner's cost	Homeowner's benefits	3rd party's cost	3rd party's benefits
Land House construction Street Improvement Public Utility Wind (Capital) Solar (Capital) Energy Storage (Capital) Controls Soft Costs & additional MG costs	House Sales House Price Subsidy	Subsidized house price	House price subsidy Energy efficient home Tax Credit	House price subsidy Wind (O&M) Solar (O&M) Energy Storage (O&M)	Energy value (production) Production Tax Credit Residential Wind Tax Credit Solar & Fuel Cell Tax Credit

The developer's profit percentage is calculated from the developer's profit and developer's cost ratio. The developer's profit is its total costs subtracted from its total benefits. On the other hand, the house price subsidy comes from the difference between O&M and revenue from renewable energy and various tax credits. In this study, the third party works as a facilitator and is assumed not to take any profit.

4. RES and battery storage system sizing in the buildings

A measure of sobriety and efficiency is required before starting any project related to RES deployment for residential, commercial, or industrial usage. In fact, energy sobriety is defined as the ability to identify the main need for energy and avoid waste. The good dimensioning of the loads' demand can ensure this issue. The oversizing of the demand increases the number of panels and batteries, and consequently the size of the power converters. Generally, oversizing increases the installation cost and the system is underutilised, thereby decreasing the profitability of the system. Energy efficiency can be defined briefly as the capability to reduce the amount of required energy in order to satisfy users' need for a specified service. Different factors can be considered to increase energy efficiency, from the building envelope to the control of active equipment and energy management approaches. In addition, a suitable selection of household equipment such as the choice of lighting with LED technology and HVAC system with "inverter" technology can significantly improve energy efficiency. These studies aim to have lower energy consumption, improved compactness, a more affordable budget for the customer, and more efficient operation of the RESs. Table 3 shows the main factors that should be considered for RES dimensioning.

Table 3. The main criteria for RES dimensioning.

Criteria	Benefits
Total daily energy consumption (*Wh*)	Calculating the operating period of each equipment. Two types of services can be classified: permanent services (e.g., networking equipment, refrigerator) and temporary services (e.g., lighting, washing machine).
Peak power demand (*W*)	Some equipment has variable power consumption depending on the realised services (e.g., HVAC, refrigerator). The aim is to identify the minimum and maximum power of these types of loads. A coefficient of simultaneity should be calculated in order to specify the peak demand equivalent to the period in which all the equipment operates at its maximum at the same time.
Variations (weekly, monthly, seasonally)	The power balance and energy demand variability are determined by the occupants' activities depending on the period of the day, month, and season. During cold and hot days, the power demand is at its maximum due to the operating mode of HVAC systems in order to ensure occupants' comfort. Besides, the usage of energy consumption is not the same at the weekends compared to the other days of the week.
Load profile (large projects)	For large projects, especially industrial projects, the behaviour of each load should be measured to specify the nature of energy demand concerning the starting current and the reactive power. For example, the motors have a starting peak of current that should be considered carefully. Mainly, for some projects a power analyser (e.g., Chauvin-Arnoux, Fluke) is installed for a minimum of one month to collect data.
Motors starting peaks	Each motor has a power peak demand and the dimension of the installation should consider this peak power together with the nominal power.
Others	• Electrical installation: switchboard, grounding, power meter. • Space available for installation (ventilated and cooling room) • Roofing: surface, orientation, risk of shading, structural strength. • Secondary generators: diesel motors, characteristics, automatic start. • Operation modes: autonomous, grid-connected, hybrid system.

Therefore, RES dimensioning starts by identifying the main loads, their operation time during the day, and their equivalent daily energy consumption. Figure 3 summarises the main elements to be considered in the study (i.e. continuous power, peak power, total peak power), which allow dimensioning of the charge regulators, the battery bank, and the converters for residential developments.

The dimensioning of the whole system requires information about different important parameters (e.g., solar irradiation, consumption profile). For irradiation, it is recommended to install a local weather station to acquire weather conditions for the site of the microgrid community. There are some open-access databases that propose the irradiation for different locations in the world, such as PV-GIS (Photovoltaic geographical information system, 2022)

Loads	Quantity	Continuous power	Peak power	Total Continuous power	Total Peak power	Daily operating period	Total daily consumption
Units:		Watts	Watts	Watts	Watts	hours	Watt-hours
LED tube - large model (desk)	10	36	36	360	360	8	2880
LED tube - small model (desktop)	8	18	18	144	144	8	1152
LED tube - large model (outdoor)	4	36	36	144	144	10	1440
Freezer	1	40	80	40	80	24	960
Oven	1	1000	2000	1000	2000	1	1000
Clothes Washer	1	200	400	200	400	2	400
Cooking Plate	1	1000	2500	1000	2500	1	1000
Refrigerater	1	50	60	50	60	24	1200
TV	2	40	40	80	80	4	320
Printer	1	23	168	23	168	2	46
Desktop computer	4	120	120	480	480	7	3360
WIFI hotspot	1	10	10	10	10	24	240
Router	1	10	10	10	10	24	240
Total :				3541	6436		**14238**
			Coefficient of simultaneity:	80%	80%		
			Total :	**2833**	**5149**		

Coefficient of simultaneity:
Allows to take into account the probability that the loads start and operate simultaneously.

Total continuous power:
Used to determine the required DC power of the converter or converter-charger.

Total peak power:
Used to check that the total peak power requested by the loads is much lower than the peak power of the converter or converter-charger.

Figure 3. Example of total daily consumption estimation.

Table 4. *PV* power dimensioning.

