Remote Tribal Microgrids Guide
Version 1

Systems Engineering 5900

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Introduction: A guide full of questions

This guide will be full of questions.

If you find yourself curious to know their answers, or if you find that you already have some of the same questions – then you're in luck. The goal of the guide is not just to be a list of questions, it is to take you down the path of finding answers and to help you learn enough about microgrids that you're asking even more questions by the time you've made it to the end.

We wanted to focus on remote communities.

Within the guide, 'remote communities' are loosely defined as communities far from major urban areas that typically have limited or no connection to the electrical utility grid. These communities are more likely to be underserved when it comes to electrical power needs, and they face a more challenging task recovering from natural disasters that cause the power to go out.

The guide contains information for those with utility access as well, but given these challenges, our mission was to highlight the specific ways remote communities can take advantage of microgrids to solve their energy-related problems.

Generating power doesn't have to generate pollution.

Many remote communities rely on fossil fuel generators as a primary source of power. While a microgrid doesn't necessarily mean getting rid of these generators entirely – it can offer solutions that provide power in a cleaner, quieter and even more cost-effective way. The guide will help you navigate the best way to take advantage of those solutions.

So – here are some key things you should expect to find out:

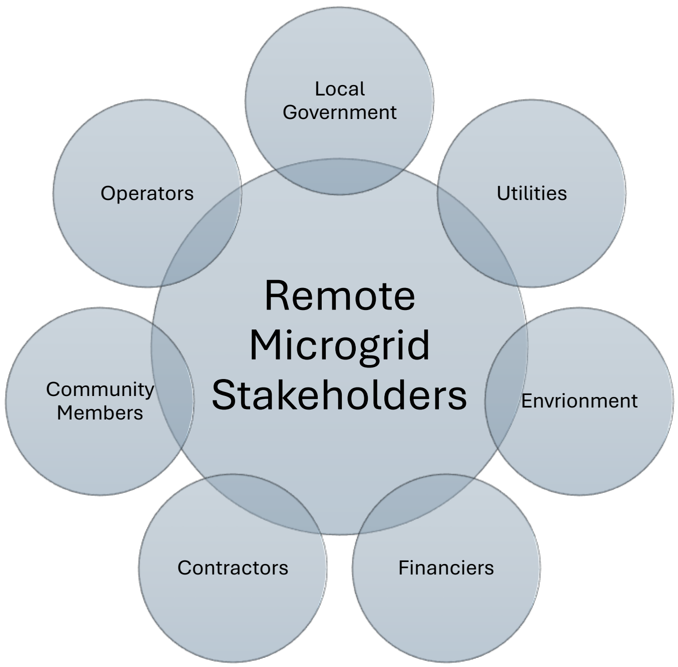
- **What are microgrids?**
- **What would make a microgrid the right choice for my community?**
- **How does it really look to implement this kind of solution?**

These questions and more are addressed within this guide.

Who are the stakeholders?

Before getting started, it's important to call out who the stakeholders are to keep in mind when it comes to the topic of microgrids for remote communities.

Stakeholders are any entities that have an interest or are involved with a given system. The primary stakeholders involved within a microgrid project are displayed below. Understanding the relevant stakeholders and how they fit into the process of designing and implementing a microgrid is crucial for making sure that your solution addresses all the parties' needs.



Here is a quick summary of each stakeholder involved:

Local Government

- Involved with microgrid regulations, policy, incentives and implementation
- Assists public-private partnerships engagement

Utilities

- Provides grid connectivity, backup power, and technical expertise.
- Interested in integrating the microgrid into the broader grid, ensuring better overall reliability

Environment

- Represents sustainability objectives including cutting carbon emissions, promoting renewable energy adoption, and ensuring the microgrid supports climate goals

Financiers

- Provide funding for the project through loans, investments, or grants
- Interested in financial aspects such as return on investment (ROI), project risks, and economic viability

Contractors (or Integrators)

- Design, build, and create the microgrid system infrastructure
- Interested with meeting deadlines, budget constraints, and ensuring quality of construction

Community Members

- End-users who benefit from the microgrid's operations and have the need of accessing affordable, reliable power
- Involved in the decision-making process and long-term benefits

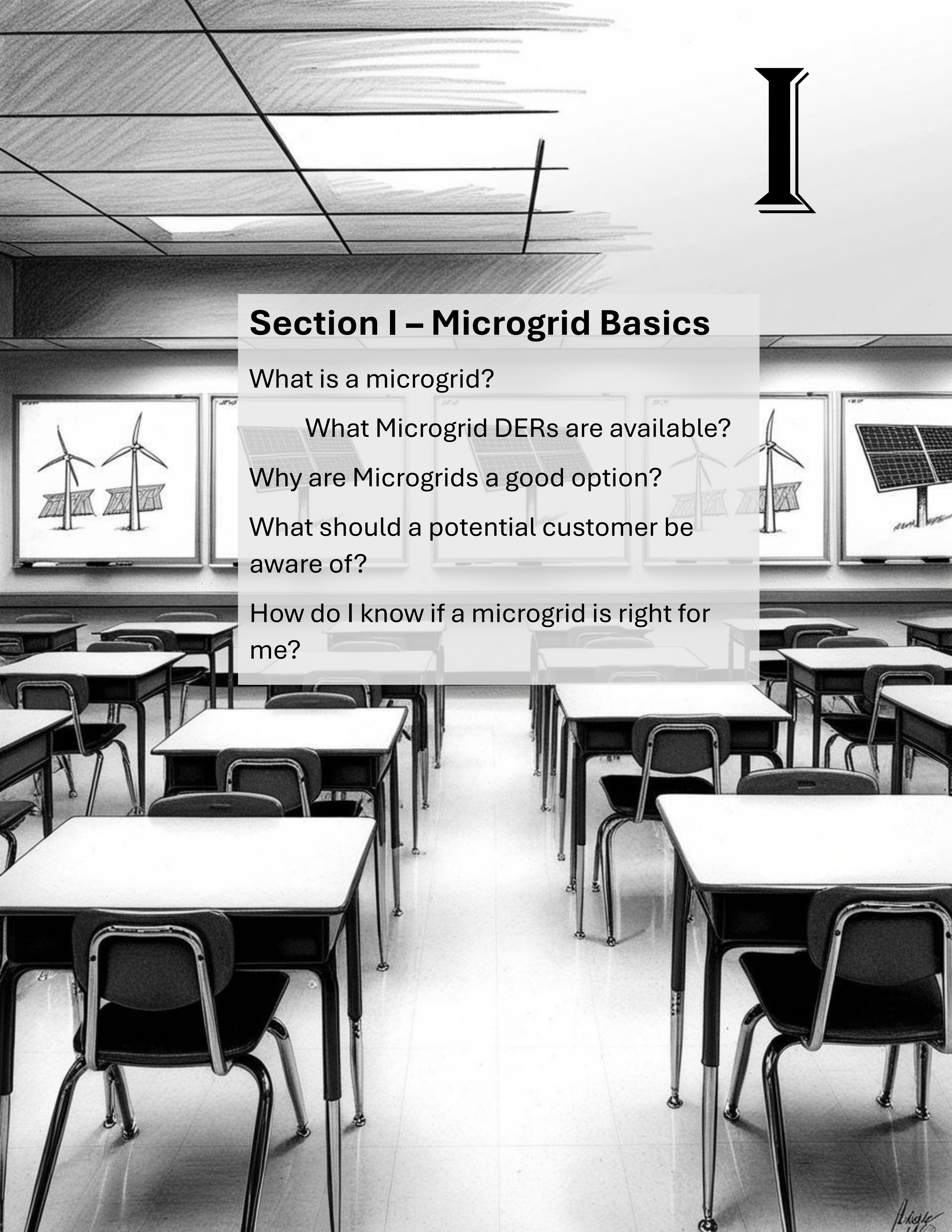
Operators

- Responsibility of managing and maintaining the microgrid to ensure optimal performance and uptime (or time that microgrid is in operation)
- Concerned with microgrid efficiency, technical troubleshooting, and adapting to changing energy needs

Some useful technical definitions

These are some helpful technical terms to be aware of as they are used throughout the guide. These definitions are less 'scientific' and more to provide the right context for understanding each term as it is used in the guide.

- **Controls –** This equipment can monitor the status of DERs, the utility, and the loads in the system to make sure power is provided in a safe, effective way. Individual DERs have their own controls that talk to a centralized system control overseeing the whole microgrid.
- **DERs –** Distributed Energy Resources refers to sources of electrical power that are physically located close to the load that they help meet. This is opposed to a centralized power plant that creates a large amount of power which is transported by traditional utility infrastructure across long distances to meet loads. Engine-based generators, wind turbines, hydro-electric equipment, and solar PV are all considered DERs.
- **Dispatchable –** This refers to the ability to control the power output of a DER to produce a specific amount of power on-demand. Generators and batteries are considered 'dispatchable'. DERs that rely on natural resources, like solar PV relying on the sun to produce power, are 'non-dispatchable' because they can't be controlled the same way.
- **Energy –** The ability to do work. In the context of this guide, electrical energy can be thought of as what is stored in something like a battery that can light up a lightbulb for an amount of time. In this guide, it will often be expressed in terms of kilowatt-hours (kWh).
- **Energy Storage –** Systems such as battery energy storage systems (BESS) can contain excess energy to be used later, such as during a power outage or when electricity costs are high. Storage can also be thought of as a DER.
- **Loads –** The electrical power demand needed for homes and community facilities.
- **Microgrid –** A small number of distributed energy resources (DER) connected to a single power subsystem. At a high level, they contain loads, sources, and controls.
- **Power –** The rate at which energy can be delivered. It can be thought of as the number of lightbulbs a battery can light up at once (without considering how long the battery would last). In this guide, it will often be expressed in terms of kilowatts (kW).
- **Reliability –** with respect to electrical power grids, this refers to the ability to avoid interruptions to normal power service. A utility or microgrid that rarely goes down is considered reliable.
- **Resilience –** with respect to electrical power grids, this refers to the ability to recover from an interruption to normal power service. A utility or microgrid that can get back up and running again quickly after a failure is considered resilient.[i]
- **Sources –** Equipment that provides power to meet the loads of a microgrid. These can include the utility, generators, wind turbines, hydro-electric equipment, solar PV, and battery energy storage systems.
- **Utility –** The 'utility' in the technical context of the guide refers to electrical utility companies. These companies are responsible for creating substantial amounts of electrical power in one or a few centralized locations and then transporting that power across a large area. Utilities vary widely in terms of their rules, billing structures, and policies for interconnecting.



I

Section I – Microgrid Basics

What is a microgrid?

What Microgrid DERs are available?

