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ESCoBox Workshop
11th January 2017
University of Nairobi, Kenya

ESCoBox project overview

Research Consortium

ESCoBox Intelligent Micro-Grids

- UK-based
  - Academic
    - De Montfort University (Lead Partner)
    - Newcastle University
    - Institute of Development Studies
  - Commercial
    - BBOXX
  - 3rd Sector/NGO/other
    - Practical Action
    - Ashden
- Kenya-based
  - Academic
    - University of Nairobi
  - Commercial
    - SteamaCo (formerly access:energy)

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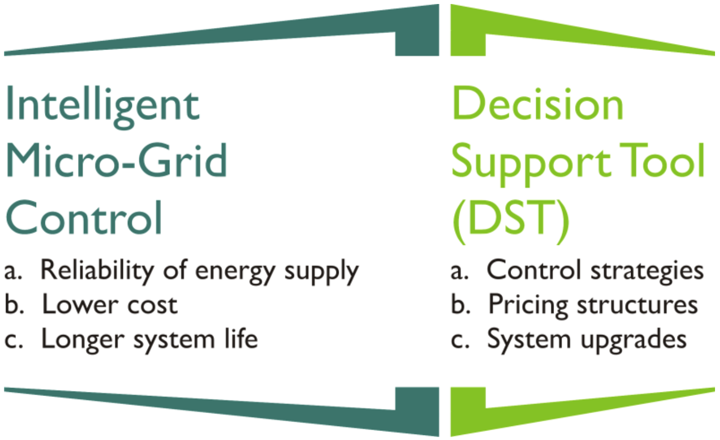
IDS
PRACTICAL ACTION Consulting
Newcastle University
BBOXX
Ashden Sustainable solutions, better lives
STEAMACO
UNIVERSITY OF NAIROBI

Funded by: EPSRC Engineering and Physical Sciences Research Council
Department for International Development

