Life Cycle Assessment of Photovoltaic Microgrids

In off-grid communities

Off-Grid | First Solar | BREN SCHOOL ENVIRONMENTAL SCIENCE & MANAGEMENT UNIVERSITY OF CALIFORNIA, SANTA BARBARA

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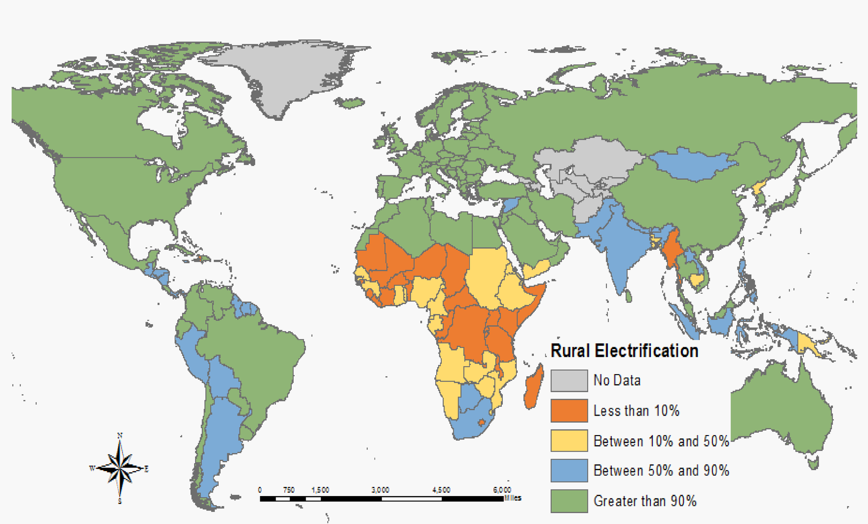
The Energy Access Problem

18% of the world's population, over 1.3 billion people, lack access to electricity.



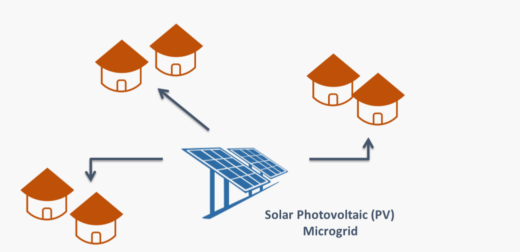
Many people without electricity live in rural off-grid communities. Supplying electricity access to these communities can provide substantial benefits, including reduced mortality, poverty alleviation, and improved overall quality of life.

Status Quo vs. Microgrids

Diesel Genset
- Expensive for a single family
- Limited access to diesel fuel

Grid Extension
- Capital intensive
- Long waiting period

Microgrids



- Microgrids are smaller, stand-alone versions of traditional grids usually powered by renewable energy.

Objectives

1. Evaluate the comparative environmental impacts of three microgrid systems:
   1. PV-Battery
   2. PV-Diesel
   3. PV-Hybrid
2. Evaluate the overall microgrid impacts from different:
   a. PV-Technologies
   b. Sourcing locations
   c. Recycling

Approach

Evaluate: A process-based life cycle assessment (LCA) was used to evaluate the environmental impacts of microgrids from resource extraction to manufacturing and end of life. The material and energy inputs/outputs for all components through their individual life cycle stages are combined to form the life cycle environmental impact of the microgrid systems. The life cycle impacts are calculated per kWh of electricity produced.

Compare: Environmental impacts per unit of electricity produced allow for an accurate comparison across PV microgrid types and other electrification options.

1 PV - BATTERY
PV array with a battery sized to meet complete daily demand. Other components include a charge controller, inverter, wiring, electricity meters, and fencing.

2 PV - DIESEL
A diesel genset is substituted for the battery backup and charge controller.

3 PV - HYBRID
Uses both a battery backup and a genset. Difference between the daily demand and PV electricity produced is met by the genset.

