DISCUSSION

The results of this analysis highlight major conclusions regarding the development of solar micrograids 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 oxidants, 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 grid mix locations.
- Establishing 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.

ACKNOWLEDGEMENTS

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Off Grid

Assessing the Life Cycle Environmental Impacts and Benefits of PV-Microgrid Systems in Off-Grid Communities

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Advisor: Roland Geyer | **Client:** Parikhit Sinha (First Solar)

BACKGROUND

Currently over 1.3 billion people (18% of the global population) lack access to an electrical grid (Figure 1). Without access, communities rely on potentially impactful alternative energy sources such as diesel generators, kerosene or biomass combustion. If communities can gain access to electricity, they receive significant benefits in terms of human health, economic development and overall quality of life.

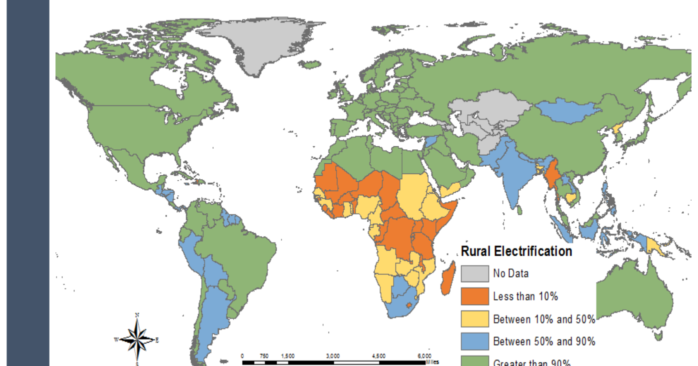


Figure 1. Global rates of rural electrification. WEO 2015

As large-scale electricity grids require a vast amount of time and money, they are not a reasonable electrification solution in many communities. An alternative solution is the use of smaller, stand-alone versions of grids known as micrograids. These microgrids typically run on photovoltaic (PV), hydro, or wind renewable energy sources and act as a stable electricity source for communities.

First Solar has recognized the benefits of microgrids and has teamed up with Powerhive to install microgrid pilot projects in Kenya with 10kW, 20kW and 50kW capacities. Solar developers are looking to increase microgrid development, and to do so they need to understand the tradeoffs between different system designs.

OBJECTIVES

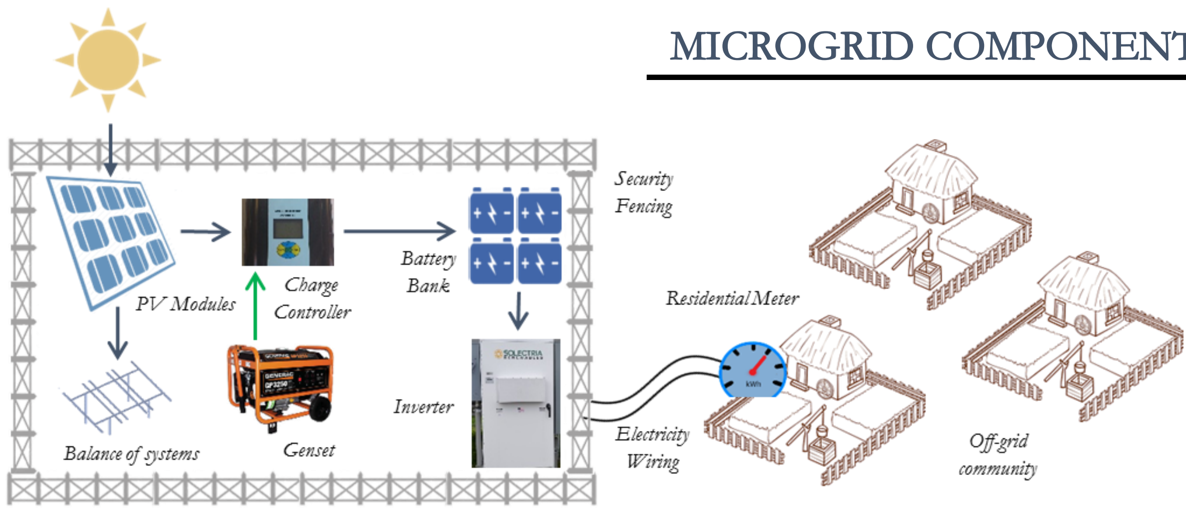
1. Evaluate the comparative environmental impacts of three microgrid systems:
   a. PV-Battery
   b. PV-Diesel
   c. PV-Hybrid &
2. Evaluate the overall microgrid impacts from different:
   a. PV-Technologies
   b. Sourcing locations
   c. End of life scenarios

SIGNIFICANCE

This analysis aids in expanding electricity access by providing microgrid developers with improved information regarding the environmental impacts of PV microgrids. Increased electrification will lead to the achievement of significant global development outcomes such as reduced mortality, local economic development, improved quality of life, and significant environmental improvements.

This study also advances life cycle research as it is only the second life cycle assessment of an entire microgrid system. Assessing a complete microgrid, rather than just individual components, better informs implementation decisions. This research also serves as a first step toward improving the overall impact of microgrids by identifying impact hotspots and opportunities for improvement of environmental sustainability.

MICROGRID COMPONENTS



APPROACH

A process based life cycle assessment (LCA) was used to estimate the environmental impacts of three types of microgrids over their lifetime: 1 PV-Battery, 2 PV-Diesel, and 3 PV-Hybrid. Each system and its components were sized based on fixed demand and meteorological parameters. A thorough life cycle inventory of all the material and energy flows for each component was developed through primary and secondary research.