Parameters	Units	Values	Description
Total daily consumption	*Wh*/day	14,238	Calculated in the previous section
Daily irradiation	*Wh*/m²/d	5,000	Daily radiation for a given state in the USA
System performance	%	65%	It is calculated by considering the yield of each component
Installation peak power	Wc	4,978	The total peak power of the installed panels.
			Pc (Wc)=1000*Total daily consumption/Daily irradiation*System performance
PV panels performance	%	90%	to be estimated according to local conditions (generally 80 to 90%)
Panel charge current	A	93	It should be less than the maximum acceptable charge current for the batteries

Table 5. Example of battery bank sizing.

Parameters	Units	Values	Description
System Voltage	*V*	48	12, 24 ou 48V
Unit voltage of the battery	*V*	12	2V or 12V for Lead-acid batteries (it can be 48V for lithium batteries)
Number of batteries in series	#	4	It depends on the assembly of the batteries
Days of autonomy	Days	1	The desired autonomy of the installation
Max depth discharge	%	50%	Recommended to keep the battery at a good state of health
Type of batteries	-	Gel	Recommended for solar installation
Battery bank capacity	*Wh*	28,476	Total daily consumption*Days of autonomy/Max depth discharge
Total battery bank capacity	*Ah*	593	Battery bank capacity/System Voltage
Maximum charging current	*% Ah*	20%	Recommended : 20%
Maximum charging current	*A*	119	Total battery bank capacity*Maximum charging current (%Ah)
Maximum charging power	*W*	5,695	Maximum charging current (A)*System Voltage
Minimum charge current	*% Ah*	10%	Recommended: 10%
Minimum charge current	*A*	59	Total battery bank capacity*Minimum charge current (%Ah)
Minimum charging power	*W*	2,848	Minimum charge current*System Voltage
Maximum discharge current	*% Ah*	33%	Depends on battery technology
Maximum discharge current	*A*	196	Total battery bank capacity*Maximum discharge current (%Ah)
Maximum discharge power	*W*	9,397	Maximum discharge current*System Voltage

and Global-Solar-Atlas (Global Solar Atlas, 2022). They can be used to calculate the average monthly irradiation for a specified location. Furthermore, the orientation of *PV* panels is the most important factor in regard to installation efficiency. The azimuth should be specified for the installation site in order to maximise *PV* productivity. Furthermore, daily consumption is the main factor in the dimensioning of *PV* installation. In order to identify the number of panels that should be installed, we consider the estimated daily consumption for the same scenario, as presented in Figure 3. Table 4 shows the equivalent *PV* peak power for the studied scenario.

Moreover, for energy storage, different rechargeable battery technologies are deployed for RES energy storage in a microgrid system. They are the most commonly used and most suitable for electrical energy storage in the residential sector and in small RES plants, due to their easier installation and recycling compared to other technologies. In fact, several types of battery for energy storage are available on the market including Lead-Acid, Nickel-Cadmium, Lithium-Ion, Nickel-Metal hydride, Sodium-Sulphur, and Zinc-Bromine. These batteries have a large storage capacity for long discharge times (up to several hours) with a rate of 70% to 90%. On the other hand, the major challenges of these technologies are the cost and the cycle life, limited by the chemical degradations of the reactions. For this, many research projects have been focused on electrochemical batteries, in particular Lithium-Ion. The electrolyte materials are the main key for researchers to develop other batteries that are less expensive and have a long cycle life. Mainly, the dimension of the battery bank depends on the number of hours over which the batteries will be used to supply the power to the loads. By considering the previous scenarios presented in Figure 3, dimensioning is determined by the type of battery and the assembling topology of the batteries. Table 5 summarises the total dimension that should be realised for a battery bank.

5. Capital expenditure and operating expenses

Capital expenditure (CAPEX) is the initial investment cost to deploy a project that generates future benefits including the payments for purchasing the property, buildings, technologies, and equipment. Depending on the CAPEX scope, the operating expenses (OPEX) can be calculated to analyse the cost of a project including the personnel working during the installation phase, maintenance, equipment replacement, and safety work of the power plant. For solar *PV* power plants, the CAPEX was determined in several studies including the construction of the plant and site preparation, among other expenses (e.g., *PV* panels, inverters, cables, batteries, metal supports) (ELECTRIFYING, 2022; Felipe, 2017; Sens et al., 2022). The residents will obtain the benefits of income tax savings due to accelerated depreciation and the subsidised price. For the developer, in the first year, solar *PV* power plant is eligible for about 60% depreciation and a corporate income tax rate of 25% to 30%. In this case, around 20% of the initial investment will be recovered in the first year due to the savings on income tax. Maintenance and safety operation are ensured by the third-party company mentioned earlier. The remaining 80% of the project cost will be recovered in the future years through solar savings. Taxes for the different cities are presented in Table 6 with the RES capital cost and the capacity factor. Figure 4 shows the relation between the developer's profit and the population density (R^2= 0.334).

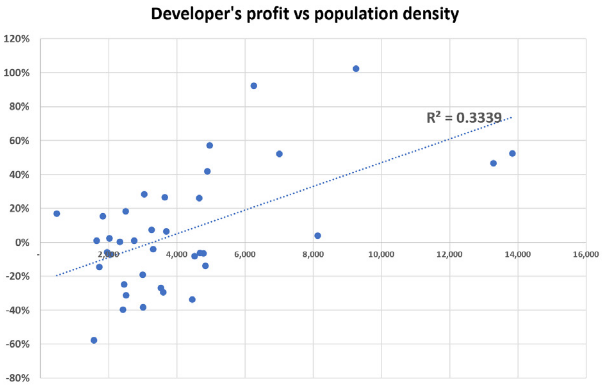

Figure 4. Relation between developer's profit from RESs and the population density.

