EPRI

September 2023

EPRI Insights

Alternatives to Traditional Grid Solutions

www.epri.com

© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved.

OFF-GRID SOLUTIONS OPERATE INDEPENDENTLY OF THE CONVENTIONAL GRID

Off-grid alternatives refer to systems or solutions that allow individuals or communities to operate independently of the conventional power grid and other utility services. These systems usually include a combination of technologies, such as on-site solar photovoltaics (PV) and wind coupled with batteries, a charge controller, power conditioning equipment, safety equipment, and other instrumentation. The ability to store excess energy generated during peak times and utilize it when demand is high enhances the viability of off-grid solutions. Advancements in energy storage technologies, such as batteries, have increased their feasibility for utility use as off-grid alternatives. These systems are not connected to the grid in any way. Some systems also utilize fossil-fuel fired generators in the absence of reliable renewable energy.

A sample off-grid system

The variability and benefit of off-grid energy solutions depend on system location, purpose, sizing, and costs. In general, off-grid energy systems can offer the following opportunities:

- Energy Independence. Off-grid alternatives provide communities or facilities with the ability to generate their own electricity independently of the central utility grid. This allows them to gain greater control over their energy supply and reduce dependence on external sources.
- Zero-Carbon Energy Generation. Use of renewable energy sources contributes to a cleaner and more sustainable energy supply, helping to reduce greenhouse gas emissions and the impacts of climate change. These alternatives could also reduce wildfire risk by reducing line loading during heat waves.
- Rural Electrification. Off-grid alternatives can provide electricity access to areas where extending the central grid infrastructure is impractical or uneconomical due to geographical barriers or high costs. Utilities can opt for off-grid solutions to serve customers in these areas, using localized power generation and distribution systems rather than investing heavily in grid expansion.

© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved.

OFF-GRID SOLUTIONS REQUIRE AN ADDITIONAL COST

- **Operation and maintenance cost.** A remote system requires a dedicated team for operational monitoring and regular maintenance to ensure load is met at all times and power quality is maintained [1].
- **Cost to maintain reliability.** There is a tradeoff between reliability and cost. To increase the reliability of variable renewable energy (VRE*), such as solar and wind, overbuilding** of the system and its components is needed. This incurs additional cost in land and equipment sizing of all resources (that is, the PV panel, battery, generator, inverter, and generator fuel).
- **Load management.** In an off-grid system, instantaneous maximum power demand needs to be tracked, and loads need to be categorized as critical or non-critical in order to address fixed and flexible loads. Investment is needed in the form of data collection, dashboard creation, and planning [2].
- **Generator-based backup system.** Most off-grid systems incorporate diesel, oil, or natural gas-based generators as dispatchable resources in case of low energy output from VRE resources. Additional costs include fuel costs for the backup generation and controls needed for ancillary services, such as black-start, voltage, and frequency support [3].

*Variable Renewable Energy (VRE)

- Targeted demand response, including the following, can be applied to decrease overall off-grid system cost and maximize clean resource utilization:

  Load shift: Battery storage can avoid curtailment and shift non-critical load during off-peak hours, changing the load profile and overall cost.

  Peak shaving: Energy saving habits and energy-efficient appliances can help reduce energy consumption.

**Overbuilt System [4]

- Overbuilt systems for VRE resources are designed to generate more power than is needed under normal circumstances. This is done to ensure that the system can meet demand during times of peak production or when unexpected disruptions occur.
- VRE resources are usually overbuilt to supply multiple times the peak load demand to ensure that load capacity is met during seasonal low VRE generation [5]. With no backup from the grid, the battery storage or generators are also built for a higher capacity that can meet the peak load and demand at any time to compensate for the variable nature of renewable energy [3].

© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved.

