A tool for pre-feasibility techno-economic comparison of rural electrification options: grid extension and off-grid systems

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Paper Number 4
Session 4
November, 15th 2017

Rural electrification and market opportunities in SSA

- 35% electrification global, 19% electrification rural areas i.e. total of ~0.6 billion without electricity access
- 8.8 outages/month – 5.4hs average outage duration
- bringing electrification from 35% to 70% (in 2040) requires $205 billion: ~half new T&D lines, ~30% off-grid solutions

Huge amount of potential new consumers especially in rural areas

High economic losses due to very low reliability of power system and widespread use of small diesel back-ups

Possible foreign driven investments
Not minor role of off-grid systems

[IEA WEO, WB Indicators, WB Enterprise Survey, IEA Africa Energy Outlook]

Rural electrification and system options in SSA

Traditional solutions for rural electrification:

- Centralized grid approach
- Small diesel generators
- *run-off-river* small hydros

- **Costs reduction for RE and energy storage**
- **Increasing attention to rural electrification issue**
- **Development of policies/strategies/regulations**
- **Increasing interest of energy giant companies**

Additional (off-grid) options in the current context:

- **Stand-alone systems**: basically PV-based, single user oriented, lead acid / lithium battery, hundreds Wp to few kWp
- **Micro-grids:** single or multiple generators supplying power to multiple users via local distribution grid (tens to hundreds of kW)
  - hybridization of existing diesel based micro-grids with PV
  - PV-storage based micro-grid
  - Integration of PV-wind-storage (and back-up diesel)

Selecting rural electrification option

Companies aiming at implementation actions in rural areas of SSA need to assess and compare the different options

Considering the:

- unavailability / uncertainty of most of the required data
- impossibility to quickly locally collect a minimum set of data

Need of tools for **pre-feasibility techno-economic analyses**:

1. to compare the most common rural electrification options
2. based on the simplest dataset or on dedicated available databases or on results from other specific tools

Pre-feasibility techno-economic analyses

- Simulation of system life-time operation for a given system architecture and component sizes set
- **Energy simulation**: hourly solution of energy balance based on steady-state models
- **Economic simulation**: cash flows analysis (IC - O&M)
- Computation of techno-economic performance indicators: loss of load probability [LLP], NPV, LCoE
- Simulation of several component sizes set and optimum detection with performance indicators
- No power system static and dynamic analysis

The proposed tool - **Framework**

TARGET

- MS Excel tool to be used at the early stage of the design process in rural electrification projects
- To provide quick pre-feasibility techno-economic analysis of the most typical options

