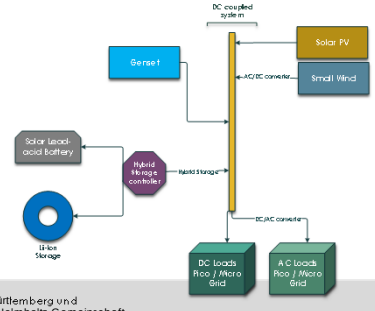
Karlsruher Institut für Technologie

Contrastive techno-economic analysis concept for off-grid hybrid renewable electricity systems (OHRES)
Based on comparative case studies within Canada and Uganda

3rd International Hybrid Power Systems Workshop
Tenerife/Spain, 8 - 9 May 2018

Mohamed M. Elkadragy
Scientist, Renewable Energy,
Battery Technical Center, Institute of Electrical Engineering (ETI).



Who we are...?
Battery Technical Center

Karlsruher Institut für Technologie

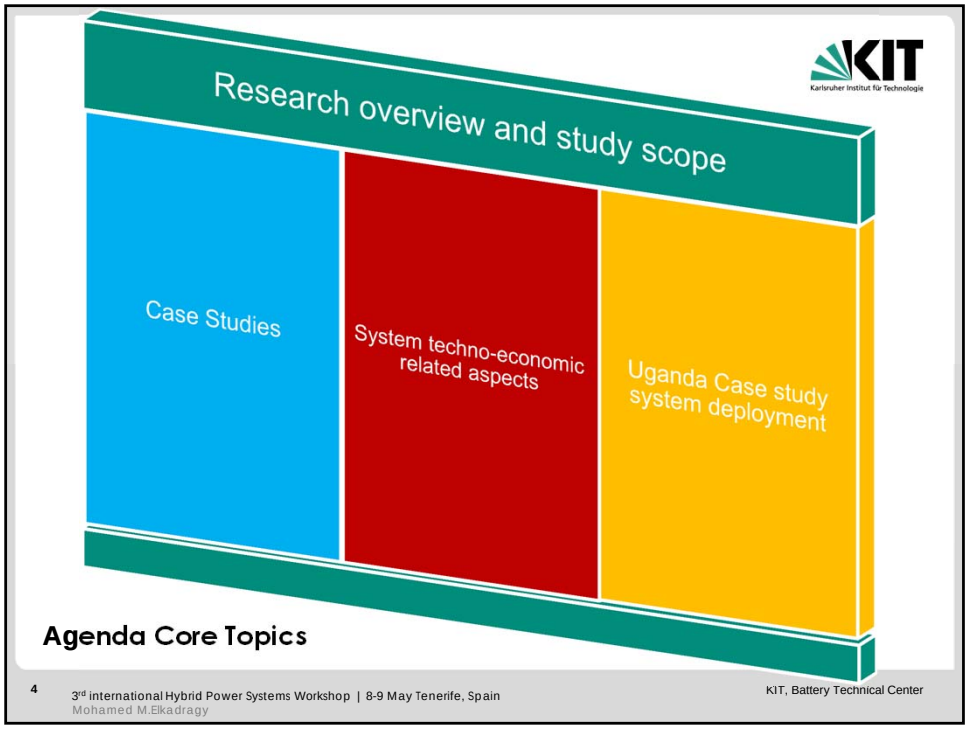
System Competence along the Value Chain

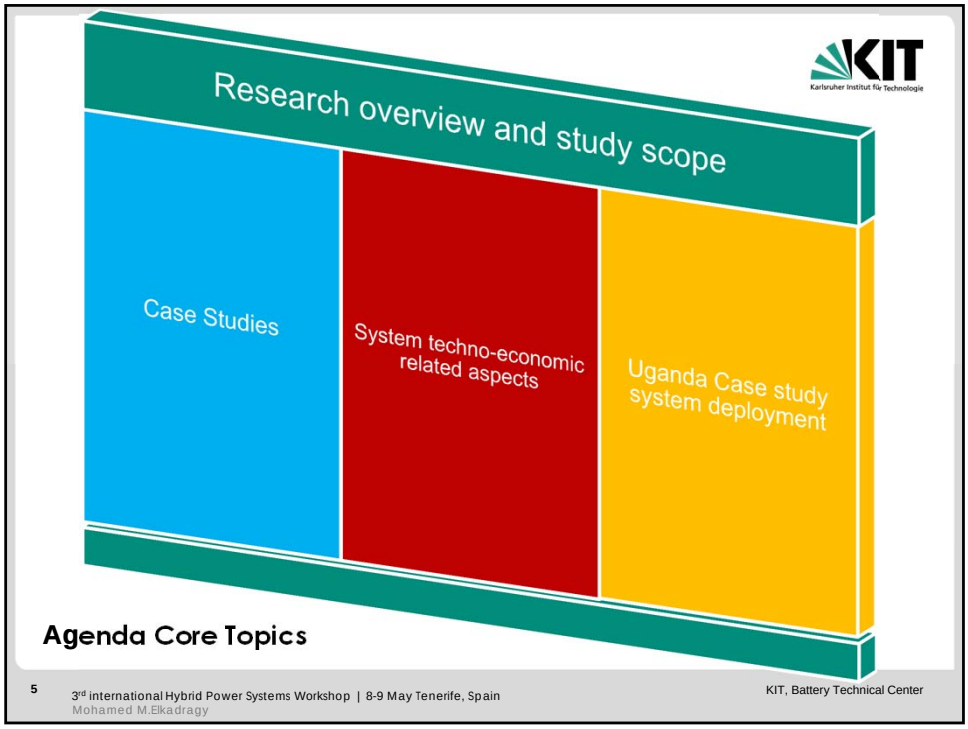
Cost-effective product design and production technologies