EXAMPLES OF GLOBAL USE CASES: ISOLATED ENERGY SYSTEMS

Stand Alone / Isolated Energy Systems Use Cases

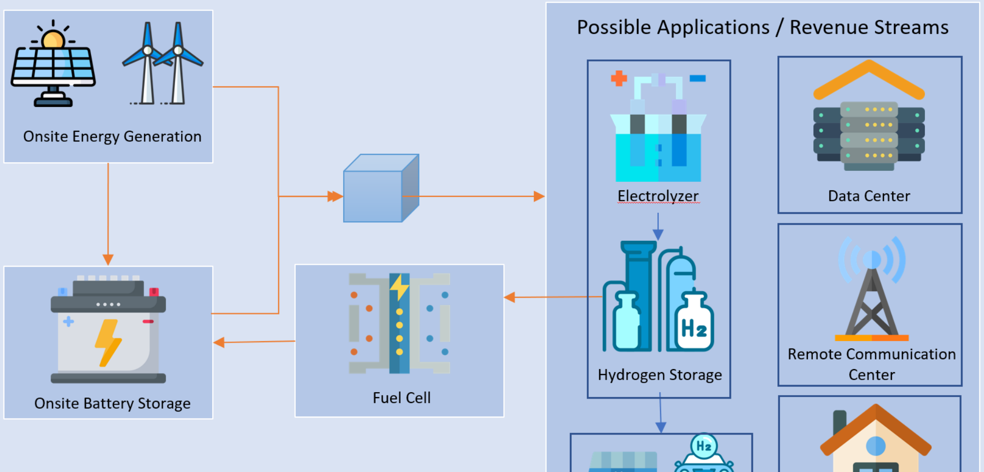


Figure: Possible pathways for utilizing stand-alone energy system.

Off Grid Data Centers:

Green Mountain Data Center: Stavanger, Norway [6]

- Located in Norway and completely disconnected from the electrical grid
- Powered entirely by nearby hydroelectric plants and on-site wind turbines
- Designed for sustainability with renewable energy and natural cooling
- Provides colocation services to customers wanting a green, resilient data infrastructure

Lefdal Mine Data Center: Norway [7]

- Situated in a former underground mine in Norway
- Utilizes on-site wind turbines and geothermal energy for power and cooling needs
- Promotes sustainability by using local renewable resources
- Offers colocation services in a unique underground facility with green operations

Remote Communication Centers [5]

- Off-grid systems help overcome the inherent limitations of traditional power systems for telecommunications that have been reliant on grid power and diesel generators.
- Solar and wind energy are the primary sources used in off-grid telecommunication applications.
- Coupled with energy storage, these systems can provide continuous and reliable power supply in places where the traditional grid is either unreliable or non-existent.
- The intermittency of solar and wind might pose significant challenges and requires additional storage to compensate.

Solar-Powered Hydrogen Production [4]

- These systems focus on replacing diesel generators with PV, batteries, and fuel cells.
- The systems use solar energy for direct consumption and use the surplus for hydrogen production (electrolyzer).
- The hydrogen can then be used to produce electricity vial fuel cells.

Remote Sites at Queensland, Australia Under Isolated Networks Strategy 2030 [1,2]

Ergon is looking into decarbonizing 39 off-grid systems that traditionally rely on diesel generators by installing residential PV and battery storage to provide a more reliable, sustainable source of power. It aims to:

- Improve service to aboriginal and remote communities
- Reduce the cost of electricity
- Increase job opportunities
- Improve climate change resilience in the islands

Wind-Powered Remote Location: St. Mary's, Alaska [3]

Mountain Village in remote Alaska has a 900-kW wind turbine and a 2-MW diesel power plant. The wind resource was added to reduce fuel dependency due to concern over fuel shipment limitations.

- The power system servers about 700 people in St. Mary and two villages (Pitka's Point and Mountain Village)
- Funded by a U.S. Department of Energy Indian Energy grant and Pitka Point Native Corporation Renewable energy
- Able to avoid a $5.3 million diesel cost.

© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved.

EPRI

DISTRIBUTED ENERGY RESOURCES AND DISTRICT ENERGY IN STAND-ALONE CONFIGURATIONS

- Distributed energy resources (DERs)in common on-grid uses are small-scale distribution-connected power generation and storage technologies (3 kW to 10 MW) located near electricity use, such as rooftop solar PV and batteries.
- Some DERs—including wind, solar, fuel cells, turbines, and storage—can connect to the grid or operate off-grid.
- Off-grid DERs enable facilities to operate independently, improving efficiency and emissions.
- Off Grid DERs are a solution for remote facilities, because they generate dedicated off-grid power, enabling independent operations and cost savings.
- Utilities can use Off Grid DERs to delay or avoid upgrades to generation, transmission, and distribution infrastructure.
- DERs can generate electricity and utilize waste heat for heating processes, improving overall efficiency, costs, and emissions.
  - District energy efficiently heats/cools multiple buildings from a central plant using steam, hot water, and/or chilled water pipes.
  - Combined heat and power (CHP) and cogeneration enable simultaneous on-site production of electricity and heat.