Why are Microgrids a good option?

What should a potential customer be aware of?

How do I know if a microgrid is right for me?

Section I – Microgrid Basics

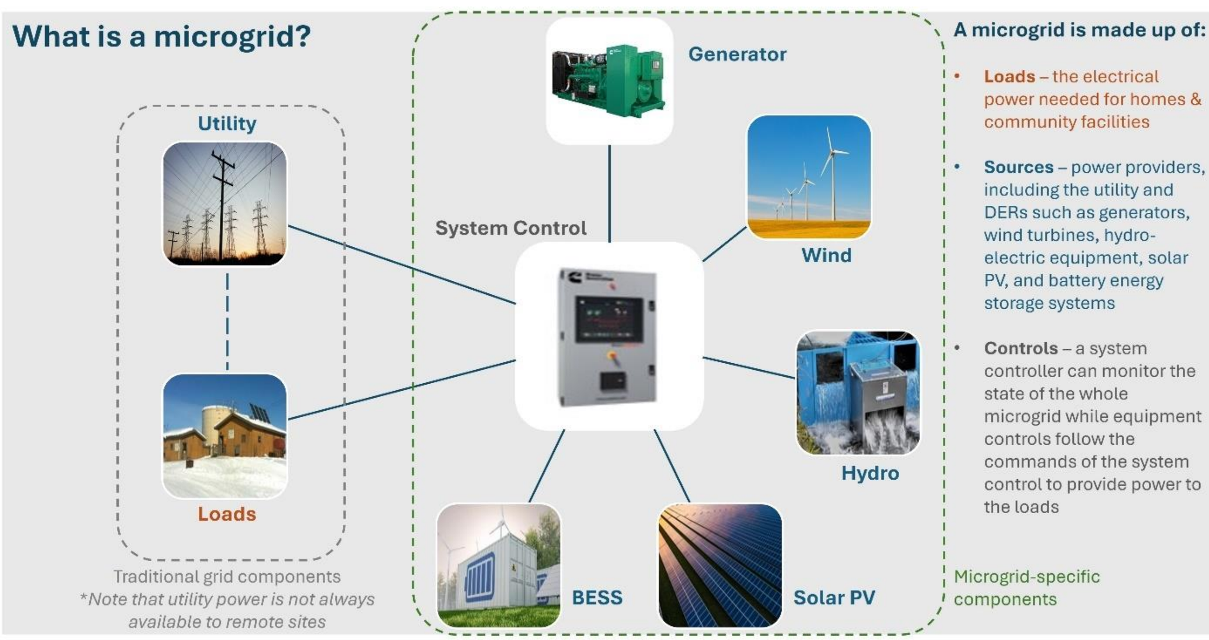
What is a microgrid?

Let's start off by defining what a microgrid is. A microgrid is a collection of distributed energy resources (DER) that are connected to a single substation. A microgrid can be connected to the main grid or operate self-sufficiently in "island mode". However, interconnection with the main grid is typically a complicated endeavor. Due to its versatility and ability to boost energy system resilience, microgrids are a topic of research and development and are even being set up within remote regions. What does it mean to be remote? If your community is not connected to a utility substation which receives energy over transmission lines, you are not connected to a centralized grid and are therefore a remote situation.

It is common for a remote community to operate on fossil fuel-based microgrids. Clean or renewable microgrids are known to provide "reliable, affordable, and resilient energy" during times of climate uncertainty[ii]. Due to recent economic market developments, renewable energy resources are financially affordable and can provide communities with energy without negative impacts such as localized air pollution and fuel supply chain disruptions.

The microgrid will be expected to experience and manage energy supply and demand. Energy supply is produced by the DERs, and a microgrid can be composed of one or more of them. These resources address the load which is the electric demand that the microgrid must meet and is caused by energy needed for day-to-day activities such as lighting, heating and cooling.

On the controls side, the system controller monitors the state of the microgrid while considering changes in energy generation. The system controller is important for ensuring the smooth functioning of the microgrid while accounting for any issues such as increased demand or decreased energy production.



According to the article *Microgrids: A review, outstanding issues and future trends*, there are several technical challenges with microgrids, including:

- **Appropriate Design**: This is about creating the best and appropriate microgrid design while understanding ambient energy resource availability and energy load demand.
- **System Security**: This is about keeping the microgrid functional during extreme stressful situations through contingency plans such as load shedding, meaning reducing energy supply during high demand to not cause damage to the grid.
- **Balancing between generation and load in island mode**: This is one of the most common issues faced by microgrids in island mode. The microgrid must continuously balance generation, and load demand, or instability in the system may occur.[iii]

What Microgrid DERs are available?

There are a variety of Distributed Energy Resources (DERs) that can be used for a microgrid. DERs include renewable energy technologies, storage and combined heat and power (CHP). DERs not only provide energy generation but also provide energy savings, cost savings and resilience.[iv]

For this guide, the main DERs of interest are solar, wind, small-scale hydro, diesel generators, and natural gas generators. These DERs are technologically mature and are the most realistic and accessible for remote regions. These options also include several renewable energy resources. Battery energy storage systems are also considered since storage units can assist with renewable energy integration.

Listed in the figures below are some of DERs that can be utilized in a microgrid system with their respective descriptions, including the pros and cons for each. Note that the values listed for cost are estimates and can vary widely depending on several factors such as location and project size. The cost Estimated Cost values are based on those found in the industry's recognized energy modeling software, Xendee. These values are subject to change and may be different in the future due to economic factors such as inflation and technological advancements.

A further list of technologies can be found in the Appendix and are potential alternative solutions depending on community needs and availability of financial and/or environmental resources.

Battery Energy Storage System (BESS)

- **Description:** Batteries or other storage technologies that store excess energy when production is higher than demand and release it when demand exceeds production.
- **Estimated Cost:** $370/kWh*
- **Pros:**
  - Improves reliability of renewable energy systems
  - Reduces waste of excess energy
- **Cons:**
  - Constraints on storage space and conditions
  - Battery life can be limited
  - Long duration storage can be high cost

Solar Photovoltaic (PV)

- **Description:** The system is composed of PV cells that convert solar radiation to electrical energy
- **Estimated Cost:** $1,900/kW*
- **Pros:**
  - Low maintenance costs
  - Carbon emission reduction
- **Cons:**
  - Relies on sun/unreliable in cloudy weather
  - Non-dispatchable (can't control when power is available)

Diesel Generator

- **Description:** These generator sets use diesel fuel in an Internal Combustion Engine (ICE) to turn an alternator that generates electricity.
- **Estimated Cost:** $350/kW*
- **Pros:**
  - Quick start-up
  - Dispatchable (use when needed)
- **Cons:**
  - High/increasing fuel costs
  - High carbon emissions

Natural Gas Generator

- **Description:** These generator sets use natural gas in an Internal Combustion Engine (ICE) to turn an alternator that generates electricity.
- **Estimated Cost:** $2,400/kW*
- **Pros:**
  - High fuel efficiency
  - Dispatchable
- **Cons:**
  - Slow start up
  - Expensive fuel storage
  - Higher cost than diesel generators

Wind Turbines

- **Description:** Wind rotates turbine blades to that turn an alternator to produce electricity.
- **Estimated Cost:** $5,000/kW*
- **Pros:**
  - Carbon emission reduction
  - Low production costs
- **Cons:**
  - Relies on wind speeds, non-dispatchable
  - Visual and noise pollution
  - High cost

Small Scale Hydroelectric

- **Description:** Energy from flowing water turns an alterntor, producing electricity.
- **Estimated Cost:** $4,500/kW*
- **Pros:**
  - Carbon emission reduction
  - Minimal ecological damage compared to larger hydroelectric projects
- **Cons:**
  - Requires running water
  - Generation limited by water flow rate
  - Seasonal variability

*Figure 1: Available DERs. *Note that values are estimates from Xendee and may not reflect actual values depending on location. References include [v], [vi], [vii]*

Why are Microgrids a good option?

Microgrids offer numerous benefits, particularly in terms of reliability, environmental impact, economic growth, flexibility, equitable energy transitions, sovereignty, and community wellbeing. They enhance reliability by providing power during natural disasters and grid outages, ensuring critical systems remain operational. Environmentally, microgrids reduce reliance on carbon-based energy, lower greenhouse gas emissions, and decrease noise pollution. Economically, they lower utility costs, reduce maintenance needs, create job opportunities, and can increase property values. They also support the growth of industries that require reliable power, such as medical and educational sectors.

Reliability: Microgrids provide power during natural disasters and grid outages, ensuring critical systems, like medical and other emergency equipment, remain operational.

Example: **Blue Lake Rancheria in California** was subjected to a wildfire event in the area, which caused a shutdown of the grid. The Microgrid was built just in time to give energy to essential services when energy was cut.

Environmental Impact: Energy systems like solar and wind reduce reliance on carbon-based energy generators, lower greenhouse gas emissions, and even decrease noise pollution. Offsetting emissions from fossil fuel sources reduces the production of ground-level ozone which damages crops, trees and other vegetation. Fossil fuel emissions also create acid rain, which affects soil, lakes and streams and enters the human food chain via water, produce, meat and fish.

Example: **Soboba Band of Luiseño Indians** has 1.5 MW of rooftop solar and a 6 MWh energy storage system, which saves 20,000+ tons of CO_2 in emissions.

Economic Growth: Microgrids lower utility costs, reduce maintenance needs, create job opportunities, and can increase property values. Less expenses on fuels increases the economic wealth of the customer, increasing buying power.

Example: **Kodiak island in AK** has a hydro plant that saves 70% in operation costs from the diesel plant, which costs about $100k/day. The island is sourced from >99% renewables with the wind turbines in full operation.

Example: **Blue Lake Rancheria** sees about $150,000 in annual electricity savings to about 10,000 people.

Public Health: Renewables improve air quality and reduce health issues like carbon monoxide poisoning by offsetting/decreasing the emissions from dirty polluting technologies.

Example: **The Environmental Protection Agency** states diesel exhaust can lead to serious health conditions like asthma and respiratory illnesses, and can worsen existing heart and lung disease, especially in children and the elderly. Renewables emit no pollutants.

Sovereignty: Microgrids support local ownership and governance, giving communities control over their resources.

Example: **California Resolution # 23-0302-09** recognizes the importance of sovereignty, especially after tribal experiences of historical violence, exploitation, dispossession and the attempted destruction of tribal communities within the state. The support towards energy sovereignty is supported by consultations, improved protections, increased access to funding, and increased workforce development for clean energy initiatives.

Equitable Access: Microgrids provide modernized energy solutions to more people, ensuring equitable access to reliable and sustainable energy. In some cases, this can help reduce disproportionate poverty.

