Supplementary Materials: Modeling of a Village-Scale Multi-Energy System for the Integrated Supply of Electric and Thermal Energy

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1. Results

In this section are reported additional graphs representing the dispatch strategies for Summer, Autumn and Winter days, as they are not reported in the manuscript for brevity. It is evident from the pictures how winter days are more relying on fossil fuels combustion, Figure S3 and Figure S6. It is also noteworthy how in summer the load of the school is zero, since it is closed for vacations, Figure S4 and the different thermal demand of a weekend Figure S5, distinguishable from a different pattern in thermal domestic needs and, again, no loads from the school.

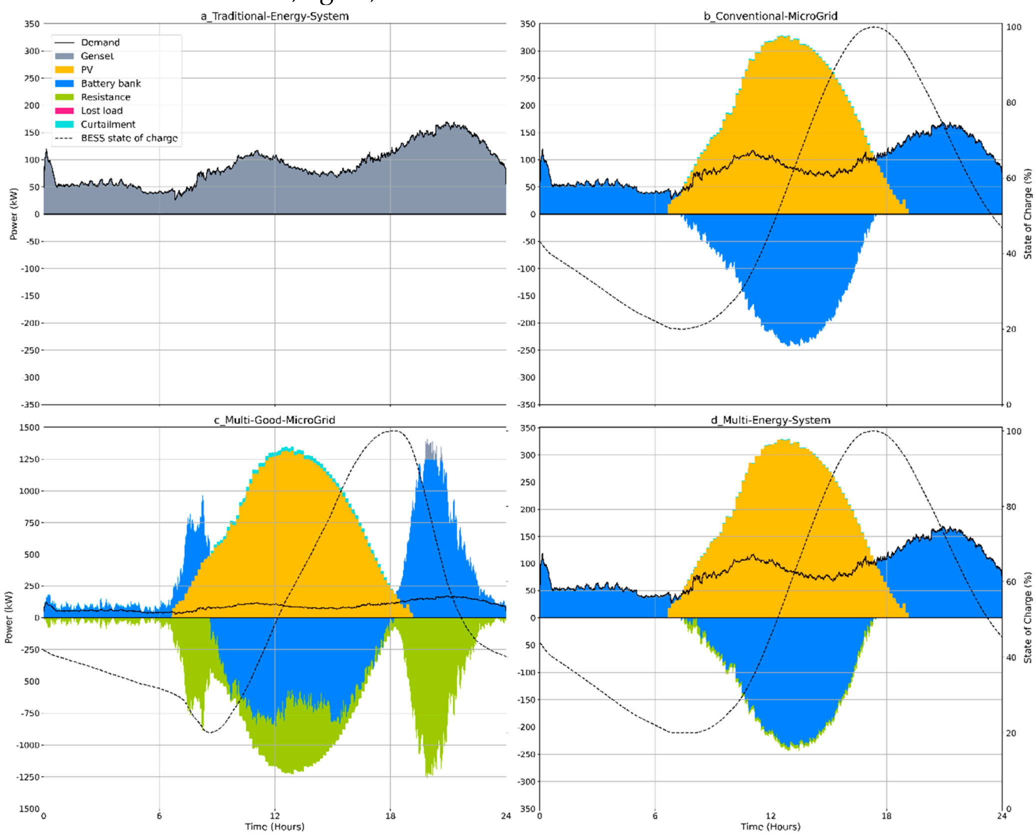

Figure S1. Summer Electric energy dispatch strategy in the four modelled scenarios, namely: (**a**) Baseline; (**b**) Conventional micro-grid; (**c**) Multi-good micro-grid; (**d**) Integrated multi-energy system. The represented day is December 21st.