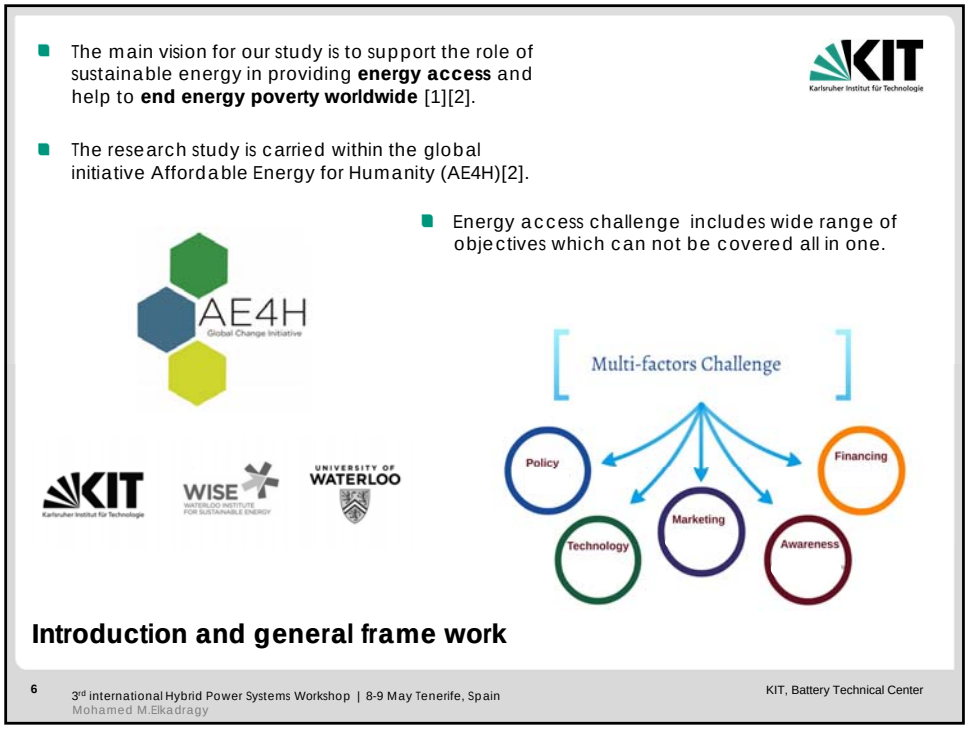
Material → Cell → Battery → Converter → Production Technology → System Integration

- Interdisciplinary cooperation of different KIT institutes
- R&D scope
  - High energy materials and compact cell designs
  - Modular battery designs
  - optimized production processes
  - Storage systems design and analysis


Expectations
Reality
General Overview for the current presented topic
Go through the paper "detail"
Get Engaged "Cooperation"
3
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center

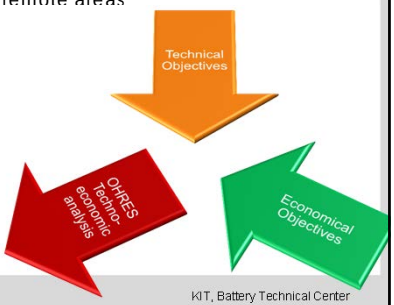

Research overview and study scope
Case Studies
System techno-economic related aspects
Uganda Case study system deployment
Agenda Core Topics
4
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center

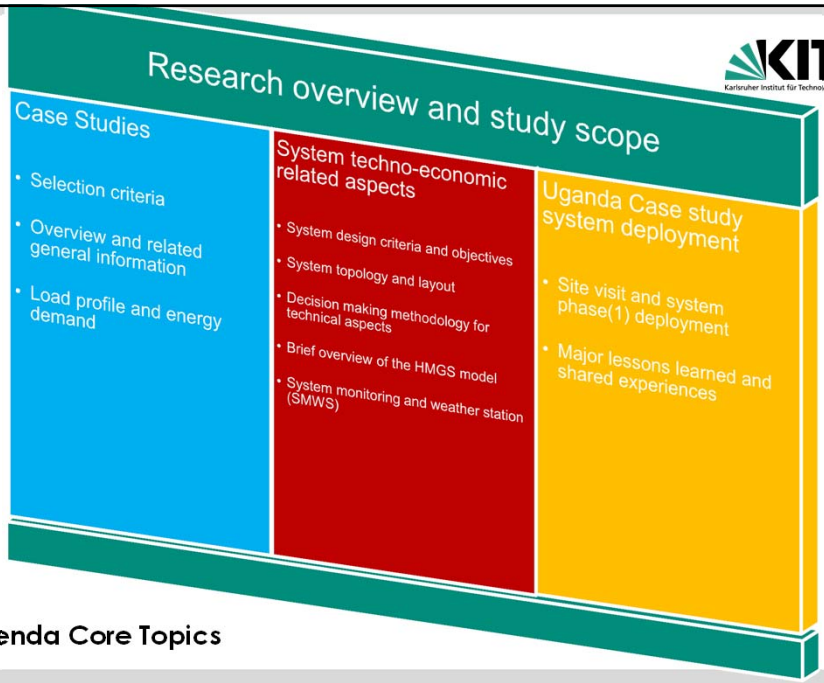

Research overview and study scope
Case Studies
System techno-economic related aspects
Uganda Case study system deployment
Agenda Core Topics
5
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center


The main vision for our study is to support the role of sustainable energy in providing energy access and help to end energy poverty worldwide [1][2].
The research study is carried within the global initiative Affordable Energy for Humanity (AE4H)[2].
Energy access challenge includes wide range of objectives which can not be covered all in one.
AE4H
Global Change Initiative
Multi-factors Challenge
Policy
Financing
Technology
Marketing
Awareness
Introduction and general frame work
6
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center

Study scope and objectives

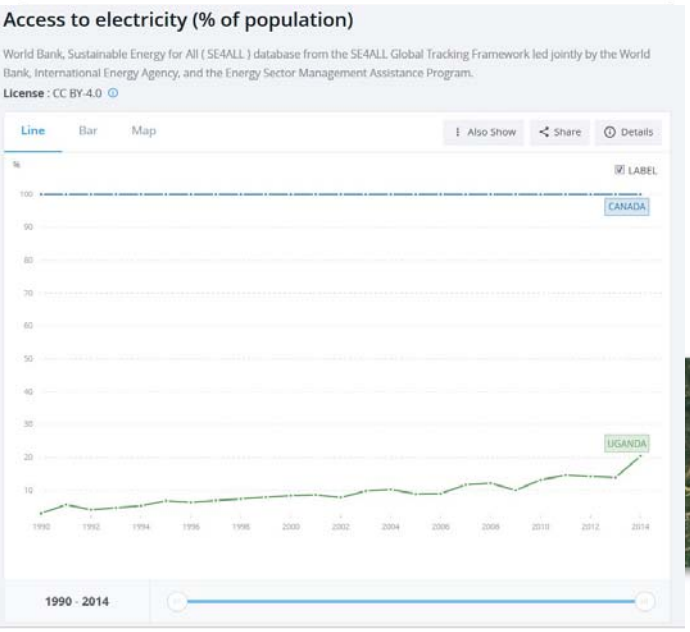
- **The lack of reliable data** related to system performance combined with economical analysis.
  - Due to the **absence of standardization**
- Our main focus: **techno-economic aspects**
  Off-grid Hybrid Renewable Electrical Energy systems (OHRES)
  How technical, economic "environmental & Social" affects economic feasibility, sustainability.
- **comparative sturdy based on contrastive case studies** in remote areas
  - Identifying the common problems and challenges
  - Propose possible generic approaches and solutions