Several factors are integrated to calculate the exact CAPEX and OPEX values. This work estimated the costs for the microgrid community deployment in 37 cities of the USA. The calculation of the parameters is specific to the microgrid and power consumption in each community. To calculate the cost across energy sources, the levelised cost of energy (LCOE) is used including the invested cost in period I_i, the cost of diesel in period F_i which is considered as a backup, the loss and penalty in year Pen, the depreciation in year D_i, the cost of maintenance in period M, the tax credit in year TC, the energy output in period E_i, the tax levy T_i, and the royalties of the corresponding year R_i. The LCOE is calculated as follows:

$$LCOE = \left[\frac{S_{i=0}^{n}(I_i+M_i+F_i-TC_i-D_i-T_i+Pen_i+R_i)}{(1+r)^i}\right] \Big/ \left[\frac{S_{i=0}^{n}E_i}{(1+r)^i}\right]. \qquad (2)$$

It is the equivalent ratio of lifetime costs to lifetime electricity generation discounted back to a given year (Hernández et al., 2020).

6. Results and discussion

Developers make their profit by selling houses to potential buyers. The developer's profit varies from 102%

Table 6. List of cities with their RES values and tax credits.

City	Electricity rate	Renewable energy capital cost	Wind energy value (production)	Solar energy value (production)	Energy storage size	Population density	Residential wind tax credit	Solar and fuel cell tax credit
Beaver, UT	0.1	33629100	28106460	14845992	4052.466	480	1200000	2129868
Fayetteville, AR	0.0942	34669302	27503649	13186568	4177.8	1,657	1200000	2302560
Cheyenne, WY	0.1047	23055079	40128843	10679399	2778.237	2,024	800000	1525446
Morgantown, WV	0.112	39522895	39744877	14892538	4762.692	3,020	1400000	2532816
Virginia Beach, VA	0.1105	28255406	40391143	12286193	3404.907	1,840	1000000	1813266
Cleveland, OH	0.1183	30335127	53030937	10173241	3655.575	4,847	1200000	1583010
Valdosta, GA	0.1094	26868470	35142954	11042651	3237.795	1,571	1000000	1583010
Boise, ID	0.1005	27215204	24858080	10304490	3279.573	2,749	1000000	1640574
Portland, ME	0.165	32762265	48123798	18627307	3948.021	3,052	1200000	1985958
Detroit, MI	0.1692	33455733	52088303	19868769	4031.577	4,788	1200000	2101086
Grand Rapids, MI	0.1692	24788066	70856930	11439423	2987.127	4,530	1000000	1237626
Minneapolis, MN	0.1248	22188244	39141667	10056351	2673.792	8,130	800000	1381536
Indianapolis, IN	0.1225	30161760	45422069	10986755	3634.686	2,454	1200000	1554228
Wichita, KS	0.1187	21148042	38523579	9371870	2548.458	2,421	800000	1208844
Great Falls, MT	0.1072	27388571	35431891	10272185	3300.462	2,516	1000000	1669356
Raleigh, NC	0.106	21668143	36150791	8320217	2611.125	3,315	800000	1295190
Minot, ND	0.0944	22534978	28992739	7774101	2715.57	1,733	800000	1439100
Albuquerque, NM	0.1253	27735305	42104324	16432232	3342.24	3,003	1000000	1726920
Seattle, WA	0.0975	23055079	22978621	6442103	2778.237	9,260	800000	1525446
Portland, OR	0.1101	23228446	26102771	8246943	2799.126	4,966	800000	1554228
Salem, OR	0.1101	20801308	34241309	6634148	2506.68	3,652	800000	1151280
Atlantic City, NJ	0.1618	24961433	61001747	12292606	3008.016	3,535	1000000	1266408
Albany, NY	0.1827	34842669	58925842	23081151	4198.689	4,455	1200000	2331342
Tucson, AZ	0.117	40042996	33159903	23415794	4825.359	2,330	1400000	2619162
Amarillo, TX	0.1139	20974675	36348642	10009756	2527.569	1,963	800000	1180062
Dallas, TX	0.1139	23575180	28641215	12304954	2840.904	3,700	800000	1611792
Corpus Christi, TX	0.1139	20627941	38832875	8520297	2485.791	2,048	800000	1122498
San Antonio, TX	0.1139	23055079	33354851	11203142	2778.237	3,261	800000	1525446
Houston, TX	0.1139	29295608	37468034	14184283	3530.241	3,600	1000000	1985958
Sacramento, CA	0.2143	20107840	62019115	15574951	2423.124	4,660	800000	1036152
Fresno, CA	0.2143	15774348	61420877	13828442	1900.899	4,682	600000	892242
Los Angeles, CA	0.2143	16467816	48449143	16133957	1984.455	7,009	600000	1007370
San Francisco, CA	0.2143	20107840	66167502	15324392	2423.124	6,266	800000	1036152
Boston, MA	0.2232	22534295	99468273	11065122	2715.57	13,841	1000000	863460
Denver, CO	0.1214	26695103	43057132	13096671	3216.906	4,900	1000000	1554228
Colorado Springs, CO	0.1214	22188244	35380809	11641485	2673.792	2,510	800000	1381536
Miami, FL	0.1165	46110158	31397924	25008244	5556.474	13,286	1600000	3050892
Average	0.133522	26535885	42815125	12934290	3197.711	4163.61	972973	1605569

to -58%. The bar charts in Figure 5 show that Seattle, WA, offers the highest developer's profit available. Valdosta, GA, offers the lowest developer profit compared to other cities.

