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Previous results

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Dr. Herena Torio

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Agenda

Part 0 – What do we need?
Demands

Part I – First potential analysis
Agent-based model for the community

Part II – First potential analysis
Mini-grid optimization and sizing: the cost of energy independence

Part III - The challenges
Vulnerability analysis

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Part 0 – What do we need?

Electricity access in the region

Municipio	Vereda	Personas residentes	Con Energía	Sin Energía
SAN CARLOS	Calderas	65	58	7
	Camelias	47	38	9
	El Chocó	112	101	11
	El Tabor	63	56	7
	Fronteritas	47	47	0
	La Florida	134	120	14
	La Hondita	121	105	16
	La Rápida	33	31	2
	Palmichal	293	277	16
	Pío XII	163	145	18
	Puerto Rico	148	134	14
	Vallejuelos	289	278	11
SAN RAFAEL	Arenal	237	217	20
	El Brasil	245	229	16
	El Guadual	67	67	0
	La Pradera	153	153	0
	La Rápida	231	227	4
	Los Centros	126	120	6
	Playas Cardal	148	148	0
	Quebradona	100	100	0
	Tesorito	74	74	0
GRANADA	El Chuscal	18	18	0
	La Quiebra	61	59	2
	Los Medios	248	239	9
	La Aguada	182	172	10
	Calderas	No registra	No registra	No registra
	San Miguel	No registra	No registra	No registra
TOTAL		3405	3213	192
TOTAL SOLO EL DRMI		1151	1086	65

Fuente: Base de datos municipales SISBEN – 2016. DRP – Estrategia de participación social

Village	With Electricity	Without Electricity
Arenal de San Rafael	217	20
Las Camelias de San Carlos	38	9
Las Florida de San Carlos	120	14
Total	**375**	**43**
Percentage	**89.7%**	**10.3%**

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Part 0 – What do we need?

Energy for cooking

Tabla 38. Residentes del DRMI y su área de incidencia con combustible para cocción de alimentos

Municipio	Vereda	Personas residentes	Electricidad	Gas propano (cilindro o pipeta)	Material de desecho, leña, carbón de leña	Ninguno
SAN CARLOS	Calderas	65	26	1	36	2
	Camelias	47	6	0	41	0
	El Chocó	112	2	13	94	3
	El Tabor	63	7	6	47	3
	Fronteritas	47	2	6	39	0
	La Florida	134	10	2	122	0
	La Hondita	121	20	13	86	2
	La Rápida	33	1	10	22	0
	Palmichal	293	8	44	220	21
	Pío XII	163	8	3	152	0
	Puerto Rico	148	12	14	115	7
	Vallejuelos	289	0	22	264	3
SAN RAFAEL	Arenal	237	37	49	151	0
	El Brasil	245	16	15	213	1
	El Guadual	67	0	0	67	0
	La Pradera	153	10	0	143	0
	La Rápida	231	21	38	166	6
	Los Centros	126	2	0	118	6
	Playas Cardal	148	24	13	111	0
	Quebradona	100	0	0	100	0
	Tesorito	74	0	0	74	0
GRANADA	El Chuscal	18	0	0	18	0
	La Quiebra	61	16	5	40	0
	Los Medios	248	91	28	128	1
	La Aguada	182	2	27	153	0
Total		3405	321	309	2720	55
Total sólo en el DRMI		**1151**	**108**	**104**	**921**	**18**

Fuente: Base de datos municipales SISBEN – 2016. Y DRP – Estrategia de participación social

Village	Electricity	Gas	Waste
Arenal de San Rafael	37	49	151
Las Camelias de San Carlos	6	0	41
Las Florida de San Carlos	10	2	122
Total	**53**	**51**	**314**
Percentage	**13**	**12**	**75**

Part 0 – What do we need?

Electricity demands

Domestic electricity demands

Notes from first survey, 10 households

- 2,3 person per household
- 8 out of 10 households use washing machine for 1.8 days/week and 2.6 h/day
- every house use 1 refrigerator 7 h/day
- average of 12 LED bulbs in 8 houses and an average of 5.25 h/day
- 4 households with electric oven, less than 1h/day (0.85 kwh)
- 8 houses with blender, being used 5 day per week, less of 1 h/day

- **Average demand: 153kWh/month per household**

Part 0 – What do we need?

Electricity demands

Domestic electricity demands

Notes from first survey, 10 households

- **Average demand: 153kWh/month per household**

Yearly consumption	**1891 kWh/a**	**5,2 kWh/day**

- **Seasonal pattern**

Months	Avg. Consumption (kWh/3 months)	Avg. Consumption (kWh/day)
28 Aug – 30 Nov	536	5,95
30 Nov – 26 Feb	461	5,12
26 Feb – 27 May	496	5,51
27 May – 29 Aug	398	4,42

