Integrating a Solar PV System with a Household Based Backup Generator for Hybrid Swarm Electrification:

A Case Study of Nigeria

Rolex Muceka

Africa-EU renewable Energy Research and Innovation Symposium (RERIS 2018)

23 January 2018, *Lesotho*

Presentation outline

Background → Methodology

↓

Results and Discussion → Conclusion

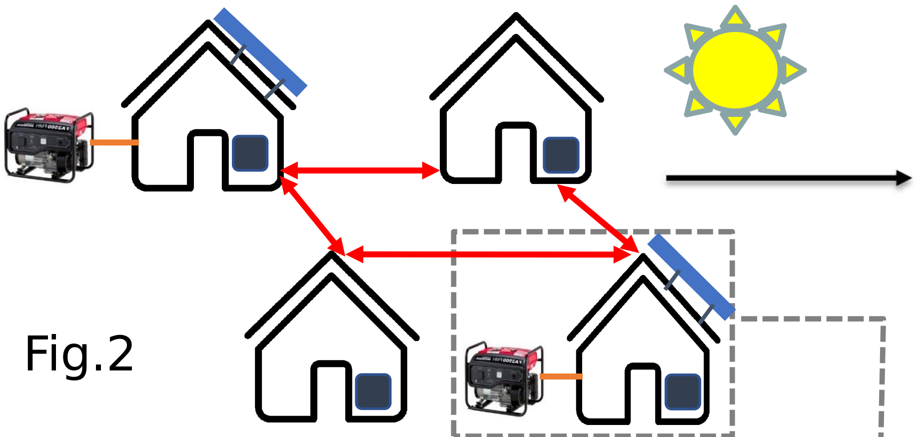
Background ~ SSA

Fig 1. Average number of power outages in Africa (IRENA, 2016)

Starting a generator

Refueling a generator

Methodology



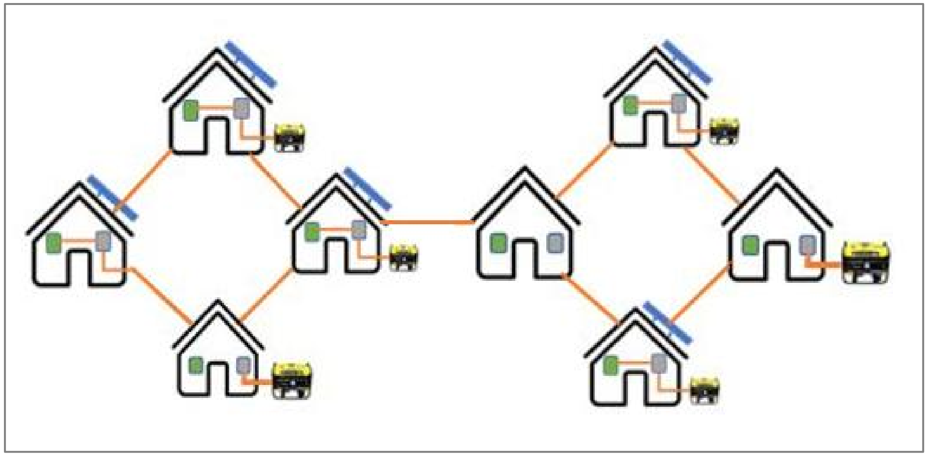
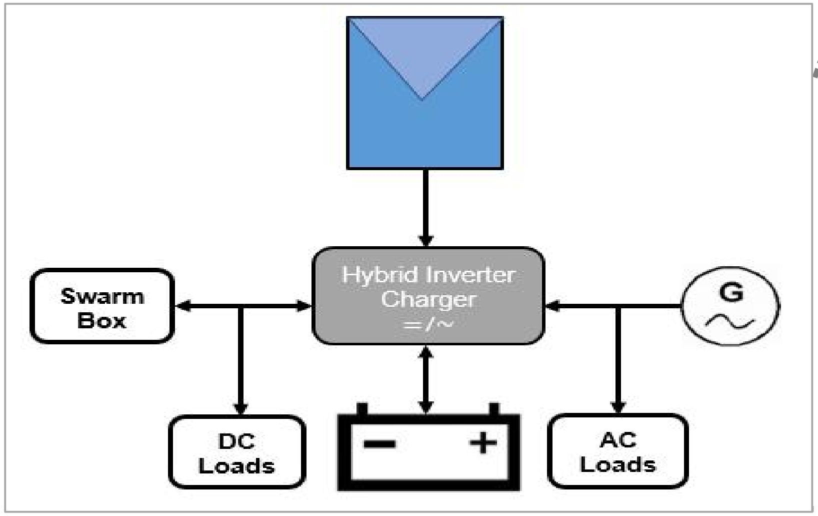
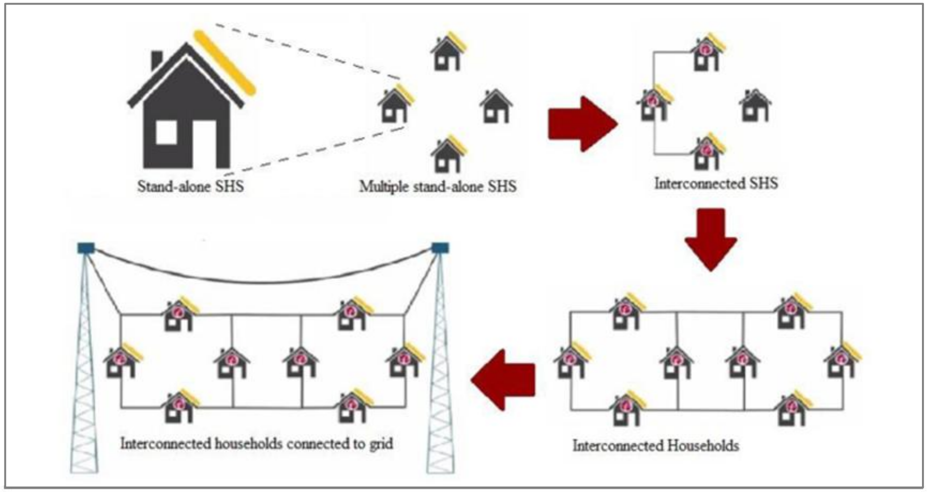