Results

Overview

Category	Home Genset	Grid Extension	PV-Battery	PV-Diesel	PV-Hybrid
Climate change	1.41E+00	5.77E-01	1.10E-01	9.71E-01	2.67E-01
Eutrophication (Algal Blooms)	3.73E-05	4.50E-08	2.03E-04	4.13E-05	2.04E-04
Particulate Matter (Air Pollution)	8.45E-03	1.76E-03	4.25E-04	5.74E-03	1.34E-03
Photochemical Oxidants (Smog)	2.59E-02	2.44E-03	5.13E-04	1.75E-02	3.26E-03
Acidification	1.56E-02	3.88E-03	1.34E-03	1.06E-02	3.02E-03

Environmental Impacts of Energy Access Options Per kWh

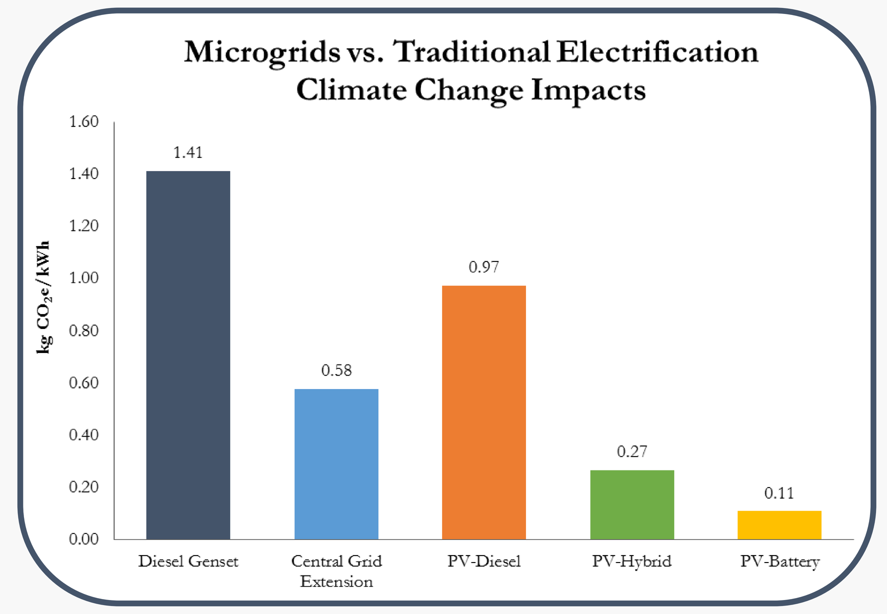
PV-Battery Savings in 4 of 5 Categories

The PV-Battery system had the lowest impact (green highlights) per kWh in the climate change, particulate matter, photochemical oxidants, and acidification categories in large part because it didn't rely on fossil fuels for electricity production. Despite this, there was a potential tradeoff for the PV-Battery system in the eutrophication category.

46-92% Climate Savings for Battery Backups

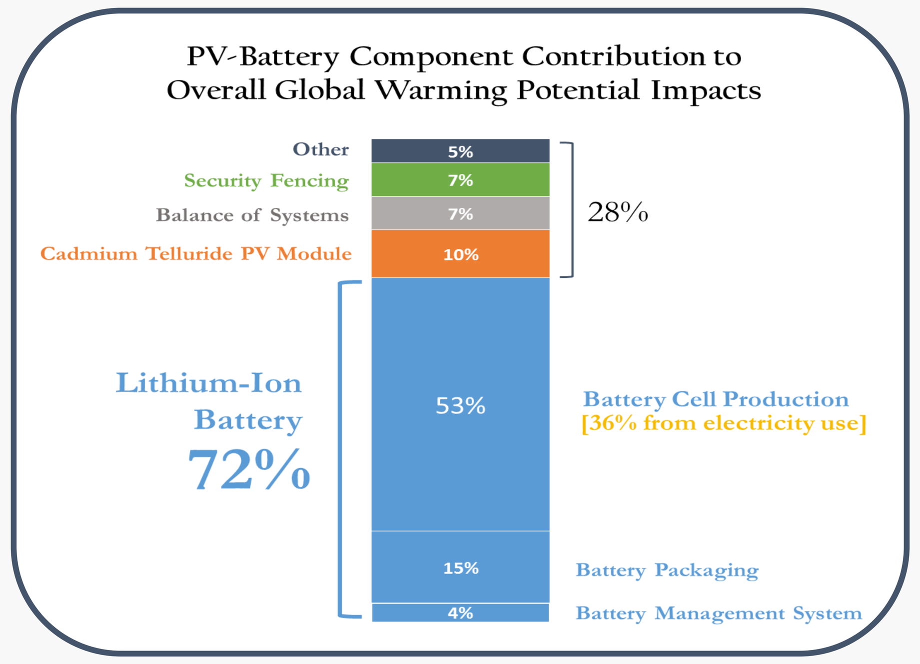
Compared to home gensets (navy), PV microgrids save 31-92% in climate change impacts. Compared to central grid extension (light blue), the PV-Battery (gold) and PV-Hybrid (green) systems had substantially lower climate change impact per kWh of electricity production (81% and 54% respectively), while the PV-Diesel system (orange) had higher impacts per kWh. Similar savings were seen in the other benefit categories.