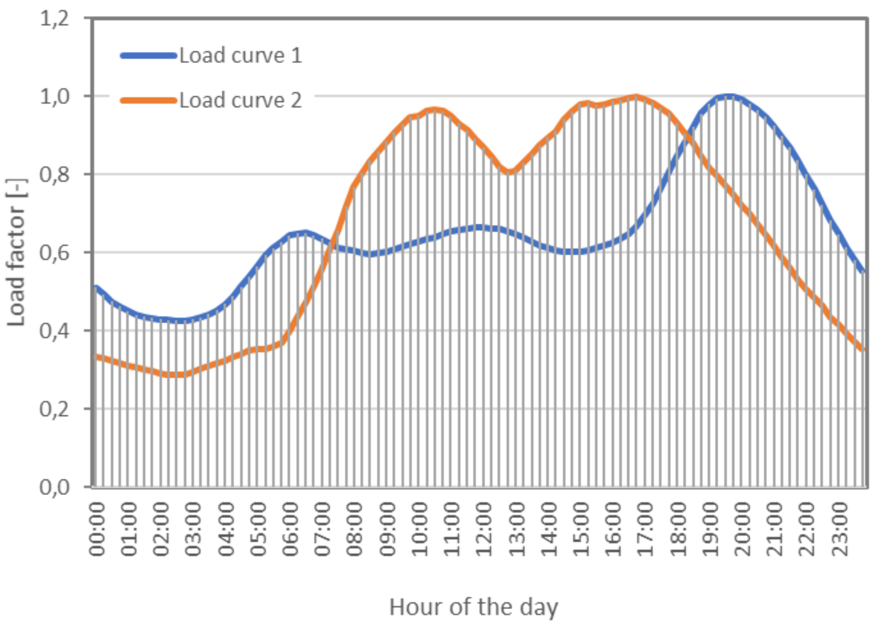
Part 0 – What do we need?

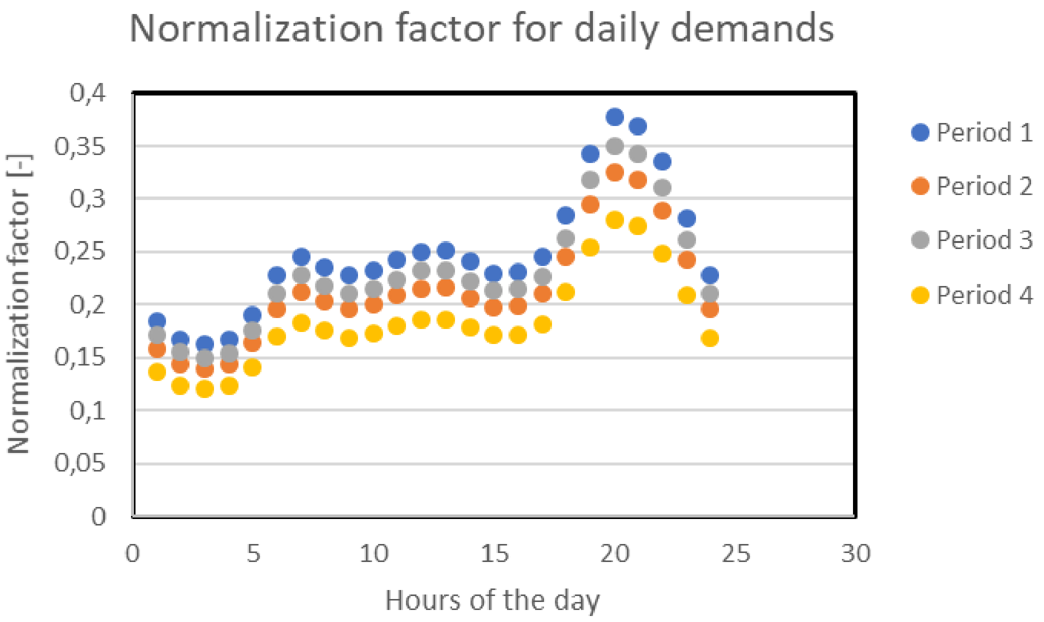
Electricity demands

Domestic electricity demands

Notes from first survey, 10 households

Period	Peak load (kW)
1	0.38
2	0.32
3	0.35
4	0.28





Building upon previous results

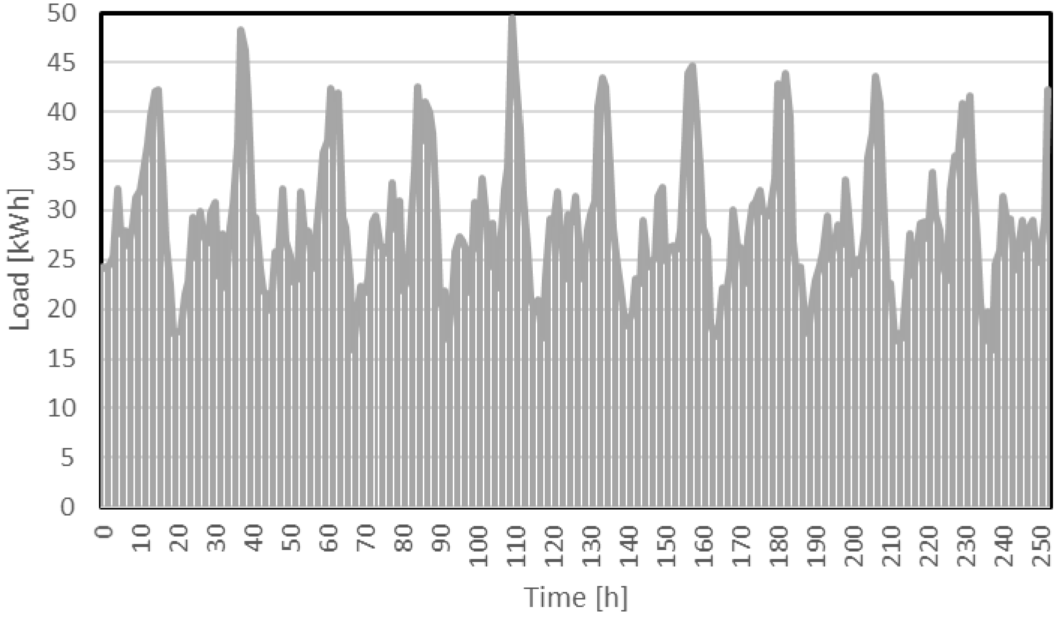
Part 0 – What do we need?