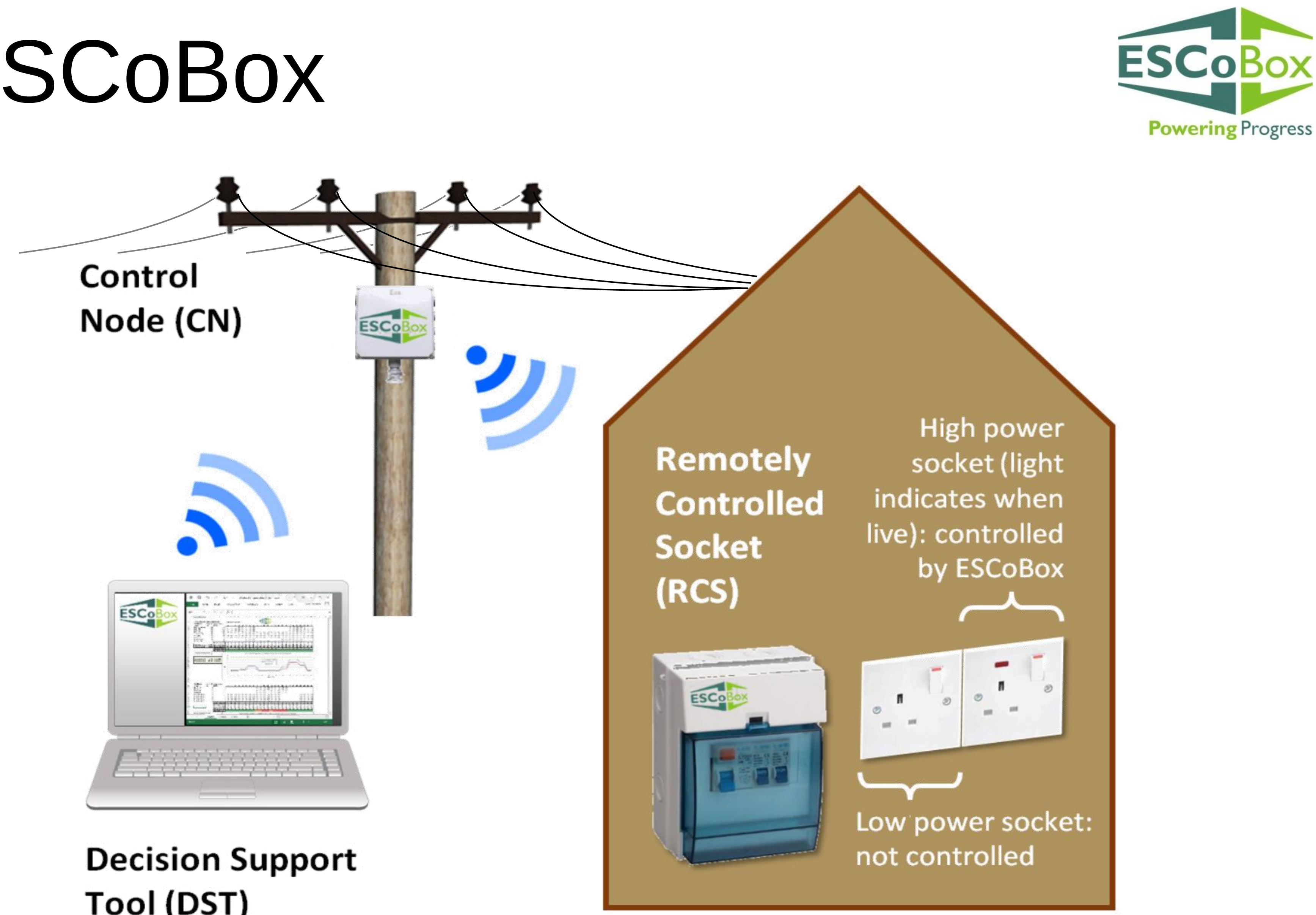
ESCoBox

ESCoBox
Powering Progress

- Applies ‘smart grid’ techniques to mini-grids
- Lowers cost of energy supply
- Improves reliability of energy services
- Reduces reliance on batteries
- Remote monitoring and control
- Cashless micro-payments
- Demand-Side Management (DSM)
  - Price incentives
  - Timeslot allocation
- Decision Support Tool (DST)
  - Design, management and growth of mini-grid system
  - Management and growth of ESCo business



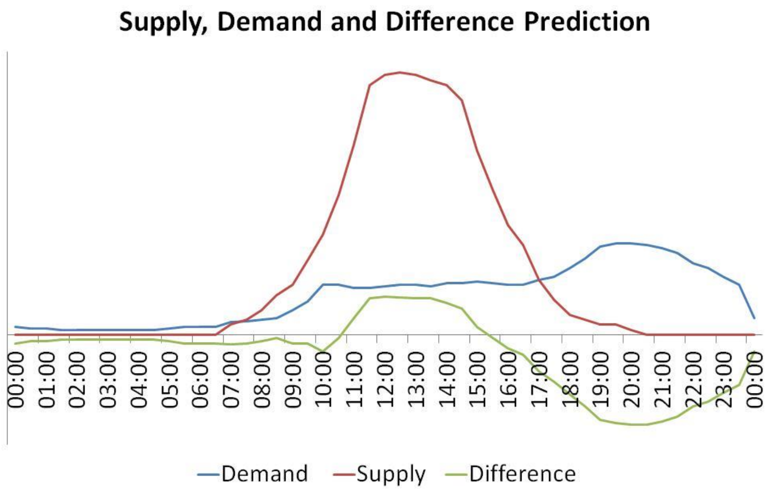
ESCoBox



ESCoBox
Powering Progress
Control Node (CN)
ESCoBox
Remotely Controlled Socket (RCS)
High power socket (light indicates when live): controlled by ESCoBox
Low power socket: not controlled
ESCoBox
Decision Support Tool (DST)
ESCoBox

Demand-Side Management

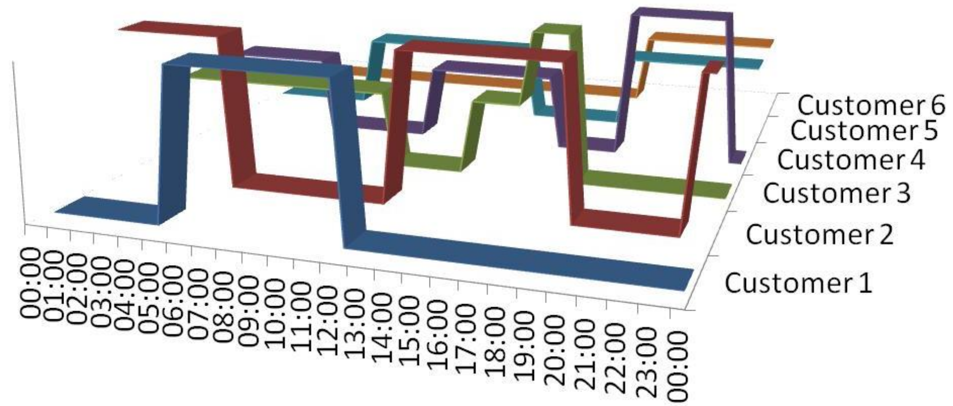
- Need to balance supply and demand
  - Difficult on renewable-powered grids
  - Batteries (or other energy storage) can help
    - But are expensive, short-lived and fragile
  - DSM can reduce reliance on batteries
    - Time-shifting of demand (used in this project)
    - Demand curtailment
    - Financial incentives encourage participation
    - Saves cost, improves reliability
    - Only applicable to certain (i.e. dispatchable) loads



Timeslot Allocation

- Applied to loads that can be time-shifted
- Timeslots offered at reduced tariff
  - Loads with (comparatively) high power demand
    - Typically, commercial loads
    - Additive (not a limitation on availability)