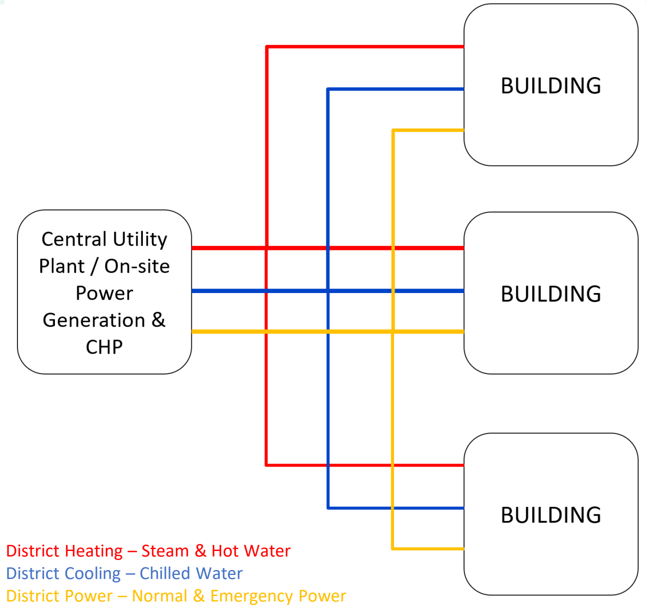
Applications in Stand-Alone Configurations

DER (1)

Off-grid DERs operate continuously to match demand. Their high efficiency minimizes costs and emissions; reliability is critical, but maintenance is expensive. Engines and gas turbines are often most cost-effective. Engines and microturbines suit smaller systems, while gas turbines suit larger ones. Fuel cells offer environmental benefits, but are expensive. Renewables, such as solar, wind, and hybrids, work where fossil fuels are limited in availability, permitting is difficult, and/or grid extension is expensive. In remote areas, fossil-fuel-fired generator logistics have high costs, so hybrid renewable systems can be more cost-effective over the long term.

District Energy(2,3)

For off-grid facilities with multiple buildings that need heating, cooling, and power, an on-site district energy system could be beneficial. Although currently fossil-fuel based, district systems can utilize renewables such as biofuels, solar, and geothermal. CHP requires generation technologies that produce excess heat, such as diesel engines, gas turbines, fuel cells, microturbines, or nuclear facilities. Additional heat capture equipment increases costs. CHP incremental project costs are site-specific but are approximately $400/kW for piping, heat exchangers, and engineering.



© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved.

OPPORTUNITIES FOR UTILITIES

Stand-alone renewable energy systems offer utilities a way to serve rural and remote communities that would otherwise be too costly to connect to conventional transmission and distribution infrastructure. At the same time, properly integrated off-grid systems can benefit utilities by reducing grid expansion costs and supporting stability [1,2,3,4].

Business Model Trends

- **Community model.** The utility owns and operates a local solar+storage system, serving a small community or area off the main grid. Customers pay the utility for their power usage.
- **Pay-as-you-go.** Customers pay the utility incrementally as they use the off-grid system, enabled by prepaid metering and mobile payments.
- **Micro-utilities.** The utility establishes a separate subsidiary or spinoff for off-grid systems, which is essentially its own utility startup.
- **Equipment sales.** The utility sells solar systems, batteries, and backup generators directly to customers and provides financing options.

Alternatively, instead of acting as a full-service provider, the utility can act as:

- **An original equipment manufacturer (OEM)** that sells hardware and provides design and engineering consulting services for system planning and construction.
- **An integrated contractor** that uses a build-own-operate model, whereby the utility finances, builds, and operates off-grid systems on behalf of customers or communities.
- **A stand-alone grid operator** that remotely monitors and controls dispersed energy resources—such as solar, batteries, and back-up generators—to orchestrate a cohesive off-grid system.