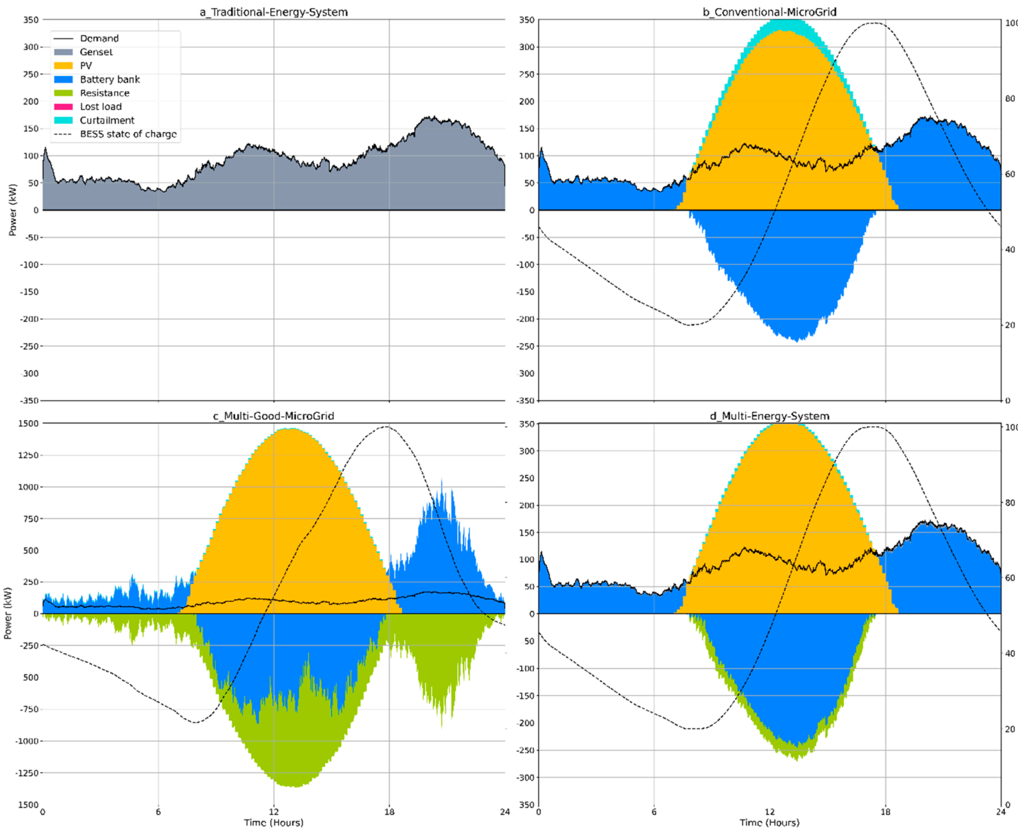

Figure S2. Autumn Electric energy dispatch strategy in the four modelled scenarios, namely: (**a**) Baseline; (**b**) Conventional micro-grid; (**c**) Multi-good micro-grid; (**d**) Integrated multi-energy system. The represented day is March 21st.