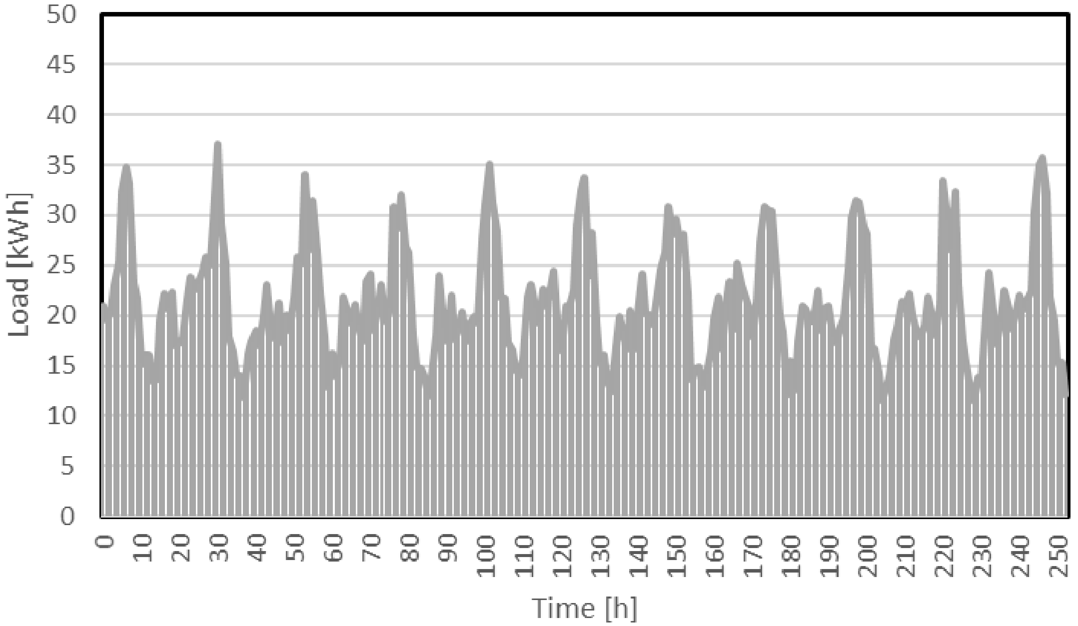
Electricity demands

Domestic electricity demands

- Relatively high base loads
- Relatively low Seasonal variability

Period	Peak load (kW)
1	0.38
2	0.32
3	0.35
4	0.28





Building upon previous results

Agenda

Part 0 – What do we need?
Demands

Part I – First potential analysis
Agent-based model for the community

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Mini-grid optimization and sizing: the cost of energy independence

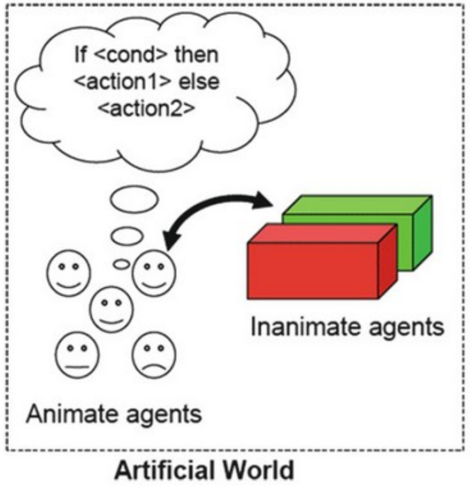
Part III - The challenges
Vulnerability analysis

Part I – First potential analysis

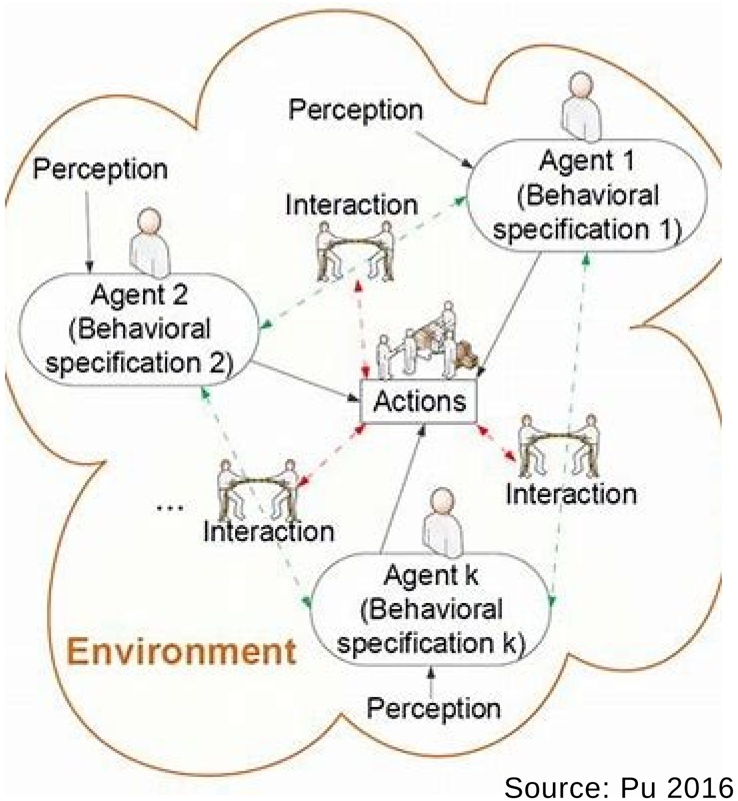
What are ABMs?

