Reducing the carbon footprint of mini-grids in Africa: the value of solar PV

Théo Chamarande, Benoit Hingray and Sandrine Mathy (paper submitted to Applied Energy, Mai 2023)
Rural electrification and carbon neutrality

❖ Paris Agreement 2015:
Global pathways reach carbon neutrality of the energy sector by 2050
Some African countries pledge for net-zero emissions by 2050-2060
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❖ Sustainable Development Goal 7:
Ensure access to affordable, reliable, sustainable and modern energy for all
More than 600 millions of people without electricity in Africa
Rural electrification and carbon neutrality

- **Paris Agreement 2015**: Global pathways reach carbon neutrality of the energy sector by 2050
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- **Sustainable Development Goal 7**: Ensure access to affordable, reliable, sustainable and modern energy for all
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- Solar mini-grids (MG), a promising solution to electrify at low cost and with low emissions?
Simulating hybrid solar/diesel MG

Irradiance from Heliosat SARAH2
Temperature from ERA5

PV production

Batteries

Genset

Typical demand profile from the literature
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For each configuration:
- Levelized Cost of Energy (LCOE)
- Carbon Footprint (CFP)

\[ CFP = \frac{K_{PV} \alpha_{PV} + K_{bat} \alpha_{bat} + K_{gen} \alpha_{gen} + \text{Fuel conso} \alpha_{fuel}}{\text{Supplied energy}} \]

And similar for the LCOE
Sizing MG with the LCOE and the CFP
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PV production

Genset

![Diagram showing PV production and LCOE vs. CFP](image-url)
Sizing MG with the LCOE and the CFP

PV production

Batteries

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LCOE [$/kWh]

CFP [g CO₂/kWh]

Normalized PV capacity [\( \cdot \)]
Sizing MG with the LCOE and the CFP

Let’s focus on these two optimums (CFP* and LCOE*) and this *envelope* curve!
These curves depend on a lot of factors:

- Costs
- CFP of components
- Lifetimes
- Demand profile
- Solar resource
Sensitivity of the results

➢ For this presentation, focus on the effect of the solar resource
Spatial variability of the optimaums

\[ 0.34\$/kWh < \text{LCOE}^* < 0.45\$/kWh \]
\[ 180 g_{CO_2,eq}/kWh < \text{CFP}^* < 300 g_{CO_2,eq}/kWh \]

Same geographical pattern for the \text{LCOE}^* and \text{CFP}^* values
Spatial variability of the optimums

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Same geographical pattern for the LCOE* and CFP* values

Renewable fraction:
LCOE* between 50% and 80%
CFP* higher than 95%
LCOE* and CFP* values highly depend on the mean capacity factor. The variability of the resource has also an impact, especially on the CFP* values.
Distance between the optiumums

LCOE

CFP
c

CFP distance

LCOE distance

LCOE*

CFP*

The characteristics of the solar resource also influence the distance between LCOE* and CFP* values.
➢ The characteristics of the solar resource also influence the distance between LCOE* and CFP* values
➢ Going from the LCOE* to the CFP* configuration requires a relatively high cost increase …
Compromises between LCOE and CFP
Compromises between LCOE and CFP

But significant CFP reduction can be obtained with moderate additional costs!
Add a virtual surcharge to the price of carbon emissive projects:

\[ \text{Project costs with emissions} = \text{Project costs without emissions} + \text{Carbon emissions} \times SPC \]

SPC : Shadow price of carbon
Effect of a shadow carbon pricing

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LCOE_{\text{with emissions}} = LCOE_{\text{without emissions}} + CFP \times SPC
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SPC : Shadow price of carbon
Add a virtual surcharge to the price of carbon emissive projects:

\[ \text{LCOE}_{\text{with emissions}} = \text{LCOE}_{\text{without emissions}} + \text{CFP} \times \text{SPC} \]

SPC : Shadow price of carbon

The IPCC (AR6 WG III) estimated the following value for 2030 to limit global warming to:

- 1.5°C between 60 and 120 $/t_{\text{CO}_2,eq}$
- 2°C between 170 and 290 $/t_{\text{CO}_2,eq}$
➢ Many mini-grids currently installed are running on diesel
To summarize …

- Many mini-grids currently installed are running on diesel
- Integrating solar energy and batteries would allow to reduce by 45 to 70% the CFP and 5 to 25% the LCOE
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To summarize …
➢ Many mini-grids currently installed are running on diesel

➢ Integrating solar energy and batteries would allow to reduce by 45 to 70% the CFP and 5 to 25% the LCOE

➢ Reduce the CFP of MG to its lowest values (around $200 g_{\text{CO}_2,\text{eq}}/kWh$) is possible but can strongly increase the LCOE

➢ But many compromises exist between the optimums and allow to significantly reduce the CFP with moderate additional costs

To summarize …
Thanks for your attention!

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