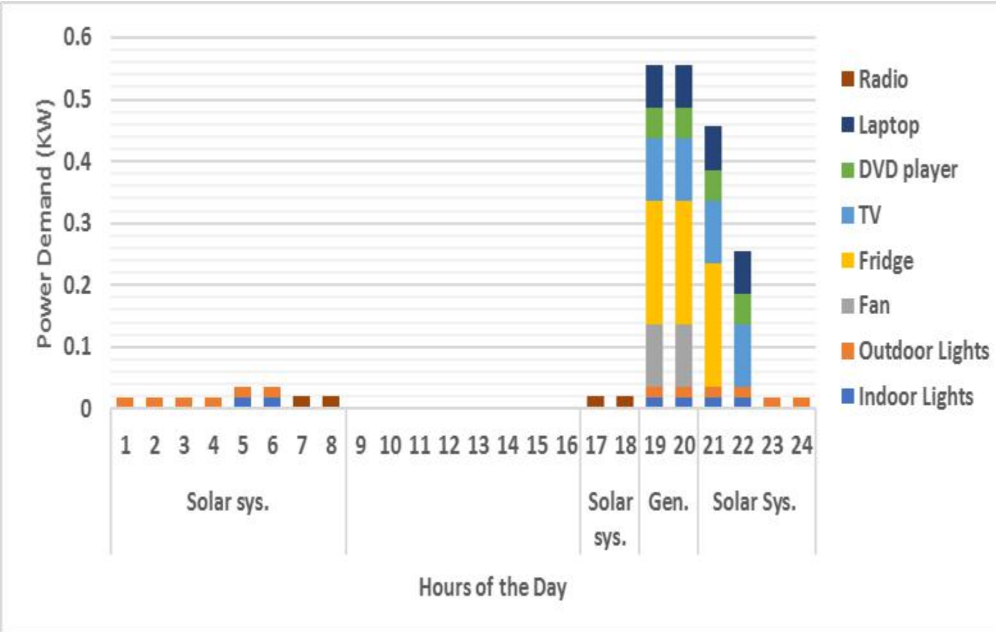
Fig.2

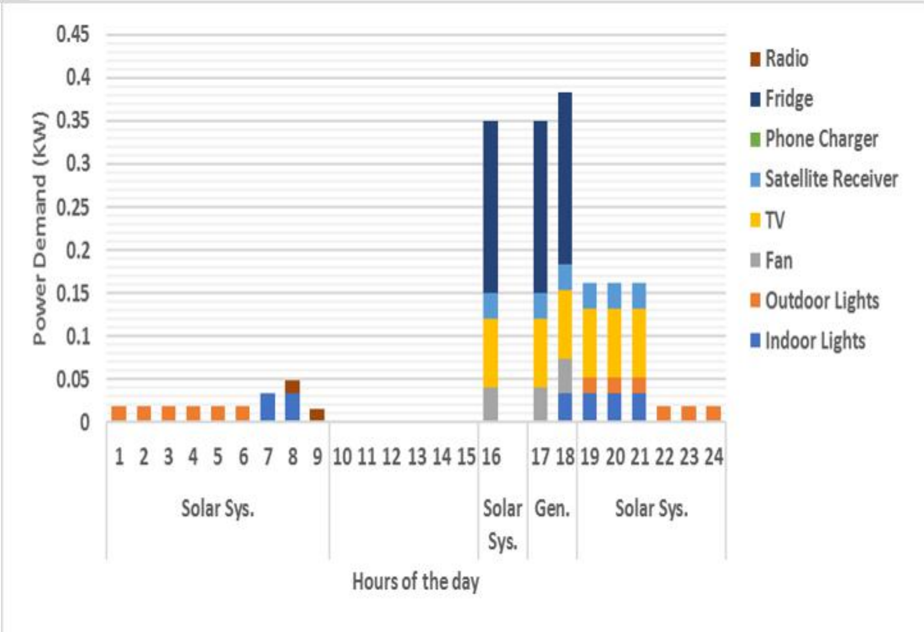




Methodology

- Calculations based on estimated load profile,





Household end user

Retail shop end user

Methodology

- Determined energy demand, energy production, battery storage, excess energy, and LCoE.

$$\text{Solar energy demand; } W_{pv} = W_{pvbat} + W_{pvday}$$

$$\text{Solar energy prodn; } P_{pv} = P_{wp} \times \frac{G}{G'} \times \left[1 + \alpha_t \left(T_a - T_{ref}\right)\right]$$

$$\text{Battery storage; } B_B = \frac{E_{bat} \times AD}{V_s \times DOD \times \eta_{inv}},$$

$$\text{Excess/Unmet energy generation} = P_{pv} - W_{pv}$$

$$ACS = ACC + AOM + ARC + AFC$$

ACC – Annual Capital Cost
CRF – Capital Recovery Factor
AOM – Annual Operation and Maintenance Cost
AFC – Annual Fuel Cost

$$LCoE = \frac{ACS}{E_{year}}$$

LCoE – Levelized Cost of Electricity
ACS - Annualized Cost of the System
E_{year} - Electrical energy consumed in a year

Results and discussion

Table 1. Technical analysis for the systems

End users	System Components	Generator (KVA)	Battery (Ah)	Inverter (VA)	Solar PV (Wp)
Household	Baseline system	1.0	-	-	-
	Designed system	1.0	150	850	300
Retail shop	Baseline system	1.0	-	-	-
	Designed system	1.0	200	500	400

Table 2. Economic analysis for the systems

End users	Economic Parameters	AFC ($ USD)	LCoE ($ USD/KWh)	ACS ($ USD)	ICS ($ USD)
Household	Baseline system	349.12	0.574	381.89	137.3
	Designed system	213.48	0.447	357.81	932.1
Retail shop	Baseline system	299.74	0.582	332.51	137.3
	Designed system	140.96	0.403	320.01	1069.6