- Simulation model
- Emulate actions and interactions of autonomous agents
- **Agents:** individual or collective entities, people or technologies

- **Aim:** understand the behavior of a system and what governs its outcomes**.**



Source: Crooks and Heppenstall. 2012



Source: Pu 2016

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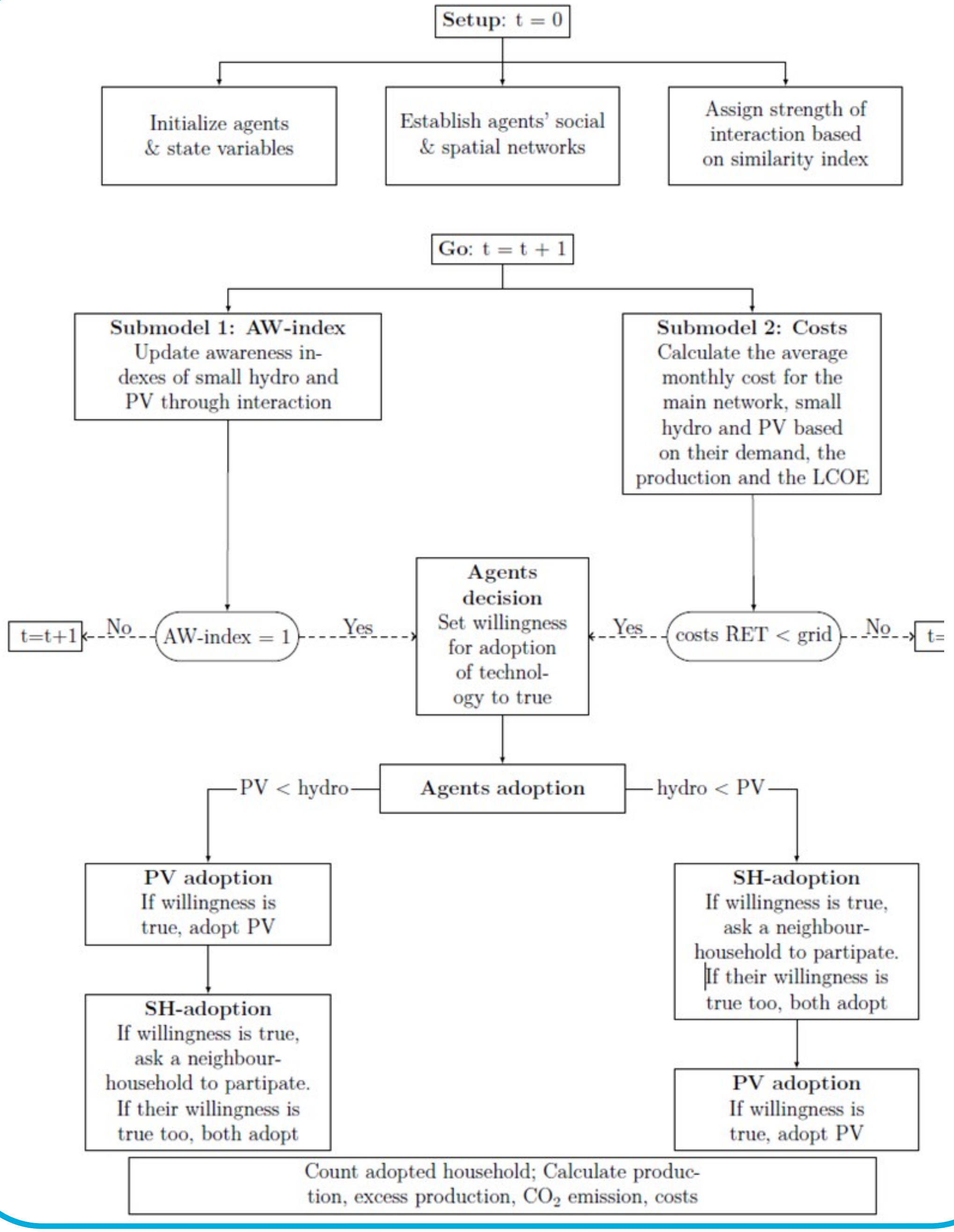
Part I – First potential analysis

How realistic is a decentralized implementation?

Main input data

Variable	Value
Demand	$153 kWh$
Number of households	116
Ratio of rurals and neo-rurals	50% rurals, 50% neo-rurals
SH initial-AW-index (neo-rurals)	random 0.25-0.5
PV initial-AW-index (neo-rurals)	0.8 * AW-SH
SH initial AW-index (rurals)	0
PV initial AW-index (rurals)	0
Simi-index (neo-rurals)	0.5 – 1
Simi-index (rurals)	0 – 0.5
Costs main grid	0.165 $US\$ / kWh$
LCOE hydro	0,045 $US\$ / kWh$
LCOE PV	0,11 $US\$ / kWh$
CO_2 emissions main grid	211,414 g / kWh
CO_2 emissions hydro	24 g/kWh
PV CO_2 emissions	41 g / kWh

Model structure



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Part I – First potential analysis

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CO_2 emissions hydro	24 g/kWh
PV CO_2 emissions	41 g / kWh

Model limits and assumptions

- Ideal battery storage (energy balancing) without costs
- LCOEs for hydro and PV rather low
- No business model considered
- No distinction on CAPEX & OPEX