Global Perspective

UNITED STATES
- Leasing model, coupled with tax subsidies

EUROPE
- Emphasis on solar and offshore renewables

ASIA
- A mix of diesel and renewable on-site generation to improve grid reliability

AFRICA
- Focus on solar

The Way Ahead

Despite promising advancements in stand-alone energy systems, it remains uncertain whether fully off-grid models can achieve widespread growth compared to the legacy electric grid in the near future. Actual adoption trends over time—along with policy decisions, costs, innovation and real-world deployment—will provide a better sense of the off-grid trajectory as these factors become more apparent.

© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved.

OFF-GRID APPLICATION TO FAST-TRACK RURAL ELECTRIFICATION

Sarawak Alternative Rural Electrification Scheme (SARES) [1]

SARES is a government-community partnership program to build a cost-effective grid and electrify remote areas. Under this program in Sarawak, Malaysia, Sarawak Energy built an off-grid system that consists of stand-alone solar or micro hydro systems to overcome the challenge of extending the existing grid in a rugged landscape, dense forest, and winding rivers. This program electrified 57 villages.

- It provides 3 kWh of reliable renewable energy to each household.
- Over 200 villages were identified for off-grid application.
- A complete electrification target is set for 2025

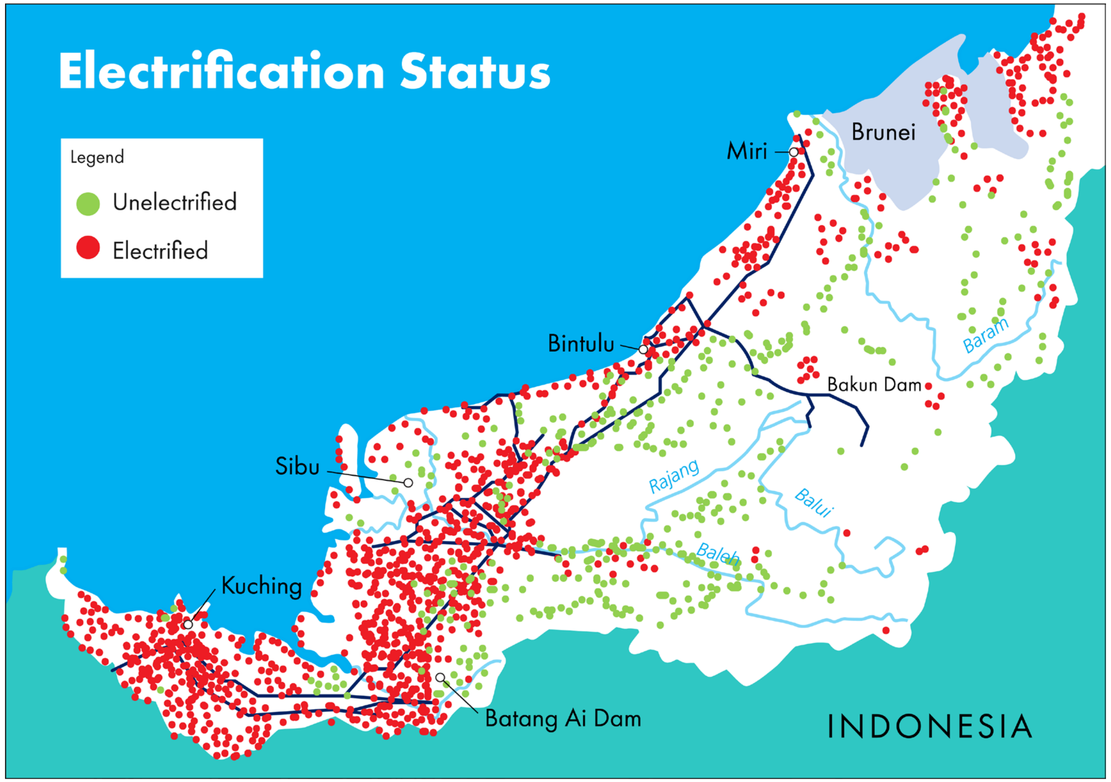
Effectiveness

- Improves reliability by providing 24-hour power to the region
- Reduces the cost of transmission line and infrastructure, compared to the conventional grid
- Acts as a catalyst for social and economic benefits
- Accelerates electrification, compared to the conventional grid
- Reduces carbon emissions and noise from diesel generators
- Reduces shipping costs and fuel requirements

Electrification in Africa [2]

The commissioning of 85 kW of solar power in Gbamu-Gbamu, Nigeria is an example of accelerated electrification in rural Africa. The initiative reduces the financial burden on the government and serves the community with lower-cost electricity than the conventional grid.