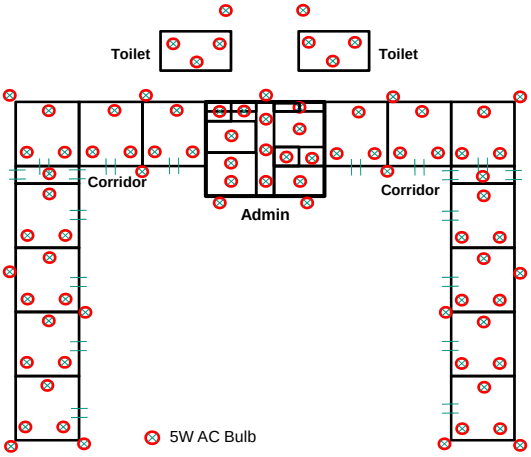


Selection criteria category for contrastive case-studies	Developed country Case-study	Developing country case-study
Local partner or end customer related	Case-study local partner has already a good understanding of renewable energy off-grid systems	Case-study local partner has already a basic understanding of renewable energy off-grid systems
	Having already social acceptance and motivation for implementing an off-grid system	*Social acceptance to be build up with the partner based on such basic understanding*
	Preferable to have local partner with previously installed off-grid system	Preferable to have local partner with no previously installed off-grid system
	To represent how the system can perform based on previously experienced user	*To represent how the system can perform in an environment which lacks previous experience*
	Ownership and full control of the facility where the system to be installed should be represented in both case-studies	
	in order to limit external critical risks on the short and medium term of the project as the purpose of use changes for the location or need to de-commission the system due to uncertainties in ownership	
	Availability of very good and trusted communication channel	
	Critical criteria which will minimize the risk of project sustainability and also reduce the effort needed in system implementation, maintenance and operation of the project lifecycle	
Location selection	Case-studies must be in clearly defined developed vs developing economies	
	In order to analyze the effect of economic and basic political influences on off-grid sectors	
Environment and renewable resources	Case-studies represents a clear contrast in terms of environmental, weather conditions which off-grid systems can be deployed in	
	To represent the extreme cases of off-grid systems implementation in order to cover the within range of cases	
Renewable energy policy and Support mechanisms	Availability of general orientation and awareness about using off-grid systems in addition to national policy	Availability of basic renewable energy supportive policy and mechanisms, preferably within the off-grid sector (micro-grids, Standalone systems)
	Will have an influence on many project aspects rather than the techno-economic ones, like logistics handling, certifications needed for components, mini-level of standards availability	
Techno-economic aspects	Remote locations with no access to the grid or very high electricity tariffs. Preferably to be a part of the remote community	
	Will support the economic feasibility of the off-grid system and project sustainability aspects	
	Both case-studies will depend on Hybrid off-grid system consists of solar PV and mini-wind (if feasibility) and electrical energy storage (Hybrid Battery storage) as a main electrical energy resource	
	Having similarity in the renewable energy resources used and system layout, which is a need for a combative analysis	
	Case-studies should be within the same energy consumption [kWh] tier (based on World Bank framework)	
	System design and sizing will not differ much between the case-studies, which support the objective of doing a compared analysis	

Summary of case-studies selection criteria

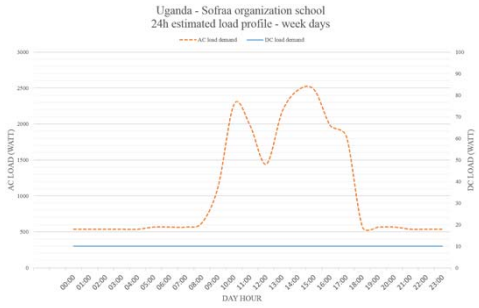


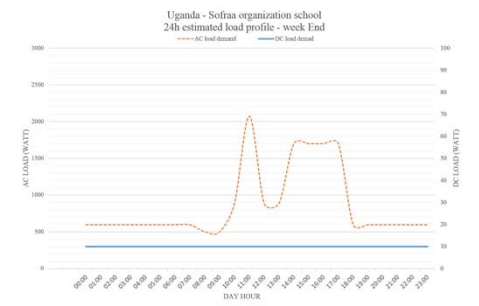
Case-studies overview
General info



Case-studies overview
Load survey and distribution – The case of Uganda

Item	Type	Watts	Number	Total Watts
Lamp	AC 220V	5	82	410
Computer	AC 220V	40	30	1200
Printer	AC 220V	500	1	500
Projector / TV	AC 220V	300	2	600
Standing Fan	AC 220V	30	5	150
SMWS	DC 24/12 V	10	1	10
Pump	AC 220V	1200	1	1200
Mobile charger	AC 220V	220	1	220





Uganda

- During **week-day**s the total connected load (TCL) peak is **up to 2500 Watt**.
- During the **weekend** the TCL peak reaches **2075 Watt**.

Canada

- Total connected loads (TCL)possible peak demand is **up to 2200 Watt**.