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Part I – First potential analysis

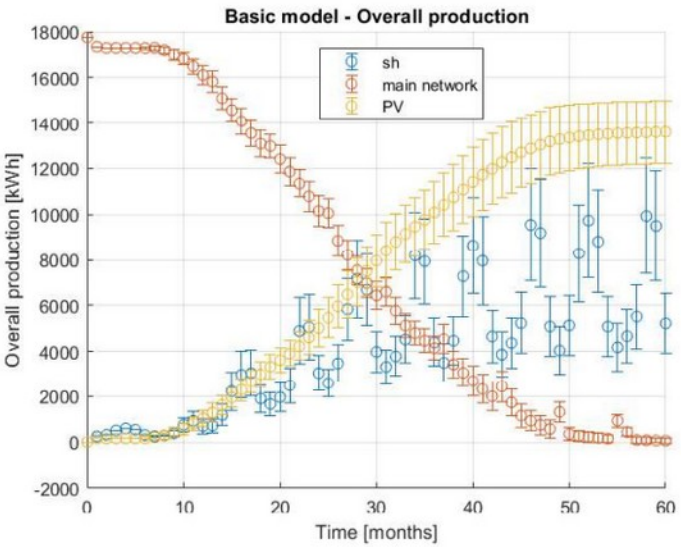
How realistic is a decentralized implementation?