- It serves 400 households.
- Its 24-hour power supply ensures replacement of traditional kerosene lanterns.
- It improves access to better street lighting and the internet, while enhancing business engagement.
- It includes microfinance programs, such as appliance financing [3] offered by Rubitec and Mini-Grid Innovation Lab, to provide affordable monthly payment-based home appliances [4,5].



Sarawack Electrification and Transmission map shows the region using an off-grid approach for fast electrification before existing lines can be extended

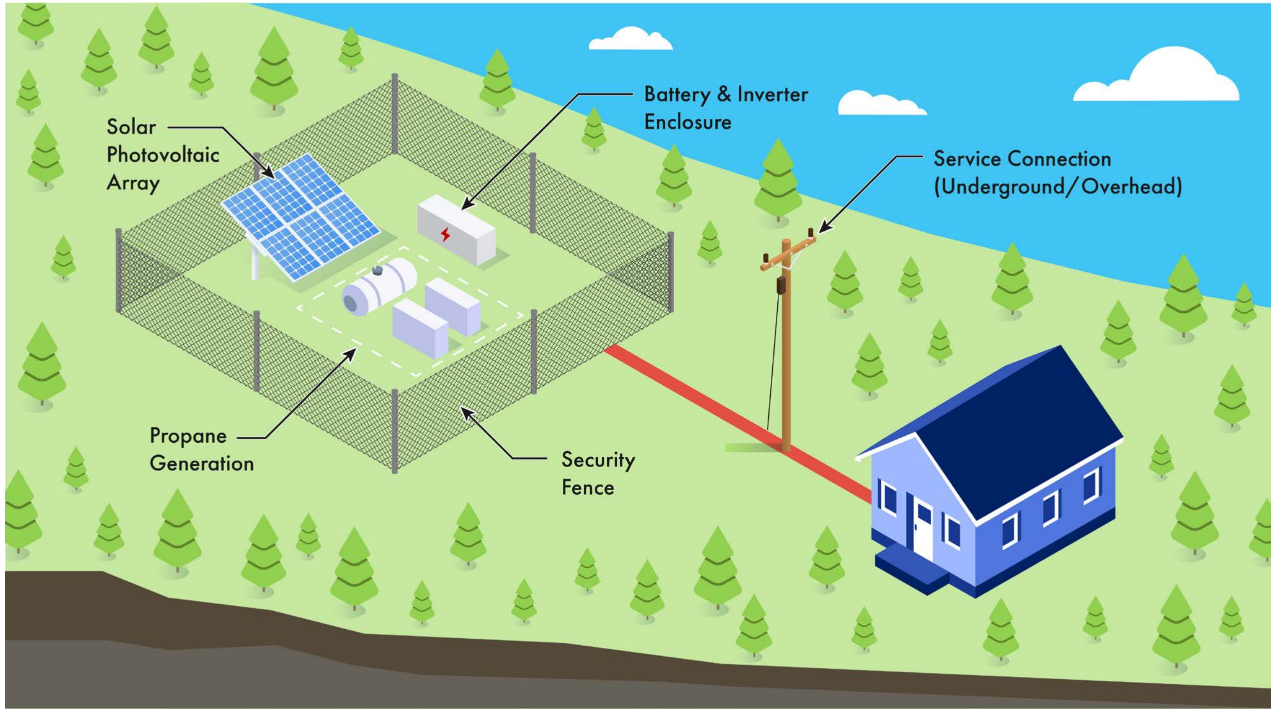
© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved.

UTILITY-OWNED OFF-GRID SOLUTIONS

PG&E Remote Grid Program [1]

Pacific Gas and Electric Company (PG&E) offers off-grid or stand-alone system solutions to areas with a high-wildfire risk and low-density populations to reduce wildfire risk, improve reliability, and reduce public safety power shutoffs (PSPS) in these areas.