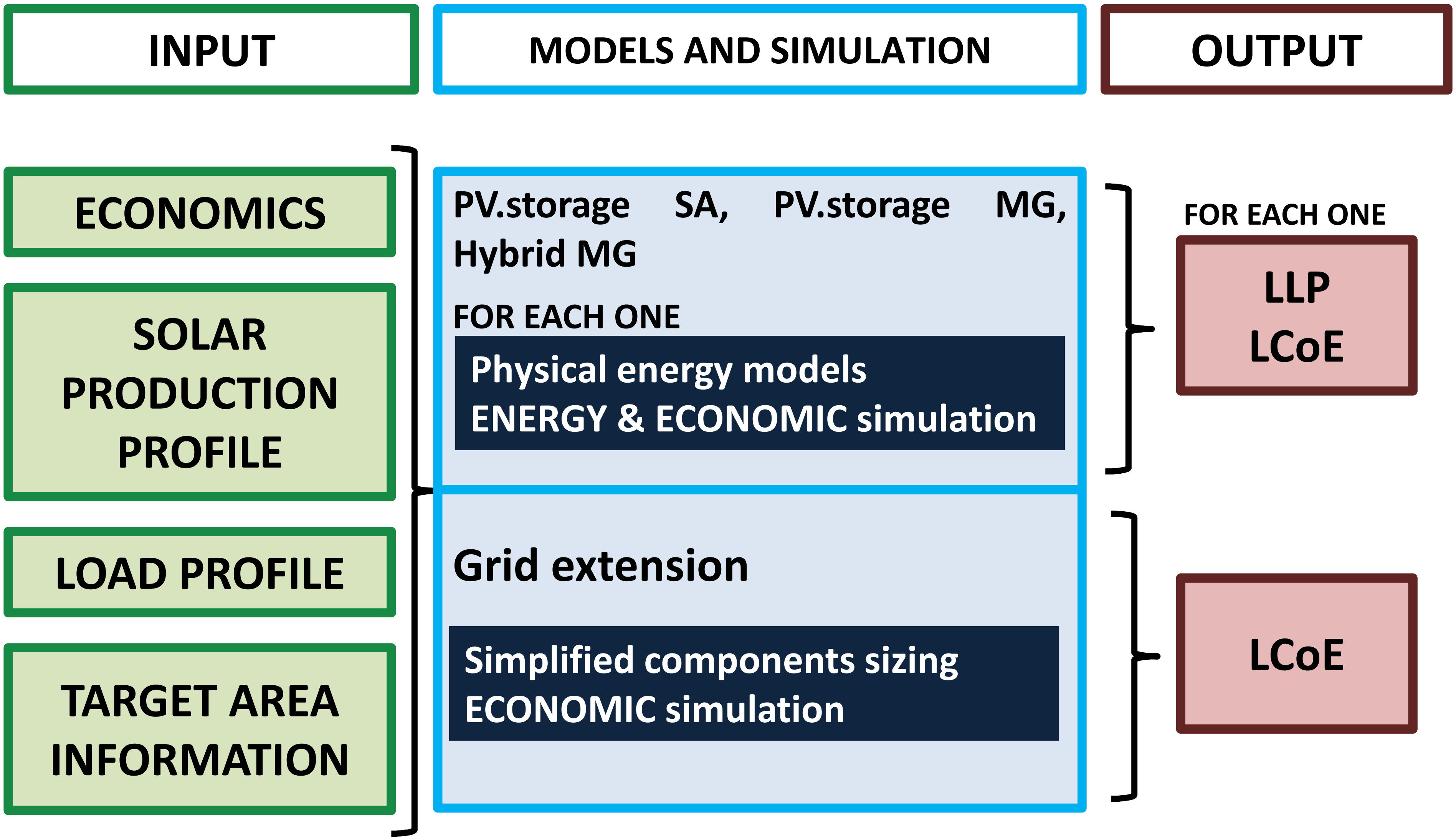
CONSIDERED OPTIONS

Stand-alone PV-storage	Microgrid PV-storage
Hybrid Microgrid: diesel + PV + storage	Grid extension

KEY FEATURES

- Specific models and parallel optimization / analysis of the options for quick comparison
- Integration of dedicated tool results for key input data (resources and load)

The proposed tool - Structure



[SA stand-alone, MG microgrid]

The proposed tool - Input

ECONOMICS

For each component:

- Investment cost

SOLAR PRODUCTION PROFILE

Hourly yearly generation [Wh] profile for 1 kWp PV is obtained via www.renewables.ninja/# which is based on NASA MERRA database (worldwide coverage).

- Possibility to add seasonal varibility to the profile ?

General information

Optimized tilt angle 17.4

Advised Azimuth 180

Get Solar Profile

Go to Input sheet

Upload Solar Profile

Renewables.ninja

LOAD PROFILE

Pre-defined classes of users available. Basis of realistic load profiles for each class developed with *LoadProGen* tool*