The developer's profit depends on the market price of a house and the cost of building a microgrid community. Figure 6 represents the relation between the ratio of house sales price to house construction cost and the developer's profit. It is clear from the graph that wherever it is cost-economical to build houses, yet the real estate market is good, the developer makes a good profit in such places. Seattle, WA, and San Francisco, CA, offer the most profit for the developer, resulting from a higher ratio of the house sales price and house construction cost. On the contrary, in the case of Valdosta, Wichita, Morgantown, Albany, etc., the developer does not make much profit because of the lower ratio of the house sales price and house construction cost. It is also observed that places with higher house prices correlate (R^2= 0.795) to developers' profit.

House price subsidies vary from city to city. It can vary by a reasonable amount, even in the same states. California, San Francisco and Los Angeles have a house price subsidy of 9%, but Fresno and Sacramento have 22% and 16%, respectively. The solar and wind resource files are different for each of these places as well as the real estate data (Figure 7).

San Francisco and Los Angeles' price subsidies being closer also proves that these data can be used to understand a neighbouring city's costs and benefits. In Figure 8, a chart shows all the cities' house price subsidies. The house price subsidies vary from 4% to 43%, and the average is 20%.

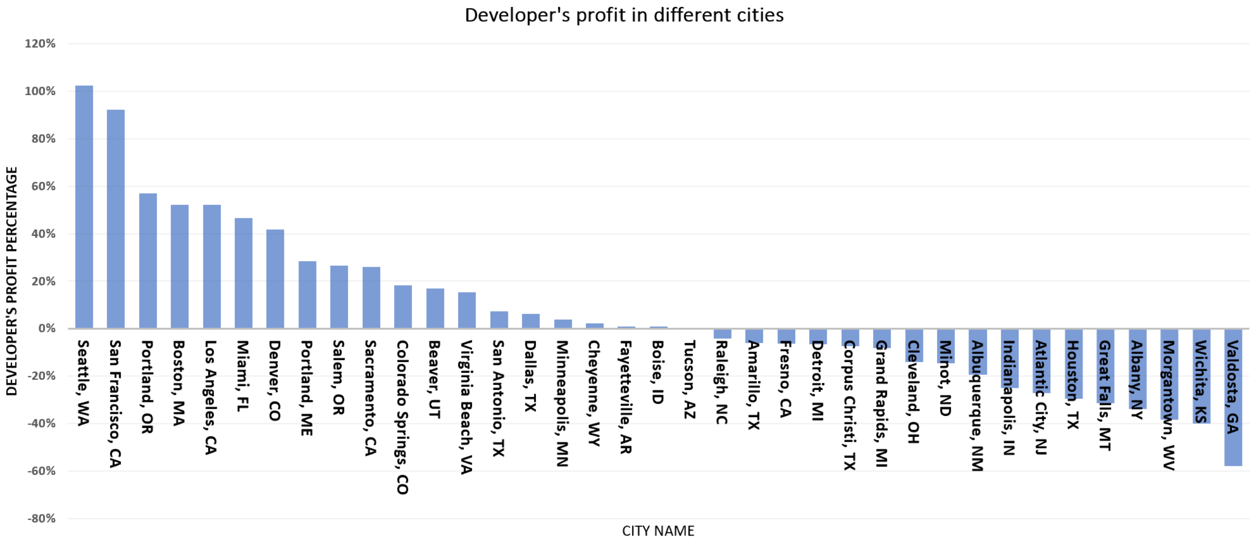

Figure 5. Developer's profit from selling houses in different cities of the United States.