- The utility will apply the program to serve a small number of customers for which the program is less expensive than building conventional power lines through steep and dense forestation.
- The program is limited to small-scale (20-kW) load.
- The load will be met with onsite PV, batteries, and a propane-based generator. There will be no import or export of power, so the system will be classified as an on-site distribution asset, rather than a generation unit.
- This program aims to reduce use of mobile diesel generators in blackout scenarios due to wildfires.
- Lake, Sonoma, and Tulare counties are identified as potential implementation areas.



Proposed off-grid connection enables PG&E to serve remote costumers, while minimizing wildfire ignition risk due to electrical equipment. The off-grid system will consist of a solar array, propane based generator, and batteries to provide reliable power.

Effectiveness [2]

- Improves reliability by reducing PSPSs
- Reduces ignition probability from down live-conductor and overhead power lines
- Reduces vegetation management costs for long transmission lines
- Eliminates the cost of hardening and monitoring energized lines in high-wildfire-risk areas
- Eliminates maintenance and replacement costs for overhead lines after extreme weather events, such as high winds and wildfire
- Reduces transmission line costs in steep and rugged terrain

© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved.

REFERENCES

Slide 3

1. M. Jacobson, "The cost of grid stability with 100% clean, renewable energy for all purposes when countries are isolated versus interconnected." *Renewable Energy*, v. 179, pp. 1065-1075, December 2021. https://www.sciencedirect.com/science/article/abs/pii/S0960148121011204.
2. A. Walton, "Load management in remote-area power-supply (RAPS) systems." *Journal of Power Sources*, v. 35, pp 431-4, September 1991. https://www.sciencedirect.com/science/article/abs/pii/0378775391800634.
3. M. Grami, M. Rekik, and L. Krichen, "Interaction between diesel generators to participate in ancillary services," in 2014 15th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA). Hammamet, Tunisia, pp. 859-864, December 2014. https://ieeexplore.ieee.org/document/7086794.
4. W. Driscoll, "Overbuilding Solar at up to 4 Times Peak Load Yields a Least-Cost All-Renewables Grid." *PV Magazine,* May 14, 2020. https://pv-magazine-usa.com/2020/05/14/overbuilding-solar-at-up-to-4-times-peak-load-yields-a-least-cost-all-renewables-grid/.
5. R. Socolow, et al., "Grid-Scale Electricity Storage." Andlinger Center for Energy and the Environment, July 25, 2017. https://acee.princeton.edu/distillates/grid-scale-electricity-storage/#technology.

Slide 4

1. Ergon Energy, "Decarbonising Isolated Communities." Ergon Energy, August 3, 2022.
2. Ergon Energy, "Isolated Networks Strategy 2030." March, 2021. https://www.ergon.com.au/__data/assets/pdf_file/0007/912166/Isolated-Networks-2030-Strategy.pdf.
3. U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Wind Energy Technologies Office, "The Winds of St. Mary's, Alaska." May 16, 2022, www.energy.gov/eere/wind/articles/winds-st-marys-alaska.
4. P. Molina, "PV-powered Hydrogen Generation Tech for Off-grid Areas." *PV Magazine*, September 13, 2022. www.pv-magazine.com/2022/09/13/pv-powered-hydrogen-generation-tech-for-off-grid-areas.
5. HOPPECKE, "Off-grid telecommunications." August 18, 2022. https://www.hoppecke.com/en-us/applications/sun/off-grid-telecommunications/.
6. Green Mountain, "Renewable Power; 100% renewable hydropower for all our data centers." August 15, 2023. https://greenmountain.no/why-green-mountain/renewable-power/.
7. Business Norway, "Leftdal Mine Datacenter is a large-scale data centre in a deep Norwegian mine." https://businessnorway.com/solutions/leftdal-mine-datacenter-large-scale-data-centre-in-a-deep-norwegian-mine

Slide 5

1. U.S. Department of Energy, National Renewable Energy Laboratory, "Using Distributed Energy Resources." May 2002. https://www.nrel.gov/docs/fy02osti/31570.pdf.
2. International Renewable Energy Agency (IRENA), "Renewable Energy in District Heating and Cooling: A Sector Roadmap for Remap," March 1, 2017. https://www.irena.org/publications/2017/Mar/Renewable-energy-in-district-heating-and-cooling.
3. U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, "Combined Heat and Power Technology Fact Sheet Series, District Energy Systems Overview." September 2020. https://www.energy.gov/eere/amo/articles/combined-heat-and-power-technology-fact-sheet-series-district-energy