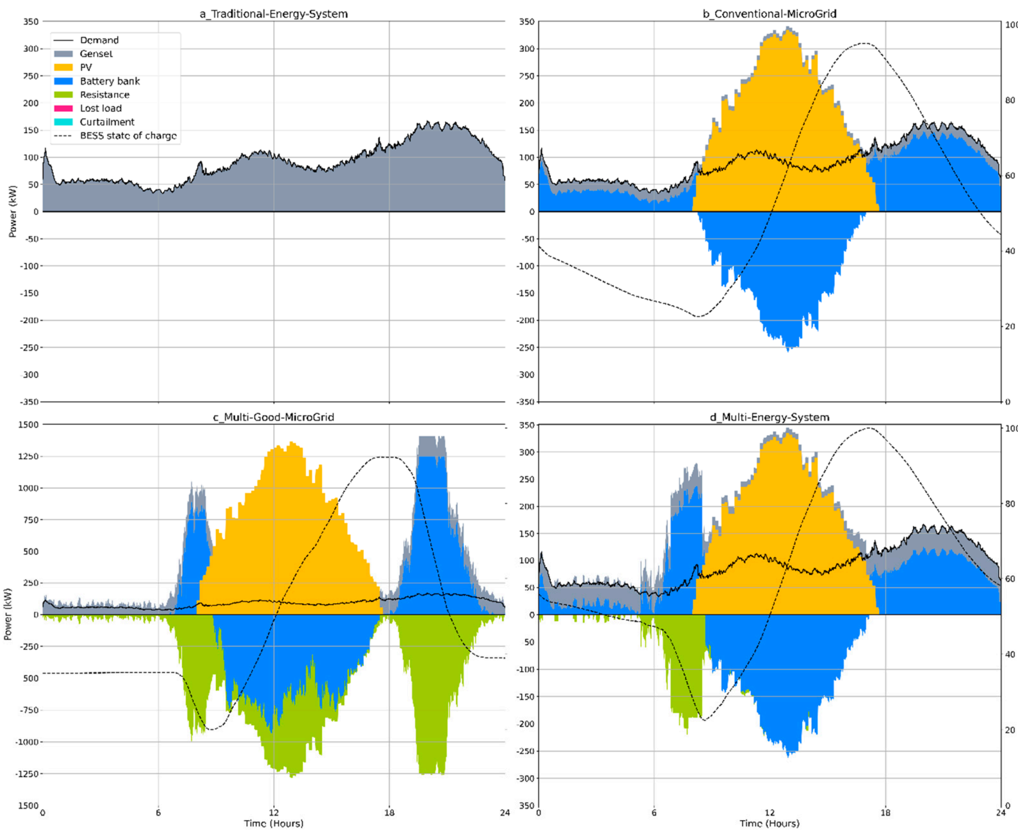

Figure S3. Winter Electric energy dispatch strategy in the four modelled scenarios, namely: (**a**) Baseline; (**b**) Conventional micro-grid; (**c**) Multi-good micro-grid; (**d**) Integrated multi-energy system. The represented day is June 21st.