Example: Navajo and Hopi Nations are electrifying 300 individual homes with 2.5 kW off-grid solar and battery storage systems.

Example: San Xavier District of the Tohono O'odham Nation was rewarded with a 50/50 price match with DOE resulting in $434,534.38 system costs savings.

Several remote and tribal communities are currently operating with microgrids. High-level overviews of these communities are provided on the next couple pages. Each community has unique characteristics that necessitate specific microgrid configurations based on their ambient environment and can offer a way to relate the size of the system to the outcomes they produce. The examples show unique examples of successful deployments and operations.

Kodiak, AK

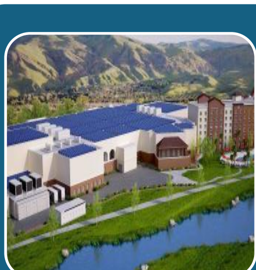
- 15,000 people demanding 28 MW from hydropower and wind provides 99% of energy needs
- Total capacity designed for 42 MW of capacity
- Crane loads are controlled to reduce stresses on microgrid system

Cordova

- Electricity comes from two hydro plants or diesel engines
- 1 MW battery energy system

Blue Lake Rancheria

- Provides approximately $150,000 in annual electricity savings to about 10,000 people
- $5 million grant supports tribal government offices, EV charging, a convenience store and gas station, a hotel and casino, and energy and water systems



Soboba Band of Luiseño Indians

- 1.5 MW of rooftop solar and a 6 MWh energy storage system
- 20,000+ tons of CO_2 Emissions Avoided

Chemehuevi Tribe's Community Center

- 90 kW carport system, 25 kW/125 kWh flow battery energy storage
- Electricity cost reduced $11,042, or nearly 50% reduction from annual average

Paskenta Band of Nomlaki Indians, California

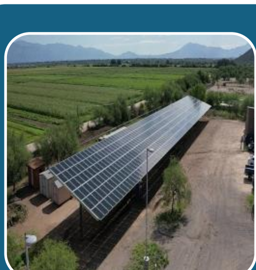
- $32M Grant from California Energy Comission
- 9th tribe in California to receive micrigrid support

Barona

- 1.5 megawatt/6.6 megawatt hour zinc bromine flow battery project
- Support six facilities critical to health, safety, and welfare

Navajo and Hopi Nations

- Electrifying 300 homes with 2.5 kW off-grid solar and battery storage systems



San Xavier District of the Tohono O'odham Nation

- $869,068.77 Total Cost
- 50/50 split between recipients and DOE ($434,534.38 each)

Standing Rock Sioux Tribe, North Dakota

- 1.7-megawatt (MW) wind turbine, 6.1 gigawatt-hours (GWh) of electricity per year
- Displaces approximately 85% of the load

What should a potential customer be aware of?

Despite the numerous potential benefits that microgrids can bring to a community, it is not uncommon for a proposed project to see pushback from community members. Often, this pushback stems from a lack of open dialogue between project developers and the community members. Failing to spread awareness of the project, its benefits, and potential drawbacks early on can lead to distrust of the project developer. The project developer needs to ensure the cultural practices of the affected community are understood and respected. The value of gaining the 'social license' from a community to move forward with a microgrid project is shown in stages in The Pyramid Model figure below.

Beyond a lack of communication, it is important to acknowledge other important concerns regarding microgrids. These concerns can include: [viii]

- Overdevelopment of land and loss of habitat for local wildlife
- Upfront monetary cost of the microgrid to the community
- Reliance on fossil fuels
- Mistrust of government or external companies with unclear goals/reasoning for proposing development in a remote tribal community
- Knowledge gaps
- Communication gaps
- Incorrectly accounting for growth in load demand over time

Some ways to address these concerns are consulting with local environmental agencies on appropriate land use, open communication between community members on higher-level discussions with government officials.

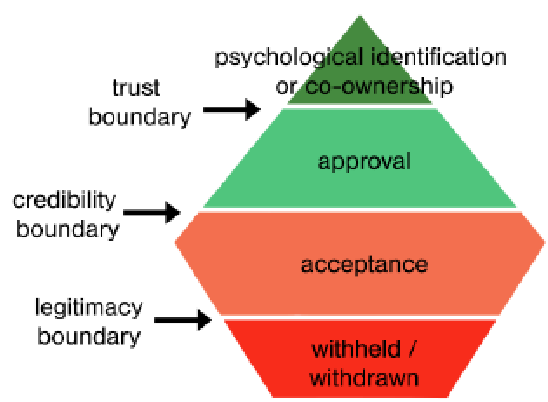


Figure 2: Pyramid Model for social license, as found in 'Energy Projects, Social License, Public Acceptance and Regulatory Systems in Canada: A White Paper by Colton, Corscadden et. al.[ix]

How do I know if a microgrid is right for me?

To determine if a microgrid is suitable for your community, it's crucial to understand the benefits and challenges listed in this guide as a starting point. Clean energy microgrids offer independent energy solutions, which can be particularly advantageous for remote and tribal communities that face difficulties connecting to larger power grids or need supplemental energy. While the initial setup and maintenance of a microgrid can be costly, government funding can help offset these expenses, making the investment more feasible. Comprise a budget and determine how much should be allocated for energy investments.

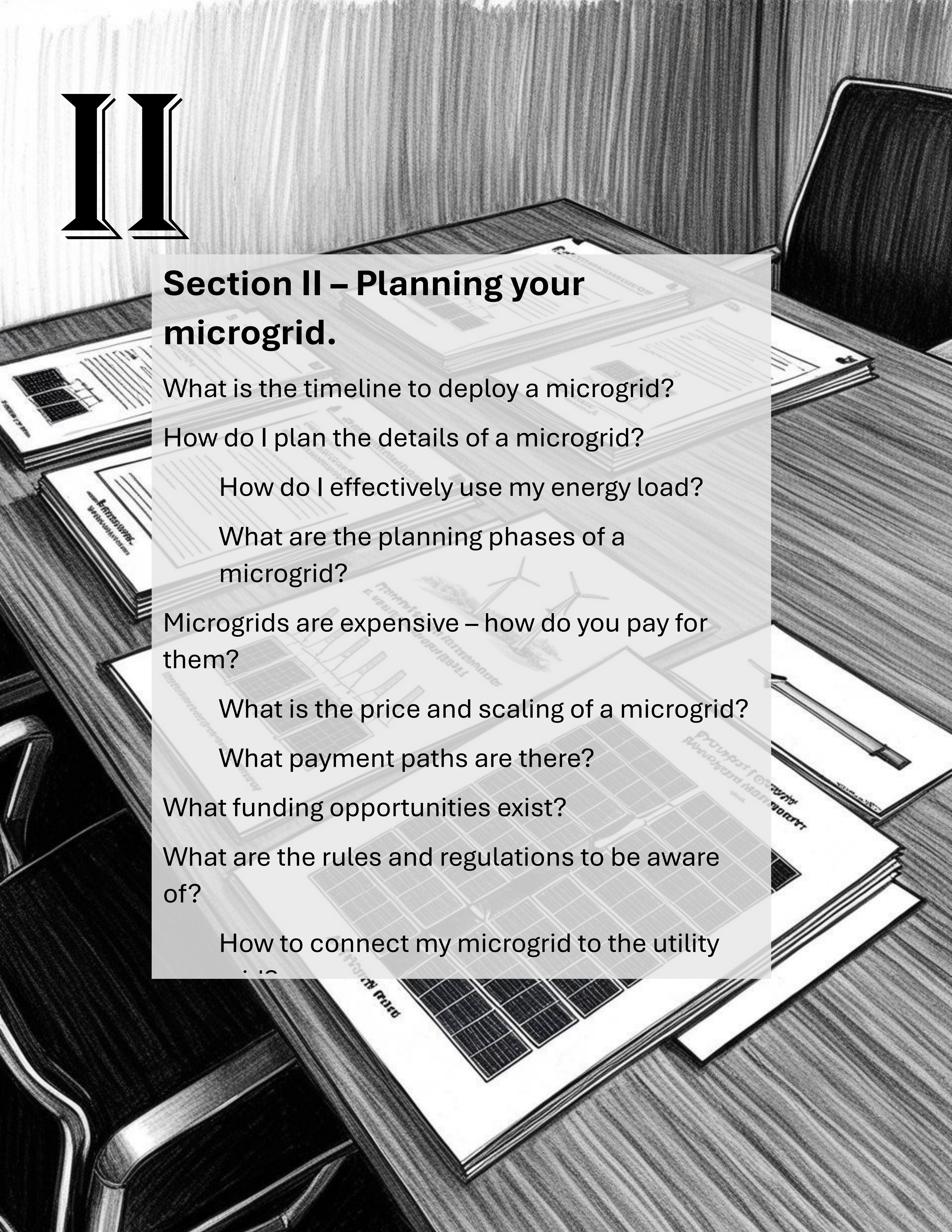
Assess whether the sustainable energy provided by microgrids would be beneficial. These systems can enhance the quality, consistency, and security of electricity for community stakeholders. However, efficient power generation depends on local weather conditions and the likelihood of natural disasters. For example, solar panels may be less effective in northern locations during periods with significantly reduced sunlight. Or, if the average wind speeds are sufficient for generation, assess if the peak wind speeds require a stronger and potentially more expensive system.

If your community can achieve optimal performance from a microgrid, it can offer stable and potentially lower electricity prices, protecting your community from dramatic price fluctuations that can impact budgeting and financial planning. Aligning these benefits with your community's energy goals is crucial to determine if the cost of the system and the energy savings are sufficient for investment.

Consider the tradeoffs involved in implementing a microgrid. The initial costs are substantial, and it can take time to see a return on investment. Factors such as the level of external investment, the types of renewable energy sources used, and the required infrastructure investments influence the time it takes to achieve a return on investment, which can range from five to twenty-five years. Ask the question if your needs allow a payback period in this range? Ongoing operations and maintenance costs should also be factored in.

Evaluate the environmental and regulatory aspects of a microgrid for your community. Even clean energy microgrids can have environmental impacts, such as the need to clear land for solar panels or wind turbines. Compliance with local and federal regulations is essential to avoid legal issues and ensure the project is structured for success. Communities need to evaluate their specific circumstances to develop tailored business cases for their stakeholders, considering factors like local wildlife, cultural sites, and community preferences. If fishing is integral to the community, avoid a hydro system that has a significant impact on marine life.

Deciding if a microgrid is right for your community involves weighing the potential benefits of energy independence, sustainability, and resilience against the costs and challenges of implementation. Communities interested in this technology should consider forming a research team to explore the feasibility and benefits further. This team can conduct a detailed techno-economic analysis to provide a clear timeline and cost-benefit assessment. More details on these benefits and considerations are discussed throughout the guide.