REFERENCES

Slide 6

1. B. Hannes and M. Abbott, "Distributed Energy: Disrupting the Utility Business Model." Bain, April 17, 2013. https://www.bain.com/insights/distributed-energy-disrupting-the-utility-business-model/.
2. IEA, "Executive Summary – Unlocking the Potential of Distributed Energy Resources." https://www.iea.org/reports/unlocking-the-potential-of-distributed-energy-resources/executive-summary.
3. SolSmart, "Solar Energy Toolkit: Community Solar." January 20, 2017. https://solsmart.org/resource/community-solar#:~:text=Under%20the%20utility%20ownership%20model,their%20share%20of%20the%20panels.
4. A. Moreno and A. Bareisaite, "Scaling Up Access to Electricity: Pay-as-You-Go Plans in Off-Grid Energy Services." World Bank Group, 2015. https://documents1.worldbank.org/curated/en/687851468320946678/pdf/93786-REVISED-LW34-fin-logo-OKR.pdf.

Slide 7

1. Sarawak Energy, "Rural Electrification." https://www.sarawakenergy.com/what-we-do/rural-electrification/.
2. M. Tilleard, G. Davies and L. Shaw, "Minigrids Are the Cheapest Way to Bring Electricity to 100 Million Africans Today." *GreenTech Media*, April 20, 2018. https://www.greentechmedia.com/articles/read/minigrids-are-the-cheapest-way-to-electrify-100-million-africans-today.
3. A. Allee, "Electricity Comes to Nigeria, but Who Will Use It?" *Microgrid Knowledge,* November 14, 2019. https://www.microgridknowledge.com/google-news-feed/article/11429297/electricity-comes-to-nigeria-but-who-will-use-it.
4. T. Oredola, "Amosun commissions 85kw solar power plant for rural dwellers. *The Guardian,* February 14, 2018. https://guardian.ng/energy/amosun-commissions-85kw-solar-power-plant-for-rural-dwellers/.
5. Energy 4 Impact, "Appliance financing unlocks energy consumption among rural mini-grid customers," September 8, 2019. https://energy4impact.org/news/appliance-financing-unlocks-energy-consumption-among-rural-mini-grid-customers.

Slide 8

1. Pacific Gas and Electric Company, "Remote Grid Program." https://www.pge.com/en_US/safety/how-the-system-works/electric-systems/remote-grid-program/remote-grid-program.page.
2. J. St. John, "PG&E Plans Utility-Owned 'Remote Grids' for Isolated Communities." *GreenTech Media,* February 2, 2021. https://www.greentechmedia.com/articles/read/pge-plans-utility-owned-remote-grids-for-isolated-communities.

ACKNOWLEDGMENTS

EPRI Insights documents provide a snapshot of current events, industry forecasts, and R&D with the goal of providing insights that may inform energy strategy. These reports aim to cover the full electricity and integrated energy system pipeline, while also providing more in-depth information on key technologies and trends each quarter.

While based on sound expert knowledge from research programs across EPRI, they should be used for general information purposes only; they do not represent a position from EPRI.

This product was developed with input from EPRI members and subject matter experts from across EPRI. EPRI thanks the internal and external experts and stakeholders for their contributions that helped shape this document.

This report describes research sponsored by EPRI. This publication is a corporate document that should be cited in the literature in the following manner:

Program on Technology Innovation: EPRI Insights: Alternatives to Traditional Grid Solutions, September 2023. EPRI, Palo Alto, CA: 2023. 3002028130.

Principal Investigators

P. Patel, PPatel@epri.com

P. Vij, Pvij@epri.com

A. Jagdale, AJagdale@epri.com

C. Chandrasekaran (Summer intern)

Subject Matter Experts

J. Baum, JBaum@epri.com

J. Shook, JShook@epri.com

B. York, BYork@epri.com

B. Seal, BSeal@epri.com

H. Kamath, HKamath@epri.com

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

3002028130

© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute, EPRI, and TOGETHER...SHAPING THE FUTURE OF ENERGY are registered marks of the Electric Power Research Institute, Inc. in the U.S. and worldwide.

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com