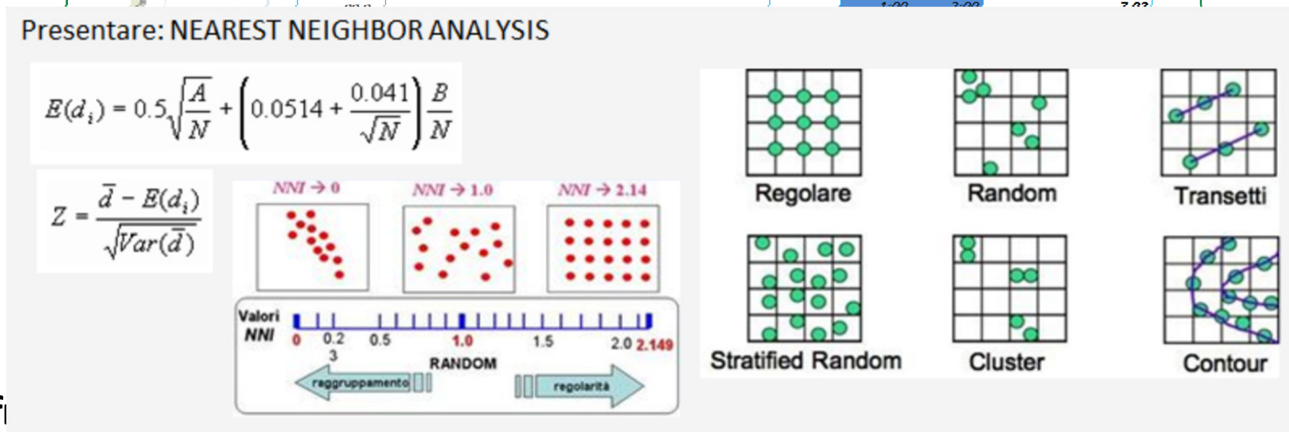
- Given the nr. of users for each class, the tool automatically generates a year load profile randomly aggregating profiles taken from the pools
- User can provide metered profiles if available

Aggregate Daily Load Demand

Hours		Load profile [kW]
0:00	1:00	6.58
20:00	21:00	76.35
21:00	22:00	68.61
22:00	23:00	48.69
23:00	0:00	20.19

TARGET AREA INFORMATION

- Estimate of average distance between potential consumers based on nearest neighbour analysis
- Assessment of total local distribution grid length



*Politecnico di Milano, f

it-it.facebook.com/energy4growing2014/

The proposed tool – **Models & Sizing**

MODELS FOR ENERGY SIMULATION

- **STORAGE**: **(1)** water tank equivalence with charging/discharging efficiencies **(2)** State of Charge reference simulation parameter **(3)** rain-flow cycle counting method for life-time modelling
- **DIESEL**: **(1)** single unit **(2)** constrained to peak-minimum power limits **(3)** generation-to-fuel consumption curve **(4)** life-time based on operating hours
- **PV**: based on *RenewableNinja* model

SIZING AND OPERATIONS

- **for SA PV+storage and MG PV+storage**: **(1)** identification of optimum sizes searching space based on initial intuitive sizing **(2)** straightforward simulation based on load-following and SOC monitoring
- **for hybrid MG**: **(1)** diesel as prevalent generator (PV+storage as means to optimize diesel fuel consumptions, diesel not as back-up of PV) **(2)** identification of optimum sizes searching space based on increasing sizes of PV and storage starting from MG based only on diesel **(3)** simulation based on *if & else* logics for power sources dispatchng based on load following and cycle charging approaches