II

Section II – Planning your microgrid.

What is the timeline to deploy a microgrid?

How do I plan the details of a microgrid?

- How do I effectively use my energy load?
- What are the planning phases of a microgrid?

Microgrids are expensive – how do you pay for them?

- What is the price and scaling of a microgrid?
- What payment paths are there?

What funding opportunities exist?

What are the rules and regulations to be aware of?

- How to connect my microgrid to the utility grid?

Section II – Planning your microgrid

What is the timeline to deploy a microgrid?

The figure below shows an expected timeline for microgrid development. [x] Based on this figure from PG&E, the expected length of microgrid development would be 3 to 5 years. This is an estimate for community microgrids with established infrastructure and closer distances to the main utility grid. This is the expected length of microgrid development if funding and resources are available. An adjusted timeline is added below.

Stage	Approximate Time	Description
Stage 1: Assessment and Feasibility	6-9 months	- Understand community energy needs - Conduct feasibility studies on technical, environmental and financial aspects of the microgrid - Define and engage stakeholders - Draft initial project concepts and research potential funding sources along with regulations
Stage 2: Design and Technical Studies	1-1.5 years	- Create more detailed microgrid designs - Conduct interconnection studies/ island mode studies - Refine expected cost and timeline
Stage 3: Application and Approval	3-6 months	- Obtain permits for construction - apply for grants, loans and other sources of funding - Finalize agreements with governing bodies - Risk assessment
Stage 4: Construction and Commissioning	1.5 – 3 years	- Obtain equipment and work with contractors - Follow construction plans and implement microgrid
Stage 5: Operation and Maintenance	10+ years	- Operate microgrid and monitor behavior - Perform operation and maintenance to ensure reliability

Figure 3: Expected Microgrid Timeline [xi,xii]

However, if difficulties in communication and differences in priorities exist, remote communities may take longer in all stages of microgrid development. For remote microgrid regions, the timeline can be significantly longer due to complications in construction and permitting. Without confirmed funding and resources, development may range from 5-20 years.

How do I plan the details of a microgrid?

Simulation is a key activity to design a microgrid given the various complex factors in play. There are several software options available for microgrid capacity simulation, but four primary options are listed below.

These options allow for general modelling and are accessible to everyone. Subscription-based software will have additional functionality and flexibility with microgrid design and optimization. Though interesting to explore, a working knowledge of how to use the modelling software is not required for use by community members. However, microgrid integrators should have access to at least one of these software options or some equivalent. Although community members may not need to operate these software options, making sure that whichever microgrid integrator you choose to work with has a strong command of a simulation tool like these is key. Knowledgeable community members will help ensure the planning can start off on the right foot.

Free Software

NREL System Advisor Model (SAM)

SAM conducts calculation on performance and financial metrics for a variety of renewable energy projects. The model contains a variety of different renewable energy generation and storage technologies and is free to use.

REopt®

REopt® provides techno-economic analysis capability for microgrids. This tool can be used to model microgrids and general DERs in a campus or building context. REopt® can be used to provide financial models to help reduce costs, calculate emissions and provide insights on microgrid resiliency.

Subscription Based Software

Hybrid Optimization Model for Multiple Energy Resources (HOMER) Pro

HOMER Pro was originally developed with NREL and was designed to conduct low-cost solutions for standalone microgrid systems—making this an attractive option for remote microgrid analysis. Analysis can be done on DER generation, carbon emissions, and costs. For reference, the Base subscription is set at $125/month while the Expert subscription is set at $379/month.

Xendee

Xendee helps developers optimize Return on Investment (ROI).. Xendee helps a variety of users from customers, developers, financiers, to regulators through a simplified design interface. Xendee utilizes simplified inputs that relate to the user needs such as costs and CO_2 emission reduction. Xendee is free in an academic context but have different prices based on subscription ranging from $415/month to $650/month with upfront payment discounts.

Microgrid Modeling: Software Comparison

Features	SAM	Reopt	DER_VET	HOMER	XENDEE
Resiliency Studies		✓	✓	✓	✓
Peak-Shaving / Load-Response			✓	✓	✓
Reliability / Coverage Probability			✓	✓	✓
Energy Arbitrage Modeling				✓	✓
P50/P90 Analysis	✓				✓
Easy, Complete Reporting	✓	✓		✓	✓
Site-Specific Weather Data			✓	✓	✓
System Optimization		✓	✓	✓	✓
Web-Based Software		✓			✓
Free / Open-Source	✓	✓	✓		
Utility Rates / Incentives Included				✓	✓
Traditional Generation (diesel, gas, coal, etc.)	✓	✓	✓	✓	✓

Available Financial Models	SAM	Reopt	DER_VET	HOMER	XENDEE
Residential & Commercial (behind-the-meter)	✓	✓	✓	✓	✓
Residential & Commercial (front-of-meter)	✓	✓		✓	✓
Power Purchase Agreements (PPAs)	✓			✓	✓

Available Renewable Sources	SAM	Reopt	DER_VET	HOMER	XENDEE
Solar PV	✓	✓	✓	✓	✓
Battery Storage	✓	✓	✓	✓	✓
Thermal Storage		✓	✓	✓	✓
Wind	✓	✓	✓	✓	✓
Hydropower				✓	✓
Solar Water Heating	✓	✓			✓
Fuel Cells	✓			✓	✓
Geothermal Power	✓	✓		✓	✓
EV Charging			✓	✓	✓

Figure 4: Microgrid software comparison from Mayfield Renewables [xiii]

How do I effectively use my energy load?

When implementing a microgrid, it is important to think about how the community can make the best use of the energy provided. A growing community looking to save energy can do so through conscious behavior changes to improve energy efficiency. This is handled by recognizing the efforts to help reduce energy usage and getting a community onboard to commit to these changes.[xiv] The figure below actions that can be taken to reduce energy consumption in buildings. Community member support to make energy conscious behavioral changes can be challenging. The study done by the Journal of Energy Chemistry [xv] outlined the effectiveness of modeling the behavior by the community leader, written commitments by the community members, and feedback on savings show the most effective intervention methods for enacting change.

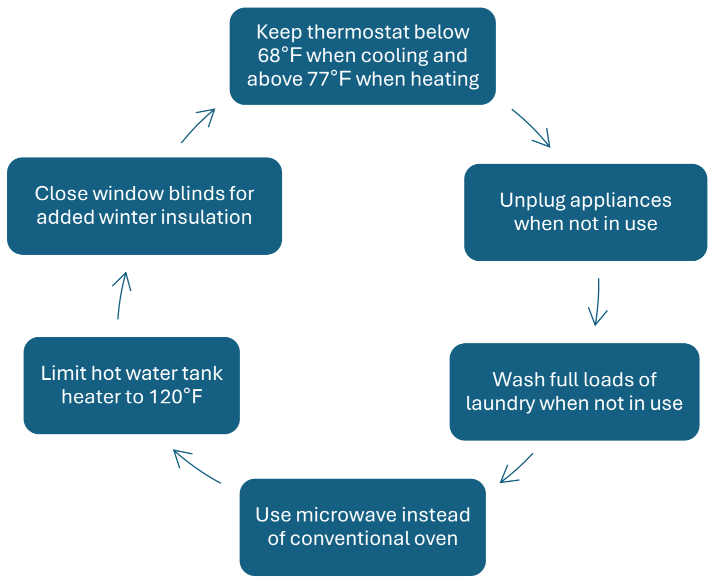


Figure 5: Energy efficiency actions to be taken at home

Another significant opportunity that microgrids provide is the expansion of energy uses within a community. For instance, a community aiming to boost its economy by developing new facilities, such as manufacturing plants or data centers, or by expanding agricultural operations, will inevitably require an increased power supply. The integration of a microgrid can supplement the existing energy infrastructure, ensuring that these new ventures have an increasingly reliable source of power.

What are the planning phases of a microgrid?

Once a microgrid system is built, planning for future growth involves several key processes to ensure its continued success and scalability.

Concept Planning: This stage focuses on identifying new natural ambient energy options, such as expanding solar arrays or integrating wind turbines. It also involves utilizing existing tools and technologies to enhance the system's efficiency. Optimization considerations are crucial, ensuring that any expansions are designed to maximize energy capture and minimize waste.

Development: Ensuring the reliability of the expanded system is paramount. This involves rigorous testing and validation of new components to ensure they integrate seamlessly with the existing infrastructure and can withstand operational stresses and environmental conditions.

Deployment: This phase involves the practical implementation of new components and technologies. Careful coordination and project management are essential to ensure that all new elements are correctly installed and operational without disrupting the existing system.

Operation: A skilled workforce is vital for maintaining and managing the expanded microgrid. This includes ongoing training for local technicians and engineers to handle new technologies, troubleshoot issues, and perform regular maintenance. Continuous education ensures that the workforce can adapt to technological advancements and maintain system efficiency.

Future Expansions: Planning for future expansions involves scaling the microgrid infrastructure to meet growing energy demands. This includes strategic planning for land use to accommodate new installations and managing load changes to ensure the system can handle increased demand. Workforce development remains a critical component, ensuring that there are trained professionals ready to support new developments and maintain the expanded system.

Disposition: Consider recycling and disposal planning early. Energy systems can be relocated and repurposed if a better system can replace it. For systems that use an energy storage system, such as a battery bank, plan for battery end-of-life programs. Arrange recycling programs to ensure proper handling and recycling.

Microgrids are expensive – how do you pay for them?

What is the price and scaling of a microgrid?

According to NREL, "the analysis of total microgrid costs per megawatt shows that the community microgrid market has the lowest mean, at $2.1 million/MW of DERs installed". [xvi] Note that 1 MW is equivalent to 1000 kW, meaning that the expected price for DERs will be $2100/kW. Since this is a general estimated cost and is not focused on a particular DER source, it is best to conduct an economic analysis with professionals to obtain more accurate cost estimates.

As a rule, the community microgrid scale will be at the kW scale with a figure listed below. Using the expected capacity and estimated cost per kW above, community members can determine a rough estimate for total costs of DERs.

Microgrid Generation Capacity	Possible Connections
5 kW	1 home[5]
25 kW	10 homes
250 kW	100 homes or 3 retail buildings
500 kW	200 homes or 5-6 retail buildings or 1 supermarket or 1 health clinic or 1 small school
1.5 MW	600 homes or 15-20 retail buildings or 4 supermarkets or 4-5 health clinics or 2-3 schools or 1 hospital

Figure 6: Expected Microgrid Scale based on number of connections from NREL[xvii]

Note that the costs may be different depending on location and developers. Remote Microgrids may cost more depending on access to transmission lines and the main grid.[xviii] This all reinforces the importance of conducting techno-economic analysis with proper professionals in the field.