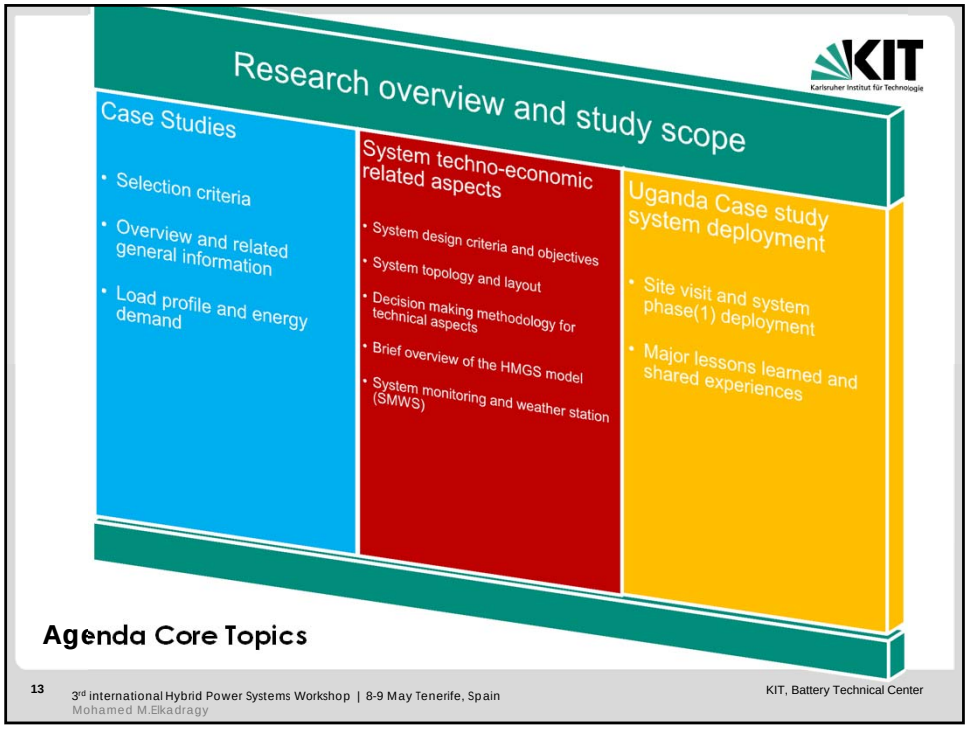
Both Case-studies

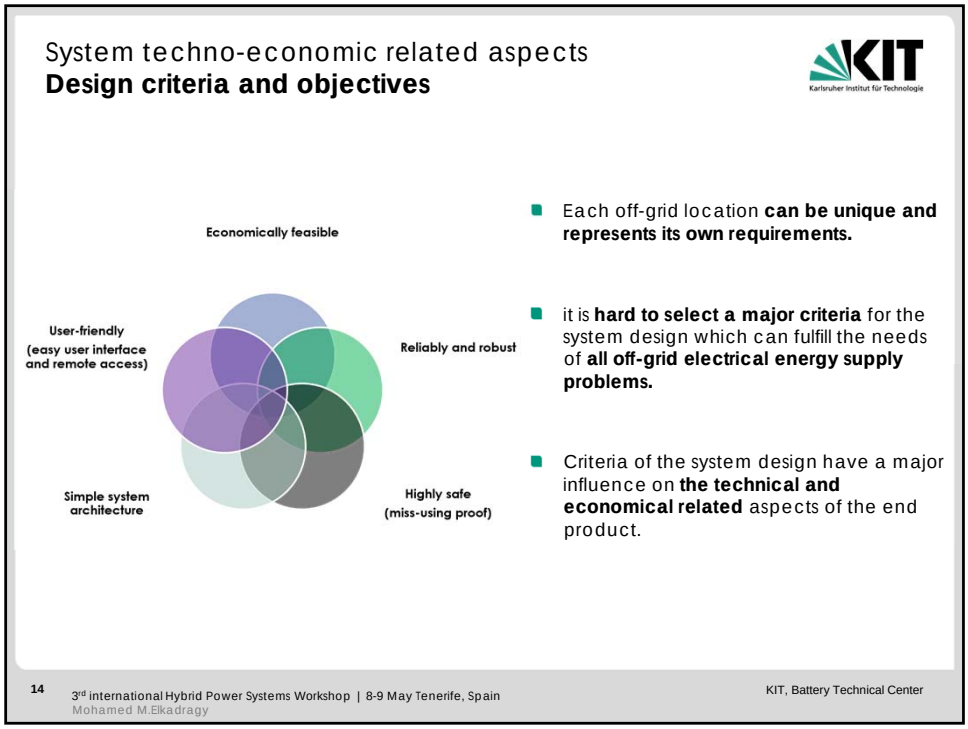
- AC and DC loads, But AC loads are dominant.

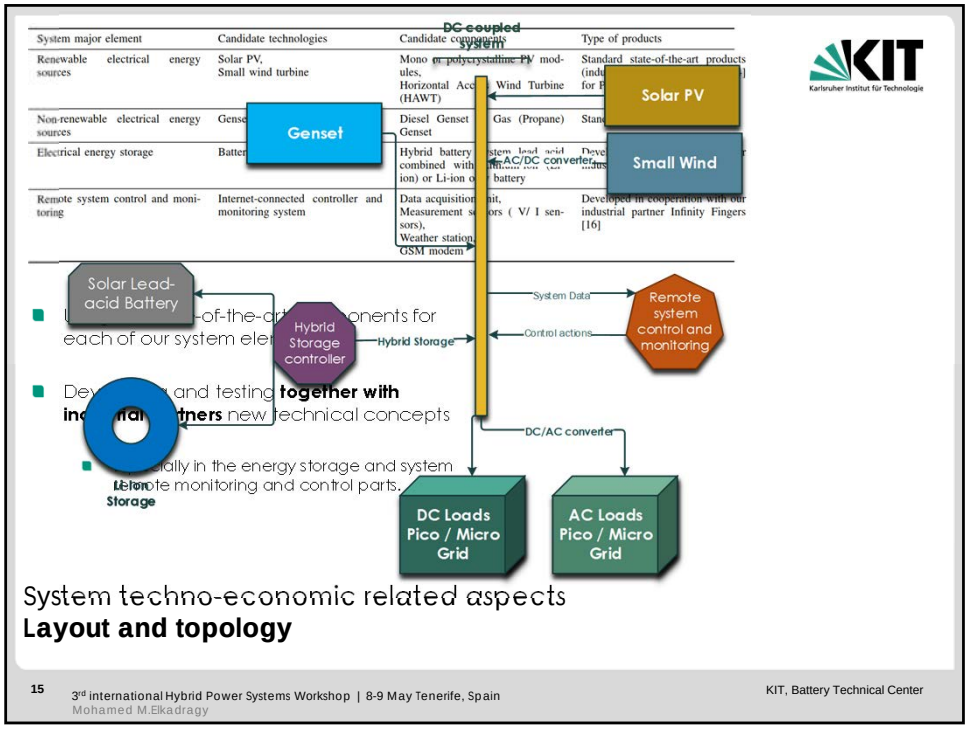
- **energy consumption (1319 -2121 kWh/year)**

