University *of Ljubljana*
Faculty *of Mechanical Engineering*

Feasibility Study of Integrating Renewables and Hydrogen Technologies into Isolated Power Supply System of a Mountain Hut

B. Drobnič, R. Stropnik, B. Jurjevčič, M. Mori

SUSTAINABLE MOUNTAIN HUTS IN EUROPE
LIFE15 CCA/ES/000058

Project description and goals

Life SustainHuts:

- EU funded project
- demonstrative project
- reduce CO_2 emissions
- implementing renewable energy

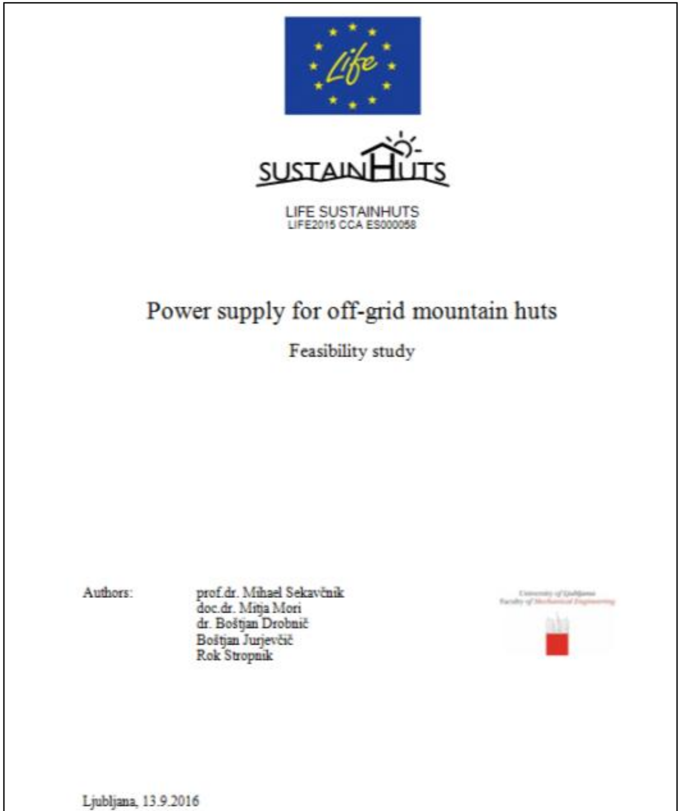
Partners

Summary of work by UL

A1.1 Demo Huts real conditions definition

- FS together with PZS and RCVT covers 2 huts in Slovenia that will be chosen from 4 available huts due to technical parameters, sustainability and renewable energy sources availability at given location: Pogačnikov dom, Vodnikov dom, **Kocbekov dom**, Dom Zorka Jelinčiča. Technicians of UL and PZS visited 3 of them: Pogačnikov dom (31.8.2016), Vodnikov dom (4.10.2016), Kocbekov dom (25.08.2016).
- As consequence, information of the **current status** of the three huts visited was collected, and a report of each hut was elaborated. In addition, a questionnaire with basic information needed for LCA study.
- A **feasibility study** was done to identify a potential solution and upgrade of current energy system installed in the mountain huts in Slovenia.
- In all huts all **mass and energy flows** were identified with all current installations, electrical appliances, generators, etc.

Feasibility study for Slovenian Huts



LIFE SUSTAINHUTS
LIFE2015 CCA ES000058

Power supply for off-grid mountain huts

Feasibility study

Authors: prof.dr. Mihael Sekavčnik
doc.dr. Mitja Mori
dr. Boštjan Drobnič
Boštjan Jurjevčič
Rok Stropnik