What payment paths are there?

As with many innovative solutions, the benefits offered by microgrids are accompanied by excessive costs. There are two main paths that can be taken to pay for a microgrid – direct purchase or a power purchase agreement (PPA).

Direct purchase is simply buying the system from a microgrid provider or set of providers, paying up front for the system as a Capital Expense, or 'CAPEX' cost.

A power purchase agreement (PPA) involves the microgrid provider installing the system but maintaining ownership of the equipment, instead selling power to the customer for a fixed rate. This is also referred to as 'energy-as-a-service' and make paying for the microgrid an Operating Expense, or 'OPEX' cost.

Some of pros (green boxes) and cons (red boxes) of each path are shown below:

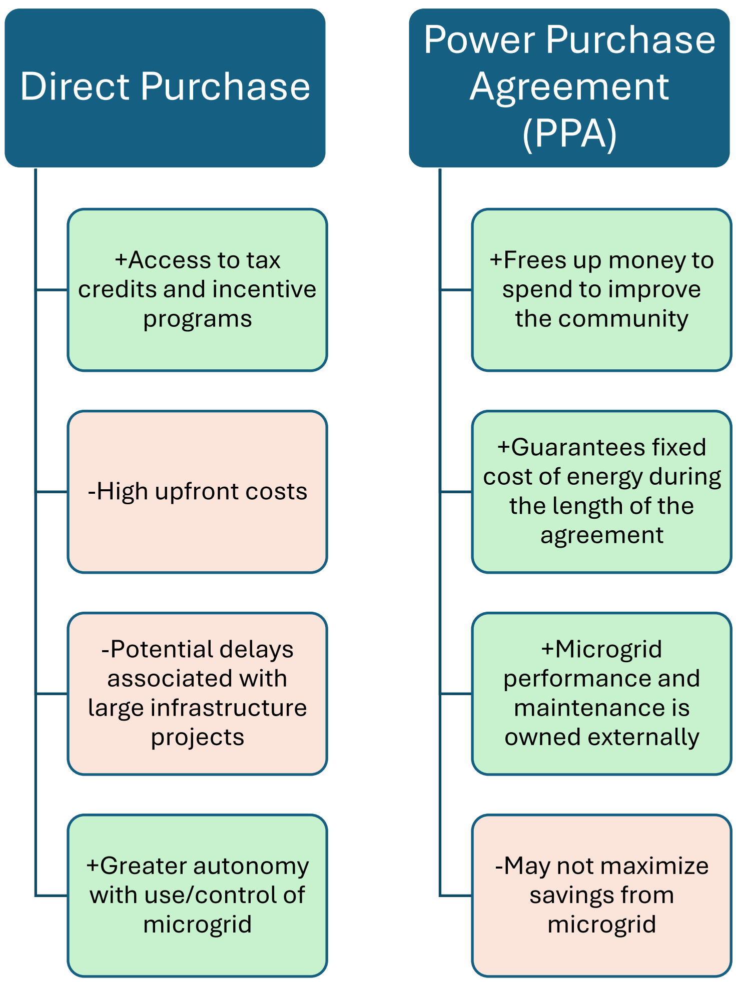


Figure 7: Comparison of main microgrid financing options[xix]

What funding opportunities exist?

There are several federal funding opportunities available for the creation of clean energy microgrids, each with distinct forms and purposes. The Department of Energy (DOE) offers numerous grants specifically for clean energy microgrid projects. These grants can support individual projects, providing necessary financial resources to initiate and develop microgrids. One notable program is the Community Microgrid Assistance Partnership (C-MAP) under the DOE's Office of Electricity. Participants in C-MAP receive technical support and/or funding to design or deploy microgrids that align with community-defined priorities or to enhance the performance of existing microgrid technologies.

The DOE is not the only federal agency offering grant opportunities. Other agencies, such as the Department of Transportation, the Department of Commerce, the Environmental Protection Agency, and the Department of Defense, also provide grants through the grants.gov database. This platform includes many grants that disseminate green energy funding from the Inflation Reduction Act2. Additionally, the DOE's Loans Program Office offers funding opportunities specifically for tribal communities[xx], supporting their efforts to develop clean energy projects.

Beyond federal funding, state governments also provide financial support for clean energy microgrids. Many states allocate funds from their own budgets to promote the development of renewable energy projects[xxi]. Furthermore, carbon credits are becoming an increasingly important funding source. Through carbon credits, entities can invest in green initiatives to offset their carbon emissions, providing additional financial resources for clean energy projects.

A collection of funding options are provided on the next page.

Source Level	Source	Description	Link
Private	MicrogridKnowledge.com	A website dedicated to everything microgrids	Home | Microgrid Knowledge
Federal	DoE	Community Microgrid Assistance Partnership	Community Microgrid Assistance Partnership | Department of Energy
Federal	DoE	Microgrid Program Strategy	Microgrid Program Strategy | Department of Energy
Federal	Grants.gov	How to search for federal govt grants	Search Grants | Grants.gov
Federal	Grants.gov	Grant-making Agencies	Grant-Making Agencies | Grants.gov
Federal	Grants.gov	Federal Grant Eligibility	Grant Eligibility | Grants.gov
Federal	DoC	Department of Commerce Grant opportunities	Grants and contract opportunities | U.S. Department of Commerce
Washington State	Commerce	Washington State Clean Energy Funds	Commerce Clean Energy Fund awards grants to 18 innovative electricity grid modernization projects benefitting Washington communities – Washington State Department of Commerce
Maryland	DoE	Maryland Energy Administration Accepting Clean Energy Grant Applications	https://www.microgridknowledge.com/government/article/33017535/maryland-energy-administration-accepting-clean-energy-grant-applications
Private	Carbon Credits	Academic paper on carbon credits and microgrids	https://www.sciencedirect.com/science/article/pii/S2405844024151377

What are the rules and regulations to be aware of?

It's important for community stakeholders to understand the rules and regulations involved with clean energy microgrids. These regulations are imposed at the federal level and the state level. Regulations come in two forms: policy and technical standards for microgrids. Policy regulations are concerned with how communities set up microgrids and, for example, how they interact with the larger national grids. Technical regulations are concerned with technical standards for how they are built.

The federal government has issued some high-level regulations for microgrids. For example, an important piece of legislation is the Public Utility Regulatory Policies Act of 1978. Another important directive from the federal government comes from an executive order handled by the Federal Energy Regulation Commission. These regulations are mostly about policy, as previously discussed. They are concerned with what communities do with the energy they create, how they integrate into the national grid, and how the microgrids are designed (size and performance requirements).

There are also technical standards. For example, there are interconnectivity standards that require some level of interoperability between microgrids. Many of these regulations are imposed by state-level governments, and they vary from state to state. It's important that stakeholders seek clarity from their individual state-level governments to ensure that they are following the specific rules set out by them.

Although there are not too many requirements imposed by federal and state governments, microgrids are becoming increasingly utilized by communities all over the country. With more communities adopting microgrids, more attention will be placed on them as a concept and interest and oversight from the government should be expected. The energy environment, not just microgrids, is rapidly developing and regulation and legislation pertaining to it will follow.

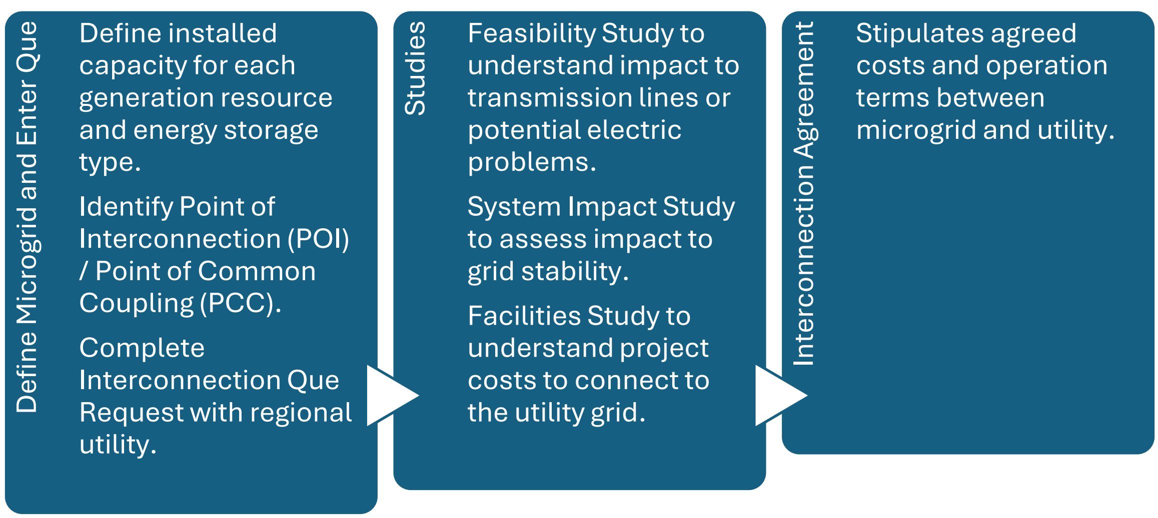
Description	Link
Public Utility Regulatory Policies Act of 1978	H.R.4018 - 95th Congress (1977-1978): Public Utility Regulatory Policies Act of 1978 | Congress.gov | Library of Congress
FERC Order No. 2222	FERC Order No. 2222: Fact Sheet | Federal Energy Regulatory Commission
Overview of Microgrid Regulation in the USA	Microgrid Regulatory Policy in the US | Greentech Renewables
Interconnection Standards	https://www.nrel.gov/state-local-tribal/basics-interconnection-standards.html#:~:text=Benefits,deployment%20of%20renewable%20energy%20systems

How to connect my microgrid to the utility grid?

A community that experiences intermittent or unreliable power from an existing utility connection may want to consider connecting their microgrid to that utility. This can reduce system losses at peak production and provide additional profit by selling energy to the utility.

The process for connecting to a utility grid can be lengthy process, sometimes taking up to 4 years. Regulation for interconnection is controlled by the states and can vary by area. However, IEEE 1547 provides standards and best practices for interconnection, all states either use this standard or site it in their interconnection processes. IEEE 1547 outlines technology neutral performance specifications for interconnection and how it can be tested for operation and safety. [xxii]

Interconnection studies will need to be performed to understand the impact the community's microgrid will have on the utility grid. The utility operator will need to understand the stability impact of their grid system and an agreed control system will need to be established. The study will determine the Point of Common Coupling (PCC) or Point of Interconnection (POI), used interchangeably. Once the studies are complete, an interconnection agreement is constructed between microgrid owner and utility owner. This agreement stipulates items such as cost of power and operation terms. This agreement becomes important in the controls system as a microgrid connected to a larger grid needs to follow grid power cycles, whereas a microgrid in island mode can operate under its own control. A summary of this process can be seen below. [xxiii]



III

Section III – Implementation and what follows: the microgrid in use.