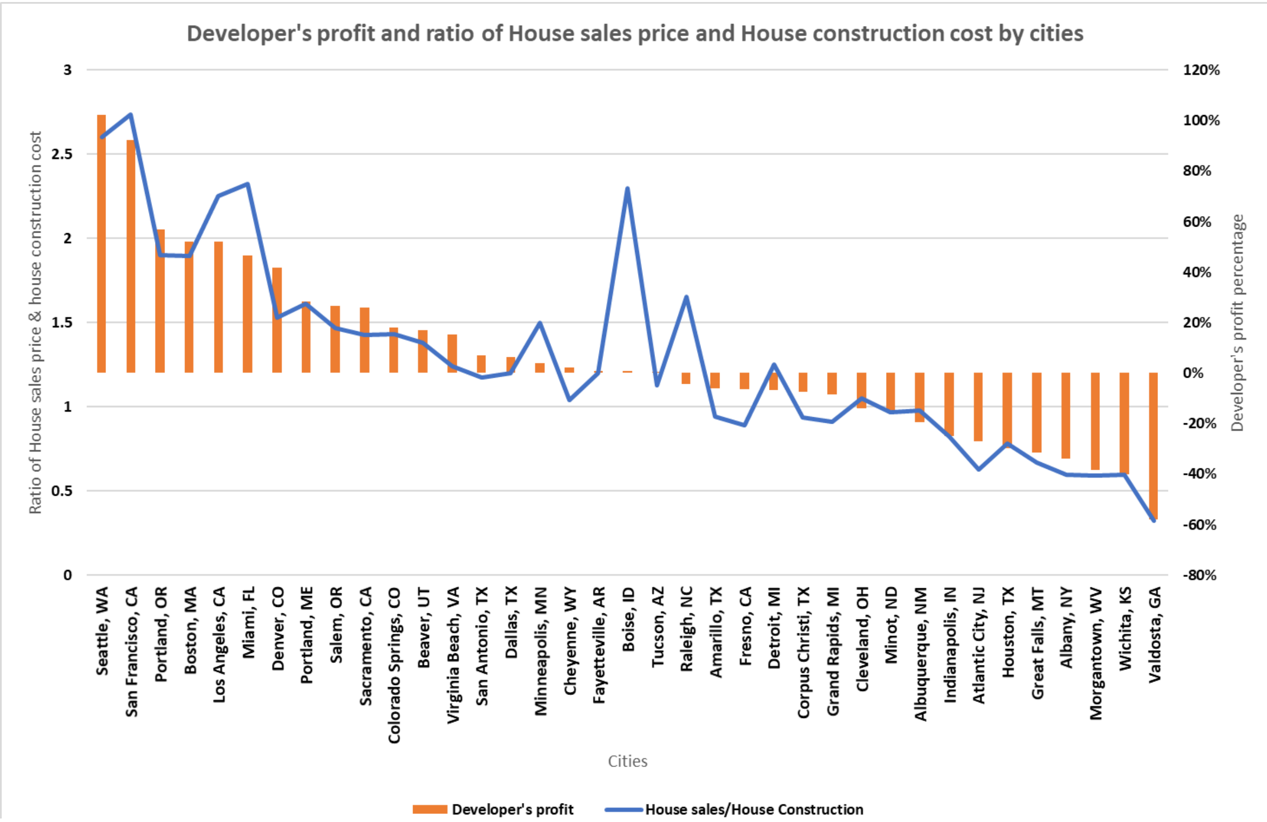

Figure 6. Developer's profit and ratio of house sales price and house construction cost.

In the proposed community, homeowners are offered a house price subsidy which lowers the house price from the market price. In Figure 8, the bar chart represents the market price in the different cities, and the line curve is for house price subsidy. From the formula to calculate the house price subsidy, the house price subsidy and house market price exhibit an inverse relationship. Figure 9 obeys this formula as we can see that as house market prices increase, the house price subsidy decreases. Homebuyers can buy houses in a neighbourhood where house prices are relatively lower to maximise the house price subsidy percentage.

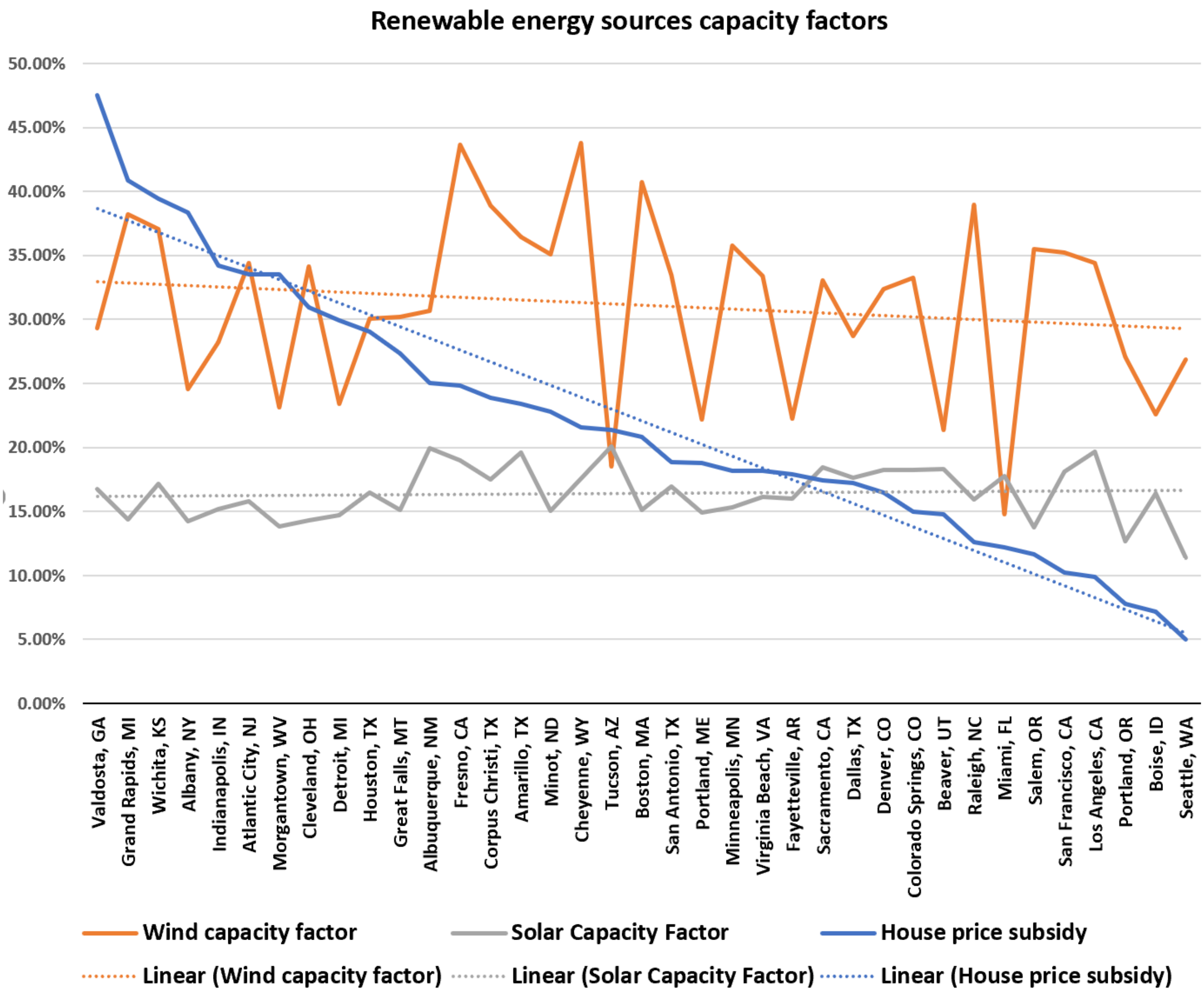

Figure 7. Renewable energy source capacity factors.