Ljubljana, 13.9.2016

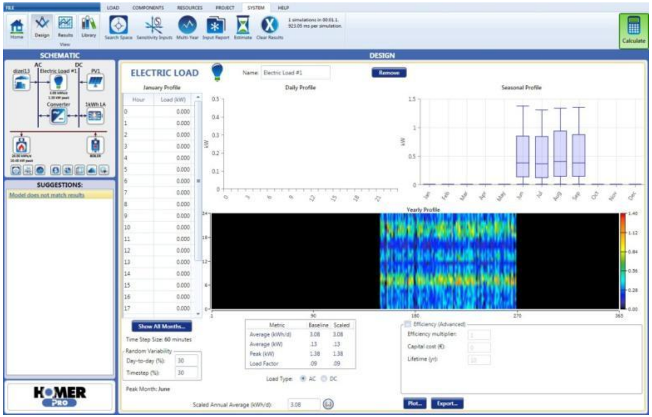
Kocbekov dom na Korošici

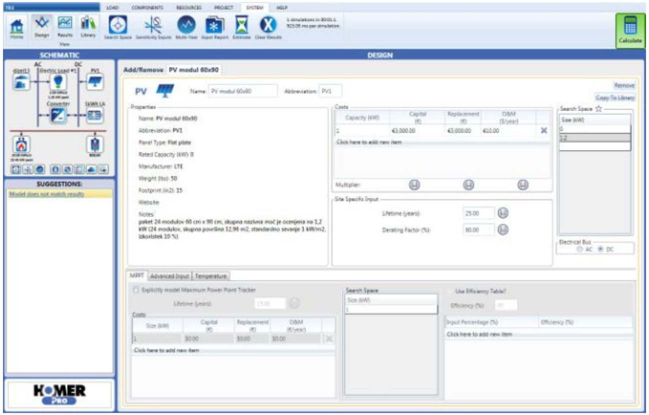
Pogačnikov dom na Kriških podih

Simulation software – Homer pro®

HOMER pro®

- simulating operation of a system through energy balances
- energy demand compared to energy supply energy flows to and from each component
- need for fuel-powered generators
- charging/discharging batteries
- various system configurations





Boundary conditions

1. Numerical simulations of modelled systems were performed for a **10-year operating period**, during which no component needed to be replaced due to exceeded **lifetime**.
2. **Load profiles** for huts were generated with the data acquired through inspection of mountain huts systems in , identification of all power consumers and estimation of typical daily load dynamics. Actual measurements of power consumption are necessary to improve the estimated load profiles as well as simualtion results.
3. **Energy production, conversion and storage** components of existing systems were identified at the locations and all the technical specifications were acquired. Economical and environmental parameters were estimated for the present study as no reliable data were available.