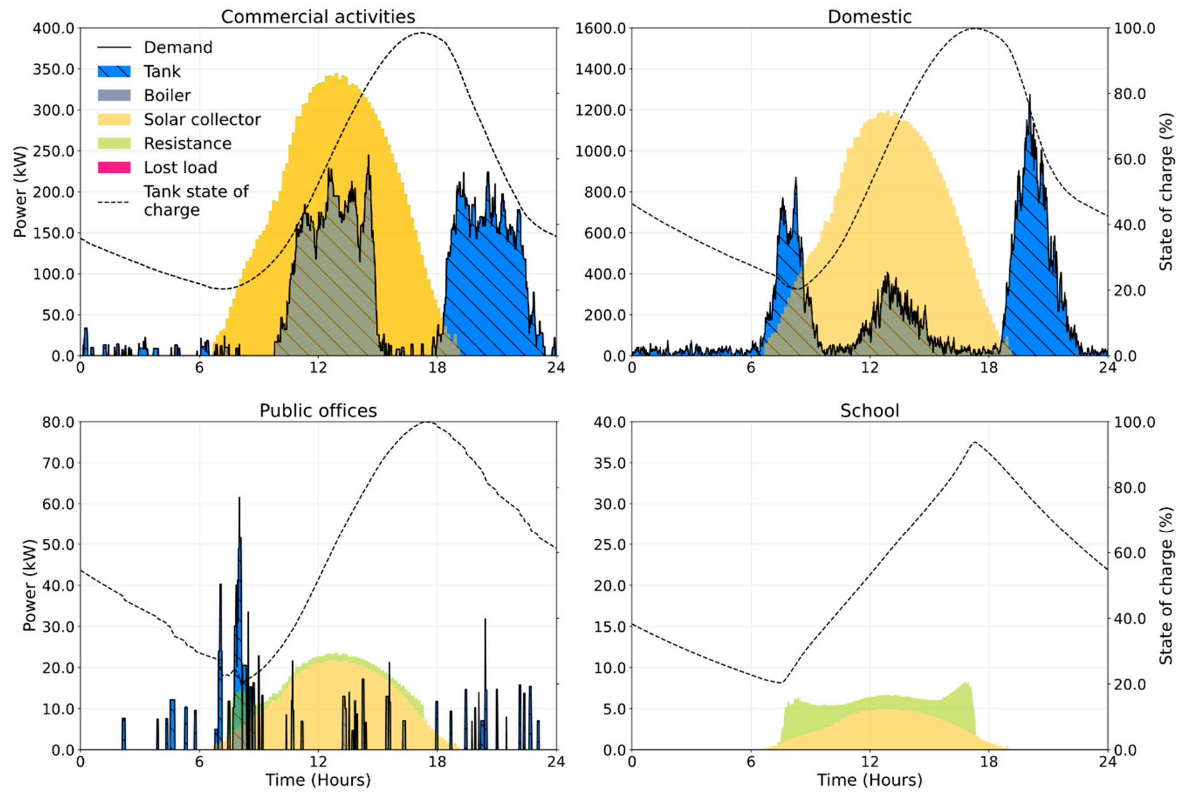

Figure S4. Summer thermal energy dispatch for representative single users for each of the four modelled user classes. The represented day is December 21st.

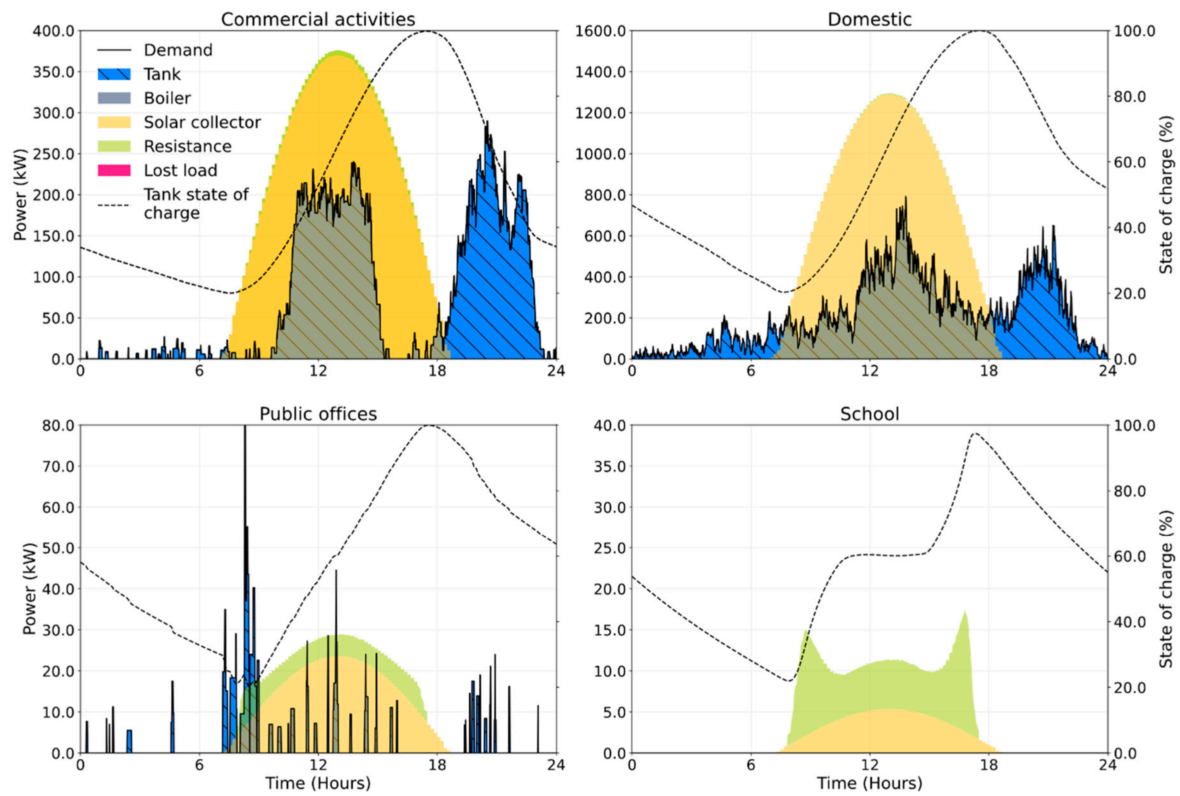

Figure S5. Autumn thermal energy dispatch for representative single users for each of the four modelled user classes. The represented day is March 21st.