Within tier-4 level of access in the multi-tier framework for household energy based on the World Bank recommendations **[6]**

Case-studies overview
Load profile and energy demand

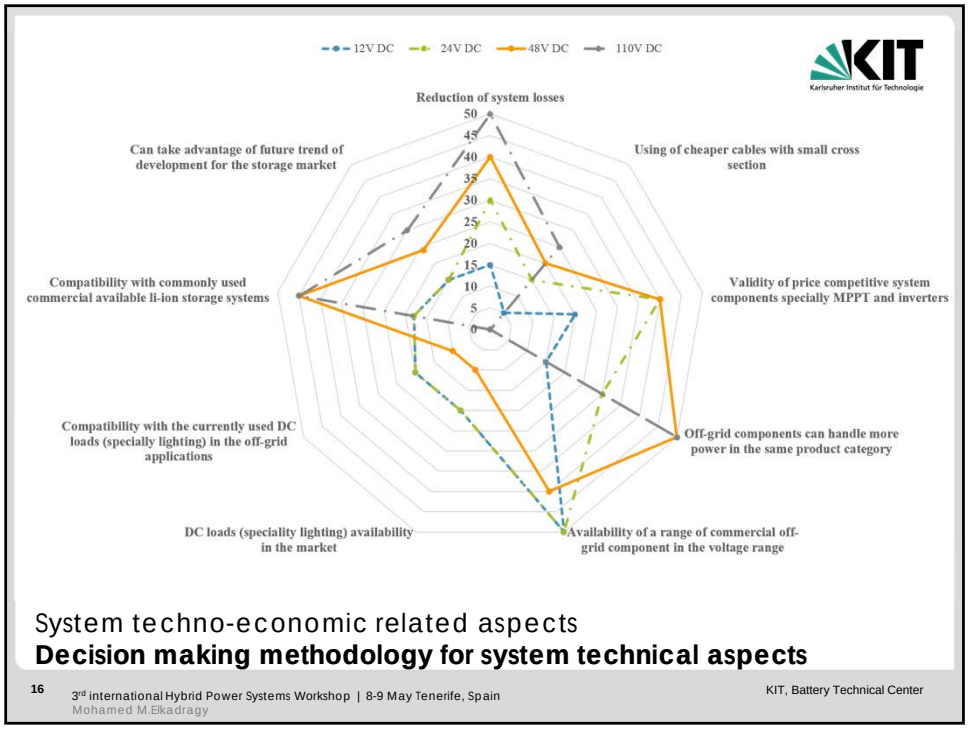

Research overview and study scope
Case Studies
Selection criteria
Overview and related general information
Load profile and energy demand
System techno-economic related aspects
System design criteria and objectives
System topology and layout
Decision making methodology for technical aspects
Brief overview of the HMGS model
System monitoring and weather station (SMWS)
Uganda Case study system deployment
Site visit and system phase(1) deployment
Major lessons learned and shared experiences
Agenda Core Topics
13
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center


System techno-economic related aspects
Design criteria and objectives
Economically feasible
User-friendly (easy user interface and remote access)
Reliably and robust
Simple system architecture
Highly safe (miss-using proof)
Each off-grid location can be unique and represents its own requirements.
it is hard to select a major criteria for the system design which can fulfill the needs of all off-grid electrical energy supply problems.
Criteria of the system design have a major influence on the technical and economical related aspects of the end product.
14
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center



System techno-economic related aspects

Layout and topology

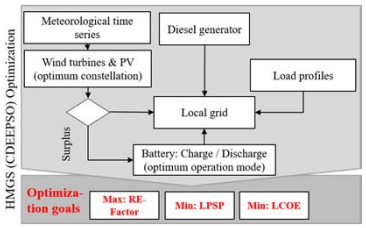


System techno-economic related aspects

Decision making methodology for system technical aspects

System techno-economic related aspects
Brief overview of the HMGS techno-economic model

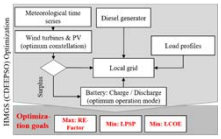
- Model development is based on the work of [18] developed originally for the assessment of standalone systems.
  - New boundaries, side conditions
  - New optimization algorithm and techno-economic calculations are added.
- Finding the **best composition of generation units and optimum energy storage operation mode** under the given optimization goals.

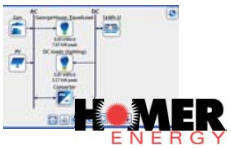


Simplified model structure of the optimized **Hybrid Micro Grid Systems** (HMGS) model

- **The optimization aims**
  - Minimize the loss of power supply probability (LPSP)
  - Minimize the levelized cost of electricity (LCOE)
  - Increase the RE share
- **C-DEEPSO** [Canonical particle swarm optimization Algorithm]
  - New population-based method built **upon swarm intelligence** and differential evolutionary technique.
  - Used as a solving algorithm instead of an original particle swarm optimization due to a **higher robustness of results**.
- **Detailed information about C-DEEPSO and HMGS in [18], [19], [20] and [21]**

- Homer energy [22] is used beside HMGS
  - OHRES feasibility analysis and system sizing optimization.





- 1- free for modifications and modelling approach optimization.
- 2- Using C-DEEPSO optimization algorithm.

- 1- Ability to design and **simulate off-grid complex systems** with accurate detailed load profiles.
- 2- Commercially proven results field based
- 3- Ability of integration with different tools as Matlab.
- 4- Includes sensitivity analysis assessment
- 5- Different storage types modelling is possible

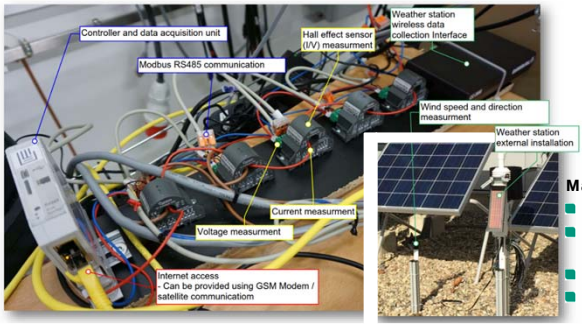
- 1- Results are not commercially field proven.
- 2- Takes into account only two evaluation criteria's LCOE and LOLP.
- 3- Automated sensitivity analysis results is not included.
- 4- Very limited storage parameters definition (Can not model different storage types in details).