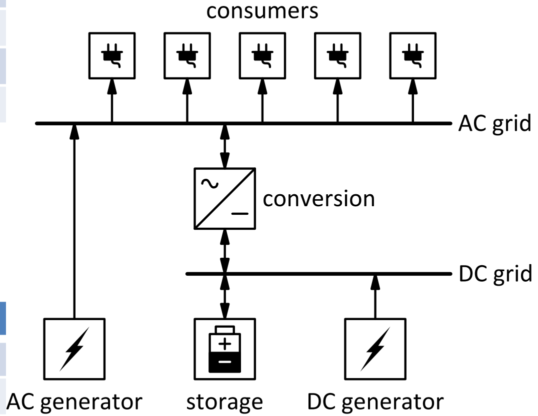
Power consumers

always on operation

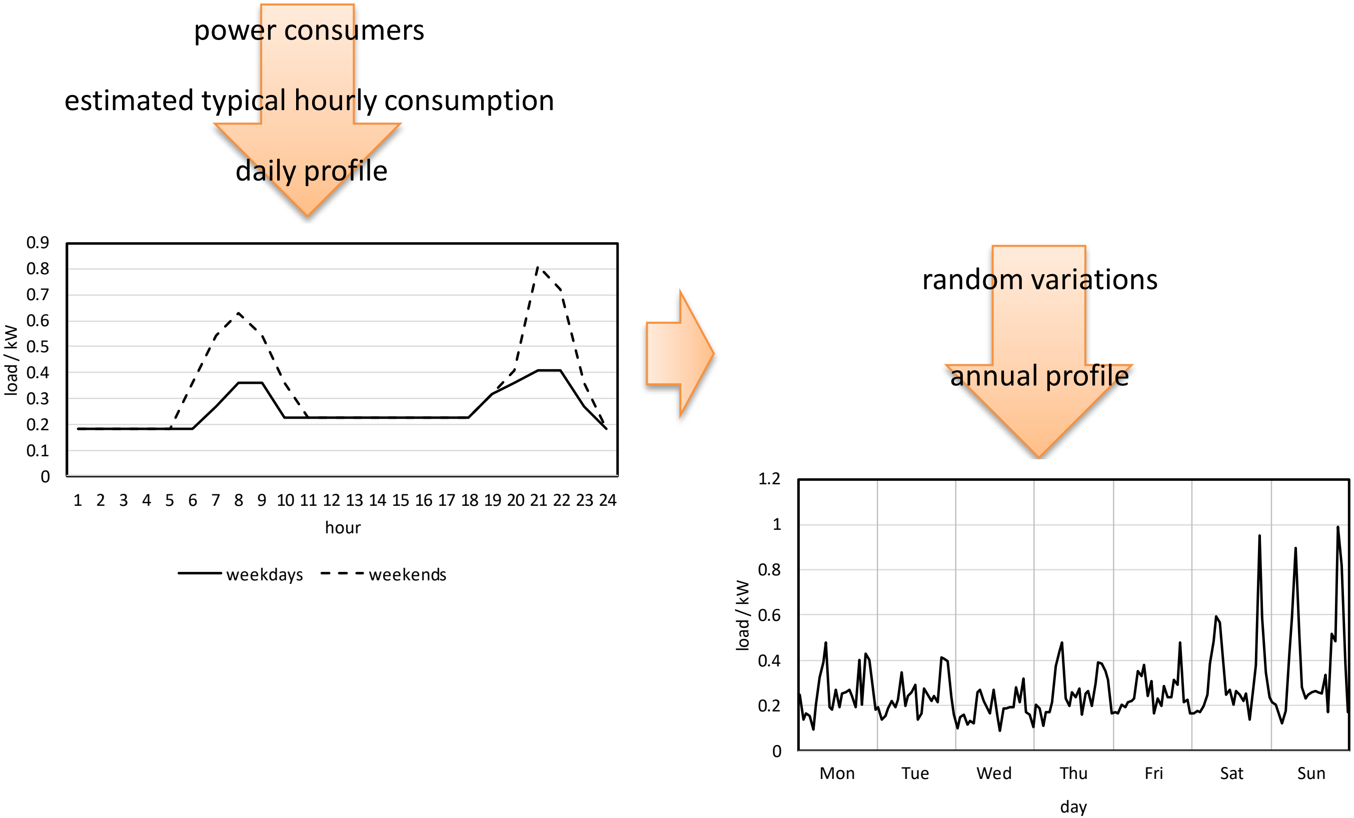
	nominal power	average power
refrigerator	150 W	45 W
freezer	200 W	30 W
communication devices	100 W	50 W
…		