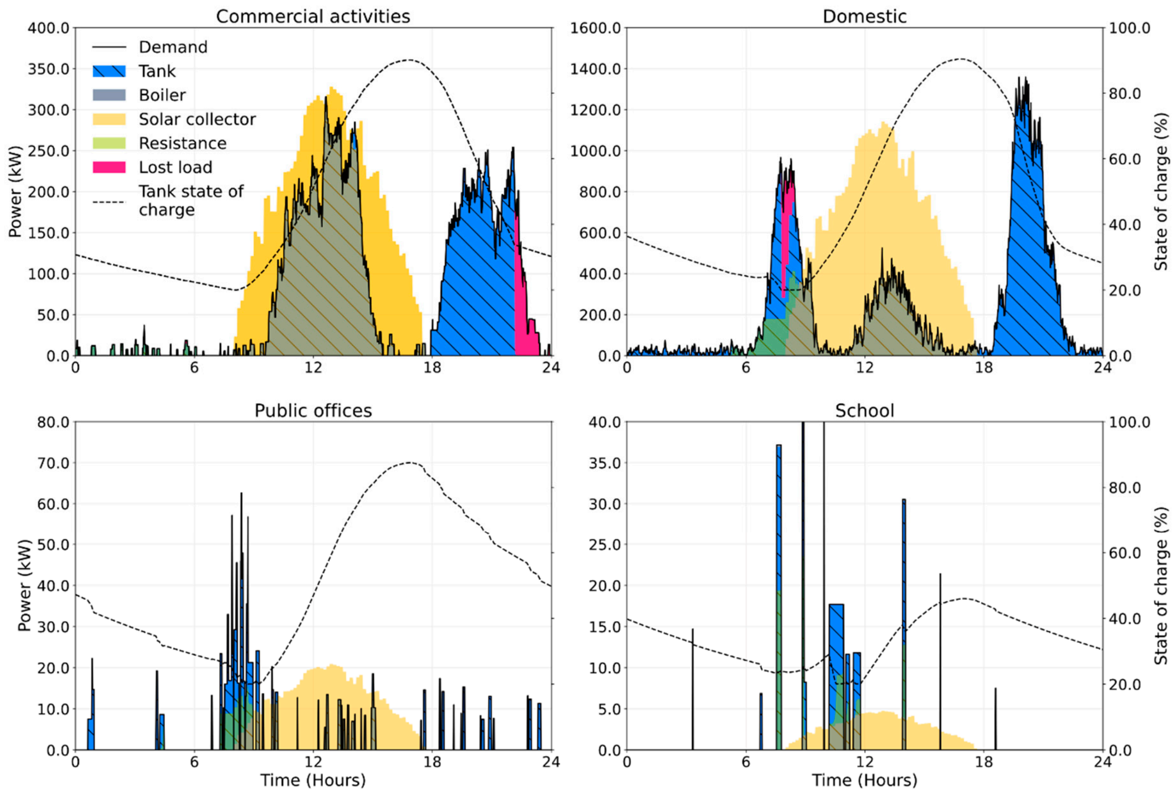

Figure S6. Winter thermal energy dispatch for representative single users for each of the four modelled user classes. The represented day is June 21st.

2. Technology Parameters

PV panels' technical parameters are based on the Yingli YL300P-35b Polycrystalline module, which has a nominal capacity of 300 W per module. The model has been selected due to its availability in the considered region. The PV output has been obtained from the tool Renewable ninja[1] based on the work of Pfenninger and Staffel [1]. The cost is of 1.67 USD/W.