Results and discussion ~ Household

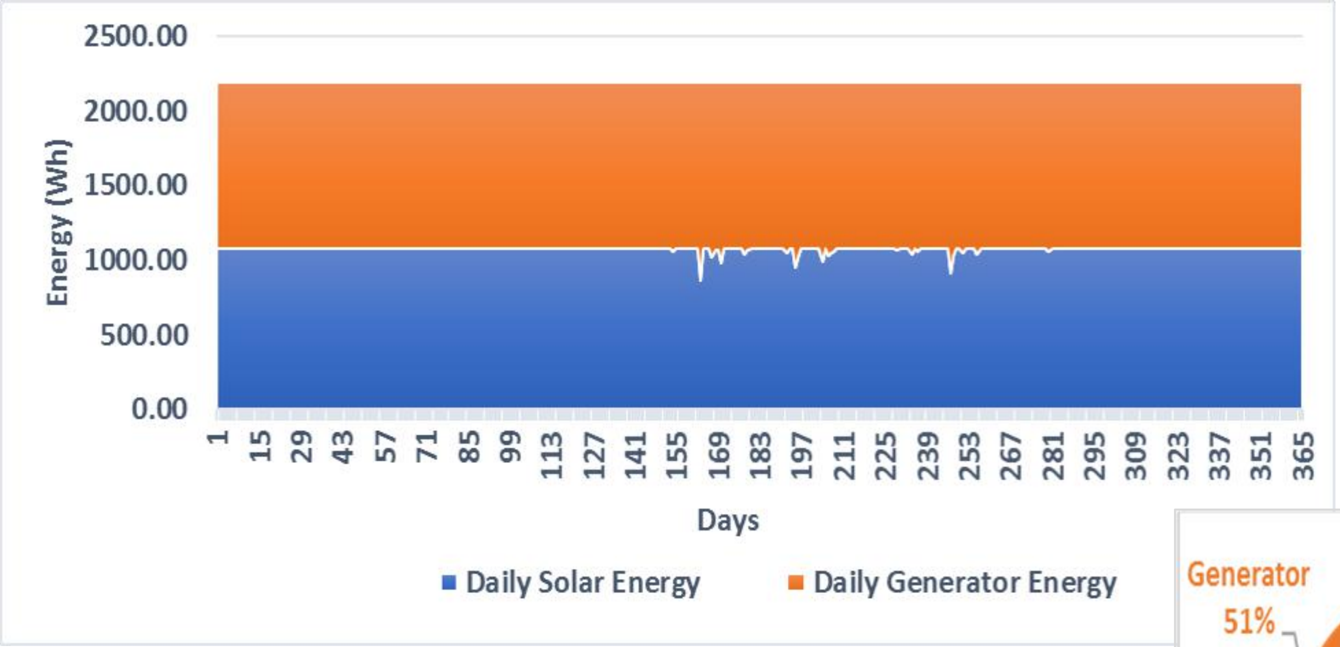
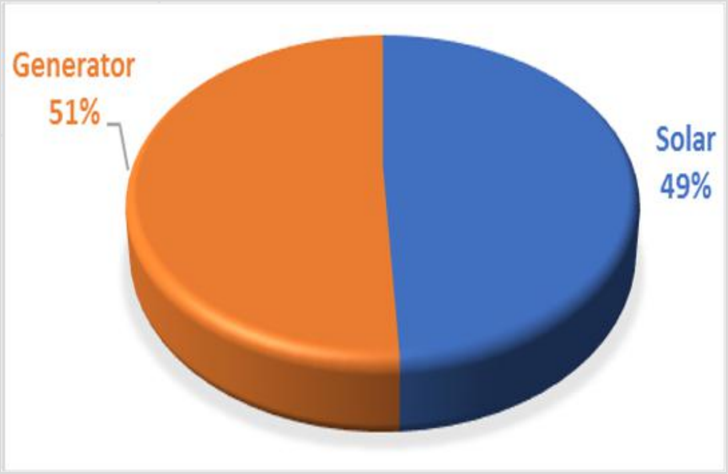
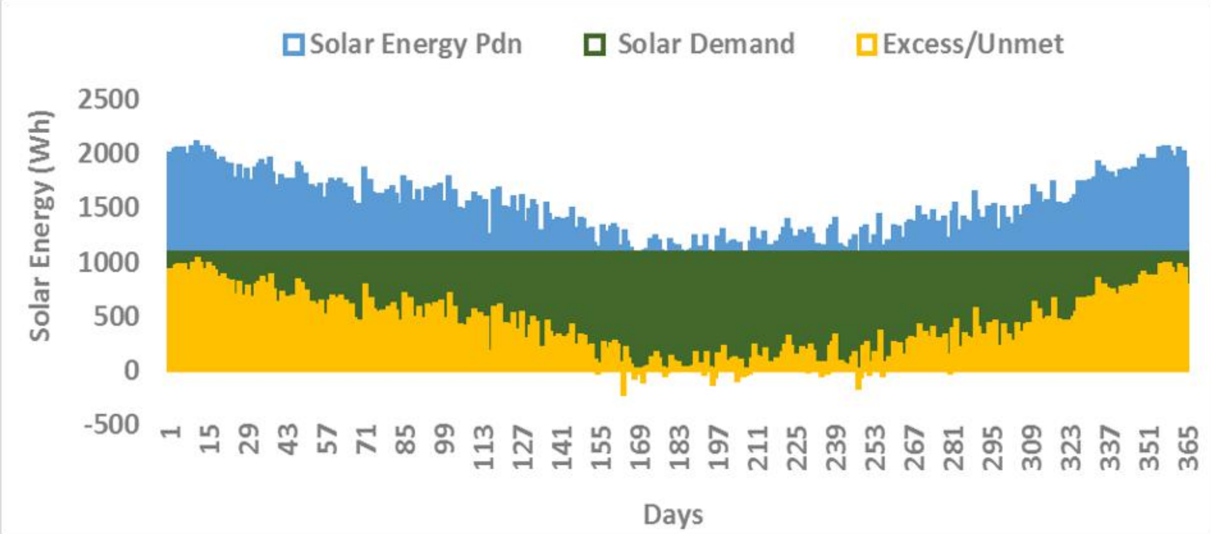