How do I work with a microgrid integrator?

How do I make community decisions about my microgrid?

What to expect while the microgrid is in use?

How do I maintain a microgrid?

Wrapping up the guide with one more question

Section III – Implementation and what follows: the microgrid in use

How do I work with a microgrid integrator?

After planning and designing a microgrid, putting those plans into action will require involvement from community leaders, members of the community and the partner company that has been selected as a microgrid integrator. Below are some practical tips for working with your microgrid project team and community stakeholders.

1. Pick the right integrator

- Any company with demonstrable experience - in particular with projects similar to your own - is a key to success.

2. Look for a focused team

- Integrators that assign their employees a large number of projects simultaneously will have less ability to focus on your microgrid and keep track of all the necessary details.

3. Assign clear points of contact

- Making sure there is a leader within the community to handle communication with a dedicated individual from the integrator will go a long way to keeping everyone informed and both sides in sync.

4. Get the integrator involved as soon as possible

- Bringing the integrator in for early design and planning will help align both sides on the best plan and can help with avoiding costly changes later in the project.

5. Choose an integrator familiar with the DERs you need

- When possible, the integrator you select should have experience with the type of equipment, if not the specific brands/models, to ensure a smooth integration of technology within your microgrid.

Figure 8: Tips for working with a microgrid integrator. These are drawn from S&C Electric's 'How to Build a Microgrid' guide[xxiv]

How do I make community decisions about my microgrid?

Decisions will need to be made throughout the life of the microgrid. Potential topics are expansion to other local areas, connection to utility grid system, retirement or upgrade of generation system or energy storage system. A consensus-based decision method has been shown to be the most effective at driving results within a community of a similar value structure. This structure includes a facilitator (the community project manager for the microgrid) and a selected group of individuals that represent project and community stakeholders. The topic of discussion can be brought to a broader audience in town-hall format before more involvement from the community members is desired. However, the decision should be made within the smaller stakeholder representative meeting.

A consensus decision is based on the principle that everyone's opinion is worth hearing and all concerns are valid. Through expressing these opinions and concerns, a decision that benefits the community is decided on. For a consensus to be had, group members need to have a common set of values. Creating a mission and vision for your microgrid community can be helpful in aligning everyone's interests and driving decisions towards that common goal. [xxv]

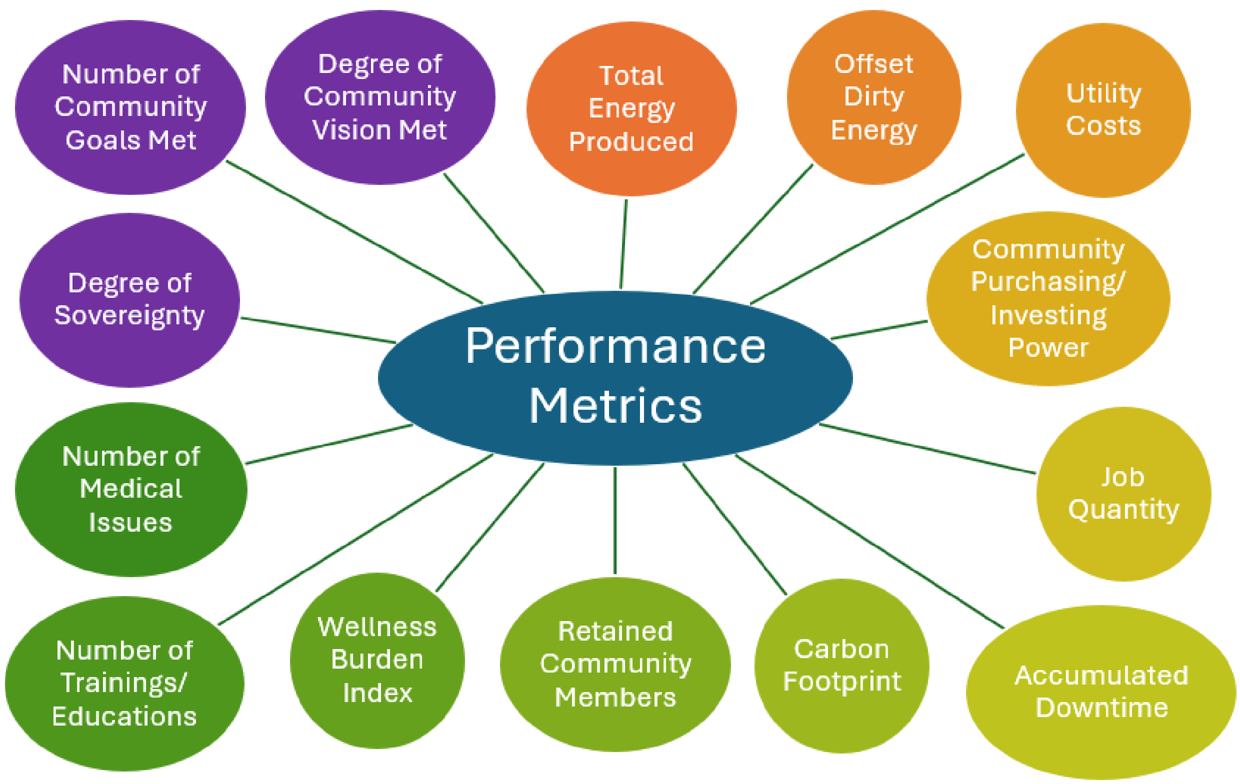
Coming to a consensus can be time consuming and difficult. It helps to have a practiced facilitator and implement strategies like "the round" if discussions are going in circles. "The round" is a practice where all members are given an equal amount of time to speak on the topic at hand, and no interruptions or comments are allowed until everyone has spoken. At the end of a round, the facilitator summarizes the discussion and re-states the issue at hand. This practice can be particularly helpful in hearing out introverted community members' thoughts as extroverts may dominate the conversation. [xxvi]

As a community moves through microgrid management, changes may present themselves in forms of planning complications that force deviation from the original plan, or issues with the microgrid that need fixing post-installment. For effective communication it is important to provide honest and timely updates to microgrid stakeholders. Using understandable language on the topic, keep to the facts, and avoid making assumptions.

What to expect while the microgrid is in use?

When microgrids are in operation, several metrics should be recorded to effectively evaluate the system's health and its impact on the serviced community. Although these metrics are not mandatory, measuring them allows for a quantitative comparison with the system's prior configuration, highlighting the positive impact created.

Key metrics include energy production and consumption, system reliability and stability, environmental impact, economic benefits, and community impact. Monitoring total energy generated, energy consumption, and the energy balance helps assess efficiency. Tracking the frequency and duration of outages and voltage stability ensures reliability. Environmental metrics like carbon emissions reduction and renewable energy penetration gauge the microgrid's sustainability. Economic metrics such as cost savings and job creation reflect the financial benefits, while community impact metrics assess improvements in quality of life and community engagement.



Long-term monitoring of these metrics can reveal trends over seasons and/or years, prompting necessary technology upgrades or other modifications. For instance, declining performance in battery storage systems, increased friction in wind turbines, decaying efficiency in solar panels, or a decreasing number of jobs may indicate the need for maintenance, replacement, or new training programs.

Energy Produced — Measured Energy Produced from the Microgrid

- By measuring energy output from the microgrid, a reliable and sustainable electricity supply can be ensured. Regular monitoring also allows for the prompt identification and resolution of any issues, ensuring a consistent power supply.

Dirty Energy Offset — Measured Energy

- By measuring the amount of energy offset from a dirty energy system, the system's effectiveness can be accurately evaluated. Different systems may perform variably depending on their geographical locations. Understanding the extent of energy offset can highlight the need for a larger energy storage system if necessary, or inform other critical infrastructure decisions.

Utility Costs Savings — Amount of Savings in Spendings on Utility Expenses

- By tracking this metric, it is possible to quantify the reduction in utility expenses resulting from the implementation of the microgrid system. This data helps in assessing the cost-effectiveness of various energy-saving implementations and can guide future investments in energy infrastructure. Understanding these savings is essential for budget planning and community economic assessment.

Community Investing Power — Amount of Funds Allocated for Infrastructure Upgrades

- Accrued community investment funds represent the financial resources accumulated over time through various initiatives and savings, such as those from reduced utility expenses. These funds can be reinvested into the community to support development projects, enhance public services, and continue to upgrade the infrastructure.

Job Quantity — Capability and Capacity of Available Workforce

- Tracking jobs created by microgrid installations, replacing outdated energy jobs, asesses workforce strength. Training and certifications show the community's ability to maintain the microgrid, reinforcing self-reliance. Growing workforce capacity justifies further energy infrastructure investment. Tracking job retention and career progression offers insights into long-term economic stability and growth.

Accumulated Downtime — Annual Duration of Non-operational Status

- Measuring the total duration of downtime for the community system reflects the integrity and robustness of the microgrid, especially under environmental conditions. Improved uptime compared to an end-of-line utility system demonstrates the microgrid's effectiveness. Significant reductions or elimination of downtime reinforce the system's necessity and benefits.

Carbon Footprint — Global Warming Potential Intensity (Excluding Biogenic Carbon)

- One of the key metrics for evaluating the success of a microgrid installation is pollution intensity, also known as the Global Warming Potential (GWP) Intensity metric. This metric reflects the embodied carbon emissions of building materials and construction processes. Maintaining GWP Intensity below a specified threshold supports global efforts to mitigate greenhouse effects.

Member Retention — Quality of Life Equates to Retention of Community Members

- Tracking community retention and growth metrics is crucial for understanding community health and sustainability. Key metrics include member retention rate, churn rate, engagement rate, feedback scores, membership growth rate, new sign-ups, and referral rates. High retention rates reflect the microgrid's effectiveness and quality of life. A growing, engaged community attracts businesses and investments, boosting local economic development.

Overall Education Level — Number of Certifications and Trainings

- Coupled with the number of jobs available, the number of education awards (higher education, trainings, certifications), is a reflection on the competency of the community to hold more diverse set of jobs, and can even expand the workforce to be utilized outside of the community.

How do I maintain a microgrid?

When it comes to maintenance for a microgrid, there are two main things to consider: who will work on it and what tasks are there to do?