on/off operation

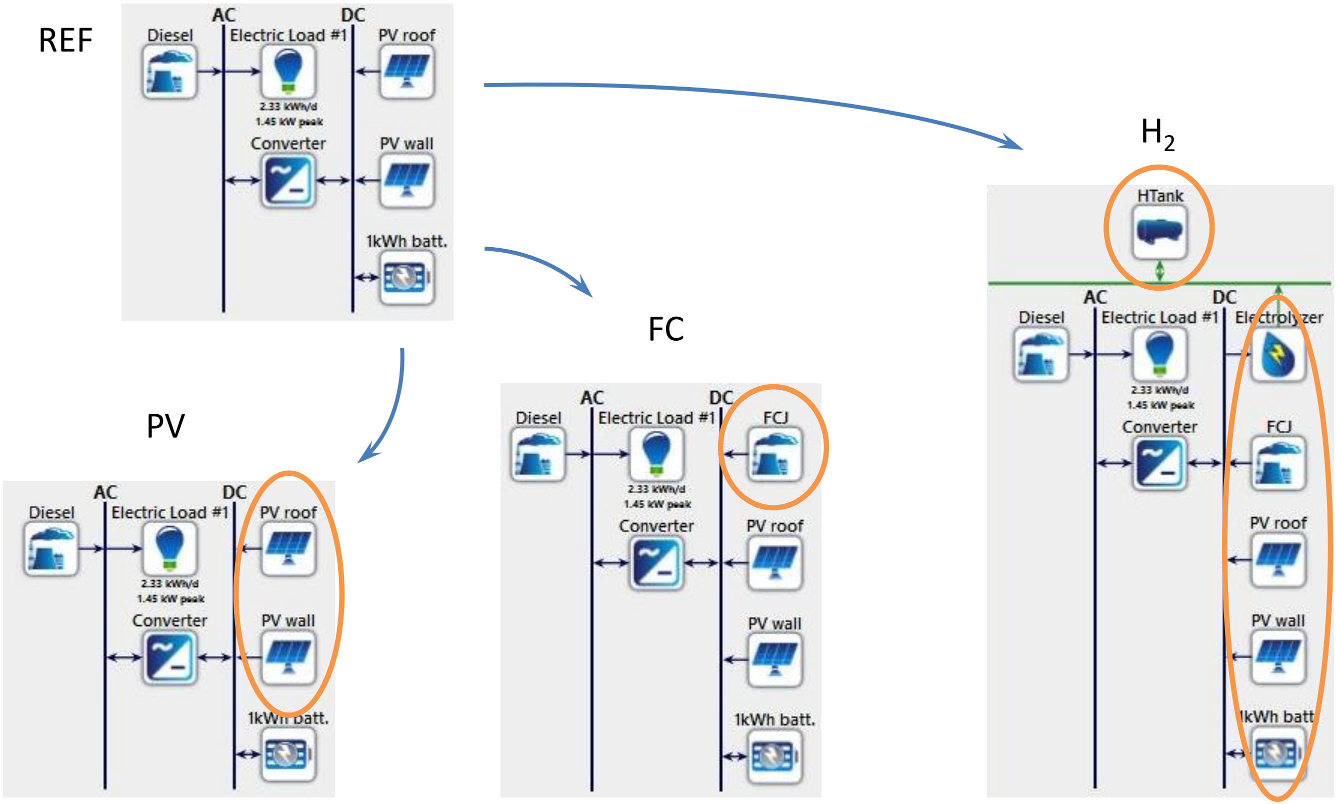
	nominal power	daily usage
lights	650 W	6 h
cash-register	60 W	18 h
water pump	800 W	0.5 h
washing machine	1000 W	0.3 h
…		



Load profiles



Analysed cases



Technical data

	REF	PV	FC	H2
AC generator				
diesel generator				
nominal power	5 kW	5 kW		
maximum efficiency	26 %	26 %		
minimum runtime	1 h	1 h		
lifetime	15 000 h	15 000 h		
capital cost	600 €/kW	600 €/kW		
replacement cost	500 €/kW	500 €/kW		
O&M cost	0.030 €/h	0.030 €/h		
DC generator				
wall mounted PV panels				
nominal power	600 W	600 W	600 W	2400 W
efficiency (STC)	12.5 %	12.5 %	12.5 %	12.5 %
temp. effect on power	-0.5 %/K	-0.5 %/K	-0.5 %/K	-0.5 %/K
nominal operating temp.	45 °C	45 °C	45 °C	45 °C
derating factor	90 %	90 %	90 %	90 %
panel slope	40°	40°	40°	40°
panel azimuth	-15°	-15°	-15°	-15°
ground reflectance	20 %	20 %	20 %	20 %
lifetime	25 years	25 years	25 years	25 years
capital cost	3000 €/kW	3000 €/kW	3000 €/kW	3000 €/kW
replacement cost	3000 €/kW	3000 €/kW	3000 €/kW	3000 €/kW
O&M cost	10 €/year	10 €/year	10 €/year	10 €/year
roof mounted PV panels				
nominal power	700 W	2100 W	700 W	2800 W
efficiency (STC)	12.5 %	12.5 %	12.5 %	12.5 %
temp. effect on power	-0.5 %/K	-0.5 %/K	-0.5 %/K	-0.5 %/K
nominal operating temp.	45 °C	45 °C	45 °C	45 °C
derating factor	90 %	90 %	90 %	90 %
panel slope	20°	20°	20°	20°
panel azimuth	-105°	-105°	-105°	-105°
ground reflectance	20 %	20 %	20 %	20 %
lifetime	25 years	25 years	25 years	25 years
capital cost	3000 €/kW	3000 €/kW	3000 €/kW	3000 €/kW
replacement cost	3000 €/kW	3000 €/kW	3000 €/kW	3000 €/kW
O&M cost	10 €/year	10 €/year	10 €/year	10 €/year
fuel cell				
nominal power			1 kW	2 kW
maximum efficiency			41 %	41 %
minimum runtime			0 h	0 h
lifetime			5 000 h	5 000 h
capital cost			3000 €/kW	3000 €/kW
replacement cost			2500 €/kW	2500 €/kW
O&M cost			0.010 €/h	0.010 €/h