Fig 3. Household energy consumed from solar and backup petrol generator in a year



Results and discussion ~Household



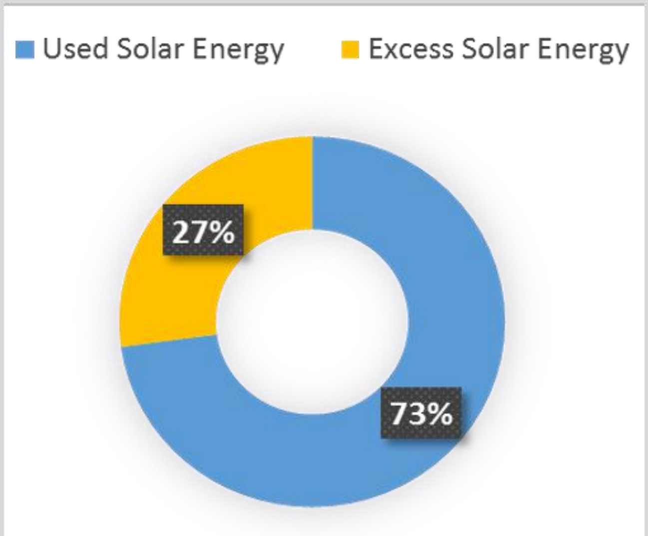


Fig 4. Household system solar energy production and consumption

Table 3. Household solar system energy analysis

Parameter	Value	Units
Total potential solar energy	540	KWh/year
Used solar energy	393	KWh/year
Excess energy generation	147	KWh/year
Ratio of excess generation	27.2	%
Average daily excess energy	428.64	Wh/day