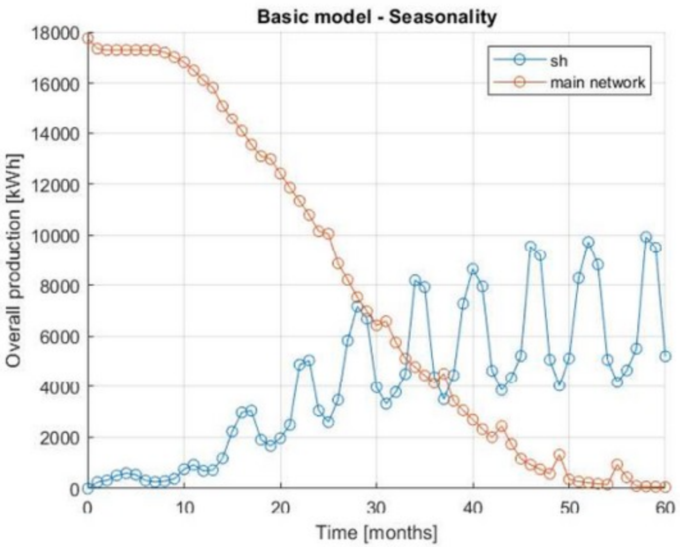
Behaviour of the basic model

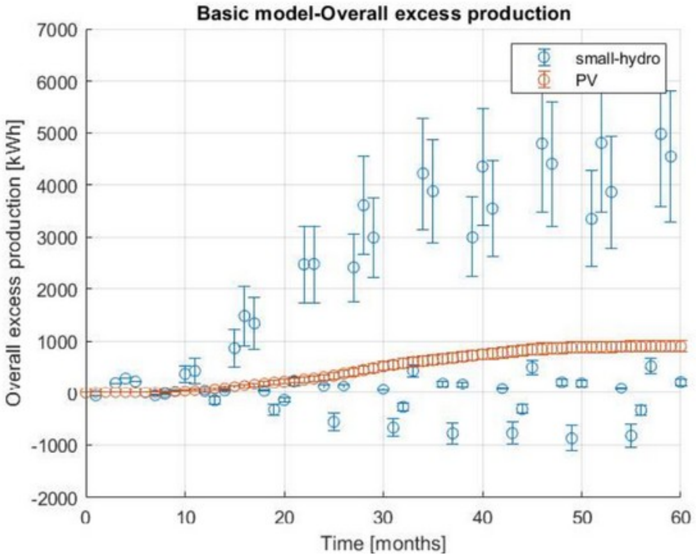
Substitution of the grid supply

Seasonality in hydro production

Seasonality in excess electricity





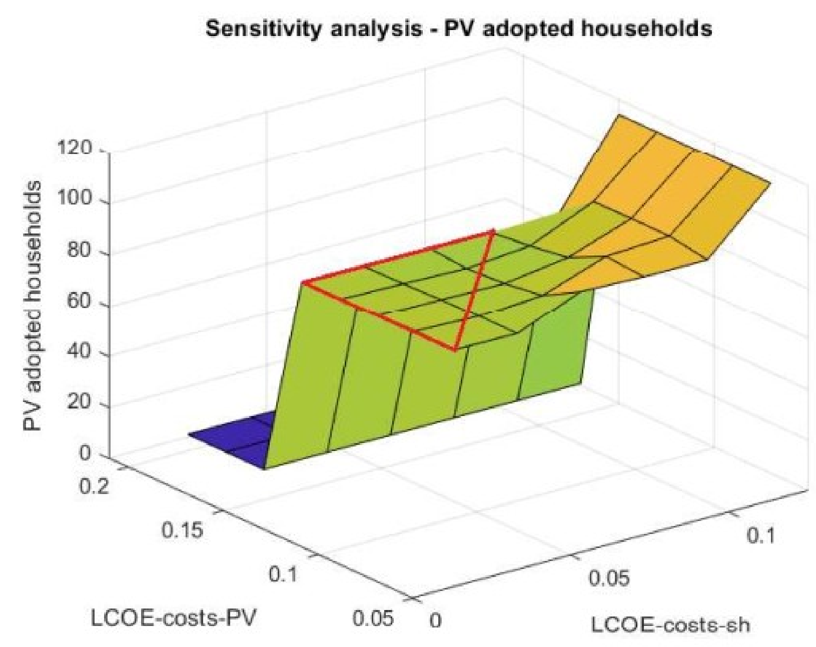


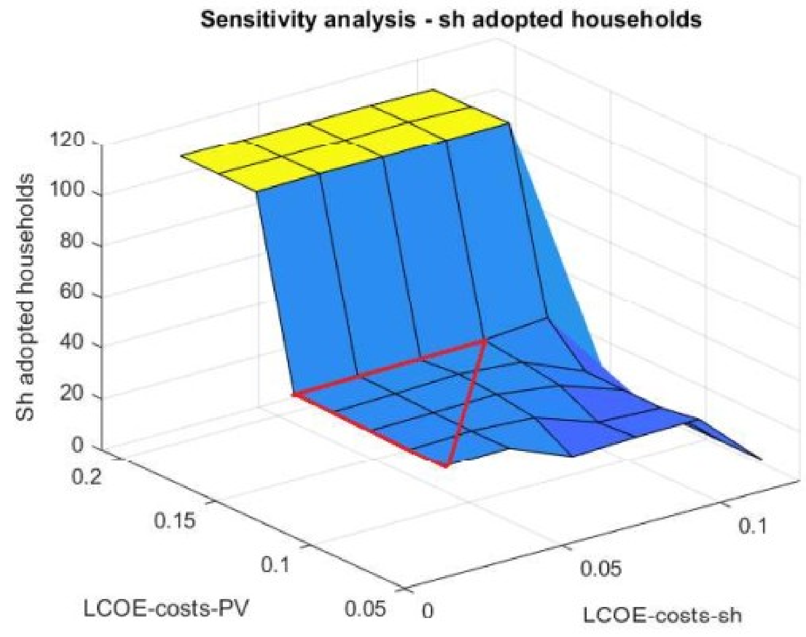
Building upon previous results

Part I – First potential analysis

Sensitivity analysis

Influence of LCOE of SH and PV on the number of adopting housholds
Base case: PV_{LCOE} =11 \$/kWh; SH_{LCOE}=0,045 \$/kWh





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Part II – First potential analysis

Technical potential for hybrid PV and hydro mini-grid

Input data for different scenarios

Component	CAPEX	OPEX (% of CAPEX over 20 years)
PV	1000 – 3000 $/kWp	15
Small hydro	1000 – 5000 $/kW	2%
Battery	2000 – 3000 $/kWh	20%

- Higher peak loads
- Low rainfall / hydro potential
- 100% RE powered – or grid-supported (% of total demand)

Part II – First potential analysis

Technical potential for hybrid PV and hydro mini-grid

Case 1 - Grid supported, with batteries

Authors: Agada, Redemption; Akoto, Bossman; Eckhardt, Markus; Petrin, Geert; Willen, Leonard

High base loads!!!

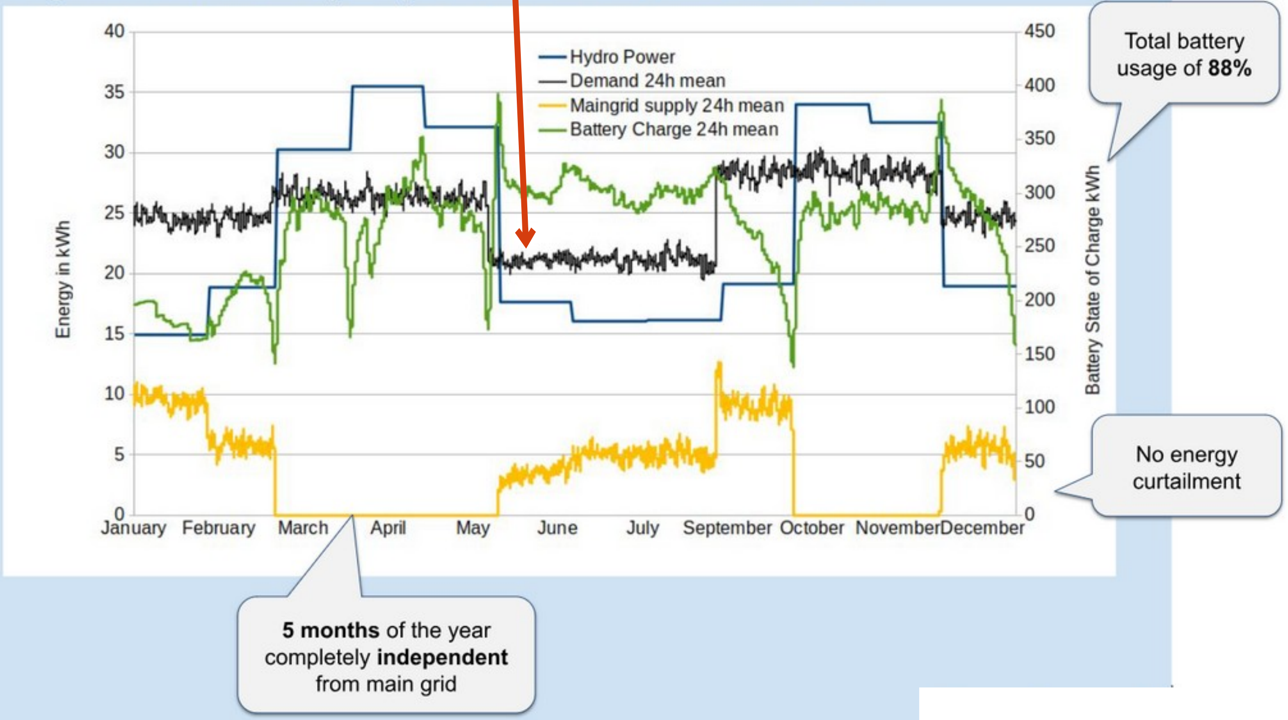
Financial Principles

Initial State of Charge 50%

	Battery	Hydro	Photovoltaic	Main Grid
Investment Cost once	2000 $/kW	2500 $/kW	2000 $/kW	0 $/kW
Operation Cost per Year	20% of Investment	2% of Investment	15% of Investment	$0.14 per kWh