energy conversion				
inverter				
nominal power	2 kW	2 kW	2 kW	2 kW
efficiency	93 %	93 %	93 %	93 %
lifetime	15 years	15 years	15 years	15 years
capital cost	150 €/kW	150 €/kW	150 €/kW	150 €/kW
replacement cost	150 €/kW	150 €/kW	150 €/kW	150 €/kW
O&M cost	0 €/year	0 €/year	0 €/year	0 €/year
rectifier (charger)				
nominal power	2 kW	2 kW	2 kW	2 kW
efficiency	93 %	93 %	93 %	93 %
lifetime	15 years	15 years	15 years	15 years
capital cost	150 €/kW	150 €/kW	150 €/kW	150 €/kW
replacement cost	150 €/kW	150 €/kW	150 €/kW	150 €/kW
O&M cost	0 €/year	0 €/year	0 €/year	0 €/year
storage				
lead-acid battery				
capacity	29 kWh	29 kWh	29 kWh	
nominal voltage	24 V	24 V	24 V	
minimum state of charge	20 %	20 %	20 %	
initial state of charge	100 %	100 %	100 %	
lifetime	15 years	15 years	15 years	
maximum throughput	400 000 kWh	400 000 kWh	400 000 kWh	
capital cost	240 €/kW	240 €/kW	240 €/kW	
replacement cost	220 €/kW	220 €/kW	220 €/kW	
O&M cost	10 €/year	10 €/year	10 €/year	
electrolyzer				
nominal power				5 kW
efficiency				50 %
minimum load ratio				30 %
lifetime				15 years
costs				not considered
hydrogen tank				
size				50 kg H_2
initial level				50 %
lifetime				25 years
costs				not considered

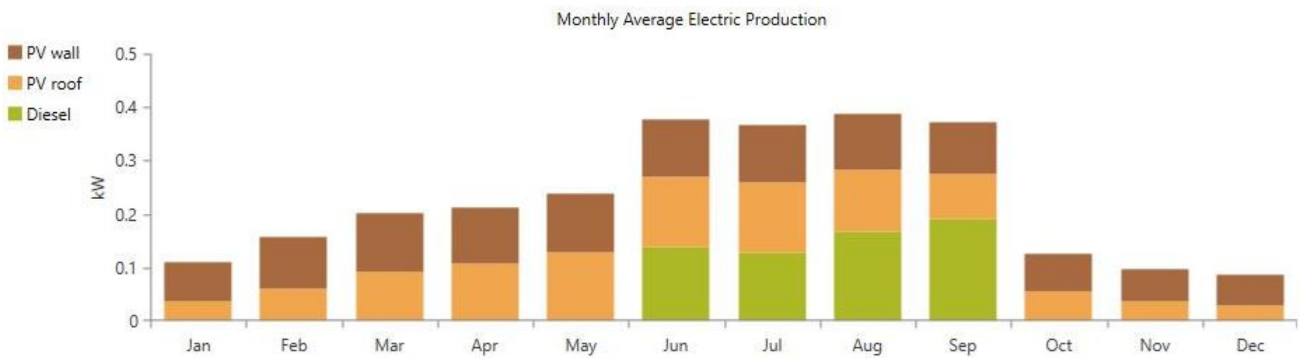
Results – Reference case

Production	kWh/yr	%
Generic flat plate PV on roof	737	36.90
Generic flat plate PV on wall	802	40.19
Diesel electricity generator	457	22.91
Total	1,996	100.00

Consumption	kWh/yr	%
AC Primary Load	850	100.00
DC Primary Load	0	0.00
Total	850	100.00

Quantity	kWh/yr	%
Excess Electricity	930.1	46.6
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	46.2
Max. Renew. Penetration	2,976.2