Results and discussion ~Retail shop

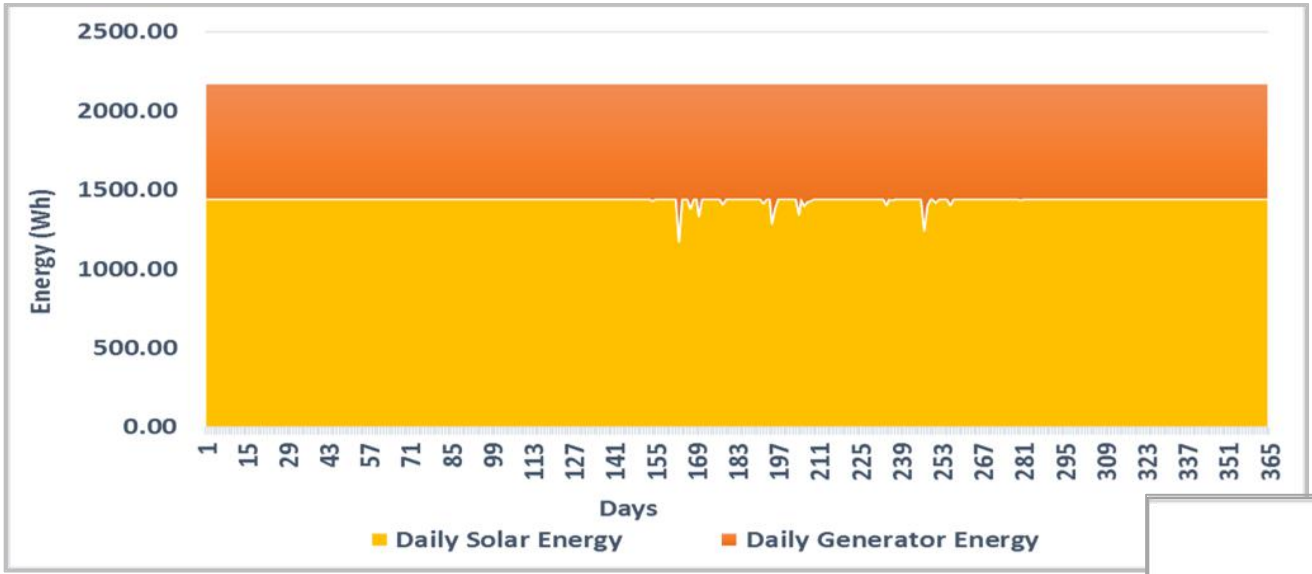
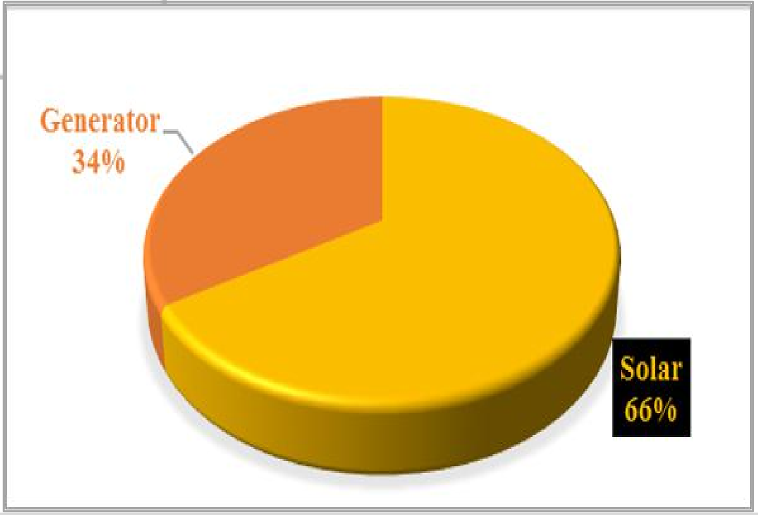
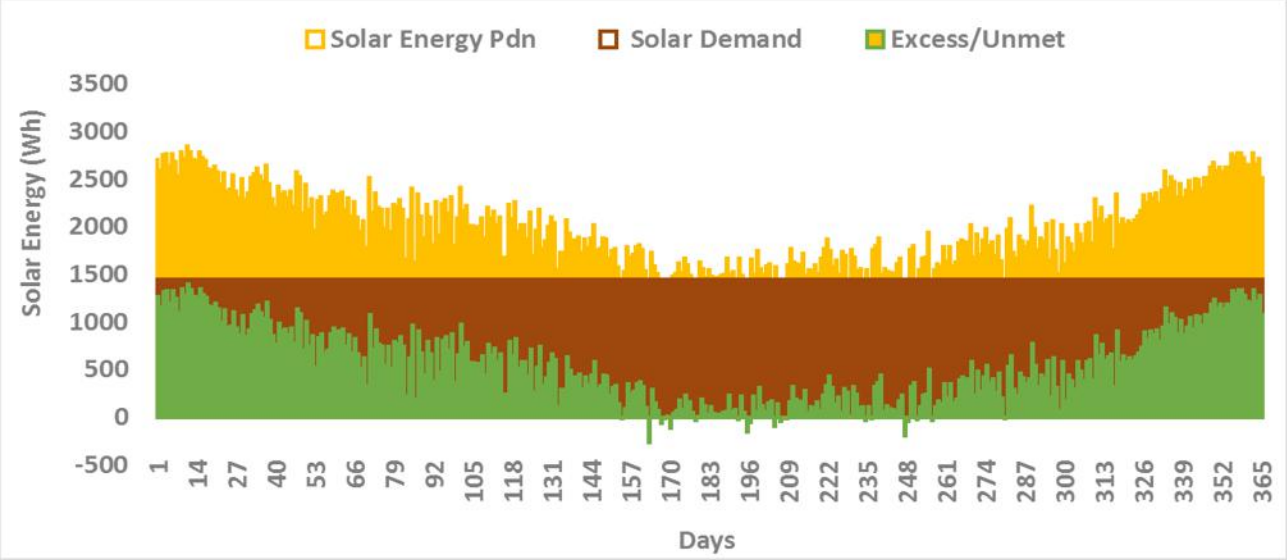