- 1- Ability of models manipulations is not available.
- 2- Technical models capabilities are more powerful than economical.
- 3- Doesn't include models for Hybrid Li-Lead-acid storage.

System techno-economic related aspects
Summery HMGS vs Homer Energy

System techno-economic related aspects

Remote system monitoring and weather station (SMWS)

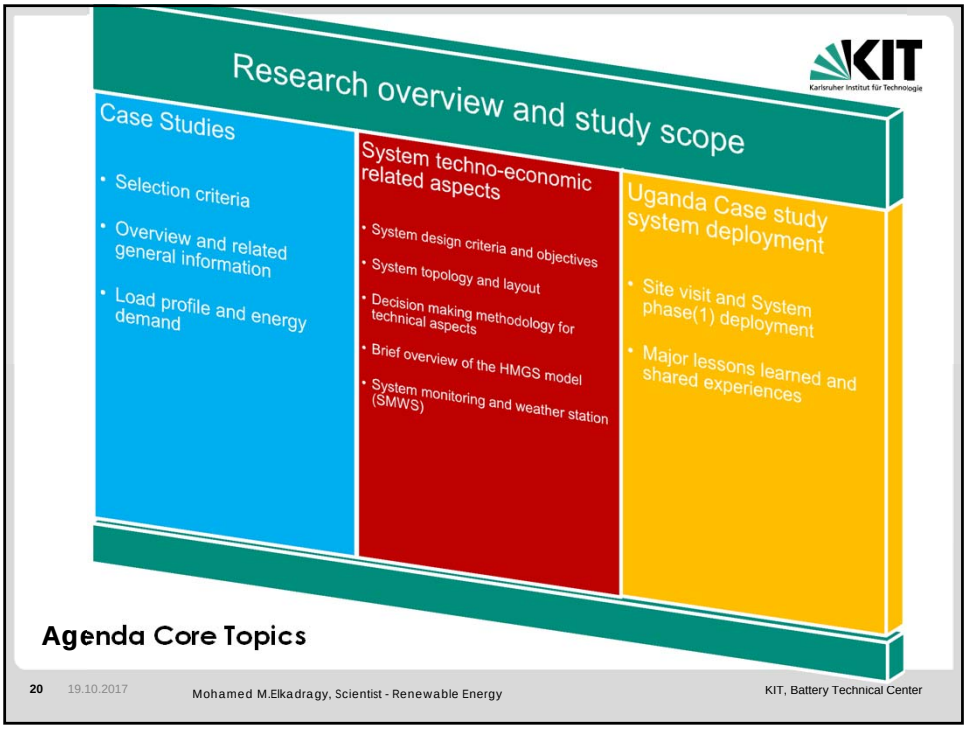


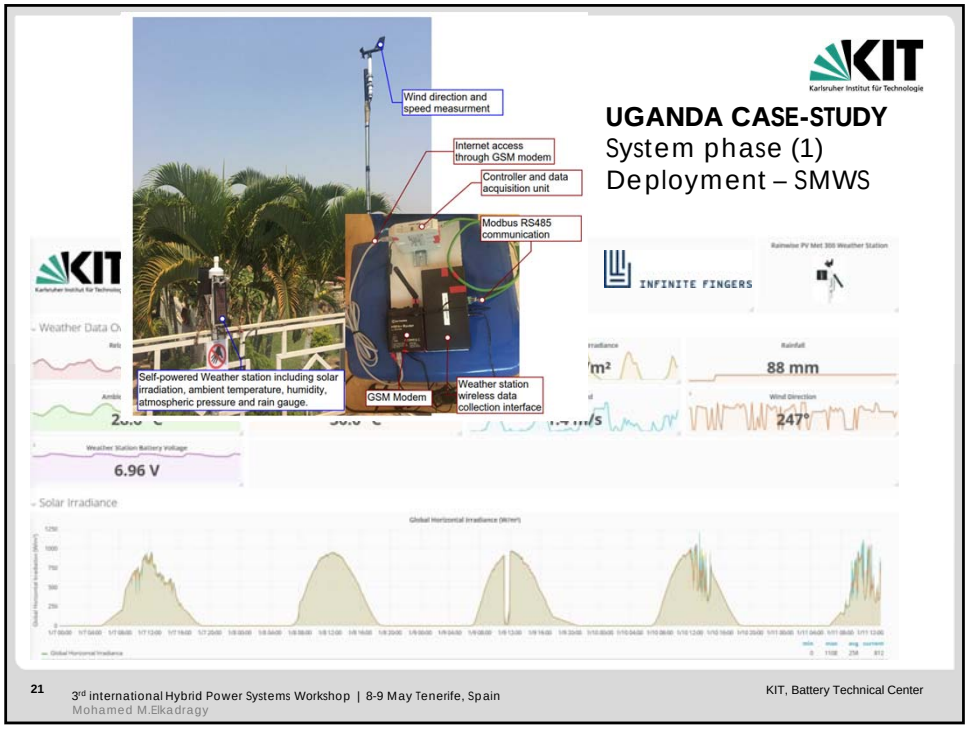
Main Components

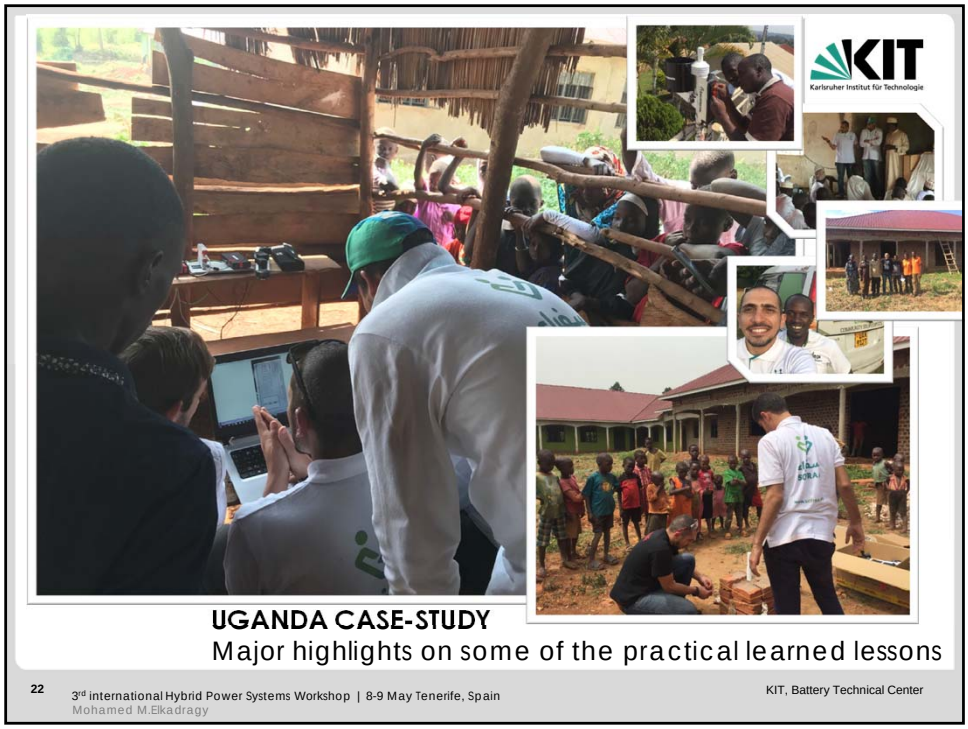
- Self-powered commercial weather station
- Hall effect sensors (voltage / current measurement)
- Controller and data acquisition unit
- GSM Modem