Referencing a guide from S&C Electric, there are three main options to consider for who can handle the operation and maintenance of your microgrid. These include:

- Do-it-yourself
- Operation and Maintenance contractors
- Your microgrid integrator

The figure below, derived from S&C's guide, weighs the pros and cons of these options. It is also important to consider the community members and ease of access to the community for third parties. Some remote communities may benefit more from training their own technicians to operate and maintain their microgrid equipment.

Figure 9: Based on an excerpt from S&C Electric's guide 'The Short- and Long-Term Care of Your Microgrid' weighing the options of different maintenance providers for a microgrid[xxvii]

While weighing who will oversee microgrid maintenance, it makes sense to be aware of what the tasks will be. Monitoring and planning maintenance for the system is a crucial task to make sure your community has reliable power without incurring large, unexpected costs for fixing equipment. The figure below lists the typical tasks and estimated costs of maintaining DERs.

Battery Energy Storage System (BESS)

- **Estimated Maintenance Cost:** $0.04 per kWh
  - For example, a battery providing 10 kW of power for 200 hours in a year would cost ($0.04)*(10kW)*(200hr) = $80 to maintain in that year
- **Typical Maintenace Tasks:**
  - Inspecting and performing minor upkeep of electrical components
  - Cleaning electrical components, enclosure, air-handling
  - Battery performance testing and battery voltage balancing

Engine-based Generator

- **Estimated Maintenance Cost:** $0.01 per kWh
- **Typical Maintenace Tasks:**
  - Inspecting and period servicing of lubrication, cooling, and fuel systems
  - Periodic testing and servicing starting batteries
  - Monthly exercising of the generator
  - Periodic replacement of consumable components like filters, belts, and spark plugs

Solar Photovoltaics (PV)

- **Estimated Maintenance Cost:** $0.04 per kWh
- **Typical Maintenace Tasks:**
  - Monitoring energy production and inverter status
  - Periodically inspecting panels for debris and damage
  - Cleaning solar panels
  - Trimming any vegetation that covers or shades panels

Wind Turbines

- **Estimated Maintenance Cost:** $16.00 per kW annually
  - For example, a turbine rated to produce 100 kW would cost $1,600 per year
- **Typical Maintenace Tasks:**
  - Inspecting the generators, gearbox, and other mechanical components
  - Checking bearings, connections, and tightening bolts as needed
  - Inspecting and repairing corrosion damange on the blades and tower foundation
  - Maintaining oil levels

Hydro-Electric Generator

- **Estimated Maintenance Cost:** $0.48 per kWh
- **Typical Maintenace Tasks:**
  - Checking for normal function of the turbines, gearbox, generator and hydraulic systems
  - Checking and changing oil for gearbox and hydraulic systems
  - Testing sensors and control for normal function
  - Periodic replacement of bearings, drive couplings, belts, and sensors

System Controls

- **Estimated Maintenance Cost:** Negligible
- **Typical Maintenace Tasks:**
  - Inspecting control cabinets for structural integrity
  - Checking control wiring, connections, and support
  - Cleaning exterior and interior of control cabinets
  - Checking for control software updates and addressing any error messages/warnings

Figure 10: Typical maintenance expectations for microgrid components. References: [xxviii], [xxix], [xxx], [xxxi], [xxxii], [xxxiii], [xxxiv], [xxxv], [xxxvi], [xxxvii]

Wrapping up the guide with one more question

We started off with three key questions. Here are the quick summary answers to those questions.

What are microgrids?

This guide described what a microgrid is by explaining the physical elements, how these elements operate, what energy technology can be used, and examples of existing microgrids.

What would make a microgrid the right choice for my community?

Planning a microgrid is outlined through detailed planning phases, payment paths, funding opportunities, and regulations.

How does it really look to implement this kind of solution?

When using your microgrid, we outline how to work with a microgrid integrator, how to make community decisions, and what maintenance can be expected.

Through the information in this guide you can assess whether a microgrid is the right choice for your community and what it will take to implement it. The actionable and approval tips listed will give you confidence to make informed choices throughout the project.

Now it is time to ask one last question –

Are you ready to start your journey towards energy independence through a renewable microgrid?

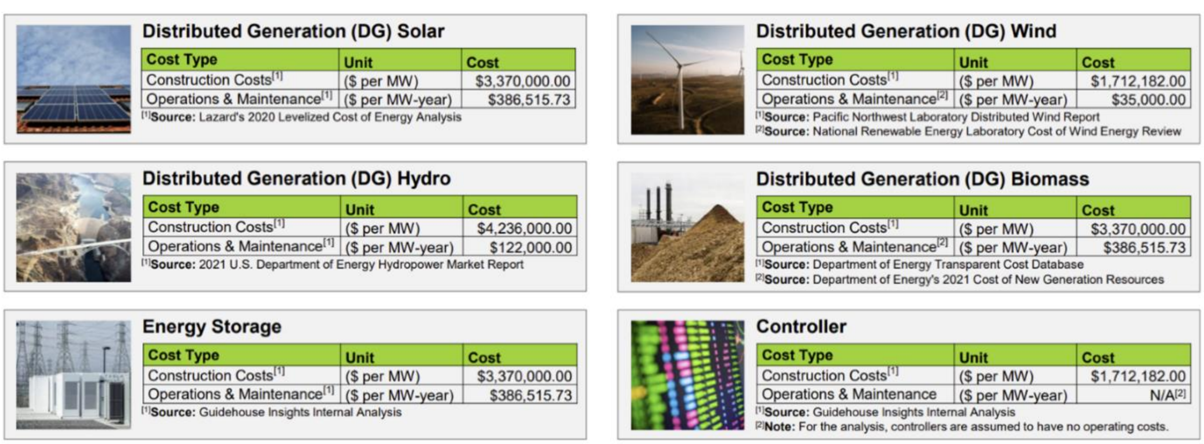
If you have feedback to share to help improve this guide for future users, please share by contacting:

Professor Semida Silveira (ss3267@cornell.edu)

Appendix

Table 1: Additional DERs of potential interest.

Technology	Description	Pros	Cons
Biogas	Fuel that is produced from the breakdown of organic matter such as food and waste	- Cost-effective fuel source - Reduces soil/water pollution - Byproduct-fertilizer	- High integration costs - Requires fuel treatment and filtration - Requires suitable amount of biomass
Fuel Cells	Utilizes the chemical energy of fuels to produce clean electricity	- Low carbon emissions - Quiet - Useful for CHP applications	- Hydrogen extraction is expensive - Expensive infrastructure development
Combined Heat Power (CHP)	Also known as cogeneration, these systems are paired with other fuel-based generation and capture/ use waste heat for heating/cooling purposes	- Is versatile and can be paired with other fossil fuel-based systems - Improves systems efficiency and reduces waste	- Not an independent energy source - Higher costs - Emissions dependent on fuel source



Distributed Generation (DG) Solar

Cost Type	Unit	Cost
Construction Costs[1]	($ per MW)	$3,370,000.00
Operations & Maintenance[1]	($ per MW-year)	$386,515.73

[1]**Source:** Lazard's 2020 Levelized Cost of Energy Analysis

Distributed Generation (DG) Wind

Cost Type	Unit	Cost
Construction Costs[1]	($ per MW)	$1,712,182.00
Operations & Maintenance[2]	($ per MW-year)	$35,000.00

[1]**Source:** Pacific Northwest Laboratory Distributed Wind Report
[2]**Source:** National Renewable Energy Laboratory Cost of Wind Energy Review

Distributed Generation (DG) Hydro

Cost Type	Unit	Cost
Construction Costs[1]	($ per MW)	$4,236,000.00
Operations & Maintenance[1]	($ per MW-year)	$122,000.00

[1]**Source:** 2021 U.S. Department of Energy Hydropower Market Report

Distributed Generation (DG) Biomass

Cost Type	Unit	Cost
Construction Costs[1]	($ per MW)	$3,370,000.00
Operations & Maintenance[2]	($ per MW-year)	$386,515.73

[1]**Source:** Department of Energy Transparent Cost Database
[2]**Source:** Department of Energy's 2021 Cost of New Generation Resources

Energy Storage

Cost Type	Unit	Cost
Construction Costs[1]	($ per MW)	$3,370,000.00
Operations & Maintenance[1]	($ per MW-year)	$386,515.73

[1]**Source:** Guidehouse Insights Internal Analysis

Controller

Cost Type	Unit	Cost
Construction Costs[1]	($ per MW)	$1,712,182.00
Operations & Maintenance	($ per MW-year)	N/A[2]

[1]**Source:** Guidehouse Insights Internal Analysis
[2]**Note:** For the analysis, controllers are assumed to have no operating costs.

Figure 11: Relevant energy generation resources with the relevant construction costs and Operations and Maintenance (O&M) costs from Guidehouse. The cost estimates are for regions within California and Puerto Rico.

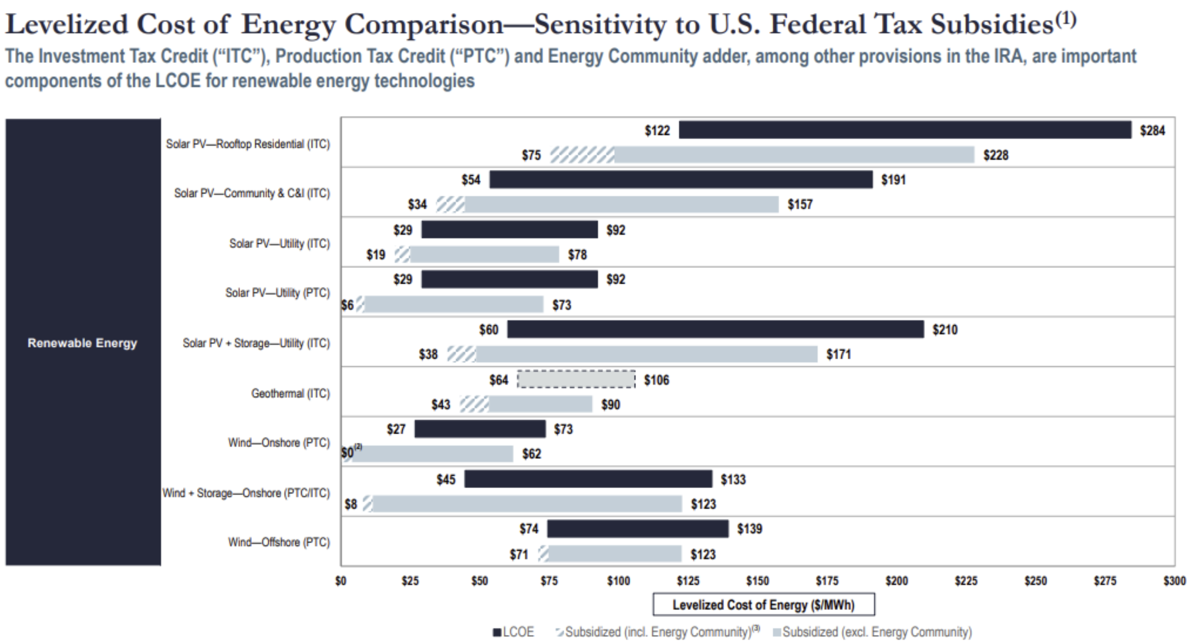


Figure 12: Levelized cost of energy estimates for various technologies.