The average house price subsidy percentage differs from one state to another. In Figure 10, we have the map of the United States showing the average house price subsidy percentage in different states. Eastern states in the USA appear to be more beneficial for homebuyers than some Western states. Georgia has the highest with a 43% house price subsidy available. The main reason is low house market price while the RESs are good, so a higher house price subsidy percentage is possible. The extreme point is the State of Washington, where the lowest house price subsidy is observed; the main reason is the high market price of houses. In Seattle, the average market price is US$701,061 compared to US$115,612 in Valdosta, Georgia. Both places have similar-sized solar *PV* systems. Valdosta has more 1000 *kW* wind energy systems installed. Wichita, KS, offers a good wind capacity factor of 37.05%. The market price of a house is US$144,112, which is also lower than in many other states. O&M cost needs to be lowered to obtain a higher house price subsidy. O&M cost is reduced when the size of the microgrid is smaller. To fulfil the community's electricity load with a smaller microgrid, the geographical area's wind and solar energy capacity needs to be good. Besides, when the timing of the peak load demand (monthly) and peak generation (monthly) matches, the system's sizing is the most optimised. For instance, the months when the energy generation is higher are December and January for Cleveland, OH, but the generic load model used has peak energy usage in July and August. As a result, 6,000 *kW* of wind and 2,750 *kW* of solar need to be installed. We can compare this to Los Angeles, CA, which has a similar capacity factor of wind energy as Cleveland, OH, but has 3,000 *kW* and 2,750 *kW* of wind and solar installed, which is significantly smaller than in Cleveland. This is because Los Angeles' highest generation period is from May to August, which is aligned with its energy consumption.

The amount of house price subsidy in dollars ranges from US$31,529 in Seattle, WA, to US$114,932 in Boston, Massachusetts. The cities in California – San Francisco for example - have a subsidy amount of US$84,633; however,

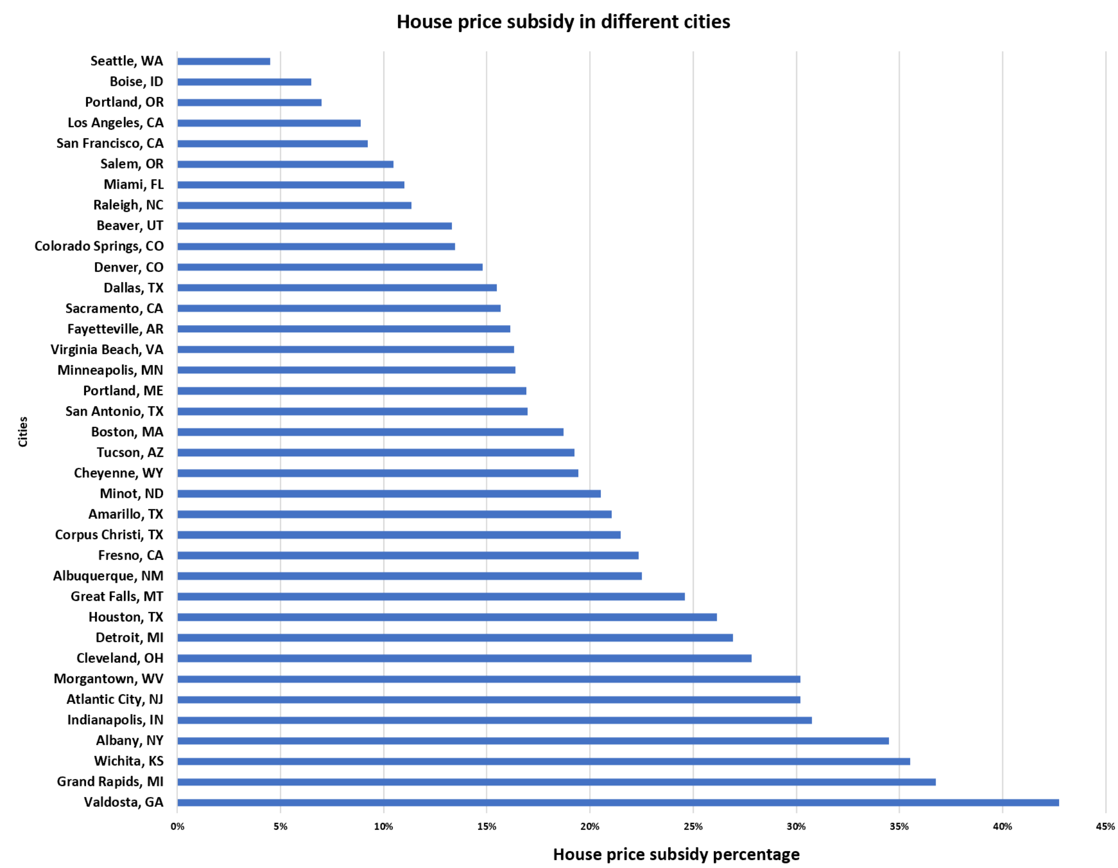

Figure 8. House price subsidy percentage per city.