Case study – Soroti Uganda

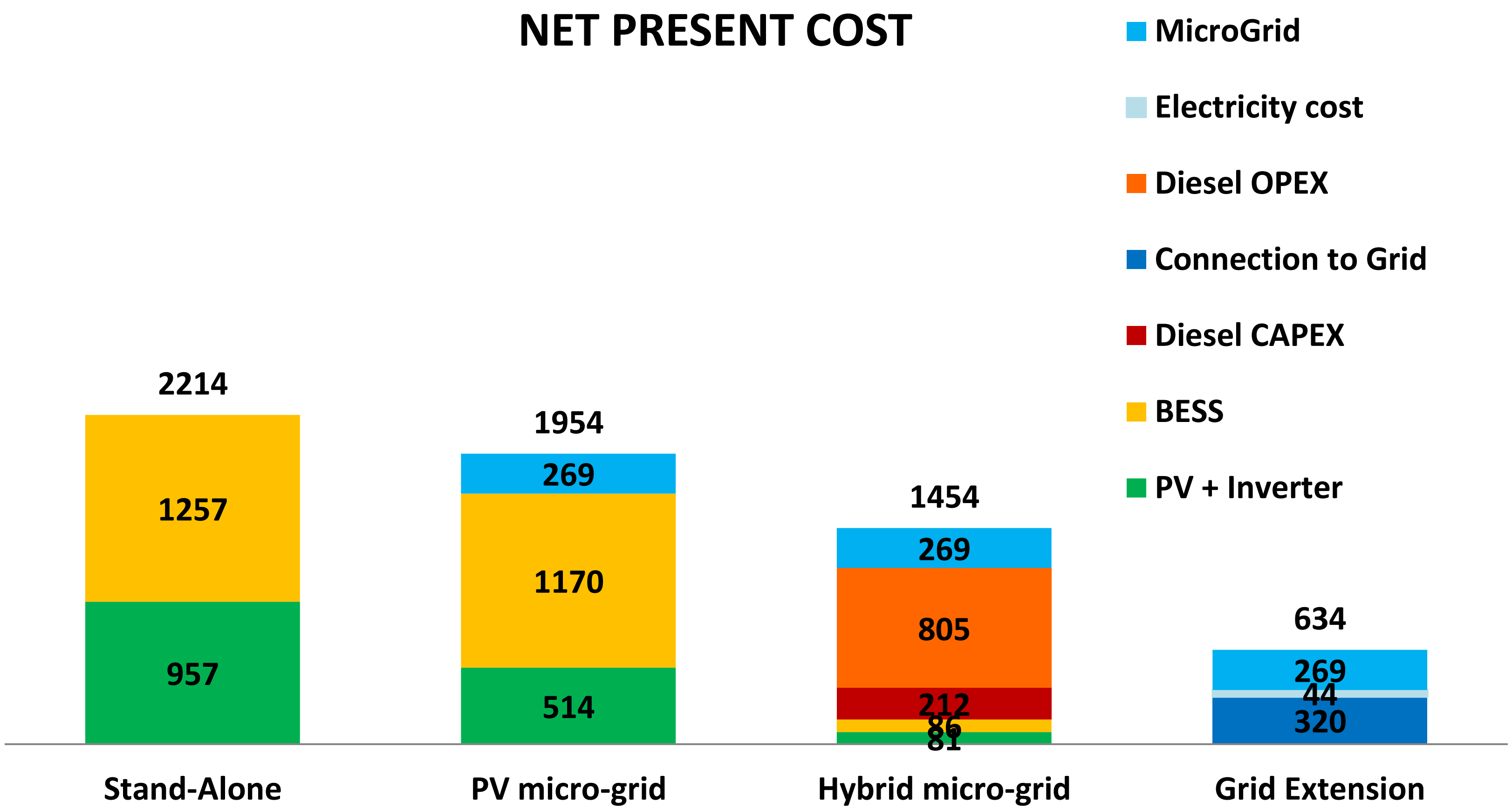
- Soroti in Uganda (Latitude:1,7150; Longitude: 33,6111)
- 1000 people (assumed households energy needs in the range 0,5 – 5 kWh/day)
- local enterprises and community services (clinics, schools, etc.)

Village analysed	
Daily electric consumption [kWh]	819
Peak Load [kW]	89
Yearly electric consumption [kWh]	299061

Main parameters	
Analysed years	20
Interest rate	8.0%
LLP	6.0%
Area [km2]	2.00
Buildings	161
Grid Distance [km]	100

PV Stand-alone		
Investment cost	4091	€/kWe
O&M costs	2.00%	
PV micro-grid		
Investment cost	2045	€/kWe
O&M costs	2.00%	
Energy Storage SA		
SHS Inverter Investment cost	650	€/kWp
SHS Storage Investment cost	925	€/kWhe
SHS Storage O&M costs	1.00%	
Energy Storage MG		
MG Inverter Investment cost	500	€/kWp
MG Storage Investment cost	700	€/kWhe
MG Storage O&M costs	1.00%	
Diesel Generator		
Investment cost	720	€/kWe
O&M costs	10.00%	

Case study – Soroti Uganda

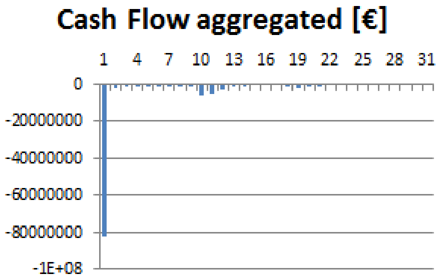


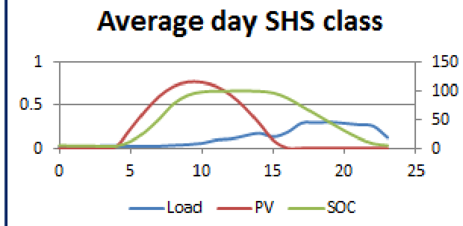
LCOE (€/KWh)	0.89	0.69	0.50	0.22

Case study – Soroti Uganda

PV stand alone

Stand Alone	kI	2,214
LOL (%)		2.94%
Overgeneration(%)		28.54%
PV (kW)		221
BESS (kWh)		648