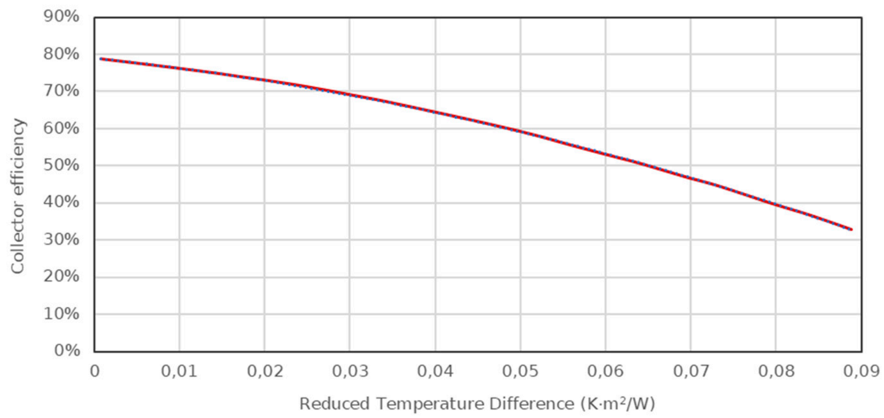

Figure S7. Solar thermal collector efficiency curve, as a function of the reduced temperature difference. The latter is defined as the difference between (a) the average fluid temperature between

[1] www.renewables.ninja

inlet and outlet of the collector and (b) the ambient temperature, divided by the radiation incident on the tilted collector surface.

Solar thermal collectors parameters are instead referred to the datasheet of the FP-GV2.15.00, a flat-plate collector with an area of 1.963 m², manufacture by First Solares Co., Ltd. The output of the solar collector is obtained by calculating a hourly time-dependent efficiency time series (based on the efficiency curve provided by the datasheet and reported in Figure), and subsequently multiplying the latter for the collector area and the incident radiation (assuming an isotropic sky model) [2]. The solar irradiation has been derived from experimental data measured in the field by means of a pyranometer.

The costs of solar thermal collectors and thermal storage are assessed based on the UNEP market assessment for solar water heaters in Chile [3], which estimates a cost of 1900 USD for a standard solar water heating system composed of a 2-4 m² collector area, and 200-300 l tank volume. Assuming also a cost share of 20% for the tank and 80% for the collectors, and average inlet and outlet temperatures to the tank of 15°C and 45°C respectively (the latter used to compute the energy storage capacity [4]), we calculate a specific cost for the collectors of 0.55 USD/W and for the hot water tank of 0.043 USD/Wh.

3. Load Profile Data

The User types and the corresponding appliances defined within RAMP are reported in Table S1 and Table S2. The detailed list of inputs is available in the form of open-source repository [5].

Table S1. User types and number of users per each type, as defined in RAMP.

User type name	Acronym	Users number
High-Income households	HI	130
Low Income households	LI	202
Small commercial activities	CA	32
School	SC	1
Public Services	PS	6
Public lighting	PL	1

Table S2. Number of electric appliances and thermal appliances defined in RAMP for each User type.

	HI	LI	CA	SC	PS	PL
Electric appliances						
Indoor bulbs	7	1	13	2	12	8
Outdoor bulbs	1	1	2	1	1	6
TV	3	2	4	1	0	1
Phone charger	4	2	5	2	8	5
Fridge	0	1	4	0	3	0
Iron	1	1	1	0	1	0
PC	1	1	1	0	1	18
Radio	1	1	7	0	0	1
Washing Machine	1	0	0	0	0	0
Street lighting	0	0	0	0	0	375
Stadium light	0	0	0	0	0	20
DHW appliances (tasks)						
Sink (generic use)	0	0	6	0	0	0
Sink (dish washing)	2	2	0	0	0	0

Sink (hand washing)	1	1	2	20	2	0
Shower	1	1	2	2	2	0
Food washing	0	0	1	4	1	0

4. Model Parameters

List of modelling parameters adopted in the four configurations. The costs of installation, inverters, cabling and connection are included in the components specific investment costs.

Table S3. Modelling parameters adopted in the four configurations.