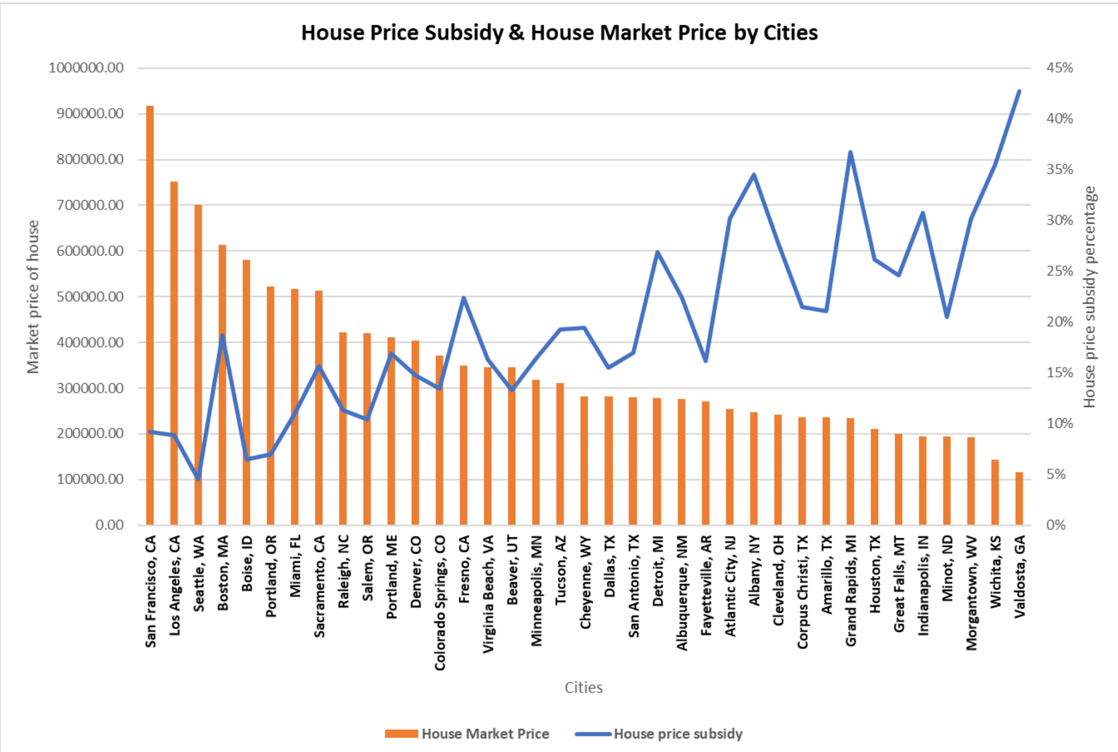

Figure 9. House price subsidy and house market price by city.

because of the high market price of houses (US$917,229), the subsidy percentage is low (9%). From Table 7, we see that 16 out of the 37 cities yield a house price subsidy percentage of greater than 20%, and the average house price subsidy amount for them is US$62,127. The average subsidy amount for the six cities with the lowest subsidy is US$50,195. Although the percentage of house price subsidy might look low for these cities, the subsidy amount of US$50,195 can attract potential homebuyers. Overall, the combination of reasonable house market price and good solar and wind energy capacity factors results in the maximum benefit for homebuyers.

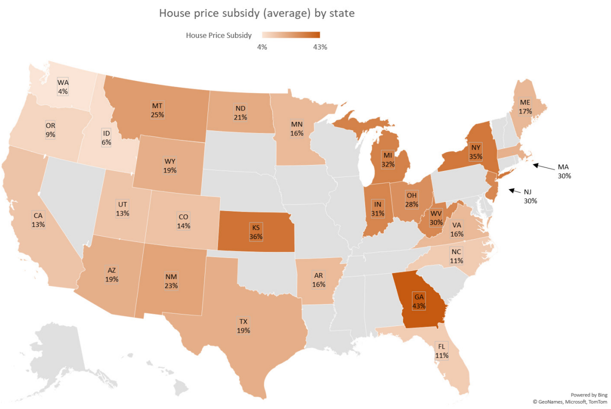

Figure 10. Average house price subsidy percentage per state.

Burgess et al. (2022) conducted a similar study on building standalone microgrids where 15 cities of the U.S.A. were considered to examine the feasibility. The study yielded developer's profit for 10 of the 15 cities. Because of the smaller number of cities, a substantial correlation could not be established between various parameters. In this study, the number of cities considered is significantly increased to 37. Since more cities are considered in our study, we can compute average house price subsidies for more states and obtain more insights. Besides, for the cost of the land to build a community, the land value was mostly collected from county tax records in Burgess' work which may not accurately reflect the latest land price. However, in our study, the land prices are directly obtained from the current market prices on real estate websites. Mainly, the work presented a map for the microgrid community deployment in 37 cities in the USA. These cities require the installation of local backup sources of energy in case of catastrophic events. The costs and benefits of the construction of a microgrid community considering aspects from land purchase to RES installation are analysed. As can be observed from Figure 11, the developer's profit is different for each city and it is dependent on the benefits brought by the RESs.

The work is a guide for the different partners and developers as well as residential consumers to select a suitable environment for microgrid deployment. As mentioned, residential consumers will obtain benefits from the subsidised price and the developer will obtain benefits by selling the community. In addition, the microgrid community has the benefit of remaining functional and operational during catastrophic events (e.g., coastal/riverine flooding, tsunamis, earthquakes, wildfires, possible damage, terrorist attacks). Another benefit is related to the electrical grid infrastructure in the USA. A large part of the US electrical grid was developed over a century ago and many parts have already exceeded their intended life. Seventy per cent of the lines and power transformers are more than 25 years old. There are even parts that are about 100 years old causing the electrical grid to have low efficiency and poor reliability. Renewing this electrical infrastructure can be more expensive than the construction of a new microgrid community.

Table 7. House price subvsidy amount and house price subsidy percentage for different cities.