GaBi software was used to calculate the lifetime environmental impacts for each microgrid system. Additionally, a central electricity grid and diesel generator (genset) were modeled for comparison. A functional unit of 1 kWh electricity output was used for comparison between systems Scenario analyses were run to study changing impact from different PV technologies, battery sourcing locations, and end of life of components.

1. PV - BATTERY SYSTEM

This system contains a PV array with a battery backup which is sized to meet complete daily demand. Other system components include a charge controller, AC/DC inverter, wiring, electricity meters, and fencing.

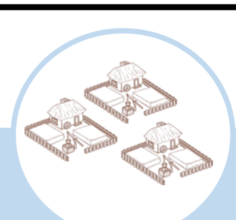
2. PV - DIESEL SYSTEM

The system substitutes a genset system instead of a battery backup and charge controller. The PV array is designed to meet 33% of the daily demand, while the remaining demand is met by the genset. This production allocation optimizes generator efficiency.

3. PV - HYBRID SYSTEM

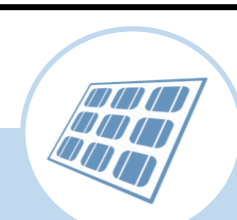
The hybrid system includes both a battery backup and a genset. Sizing and operation is based on the annual percent of No-Sun days. The difference between the daily demand and PV electricity produced is met by the genset.

BASELINE PARAMETERS



- Daily demand per household: 1.55 kWh/day
- Household size: 5.7 ppl
- Village Population: 100

- Geographic location: Kenya (1°16' S, 36°48' E)
- Monthly average DNI: 5.93 kWh/m²/day



- System lifetime: 25 years
- PV technology: Thin Film Cadmium Telluride
- End of Life: Landfill

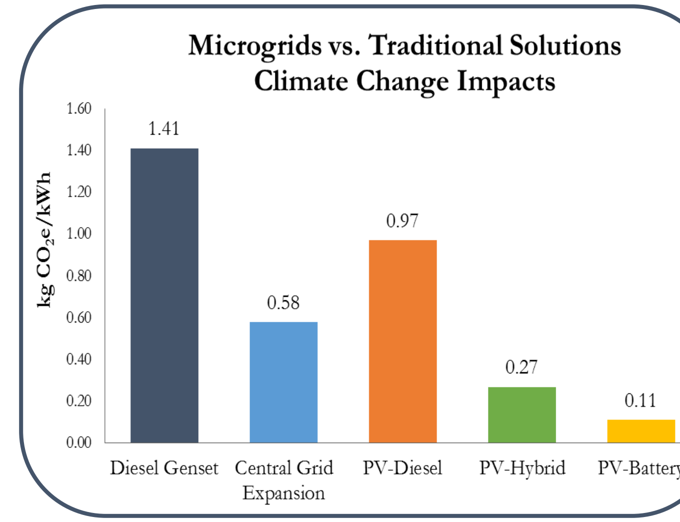
Available on the web at : http://brenoffgrid.weebly.com/ Group Project Brief | Spring 2016

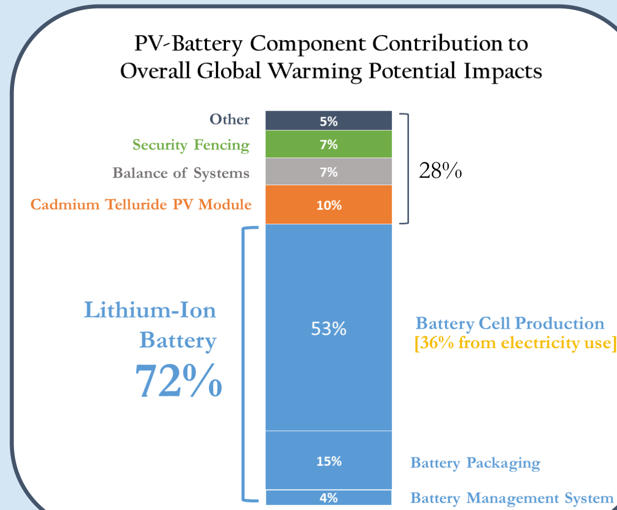
RESULTS

1. Impacts of Electrification Options

The PV-Battery system had the lowest climate change impacts per kWh of electricity production. Compared to small home diesel generators, PV microgrids save 31-92% in climate change impacts. Compared to extending the central electricity grid in Kenya, the PV-Battery and PV-Hybrid systems had substantially lower climate change impact per kWh of electricity production (81% and 54% respectively), while the PV-Diesel system has higher impacts per kWh.

Systems with battery backups have the lowest GHG impact.





2. Climate Change Impact by Component

Looking closer at the PV-Battery system, 72% of the total climate change impacts came from the lithium-ion battery with the majority of those impacts coming from the manufacturing of the battery cell. In total, 50% of the total battery impact and 36% of the total microgrid impact comes from the electricity used in the manufacturing of the battery cell. This in mind, location of manufacturing substantially influences overall climate change impact. For example, shifting the battery production from the baseline European grid mix to a Chinese grid mix increases the total microgrid climate change impact by over 35%, whereas shifting from a generalized European grid to the grid in France or Switzerland decreases overall impact 18-27%.

Battery sourcing is critical to reduce GHG impacts.

3. Impact Savings from Recycling

The PV-Battery and PV-Hybrid systems saw impact savings from recycling on the order of 7-68% depending on the category largely because of the avoided burden of primary material use. The PV-Diesel system had much smaller savings because the majority of its impacts stemmed from the burning of diesel rather than the use of metals. Adding recycling at the end of life enhances the PV-Battery benefits and minimizes its potential tradeoffs compared to other microgrid systems, home diesel gensets, and traditional electrification.

Recycling significantly reduces microgrid impacts.

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