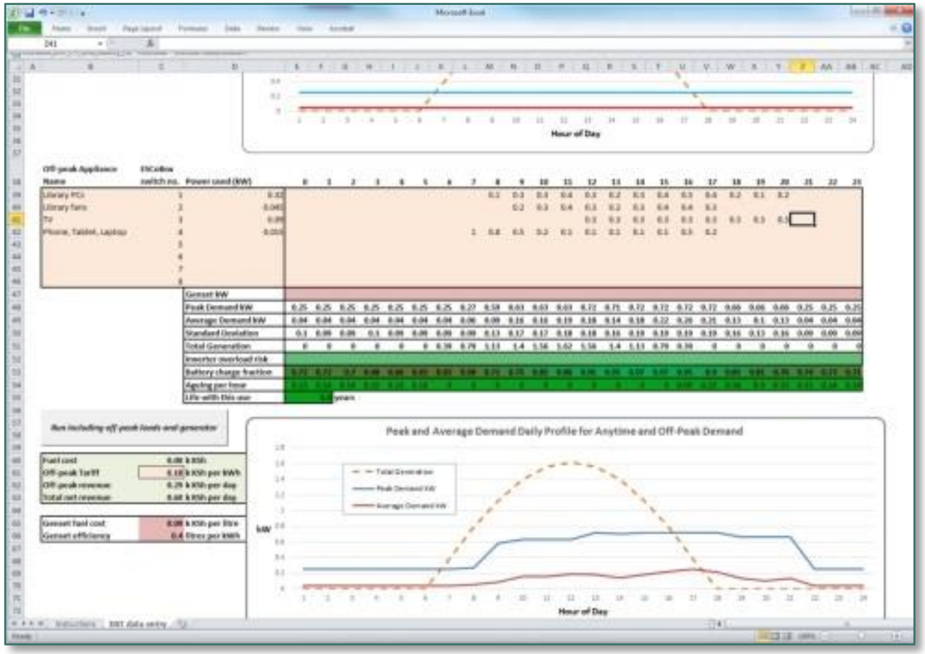
- Need to **keep it simple**!
  - Whether OECD or Developing World
  - Avoid complex tariff structures or consumer interactions



ESCoBox DST Overview

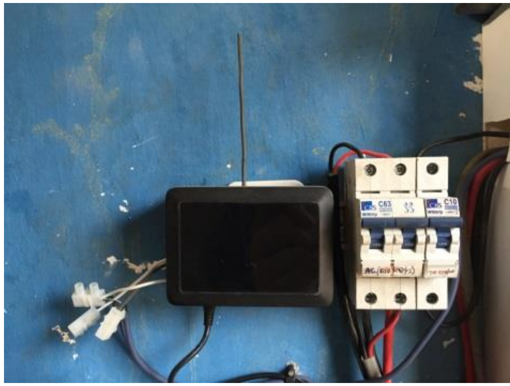
ESCoBox Intelligent Micro-Grids

- Assists designer/operator of mini-grid
  - Estimating demand profile
  - Effect of time-shifting loads (timeslot allocation)
    - Technical efficiency, reliability, sustainability and resilience
  - Revenue outcomes
    - Tariff management
    - De-risk investment decisions
      - Implementation
      - Ongoing growth of system
  - Developed in MS Excel for maximum accessibility
    - Smartphone app planned
    - Ideal for use with HOMER



ESCoBox Control System

- Mandatory control
  - Switches circuit on during low-tariff timeslot purchased by customer
  - Control Node (CN)
    - Raspberry Pi (with PiFace unit)
      - Communicates wirelessly with up to six remotely-controlled sockets (RCSs)
      - Daisy-chain CNs when >6 RCSs needed
- Advisory control
  - SMS messages inform customer of tariff changes
    - Customer choses whether to respond to SMS prompt to save money
  - Cloud-based system



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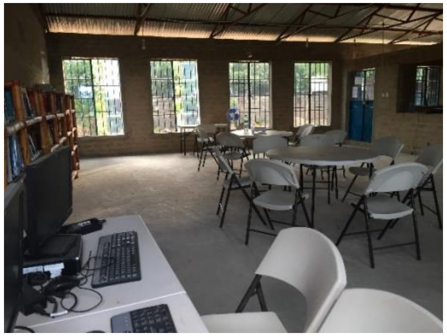
Impacts

- Created ESCoBox smart minigrid system
  - Using DSM to improve the reliability, efficiency and economic performance of minigrids
  - Assists in design, operation and expansion of minigrids
    - Greater certainty in predicting the success of tariff incentives to promote DSM
    - Improved revenues and Return On Investment (ROI)
    - Reduced risk to investors and operators of minigrids
- Field trial (ongoing)
  - Manduar Community Development Hub, The Gambia
  - Productive uses, education and capacity building
- Knowledge exchange
  - Field visits and workshops
    - Minigrid designers, operators, users
    - Educators, researchers and policy-makers
  - Improved techno-economic performance of energy systems



ESCoBox Intelligent Micro-Grids

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Main Findings

- It takes more than just electricity provision to support productive uses of energy
  - Access to markets
    - Especially through transportation of goods and people
  - Skills and quality
    - Technical and business skills
    - Quality of technology, implementation/installation, service delivery
- Non-technical challenges are much greater that technical
  - Designing a technical solution is relatively easy ***if the nature of the problem can be defined clearly!*** – this is where the social science is so important.
    - Behavioural, social, cultural and political aspects
    - Economics

Follow-up Project Ideas

- Electric vehicles for rural the developing world applications
  - Access to markets
  - DSM for minigrids
  - Anchor load
  - Freedom from oil market volatility
  - Locally appropriate
    - Low maintenance, no pollution, performance characteristics

- Technical and business skills development
  - Minigrids and ESCOs with long term sustainability

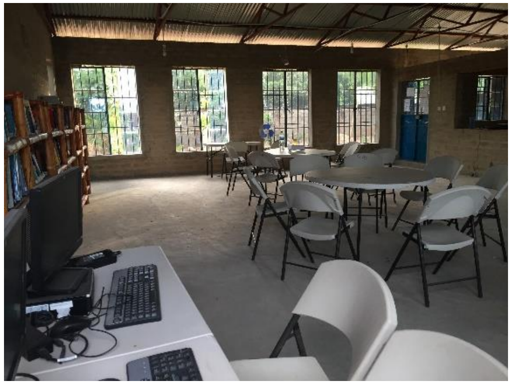
- Electric cooking
  - DSM for minigrids
  - Anchor load
  - Avoid deforestation and health

Thank You

- Further information
  - rgammon@dmu.ac.uk
  - http://goo.gl/ABGdkF
- Download DST (beta version) at:
  - http://hal.dmu.ac.uk/temp/2016/04/ESCoBox_DST_spreadsheet_R1.xlsm

Field trial

- Manduar Community Development Hub, The Gambia
  - PV-powered minigrid
  - Batteries failing
    - Poor design, installation and maintenance
    - Excessive demand
    - Inefficient operation
  - Growing demand
  - Tight budget
  - Great potential!