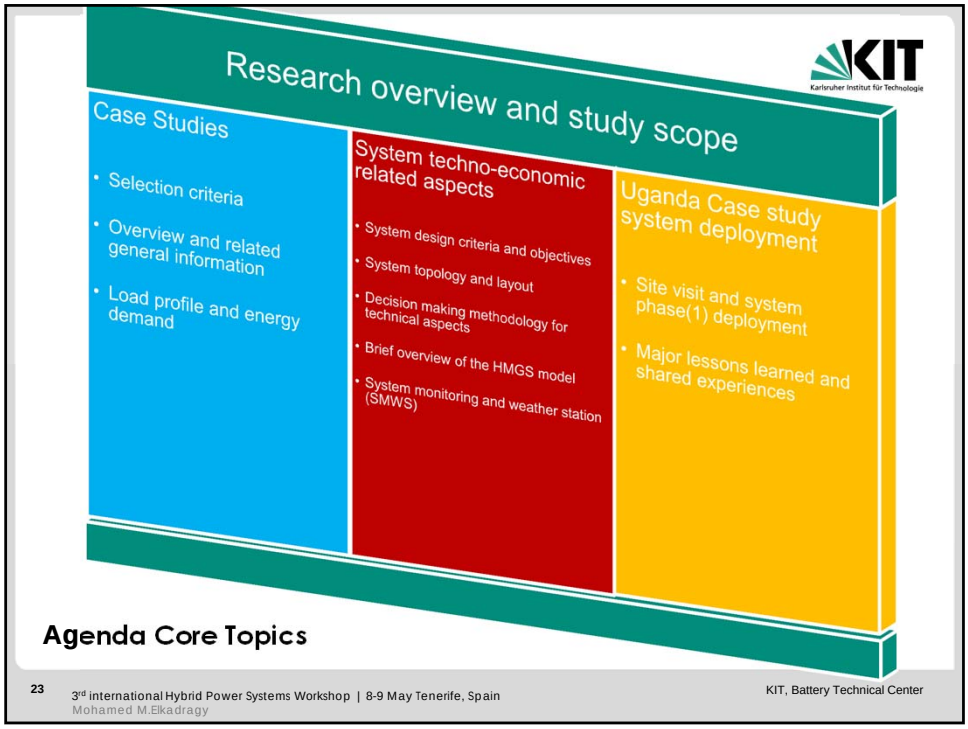
Remote System Monitoring and Weather Station (SMWS) lab cold-running test

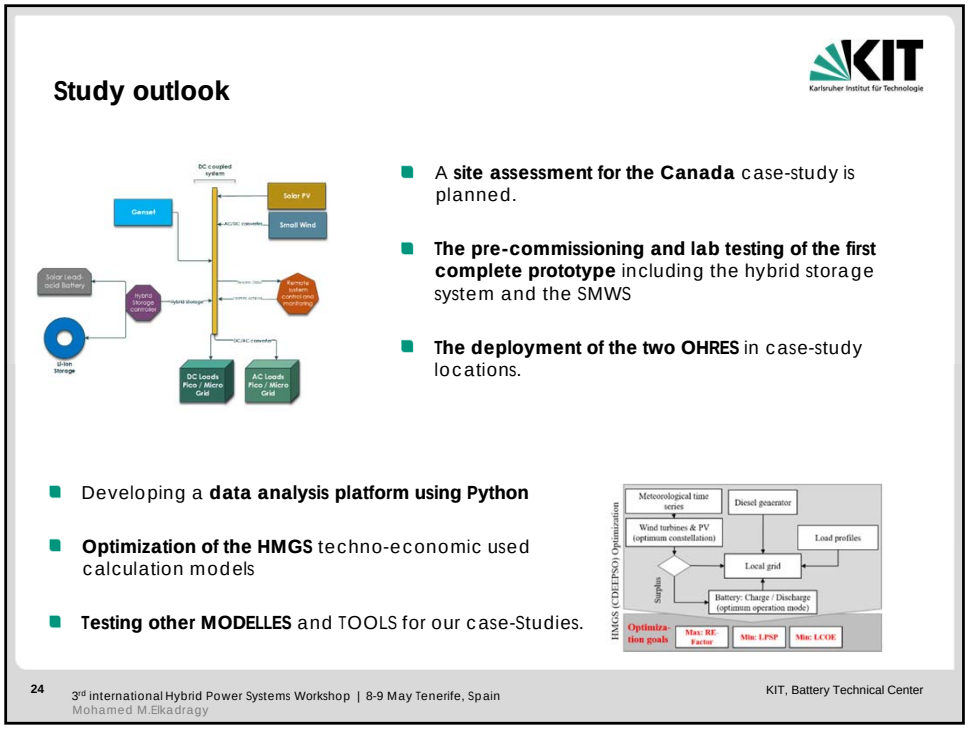
- Current sampling rate 15 sec -> Can go up to 1 Sec
- Data default refresh rate -> 15 min
- GSM or internet based data communication
- RS485 Modbus communication & CAN bus integration ability