Parameter	Unit	a) Traditional energy system	b) Conventional microgird	c) Multi-good microgird	d) Integrated multi-energy system
Periods	-	525600	525600	525600	525600
Years	-	20	20	20	20
Start Date	-	01/01/2017	01/01/2017	01/01/2017	01/01/2017
Discount Rate	-	0.037	0.037	0.037	0.037
PV Nominal Capacity	kW/Unit	-	0.3	0.3	0.3
PV Inverter Efficiency	-	-	0.986	0.986	0.986
PV Specific Investment Cost	USD/kW	-	2000	2000	2000
PV Specific O&M Cost	% Inv/Year	-	0.02	0.02	0.02
SC Nominal Capacity	kW/Unit	-	-	-	1.825
SC Specific Investment Cost	USD/kW	-	-	-	420
SC Specific O&M Cost	% Inv/Year	-	-	-	0.015
BESS Discharge Efficiency	-	-	0.95	0.95	0.95
BESS Charge Efficiency	-	-	0.95	0.95	0.95
BESS Depth of Discharge	-	-	0.2	0.2	0.2
BESS Max Discharge Time	h	-	5	5	5
BESS Min Discharge Time	h	-	5	5	5
BESS Replacement Time	years	-	20	20	20
BESS Specific Investment Cost	USD/kWh	-	550	550	550
BESS Specific O&M Cost	% Inv/Year	-	0.02	0.02	0.02
Tank Efficiency	-	-	-	-	0.999

Tank Depth of Discharge	-	-	-	-	0.2
Tank Maximum Discharge Time	h	-	-	-	2.5
Tank Specific Investment Cost	USD/kWh	-	-	-	36
Tank Specific O&M Cost	% Inv/Year	-	-	-	0.015
Generator Efficiency	-	0.3	0.3	0.3	0.3
Diesel LHV	kWh/l	9.84	9.84	9.84	9.84
Diesel Cost	USD/l	1	1	1	1
Generator Specific Investment Cost	USD/kW	200	200	200	200
Generator Specific O&M Cost	% Inv/Year	0.1	0.1	0.1	0.1
Boiler Efficiency	-	0.87	0.87	-	0.87
LPG LHV	kWh/l	0.0102	0.0102	-	0.0102
LPG Cost	USD/l	0.00202	0.00202	-	0.00202
Boiler Specific Investment Cost	USD/kW	100	100	-	100
Boiler Specific O&M Cost	% Inv/Year	0.015	0.015	-	0.015
Electric Resistance Efficiency	-	-	-	1	1
Electric Resistance Specific Investment Cost	USD/kW	-	-	100	100
Electric Resistance Specific O&M Cost	% Inv/Year	-	-	0.015	0.015
Electric Allowed LoL	-	0.00	0.00	0.00	0.00
Value of Electric LoL	USD/kWh	0.00	0.00	0.00	0.00
Thermal Allowed LoL	-	0.01	0.01	0.01	0.01
Value of Thermal LoL	USD/kWh	0.00	0.00	0.00	0.00

References

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2. Duffie, J.A.; Beckman, W.A. and Worek, W.M. Solar Engineering of Thermal Processes, 2nd ed.. ASME. J.

Sol. Energy Eng. February **1994**, *116*, 67–68. doi:10.1115/1.2930068.
3. UNEP. Solar Water Heating Techscope Market Readiness Assessment. 2014. Available on line: https://www.unenvironment.org/resources/report/solar-water-heating-techscope-market-readiness-assessment (accessed on 25 September 2020).
4. Caleffi. Produzione di acqua calda ad accumulo. IDRAULICA 1999;16. Available on line: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjQ8ZPTmcjsAhWKYsAKHdkgDoAQFjAAegQIBRAC&url=https%3A%2F%2Fwww.caleffi.com%2Fsites%2Fdefault%2Ffiles%2Fcertification_contracts%2Fidraulica_16_it.pdf&usg=AOvVaw3WNSHq7OR60JIIx-wtZ0PZ (accessed on 25 September 2020).
5. Stevanato, N.; Pistolese, S.; Lombardi, F.; Rinaldi, L. Multi-Energy Systems Py 2020. Available on line: https://github.com/Stevogallo/MicroGridsPy-MultiEnergy_Paper (accessed on 25 September 2020).