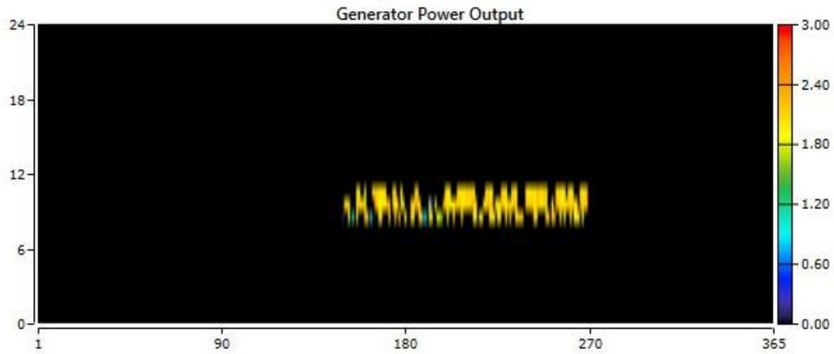


Results – Reference case

Quantity	Value	Units
Hours of Operation	272	hrs/yr
Number of Starts	122	starts/yr
Operational Life	55.1	yr
Capacity Factor	0.989	%
Fixed Generation Cost	0.717	€/hr
Marginal Generation Cost	0.700	€/kWh

Quantity	Value	Units
Electrical Production	433.02	kWh/yr
Mean Electrical Output	1.59	kW
Minimum Electrical Output	0.13	kW
Maximum Electrical Output	2.66	kW

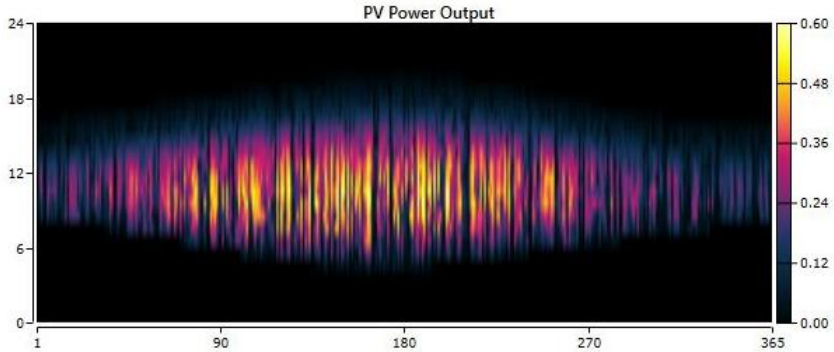
Quantity	Value	Units
Fuel Consumption	205.96	L
Specific Fuel Consumption	0.48	L/kWh
Fuel Energy Input	2,026.62	kWh/yr
Mean Electrical Efficiency	21.37	%



Results – Reference case

Quantity	Value	Units
Rated Capacity	0.70	kW
Mean Output	0.08	kW
Mean Output	2.02	kWh/d
Capacity Factor	12.01	%
Total Production	736.57	kWh/yr

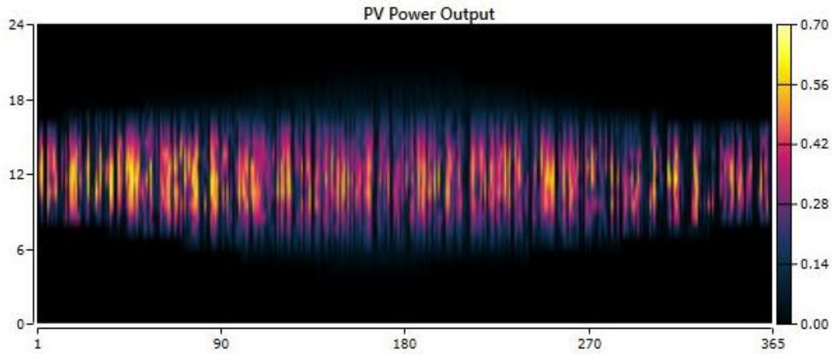
Quantity	Value	Units
Minimum Output	0.00	kW
Maximum Output	0.591	kW
PV Penetration	86.6	%
Hours of Operation	4,380	hrs/yr
Levelized Cost	0.264	€/kWh