Wind direction and speed measurment
Internet access through GSM modem
Controller and data acquisition unit
Modbus RS485 communication
Self-powered Weather station including solar irradiation, ambient temperature, humidity, atmospheric pressure and rain gauge.
GSM Modem
Weather station wireless data collection interface
UGANDA CASE-STUDY
System phase (1)
Deployment – SMWS
INFINITE FINGERS
88 mm
247°
6.96 V
Solar Irradiance
21
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center


UGANDA CASE-STUDY
Major highlights on some of the practical learned lessons
22
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center


Research overview and study scope
Case Studies
Selection criteria
Overview and related general information
Load profile and energy demand
System techno-economic related aspects
System design criteria and objectives
System topology and layout
Decision making methodology for technical aspects
Brief overview of the HMGS model
System monitoring and weather station (SMWS)
Uganda Case study system deployment
Site visit and system phase(1) deployment
Major lessons learned and shared experiences
Agenda Core Topics
23
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center


Study outlook
Genset
Solar PV
Small Wind
Solar lead-acid battery
Hybrid storage controller
Li-Ion Storage
DC Loads Pico / Micro Grid
AC Loads Pico / Micro Grid
A site assessment for the Canada case-study is planned.
The pre-commissioning and lab testing of the first complete prototype including the hybrid storage system and the SMWS
The deployment of the two OHRES in case-study locations.
Developing a data analysis platform using Python
Optimization of the HMGS techno-economic used calculation models
Testing other MODELLES and TOOLS for our case-Studies.
HMGS (CDEPSO) Optimization
Meteorological time series
Diesel generator
Wind turbines & PV (optimum constellation)
Load profiles
Local grid
Sinphn
Battery: Charge / Discharge (optimum operation mode)
Optimization goals
Max: RE-Factor
Min: LPSP
Min: LCOE
24
3rd international Hybrid Power Systems Workshop | 8-9 May Tenerife, Spain
Mohamed M.Elkadragy
KIT, Battery Technical Center

Mohamed M. Elkadragy

Scientist, Renewable Energy
Battery Technical Center, ETI – KIT
Mohamed.Elkadragy@kit.edu

Resources & References

- [1] M. Brooks, N. Moore, H. Rutherford, J. Wright, and D. Bowman, "OpenAccess Energy Blueprint," Tech. Rep., 2017. [Online]. Available: https://ae4h.org/open access
- [2] Affordable Energy For Humanity (AE4H), global initiative. [Online]. Available: www.ae4h.org
- [3] H. Holtorf, T. Urmee, M. Calais, and T. Pryor, "A model to evaluate the success of Solar Home Systems," Renewable and Sustainable Energy Reviews, vol. 50, pp. 245–255, 2015.
- [4] M. M. Elkadragy, "Renewable Electricity (RES-E) Policy Implications On Market Actors In Germany Modelling. Modelling and Analysis focusing on Onshore Wind and PV Plant Operation and Investment." p. 120, 2014. [Online]. Available: http://elib.dlr.de/93851/
- [5] M. Reeg and M. M. Elkadragy, "Changed risk premiums and equity debt requirements due to different RES-E policy instruments for market integration of renewable energies in Germany," 2014. [Online]. Available: http://elib.dlr.de/89678/
- [6] F. F. Nerini, O. Broad, D. Mentis, M. Welsch, M. Bazilian, and M. Howells, "A cost comparison of technology approaches for improving access to electricity services," Energy, vol. 95, pp. 255–265, 2016. [Online]. Available: http://dx.doi.org/10.1016/j.energy.2015.11.068
- [7] UN, "World Economic Situation Prospects 2016," p.231, 2016.
- [8] World Bank, "Access to Electricity (% of Population)," pp. 1–11, 2016. [Online]. Available: http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS
- [9] Regulatory Indicators for Sustainable Energy(RISE), Uganda country profile. [Online]. Available: http://rise.esmap.org/country/uganda
- [10] The Africa-EU Renewable Energy Co- operation Programme (RECP), Uganda renewable energy potential. [Online]. Available: www.africa-eu-renewables.org/market-information/uganda/renewable-energy-potential
- [11] Natural Resources Canada, photovoltaic and solar resource maps. [Online]. Available: www.nrcan.gc.ca/18366
- [12] The Africa-EU Renewable Energy Cooperation Programme (RECP), Uganda governmental framework. [Online]. Available: www.africa-eu-renewables.org/market-information/uganda/governmental-framework

- [13] Natural Resources Canada, Financial incentives by province. [Online]. Available: www.nrcan.gc.ca/energy/funding/efficiency/4947
- [14] Sunprism Energy Technology. [Online]. Available:http://sunprism.solar/en/
- [15] Balance of Storage Systems (BOS) AG. [Online]. Available: www.bos-ag.com
- [16] Infinite Fingers GmbH. [Online]. Available: www.infinitefingers.com
- [17] H. Borhanazad, S. Mekhilef, V. Gounder Ganapathy, M. Modiri-Delshad, and A. Mirtaheri, "Optimization of micro-grid system using MOPSO," Renewable Energy, vol. 71, pp. 295–306, 2014. [Online]. Available: http://dx.doi.org/10.1016/j.renene.2014.05.006
- [18] C. Marcelino, M. Baumann et al., "Battery storage for hybrid smart grids: Optimization and decision making analysis using c-deepso and ahp+ topsis," IEEE Transactions on Smart Grid.
- [19] C. G. Marcelino, P. E. M. Almeida, E. F. Wanner, L. M. Carvalho, and V. Miranda, "Fundamentals of the C-DEEPSO algorithm and its application to the reactive power optimization of wind farms," in 2016 IEEE Congress on Evolutionary Computation (CEC), 2016, pp. 1547–1554. [Online]. Available: http://ieeexplore.ieee.org/document/7743973/
- [20] M. Baumann, J. Peters, M. Weil, C. Marcelino, P. Almeida, and E. Wanner, "Environmental impacts of different battery technologies in renewable hybrid micro-grids," in 2017 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), Sept 2017, pp. 1–6.
- [21] P. A. C. Marcelino and E. Wanner, "Solving security constrained optimal power flow problems: a hybrid evolutionary approach, appl. intell." March 2018.
- [22] Hybrid Optimization of Multiple Energy Re- sources (HOMER Energy). [Online]. Available: www.homerenergy.com
- [23] Sofraa Worldwide Organization. [Online]. Available: www.sofraa.org
- [24] Smart energysystems. [Online]. Available: http://www.smart-energy.ag/en/