DST Subsystems

- DST enhanced through embedded subsystems
  - Load disaggregation
    - Operational data used to fine-tune assumptions
    - Strengthens DST for system management and growth
      - Strong latent demand suggests growth is inevitable
  - Battery management model
    - Enhances understanding of effects on system health

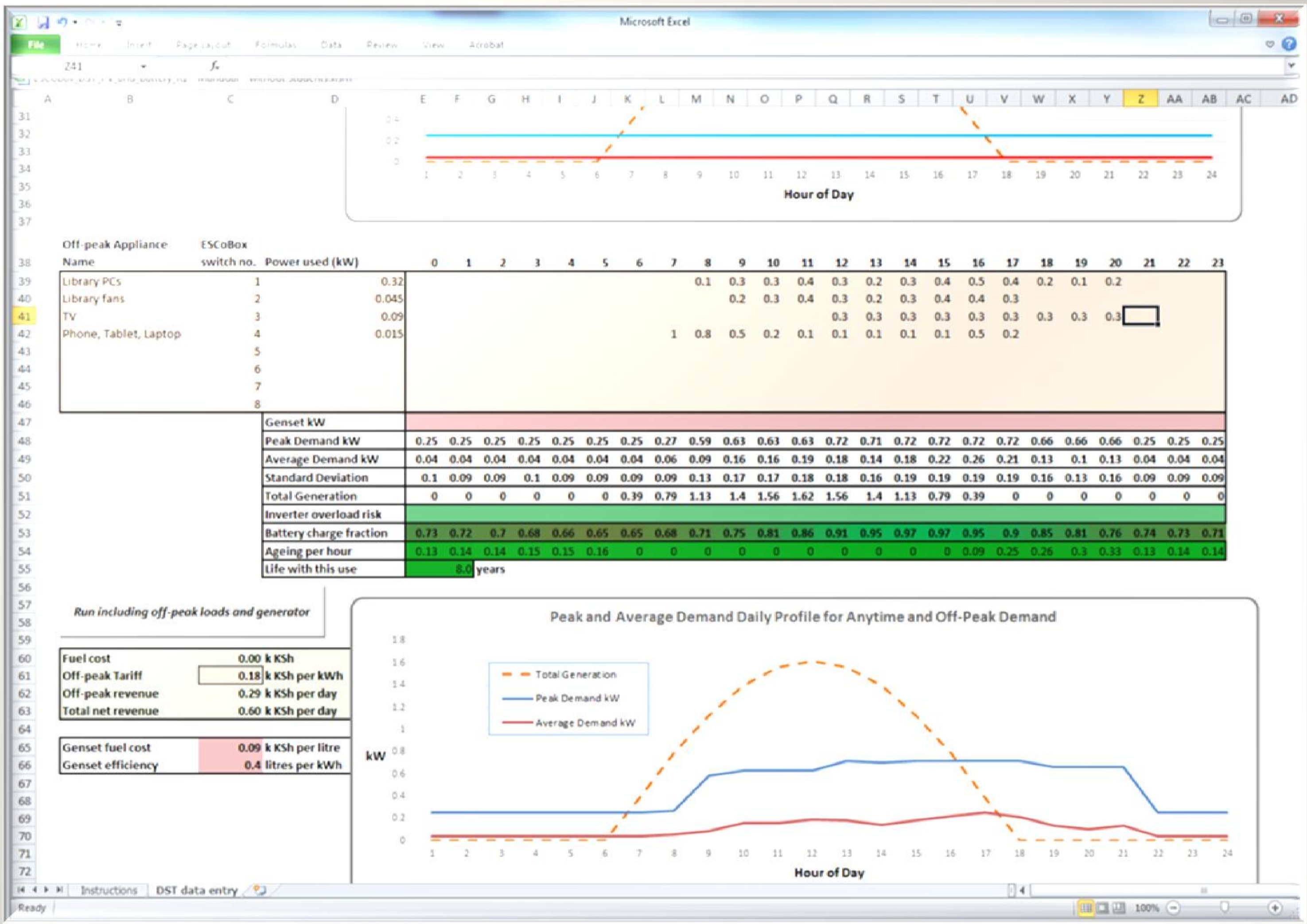
Caution

This is a decision ***support*** tool, not a decision ***making*** tool

It still requires:

- Human initiative
- Interpretation of data
- Local knowledge
- Business acumen

ESCoBox DST



Off-peak Appliance Name	ESCoBox switch no.	Power used (kW)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Library PCs	1	0.32									0.1	0.3	0.3	0.4	0.3	0.2	0.3	0.4	0.5	0.4	0.2	0.1	0.2			
Library fans	2	0.045										0.2	0.3	0.4	0.3	0.2	0.3	0.4	0.4	0.3						
TV	3	0.09													0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3			
Phone, Tablet, Laptop	4	0.015								1	0.8	0.5	0.2	0.1	0.1	0.1	0.1	0.1	0.5	0.2						
	5																									
	6																									
	7																									
	8																									