Table 2: Cost Assumptions for Construction and Maintenance

Figure 1: Simulated yearly Power Flow in Base Scenario



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Part II – First potential analysis

Technical potential for hybrid PV and hydro mini-grid

Case 1 - Grid supported, with batteries

Authors: Agada, Redemption; Akoto, Bossman; Eckhardt, Markus; Petrin, Geert; Willen, Leonard

Normal Case for Microgrid Design

max. 40% Main Grid Supply

Battery Size for half of daily demand - 402 kWh

Largest investment and annual costs

	Hydro	Battery	Main Grid
Installed Capacity	35.5 kW 71 Turbines	402 kWh	
Installation Costs	$88,815	$401,861	$0
Annual Costs (O&M,$/kWh)	$1,776	$80,372	$4,453
Provided in total	209,062 kWh	193,957 kWh	31,805 kWh

Table 3: Capacity, Cost and Total provided Energy for Base Scenario

15% of demand

Share in Cost

	Hydro	Battery	Main grid
Investment cost	18%	82%	
Annual cost	2%	98%	5%

This scenario is **expensive** due to the **battery costs**

Building upon previous results

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Part II – First potential analysis

Technical potential for hybrid PV and hydro mini-grid

Case 1 - Grid supported, with batteries

Authors: Agada, Redemption; Akoto, Bossman; Eckhardt, Markus; Petrin, Geert; Willen, Leonard

Base Scenario	Current Values
$490,677	**Installation Costs** $0
$86,601	**Annual Operation Cost** $30,802
$1,227,961	**Net Present Cost of 20 years** $262,240
$0.656	**LCOE (USD/kWh)** $0.140
85%	**Grid Independency** ~0%

> Annual cost higher compared to current values - **will never amortize**

> **~5x higher energy cost** compared to today

Part II – First potential analysis

Technical potential for hybrid PV and hydro mini-grid

Case 1 - Grid supported, WITHOUT batteries

Authors: Agada, Redemption; Akoto, Bossman; Eckhardt, Markus; Petrin, Geert; Willen, Leonard

Largest investment and annual costs

	Hydro	Battery	Main Grid
Installed Capacity	35.5 kW 71 Turbines	402 kWh	
Installation Costs	$88,815	$401,861	$0
Annual Costs (O&M,$/kWh)	$1,776	$80,372	$4,453
Provided in total	209,062 kWh	193,957 kWh	31,805 kWh

Table 3: Capacity, Cost and Total provided Energy for Base Scenario

15% of demand

Less hydro capacity compared to Base Scenario

Supplies 30% of demand

	Hydro	Battery	Main Grid
Installed Capacity	27.5 kW 55 Turbines	0 kWh	
Installation Costs	$69,277	$0	$0
Annual Costs (O&M, $/kWh)	$98,561	$0	$9,044
Provided in total	163,070 kWh	0 kWh	64,599 kWh

Table 4: Capacity, Cost and Total provided Energy for Stressor Scenario

Building upon previous results

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Part II – First potential analysis

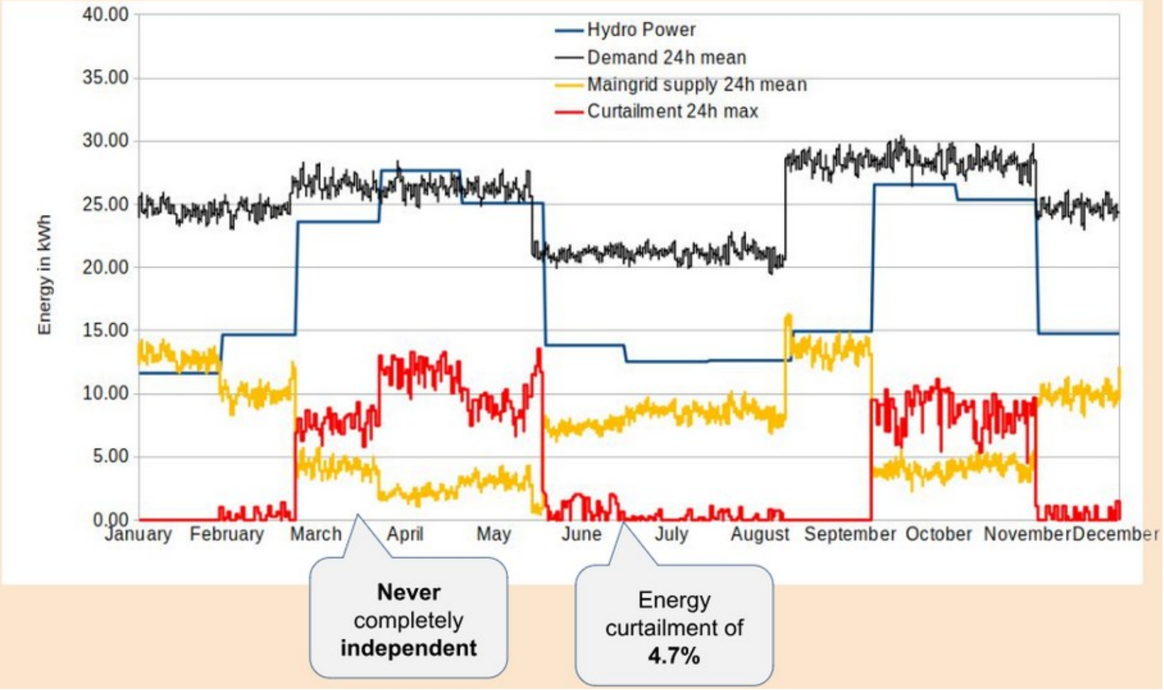
Technical potential for hybrid PV and hydro mini-grid