Results – Reference case

Quantity	Value	Units
Rated Capacity	0.60	kW
Mean Output	0.09	kW
Mean Output	2.20	kWh/d
Capacity Factor	15.26	%
Total Production	802.24	kWh/yr

Quantity	Value	Units
Minimum Output	0.00	kW
Maximum Output	0.632	kW
PV Penetration	94.3	%
Hours of Operation	4,380	hrs/yr
Levelized Cost	0.208	€/kWh



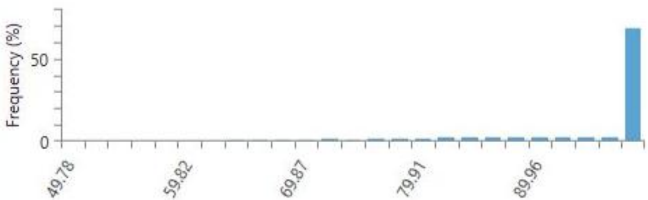
SustainHuts

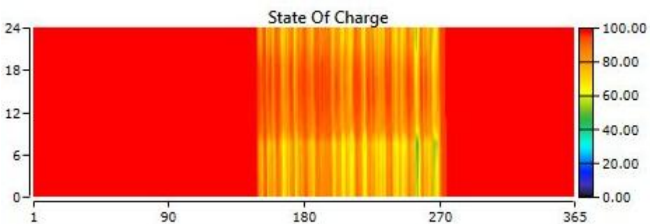
Results – Reference case

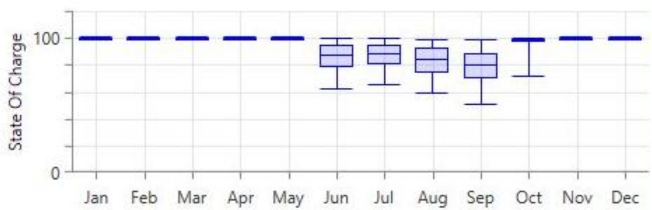
Quantity	Value	Units
Batteries	29.00	
String Size	1.00	
Strings in Parallel	29.00	
Bus Voltage	12.00	

Quantity	Value	Units
Autonomy	239.16	hr
Storage Wear Cost	0.00	€/kWh
Nominal Capacity	29.02	kWh
Usable Nominal Capacity	23.22	kWh
Lifetime Throughput	8,814.06	kWh
Expected Life	15.00	yr

Quantity	Value	Units
Average Energy Cost	0.28	€/kWh
Energy In	656.96	kWh/yr
Energy Out	525.57	kWh/yr
Storage Depletion	0.00	kWh/yr
Losses	131.39	kWh/yr
Annual Throughput	587.60	kWh/yr







Results - all

electric load and production

		REF	PV	FC	H2
total load	kWh/a	821	821	821	821
diesel gen. output	kWh/a	408			
solar 1 output	kWh/a	796	796	796	796
solar 2 output	kWh/a	909	3634	909	4543
fuel cell	kWh/a			339	413
total production	kWh/a	2112	4430	2043	5752
excess electricity	kWh/a	1080	3442	1044	625
renewable fraction[1]	%	50	100	59[2]	100