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Genset kW																								
Peak Demand kW	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.27	0.59	0.63	0.63	0.63	0.72	0.71	0.72	0.72	0.72	0.72	0.66	0.66	0.66	0.25	0.25	0.25
Average Demand kW	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.06	0.09	0.16	0.16	0.19	0.18	0.14	0.18	0.22	0.26	0.21	0.13	0.1	0.13	0.04	0.04	0.04
Standard Deviation	0.1	0.09	0.09	0.1	0.09	0.09	0.09	0.09	0.13	0.17	0.17	0.18	0.18	0.16	0.19	0.19	0.19	0.19	0.16	0.13	0.16	0.09	0.09	0.09
Total Generation	0	0	0	0	0	0	0.39	0.79	1.13	1.4	1.56	1.62	1.56	1.4	1.13	0.79	0.39	0	0	0	0	0	0	0
Inverter overload risk																								
Battery charge fraction	0.73	0.72	0.7	0.68	0.66	0.65	0.65	0.68	0.71	0.75	0.81	0.86	0.91	0.95	0.97	0.97	0.95	0.9	0.85	0.81	0.76	0.74	0.73	0.71
Ageing per hour	0.13	0.14	0.14	0.15	0.15	0.16	0	0	0	0	0	0	0	0	0	0	0.09	0.25	0.26	0.3	0.33	0.13	0.14	0.14
Life with this use	8.0 years																							

Fuel cost	0.00	k KSh
Off-peak Tariff	0.18	k KSh per kWh
Off-peak revenue	0.29	k KSh per day
Total net revenue	0.60	k KSh per day

Genset fuel cost	0.09	k KSh per litre
Genset efficiency	0.4	litres per kWh

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Baseline Demand Table

ESCoBox
Intelligent Micro-Grids

- Initially, baseline demand curve is set up
  - Number of appliance (by type)
    - Non-dispatchable, low-power loads (e.g. lights)
  - Probability of being switched on at each hour

ESCoBox Decision Support Tool

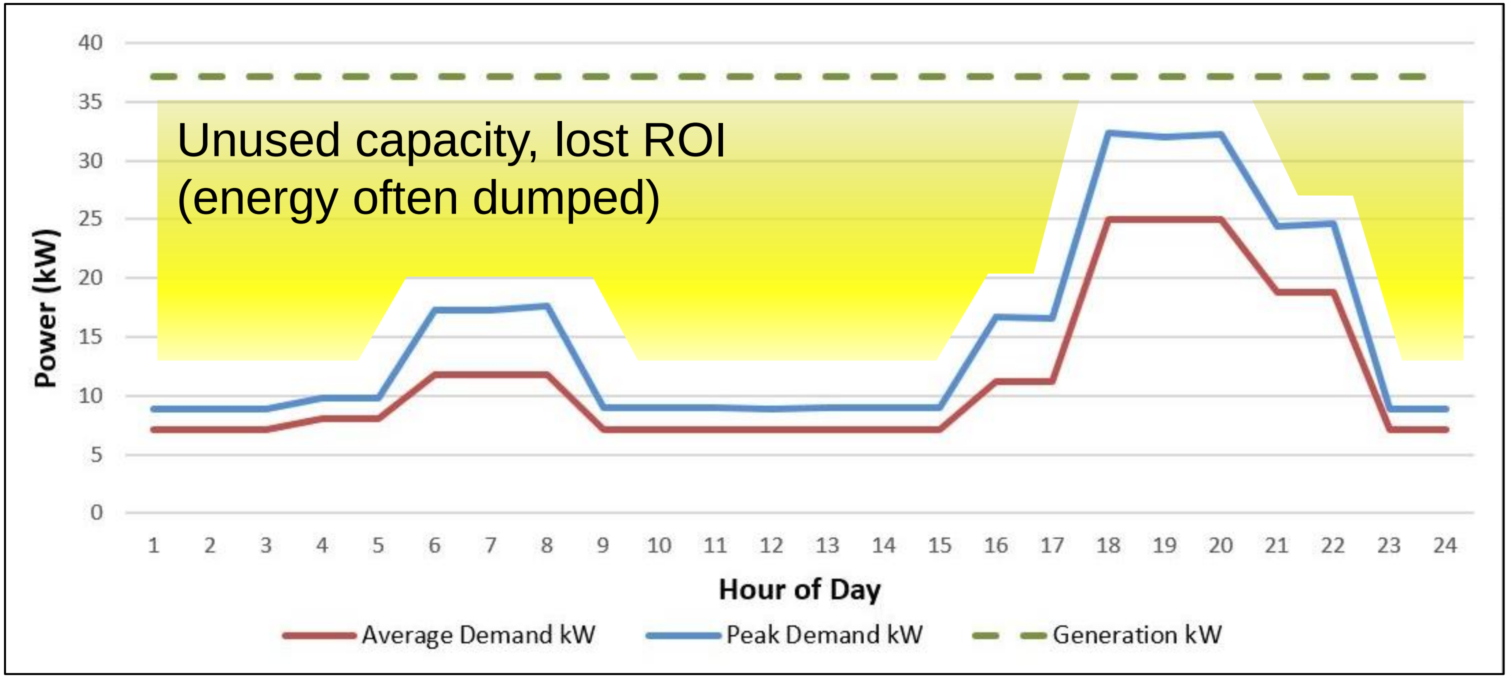
Duty Cycle by hour:

Uncontrolled

Appliance Name	Population	Power used (kW)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Light - Incandescent	100	0.04				0.1	0.1	0.1	0.1	0.1										0.5	0.5	0.5	0.4	0.4		
Light - CFL	150	0.012	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1										0.7	0.7	0.7	0.5	0.5	0.1	0.1
Light - LED	150	0.005	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1										0.9	0.9	0.9	0.7	0.7	0.1	0.1
Phone charger	200	0.005	0.6	0.6	0.6	0.6	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.6
Television-LCD	100	0.05				0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.8	0.8	0.8	0.7	0.7		
Ceiling fan	200	0.04	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.8	0.8	0.8	0.7	0.7	0.5	0.5
Refrigerator	50	0.15	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Other Appliance	50	0.8						0.1	0.1	0.1								0.1	0.1	0.2	0.2	0.2	0.1	0.1		
Other Appliance	20	0.05						0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		
		Peak Demand kW	8.9	8.8	8.8	9.8	9.9	17	17	18	9	9	9	8.9	8.9	9	9	17	17	32	32	32	24	25	8.9	8.9
Risk demand > peak	0.001	Average Demand kW	7.1	7.1	7.1	8	8	12	12	12	7.1	7.1	7.1	7.1	7.1	7.1	7.1	11	11	25	25	25	19	19	7.1	7.1
MC run length	1000	Generation kW	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37
		Standard Deviation	0.6	0.6	0.6	0.6	0.6	1.8	1.8	1.9	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.8	1.7	2.4	2.3	2.3	1.8	1.9	0.6	0.6
		Overload risk																								

Baseline Demand Profile

- Graph shows average and peak demand profiles, plus maximum power available*



* *In this case, hydro gives straight line output (solar/wind would give profiles based on empirical data)*

Timeslot Allocation Table

ESCoBox Intelligent Micro-Grids

- Mini-grid system operator (MSO) can sell allocated timeslots for high power loads
  - Enters into the Controlled Appliance table to assess effect on performance and revenue

Controlled Appliance Name	ESCoBox switch no.	Power used (kW)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Hair dryer 1	1	1									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
Hair dryer 2	2	1									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1							
Maize mill 1	3	12									0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2							
Maize mill 2	4	12									0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2							
Irrigation pump 1	5	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5						0.5	0.5	0.5	0.5
Irrigation pump 2	6	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5						0.5	0.5	0.5	0.5
Irrigation pump 3	7	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5						0.5	0.5	0.5	0.5
Irrigation pump 4	8	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5						0.5	0.5	0.5	0.5
Irrigation pump 5	9	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5						0.5	0.5	0.5	0.5
		Peak Demand kW	**16**	**16**	**16**	**17**	**17**	**23**	**23**	**23**	**37**	**37**	**38**	**38**	**37**	**37**	**37**	**38**	**38**	**32**	**32**	**32**	**30**	**30**	**16**	**16**
		Average Demand kW	**11**	**11**	**11**	**12**	**12**	**15**	**15**	**15**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**25**	**25**	**25**	**22**	**22**	**11**	**11**
		Generation kW	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**
		Standard deviation	**1.7**	**1.7**	**1.8**	**1.8**	**1.8**	**2.4**	**2.4**	**2.3**	**6.8**	**6.8**	**7.1**	**7.1**	**6.8**	**6.9**	**7**	**7**	**7**	**2.4**	**2.3**	**2.3**	**2.4**	**2.5**	**1.7**	**1.7**
		Overload risk																								