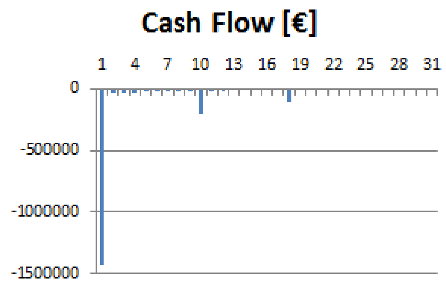


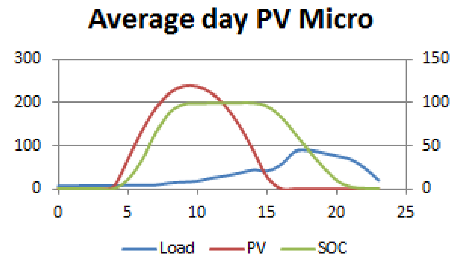


N° Class User	3

Microgrid PV

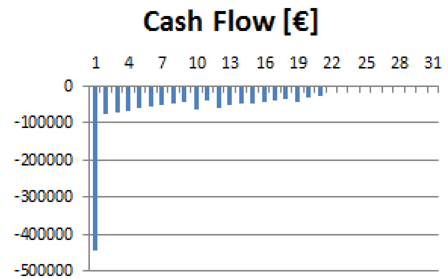
PV+BESS Micro	kI	1,954
LOL (%)		3.54%
Overgeneration(%)		20.14%
PV (kW)		230
BESS (kWh)		838

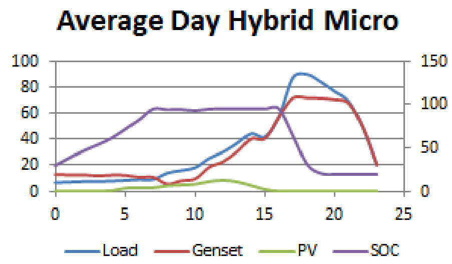




Hybrid Microgrid

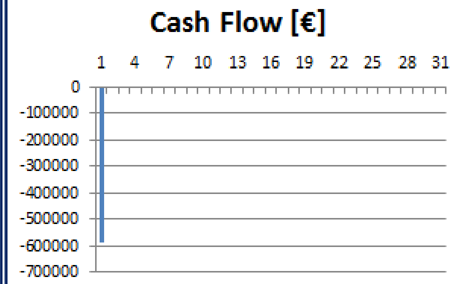
Hybrid Micro	kI	1,454
LOL (%)		1.92%
Overgeneration(%)		0.90%
PV (kW)		17.9
BESS (kWh)		58.5
Diesel (KW)		71.6





Grid Extension

Grid Extension	kI	634
MicroGrid (km)		9.30
MicroGrid (MV/LV SS)		1
Connection to Main Grid (km)		100



Conclusion: HOMER Vs CESI tool

TOPIC	CESI tool	HOMER Energy
Solar profile	From external specific database/tool which already performs hourly generation time-series.	Monthly irradiation data typically obtained from NASA website and internally converted to hourly time-series.
Load profile	Based on pre-defined typical user load and realistic load profile generated via dedicated tool.	User not supported in daily load profile definition. This has to be provided.
Grid extension	Estimate of required substations nr. and LV cable required length based on expected consumers nr. and load.	No particular modelling of the distribution grid.
Sensitivity	Can be performed for max 3 parameters	Can be performed for all parameters with extensive analysis
Models	Simplified to allow quick simulation	Advanced with fairly quick simulation
Electrification options comparison	For considered options, possibility to setup and run in parallel the comparison with single simulation	Required to different simulation (different setup) for different system architectures

Thank you for your attention

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