Case 1 - Grid supported, WITHOUT batteries

Authors: Agada, Redemption; Akoto, Bossman; Eckhardt, Markus; Petrin, Geert; Willen, Leonard

Figure 1: Simulated yearly Power Flow in Base Scenario

Figure 2: Simulated yearly Power Flow in Stressor Scenario



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Part II – First potential analysis

Technical potential for hybrid PV and hydro mini-grid

Case 1 - Grid supported

Authors: Agada, Redemption; Akoto, Bossman; Eckhardt, Markus; Petrin, Geert; Willen, Leonard

Base Scenario	Current Values	Stressor Scenario
$490,677	**Installation Costs** $0	$69,277
$86,601	**Annual Operation Cost** $30,802	$11,577
$1,227,961	**Net Present Cost of 20 years** $262,240	$167,838
$0.656	**LCOE (USD/kWh)** $0.140	$0.090
85%	**Grid Independency** ~0%	70%

Annual cost higher compared to current values - **will never amortize**

~5x higher energy cost compared to today

~Double of current yearly cost need to be invested

If feed in tariff gets implemented LCOE **will decrease even more**

Building upon previous results

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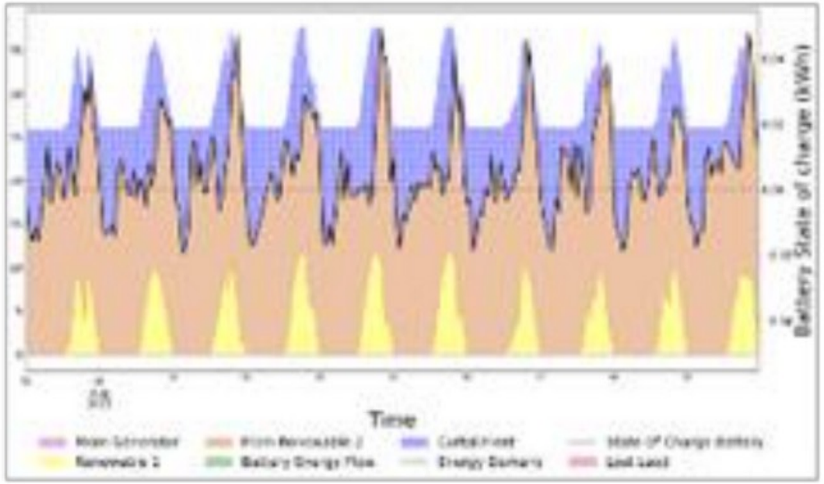
Azeez Ogunleye, David Londoño Ochoa, Hazem Abdelrahman, Mohammad Laraib Afroz, Ramiro Adorno, Tim Mauch

Part II – First potential analysis

Technical potential for hybrid PV and hydro mini-grid, 100% RE Supply

Case 2 - Blackout, grid Unsupported

- High autarky
- PV for daily peaks
- Hydro for base load
- High excess energy!!



Building upon previous results

Grid Dependence: HIGH | MEDIUM | LOW

	Base Case LLP=0.5/BI=0	Stressor 1* LLP=0.1/BI=0.5	Stressor 2 LLP=0.01/BI=0
Micro Hydro (kW)	38.95	39.47 (42.5)	57.25
PV (kW)	0	0 (0)	10
Battery (kW)	0	401.86 (0)	0
Total Cost, NPW ($)	151 488.6	683 715.8 (152 583)	190 751.8
LCOE ($/kWH_produced)	0.081	0.365 (0.081)	0.102
Excess Energy kWh/a	38 586	33 904 (52 374)	140 658
Level of self supply/ autarchy (%)	50	90 + half day B (90)	99
Lost Load (kWh)	29 388	22 001 (22 001)	2 200

* Values for system with no battery independence are given in brackets

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Part III – The challenges

		Adaptive Capacity		
Vulnerability		Low	Medium	High
Potential Impacts	High	H	H	M
	Medium	H	M	L
	Low	M	L	L

Vulnerability analysis

Case: grid connected, hydro for base load, inverters in island mode, paralell grid

Energy supply chain

		Small Hydro			Demands		
Category	Subcategory	Potential impacts	Adaptative capacity	Vulnerability	Potential impacts	Adaptative capacity	Vulnerability
Resource variation	Stressor 1 - Blackout	low	high	low	High	Medium	High

Resources:

- Low vulnerability due to island inverters and high community ownership of the hydro generators

Demands:

- Under blackout high risk of unmet peak loads
- Rather low capacity of changing htem if related to refrigeration!

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