City	House price subsidy percentage	Subsidy amount (USD)
Valdosta, GA	43%	$49,417.27
Grand Rapids, MI	37%	$86,389.91
Wichita, KS	36%	$51,170.52
Albany, NY	35%	$85,076.58
Indianapolis, IN	31%	$60,043.05
Atlantic City, NJ	30%	$77,028.97
Morgantown, WV	30%	$57,974.90
Cleveland, OH	28%	$67,565.76
Detroit, MI	27%	$74,921.36
Houston, TX	26%	$54,959.10
Great Falls, MT	25%	$48,938.66
Albuquerque, NM	23%	$62,107.06
Fresno, CA	22%	$78,191.89
Corpus Christi, TX	21%	$50,800.60
Amarillo, TX	21%	$49,672.83
Minot, ND	21%	$39,777.78
Cheyenne, WY	19%	$54,708.62
Tucson, AZ	19%	$59,744.83
Boston, MA	19%	$114,931.70
San Antonio, TX	17%	$47,522.02
Portland, ME	17%	$69,573.50
Minneapolis, MN	16%	$52,288.40
Virginia Beach, VA	16%	$56,322.32
Fayetteville, AR	16%	$43,589.35
Sacramento, CA	16%	$80,552.37
Dallas, TX	15%	$43,536.54
Denver, CO	15%	$59,795.91
Colorado Springs, CO	13%	$50,025.49
Beaver, UT	13%	$45,906.98
Raleigh, NC	11%	$47,862.07
Miami, FL	11%	$56,868.65
Salem, OR	10%	$43,880.50
San Francisco, CA	9%	$84,633.48
Los Angeles, CA	9%	$66,955.11
Portland, OR	7%	$36,534.74
Boise, ID	6%	$37,639.40
Seattle, WA	4%	$31,528.98

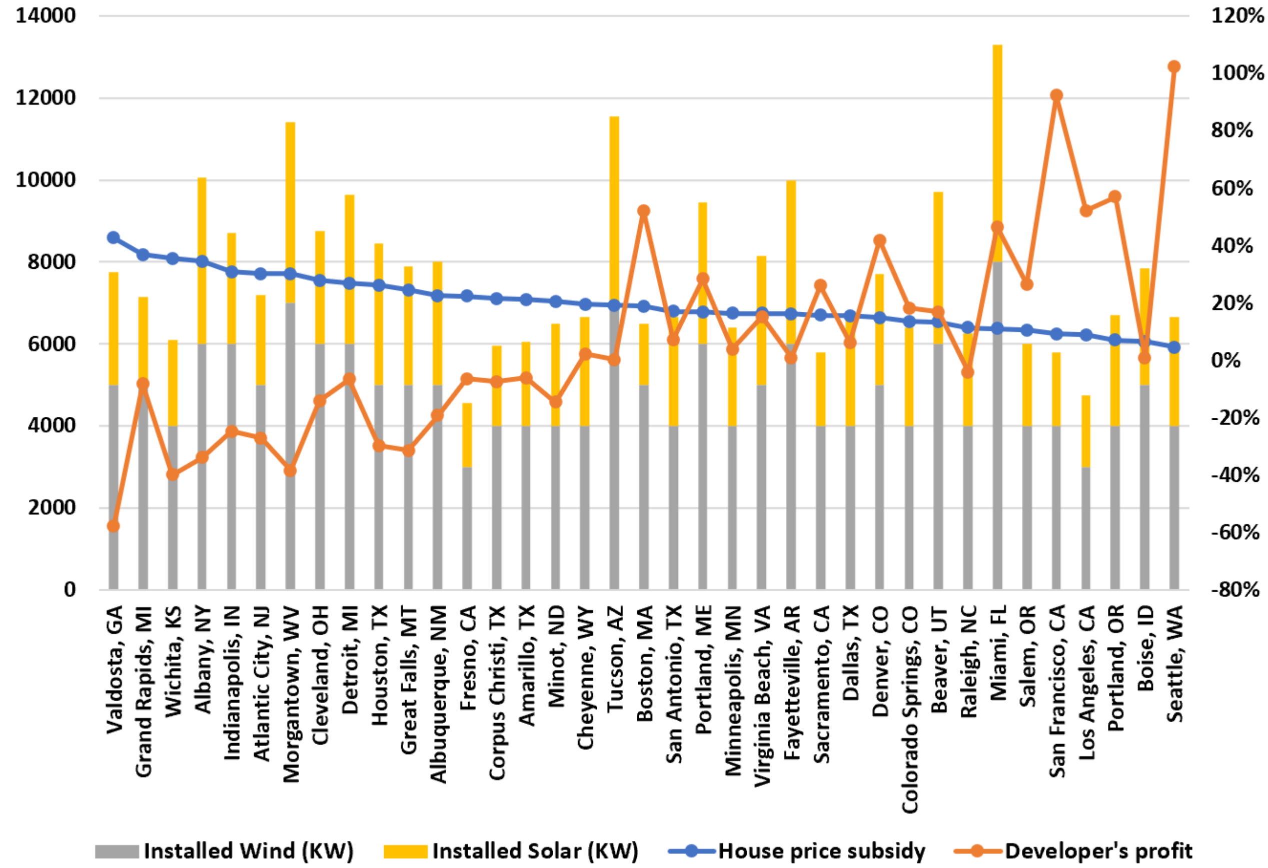

Figure 11. Developer's profit in each city is dependent on the benefits brought by the RESs.

7. Conclusions and perspectives

In this research project, an automated cost-benefit-analysis tool is created so that real estate developers and homebuyers can make sound decisions on building and buying homes in a standalone microgrid community. It is observed that places with profitable real estate markets for sellers and good solar and wind resources yield profitable investments for the developers. On the other hand, for the home buyers, good RESs play a vital role in giving them the highest subsidy, which lowers the cost of buying a house for them. The work presents a cost-benefit analysis model to select suitable areas for building a microgrid community in the United States. The work mainly considers the investment capital for land purchase and house construction. In the future, the capital expenditure and operating expenses will be detailed and the cycle life of renewable energy sources and storage devices should be considered to estimate the costs and benefits for the long term. Future work will place more focus on the operational context and the environmental conditions. The quantity of CO_2 emissions and the equivalent energy involved to build houses and to produce RES facilities should be considered to enable more accurate analysis.

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