References

[i] Awesense. (2022, November 24). *The difference between grid reliability vs resilience*. Awesense. https://www.awesense.com/difference-between-grid-reliability-vs-resilience/

[ii] Guidehouse. (2021, November). The Renewable Energy Economic Benefits of Microgrids. https://static1.squarespace.com/static/5472abbae4b0859145039552/t/6193d0e801c64e39c1662e1d/1637077225523/CSI+Final+Report_FINAL+%2811-16-21%29.pdf

[iii] Uddin, M., Mo, H., Dong, D., Elsawah, S., Zhu, J., & Guerrero, J. M. (2023, July 15). *Microgrids: A review, outstanding issues and future trends*. Energy Strategy Reviews. https://www.sciencedirect.com/science/article/pii/S2211467X23000779#b61

[iv] U.S. Department of Energy. (n.d.). *Distributed Energy Resources for Resilience.* https://www.energy.gov/femp/distributed-energy-resources-resilience#:~:text=Distributed%20energy%20resources%20(DERs)%E2%80%94,Portfolio%20Resilience%20Planning%20and%20Implementation.

[v] U.S. Department of Energy. (n.d.). *Energy Sources*. https://www.energy.gov/energy-sources

[vi] Dynamic Ratings. (n.d.). *Distributed Energy Resources (DERs).* https://www.dynamicratings.com/solutions/smart-infrastructure-solutions/distributed-energy-resources/

[vii] Carrasco, J. L., Pain, A., & Spuhler, D. (2019, May 9). *Hydropower (small-scale)*. SSWM. https://sswm.info/water-nutrient-cycle/water-distribution/hardwares/water-network-distribution/hydropower-%28small-scale%29#:~:text=In%20run%2Dof%2Driver%20systems,Source:%20PRACTICAL%20ACTION%20(n.y.)

[viii] Ofstehage, A., Wolford, W., & Borras, S. M., Jr. (2022). *Contemporary populism and the environment*. Annual Review of Environment and Resources, 47, 671-696. https://doi.org/10.1146/annurev-environ-012220-124635

[ix] Colton, J., Corscadden, K., Fast, S., Gattinger, M., Gehman, J., Hall Findlay, M., Morgan, D., Sayers, J., Winter, J., & Yatchew, A. (2016). *Energy projects, social licence, public acceptance and regulatory systems in Canada: A white paper* (Figure 1). University of Calgary, The School of Public Policy. Retrieved from https://www.policyschool.ca/wp-content/uploads/2016/06/energy-white-paper.pdf

[x] Pacific Gas and Electric Company. (n.d.). *Community microgrids*. PG&E. Retrieved December 9, 2024, from https://www.pge.com/en/save-energy-and-money/rebates-and-incentives/community-microgrids.html#:~:text=Email%20us%20at%20communitymicrogrids@pge,Mute

[xi] PG&E. (n.d.). *Community microgrids.* https://www.pge.com/en/save-energy-and-money/rebates-and-incentives/community-microgrids.html#:~:text=Email%20us%20at%20communitymicrogrids@pge,Mute

[xii] Microgrid Knowledge. (2019b, September 3). *Walk through the last of the Microgrid Development Phases: Implementation*. Microgrid Knowledge. https://www.microgridknowledge.com/resources/article/11429452/walk-through-the-last-of-the-microgrid-development-phases-implementation

[xiii] Zoucha, J. (2022, August 1). Microgrids Part 3: Microgrid modeling software. Mayfield Renewables. https://www.mayfield.energy/technical-articles/microgrids-part-3-microgrid-modeling-software/

[xiv] International Energy Agency. (n.d.). *Behavioural changes*. Retrieved from https://www.iea.org/energy-system/energy-efficiency-and-demand/behavioural-changes

[xv] Liu, Y., Xu, J., Guo, F., & Wu, G. (2019). Solar-Powered Chemical Production. *Journal of Energy Chemistry, 36*, 74-82. https://doi.org/10.1016/j.jechem.2019.06.006

[xvi] Giraldez, J., Flores-Espino, F., MacAlpine, S., & Asmus, P. (2018, October). *Phase I microgrid cost study: Data collection and analysis* ... https://www.nrel.gov/docs/fy19osti/67821.pdf

[xvii] Grid Deployment Office, U.S. Department of Energy. (2024, January). *Microgrid Overview*. https://www.energy.gov/sites/default/files/2024-02/46060_DOE_GDO_Microgrid_Overview_Fact_Sheet_RELEASE_508.pdf

[xviii] Clean Coalition. (2021). *Community Solutions Initiative final report*. Retrieved from https://static1.squarespace.com/static/5472abbae4b0859145039552/t/6193d0e801c64e39c1662e1d/1637077225523/CSI+Final+Report_FINAL+%2811-16-21%29.pdf

[xix] Microgrid Knowledge. (n.d.). *Microgrid financing: How to fund your project*. Retrieved December 8, 2024, from https://www.microgridknowledge.com/resources/microgrid-perspectives/article/11427570/microgrid-financing-how-to-fund-your-project

[xx] U.S. Department of Energy. (n.d.). *Tribal energy loan guarantee program*. Retrieved from https://www.energy.gov/LPO/Tribal

[xxi] Washington State Department of Commerce. (2021, August 25). *Commerce Clean Energy Fund awards grants to 18 innovative electricity grid modernization projects benefitting Washington communities*. Retrieved from https://www.commerce.wa.gov/commerce-clean-energy-fund-awards-grants-to-18-innovative-electricity-grid-modernization-projects-benefitting-washington-communities/

[xxii] National Renewable Energy Laboratory. (n.d.). *Basics of interconnection standards*. Retrieved from https://www.nrel.gov/state-local-tribal/basics-interconnection-standards.html

[xxiii] American Clean Power Association. (n.d.). *Interconnection*. Retrieved from https://cleanpower.org/resources/interconnection/

[xxiv] S&C Electric Company. (n.d.). *Educational material 180-4505*. Retrieved from https://www.sandc.com/globalassets/sac-electric/documents/public---documents/sales-manual-library---external-view/educational-material-180-4505.pdf?dt=638691992387593899

[xxv] Gallo, A. (2020, September 22). *7 strategies for better group decision-making*. Harvard Business Review. Retrieved from https://hbr.org/2020/09/7-strategies-for-better-group-decision-making

[xxvi] Tamarack Institute. (n.d.). *Practical Guide for Consensus-Based Decision Making*. Retrieved from https://www.tamarackcommunity.ca/hubfs/Resources/Tools/Practical%20Guide%20for%20Consensus-Based%20Decision%20Making.pdf

[xxvii] S&C Electric Company. (n.d.). *Educational material 180-4506*. Retrieved December 8, 2024, from https://www.sandc.com/globalassets/sac-electric/documents/public---documents/sales-manual-library---external-view/educational-material-180-4506.pdf?dt=638692961025775536

[xxviii] S&C Electric Company. (n.d.). Microgrids. Retrieved December 8, 2024, from https://www.sandc.com/en/solutions/microgrids/#MicrogridGuidebooks

[xxix] Agentis Electric Ltd. (2024, September 19). The importance of regular battery energy storage systems (BESS) maintenance. Retrieved December 8, 2024, from https://www.agentiselectric.ca/the-importance-of-regular-battery-energy-storage-systems-bess-maintenance#:~:text=Proper%20BESS%20maintenance%20encompasses%20a,reliable%20energy%20storage%20and%20distribution.

[xxx] Kozlowski, D. (n.d.). Onsite options. FacilitiesNet. Retrieved December 8, 2024, from https://www.facilitiesnet.com/powercommunication/article/Onsite-Options--1679#:~:text=The%20average%20operations%20and%20maintenance,%240.007%2D%240.015%20per%20kWh.

[xxxi] Cummins Inc. (n.d.). Educational material 0056662. Retrieved December 8, 2024, from https://mart.cummins.com/imagelibrary/data/assetfiles/0056662.pdf

[xxxii] SolarEdge. (n.d.). Solar system maintenance guide. Retrieved December 8, 2024, from https://www.solaredge.com/aus/for-home/info-centre/maintenance-cleaning/solar-system-maintenance-guide#:~:text=Look%20for%20cracks%2C%20chips%2C%20or,check%20mounting%20hardware%20for%20corrosion.&text=Hire%20a%20licensed%20professional%20to,%2C%20inverters%2C%20and%20mounting%20systems.&text=Remove%20dirt%2C%20bird%20droppings%2C%20or%20pollen%20to%20maintain%

20maximum%20efficiency.&text=Cut%20back%20trees%20or%20shrubs%20casting%20shadows%20on%20panels.

[xxxiii] Blewett, D. (2024, June 3). Wind turbine cost: How much? Are they worth it in 2024?. Weather Guard Lightning Tech. Retrieved December 8, 2024, from https://weatherguardwind.com/how-much-does-wind-turbine-cost-worth-it/#:~:text=%241%2C300%2C000%20USD%20per%20megawatt.,on%20wind%20turbine%20operational%20cost.

[xxxiv] Stehly, T., & Duffy, P. (2022). 2021 cost of wind energy review. National Renewable Energy Laboratory. Retrieved December 8, 2024, from https://www.nrel.gov/docs/fy23osti/84774.pdf

[xxxv] Universal Technical Institute. (2024, April 17). Wind turbine maintenance: The definitive guide. Retrieved December 8, 2024, from https://www.uti.edu/blog/wind-turbine/wind-turbine-maintenance

[xxxvi] Renewables First. (n.d.). Hydropower operation & maintenance services. Retrieved December 8, 2024, from https://renewablesfirst.co.uk/renewable-energy-technologies/hydropower/hydropower-operation-maintenance-services/#:~:text=Hydropower%20Non%2Droutine%20Maintenance&text=Such%20work%20can%20include%3A,Sensor%20replacement%20and%20calibration.

[xxxvii] Cummins Inc. (n.d.). Educational material 5300203. Retrieved December 8, 2024, from https://mart.cummins.com/imagelibrary/Asset/5300203_0920.pdf.ashx