Overload risk

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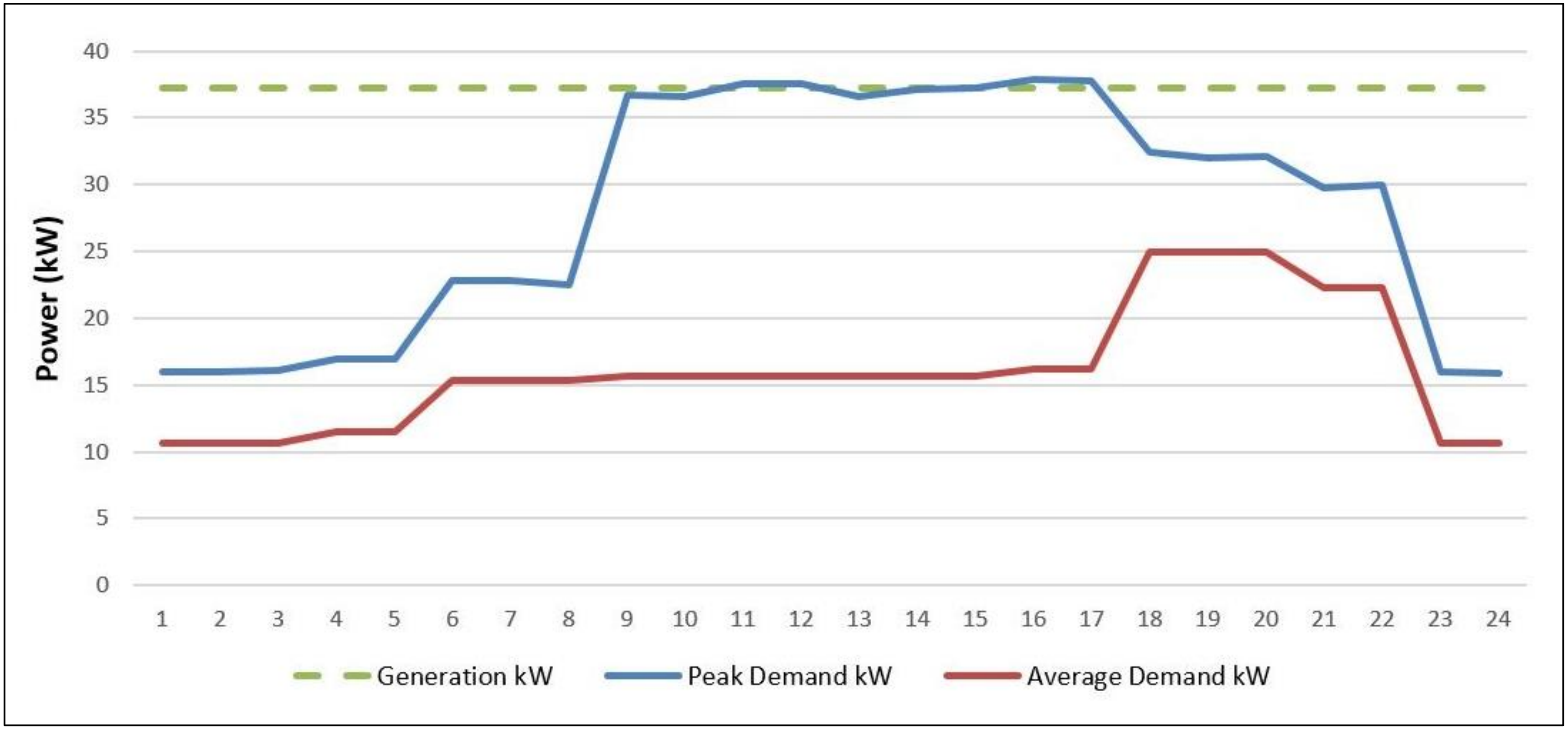
Timeslot Allocated Profile

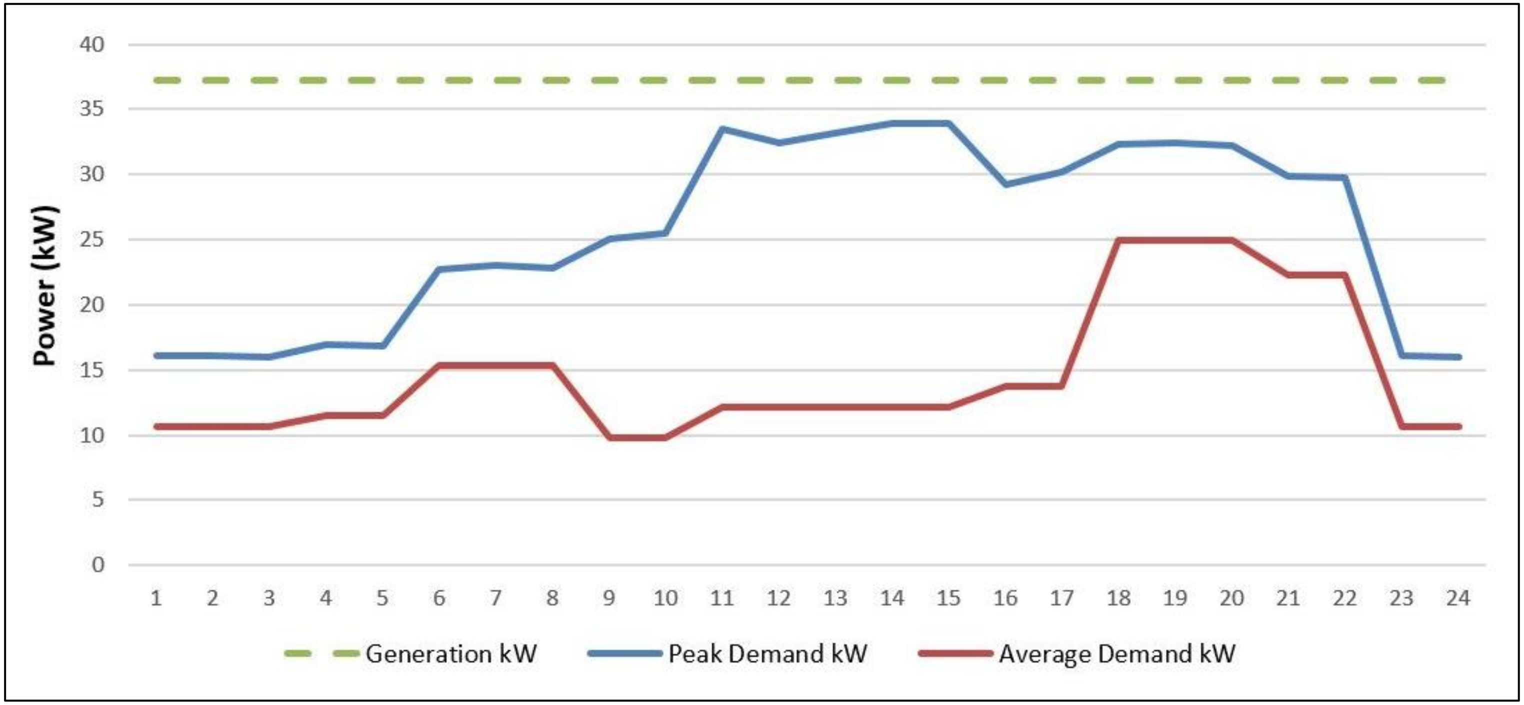
- This example illustrates potential risk of overload