Systems with battery backups have the lowest GHG impact.



Per kWh Climate Change Impacts for Energy Access

Contribution Analysis



Proportion of Total PV-Battery Impact by Component

Batteries Account for 72% of Climate Impacts

Overall, 50% of the total battery impacts and 36% of the total microgrid impacts in climate change come from the electricity used in the manufacturing of the battery cell. This in mind, location of manufacturing substantially influences the overall climate change impact. For example, sourcing the battery from China instead of the European baseline increases the total microgrid climate change impact by over 35%.

Battery sourcing is critical to reducing microgrid climate impacts

Recycling

17-65% Recycling Savings for PV-Battery

The PV-Battery and PV-Hybrid systems had the largest recycling savings (7-68% depending on the category). The PV-Diesel system had much smaller savings because the majority of its impacts stemmed from the burning of diesel fuel. Adding recycling enhances the PV-Battery benefits and minimizes its potential tradeoffs compared to the other energy access options.

Recycling significantly reduces microgrid impacts

Impact Category	PV-Battery	PV-Hybrid	PV-Diesel
Climate Change	17.7%	10.6%	0.9%
Eutrophication	65.4%	64.1%	19.3%
Particulate Matter	40.6%	15.1%	0.6%
Photochemical Oxidants	33.9%	6.7%	0.3%
Acidification	36.2%	17.9%	0.8%

Impact Savings from Microgrid Recycling

Discussion

The results of this analysis highlight major conclusions regarding the development of solar microgrids as energy access solutions. First, the PV-Battery and, to a lesser extent, the PV-Hybrid microgrid systems have significantly lower climate change, particulate matter, photochemical oxidants, and acidification impacts compared to the PV-Diesel system, home diesel generators, and central grid expansion.

This highlights the environmental and health advantages of microgrid systems with a battery backup, compared to systems that use a diesel generator, in regions with high insolation and low demand such as Kenya. This distinction in the particulate matter, photochemical oxidant, and acidification impacts is particularly significant for off-grid communities due to the local nature of these effects. While the PV-Battery design does affect these impact categories, the majority of these impacts result from the manufacturing stage, rather than during the use phase on-site in off-grid communities.

Limitations

While this analysis provides an in depth exploration into the environmental impacts of various scenarios for different microgrids, there were some limitations associated with the modeled impacts. The study didn't model:

- The socioeconomic considerations of microgrids (i.e. life cycle costing)
- Varying battery chemistries (e.g. lead acid batteries)
- The impacts from the inevitable increase in electricity demand

Takeaways for Stakeholders

Off-Grid Communities

- PV microgrids are adaptive and potentially feasible long term energy access solutions.
- PV microgrids with a battery backup provide clear environmental and health benefits, compared to other potential energy access options.

Solar Developers

- Focus on system wide comparative analysis.
- Reduce environmental impacts by including energy storage systems and sourcing batteries from low impact electricity grids.
- Establish takeback and recycling programs to reduce overall system environmental impacts.

Global Policy Makers

- PV microgrids with battery backups can bridge the energy gap and improve the quality of life in off-grid communities.

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