Fig 5. Retail shop energy consumed from solar and petrol generator in a year



Results and discussion ~Retail shop



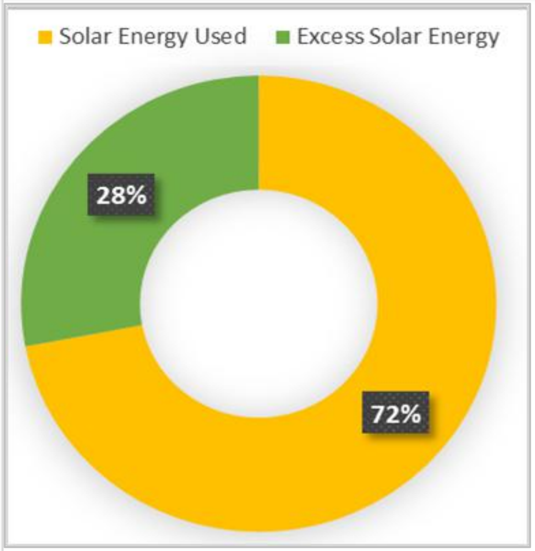


Fig 6. Retail shop system solar energy production and consumption

Table 4. Retail shop's solar system energy analysis

Parameter	Value	Units
Total potential solar energy	728.4	KWh/year
Used solar energy	525.3	KWh/year
Excess energy generation	204.1	KWh/year
Ratio of excess generation	28	%
Average daily excess energy	591.6	Wh/day

Result and discussion ~ cost summary

Table 5. Summary table

End users	Systems	LCoE ($USD/KWh)	Reduction in LCoE	AFC ($USD)	Reduction in AFC	Excess Energy (Solar)
Household	Baseline	0.574	—	349.12		
	Designed system	0.447	22%	213.48	39%	27%
	Designed system (Swarm-grid)	0.378	34%			
Retail shop	Baseline	0.582	—	299.74		
	Designed system	0.403	31%	140.96	53%	28%
	Designed system (Swarm-grid)	0.321	45%			

Table 6. Annualized cost of the systems (ACS)

End users	Systems	ACS ($ USD)
Household	Baseline	381.89
	Designed system	357.81
Retail shop	Baseline	332.51
	Designed system	320.01

30% excess solar energy in a standalone SHS (Kirchhoff, 2013)

The designed systems also cost less at the end of their lifetime

Conclusion

- Power outages are high in sub-Saharan Africa
  - High use of household based fossil-fuel backup generators
  - Fuel is costly, generators are noisy and cause environmental pollution
- Integrating solar PV system
  - results in lower fuel costs,
  - increased share of renewable energy mix for the end users.
- End users can become prosumers in a hybrid swarm grid
  - able to share or trade excess energy with neighbors,
  - providing electricity to those without individually owned backup systems

References

IRENA, “Solar PV in Africa: Costs and Markets,” 2016

Iea, “Africa Energy Outlook: A Focus on Energy Prospects in Sub-Saharan Africa,” pp. 1–242, 2014.

S. Groh, D. Phillip, B. Edlefsen Lasch, and H. Kirchhoff, “Swarm electrification-Investigating a paradigm sift through the building of microgrids bottom-up.,” in *Decentralized Solutions for Developing Economies.*, S. Groh, J. Van der Straeten, B. Edlefsen Lasch, D. Gershenson, W. Leal Filho, and D. Kammen, Eds. Springer Proceedings in Energy XXIV, 2015, pp. 3–22.

Energy Commission of Nigeria, “60m Nigerians now own power generators,” 2009. [Online]. Available: http://www.energy.gov.ng/index.php?option=com_content&view=article&id=74. [Accessed: 18-Jul-2017].

All On and Shell, “Nigeria : Energy needs assessment and value chain analysis,” 2016.

H. Kirchhoff, “Microgrid Concepts with an Agent-Based Control Scheme in the Context of the Electrification in Off-Grid Areas,” Technical University of Berlin, 2013.

Thank you for your attention.