Adjusted Timeslot Allocation

ESCoBox
Intelligent Micro-Grids

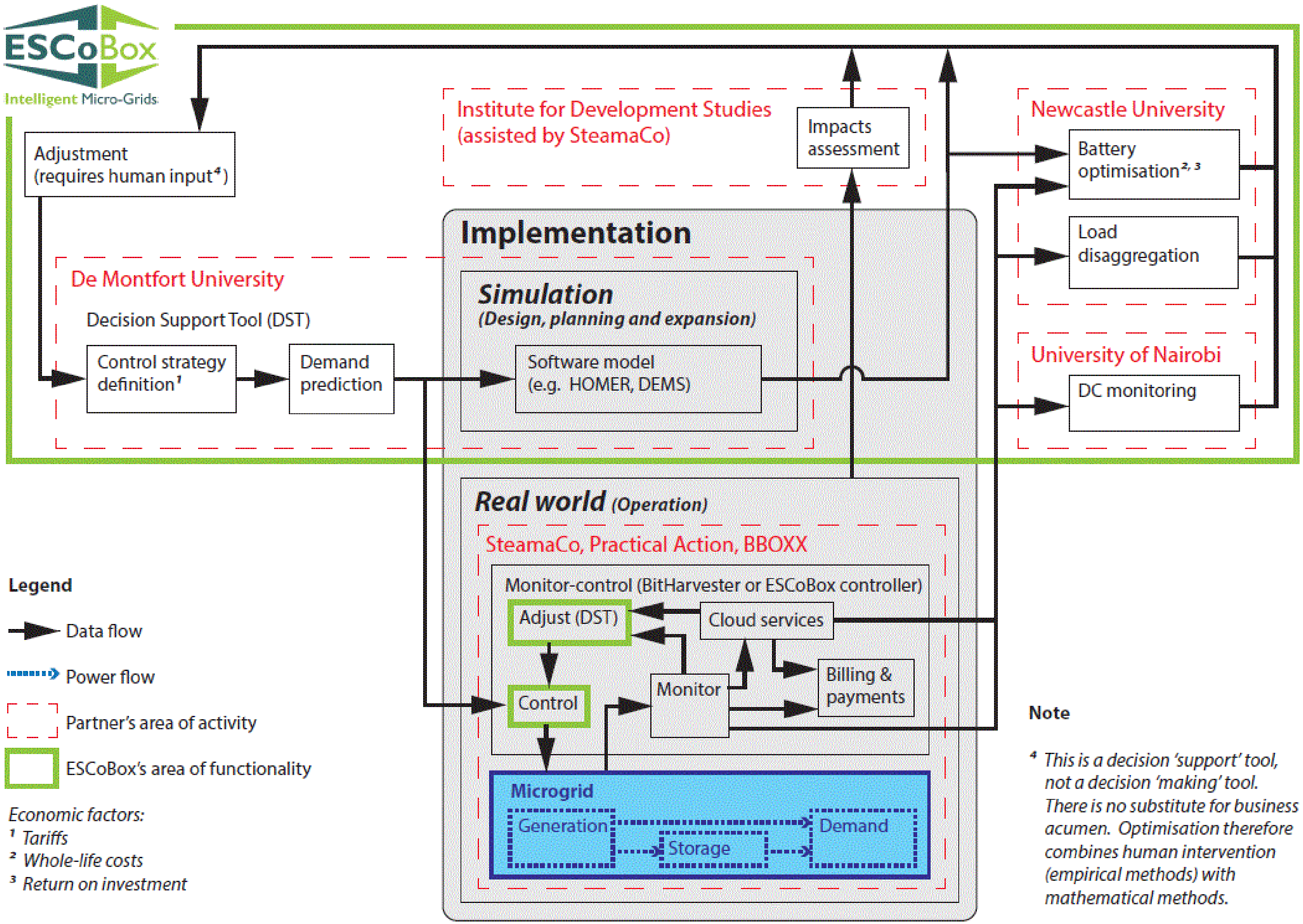
- Adjusted to reduce risk of overload
- Now safe to offer timeslots for sale
  - Once sold, upload table to CN



Impacts Assessment

- Stated aim is to reduce poverty through enabling access to affordable, reliable energy resources
  - Is this what really happens?
    - Do people earn more money?
    - Are more jobs created?
  - If not:
    - Is energy access the wrong answer…
    - … or just not enough on its own?
  - Does reduced poverty equate to improved quality of life?

Partner Roles



Technical Implementation

- Firstly, need to **keep it simple**!
  - Whether OECD or Developing World
  - Avoid complex tariff structures or consumer interactions
- Two aspects of ESCoBox system
  - Control system
  - Decision Support Tool (DST)
- ESCoBox can be used in conjunction with other systems, e.g.:
  - BitHarvester
    - Developed by ESCoBox project partner SteamaCo
  - Conlog