[1] of total load served

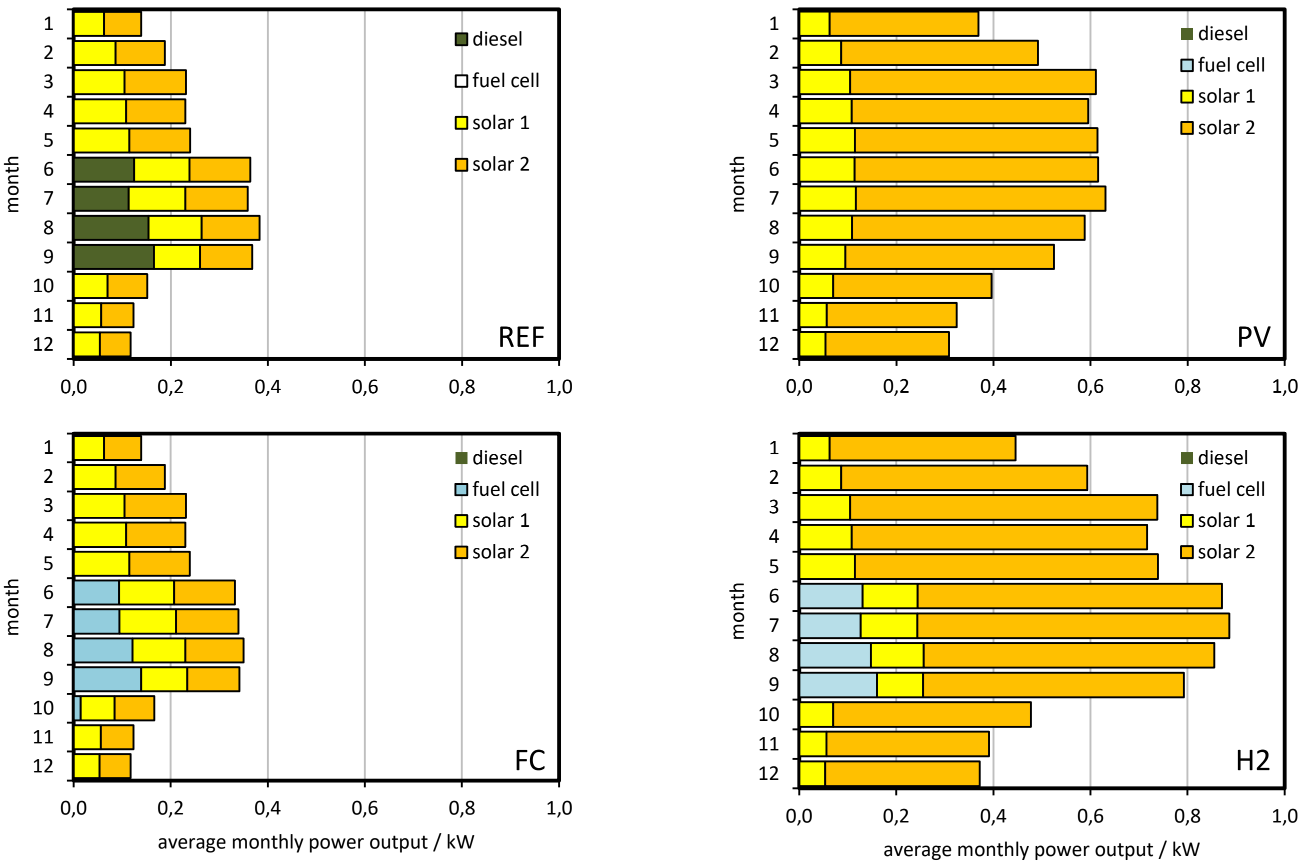
[2] off-site produced hydrogen is not considered as RES

energy effectivess

		REF	PV	FC	H2
excess electricity					
absolute	kWh/a	1080	3442	1044	625
relative	%	51	78	51	11
capacity factor					
diesel	%	1			
fuel cell	%			4	4
solar	%	15	15	15	15

SustainHuts

Results - all



Conclusions

1. **Three types of modifications** of the systems were simulated: PV, FC and H_2 to test feasibility of proposed solutions and to estimate the required capacity of additional power sources. Load profiles remained unchanged for the modified cases.

2. **Increased capacity of PV modules** proved to be sufficient solution since storage capacity is oversized for the existing systems and still adequate for the modified systems. The total capacity needs to be increased by 160 %.

3. Replacement of considerably oversized diesel generators with **fuel cell system is also possible**. Both examples showed that a 1 kW unit would be adequate but the operating regimes need to be appropriately set to provide sufficient amouont of energy for normal operation of the system.

4. Instalation of **hydrogen energy storage system** (electrolyzer, hydrogen tank and fuel cell) also requires installation of additional power production capacities (e.g. photovoltaics) **much larger** than existing ones (**by factor 3 to 4**). Furthermore, since the energy storage needs to be seasonal for the observed cases, the **storage capacity is very large** (50 kg or 1.3 m^3@700 bar of hydrogen).

Thank you for your attention!

Rok Stropnik
University of Ljubljana, Faculty of Mechanical Engineering
rok.stropnik@fs.uni-lj.si

SUSTAINABLE MOUNTAIN HUTS IN EUROPE

LIFE15 CCA/ES/000058