Technical and economical evaluation of the Greek pilot micro-grid for each operating mode

2nd Draft

February 2019

Contents

1 Introduction

In the framework of Work Package 3 "Testing" of the PEGASUS project, the measuring equipment for the pilot project of **Mega Evydrio community** has already been installed and has provided the set of measurements. This report documents the technical and economical evaluation of the Greek pilot micro grid, under different operating modes.

1.1 The pilot site

The Greek pilot micro grid is planned to be installed near the city of Farsala – in the Mega Evydrio community - and it is going to have one single point of common coupling (PCC) with the main electricity grid. It is going to be organised as a local "energy community", where the municipality of Farsala and the residents of the community of Mega Evydrio are going to participate.

1.2 The micro-grid configuration

The present situation for the Greek pilot before the establishment of the micro-grid is the following:

- The consumers buy electricity from the main grid
- The producers sell electricity to the main grid
- The prosumers buy electricity from the main grid in a net metering basis (consumption – production). If production is higher than consumption they don't earn money for the surplus of electricity

The situation after the establishment of the micro-grid for the Greek pilot will be the following**:**

- ➢ An "Energy Community" will operate the micro-grid. In the "Energy Community" will participate the local municipality, local residents, local shop owners, local electricity producers, and various other interested parties.

The Energy Community will proceed with the purchase of:

a) the new PV systems (177.5 kWp);
b) the necessary software, i.e. Energy Management System (EMS);
c) the point of common coupling (PCC).

The amount for the investment will come from the members of the energy community, from loans and from grants.

After the start of the microgrid/energy community

- ➢ the microgrid buys electricity from the main grid (and the producers / procumers), following a 'net metering' procedure,
- ➢ the microgrid sells electricity to the consumers /prosumers,

and

- consumers buy electricity from the micro-grid with a discount of x % (compared to the main grid prices),

- producers sell electricity to the micro-grid with a premium of y % (compared to the main grid prices),

while

- prosumers buy electricity from the micro-grid (consumption – production); if their production is higher than consumption they sell electricity to the micro-grid at a fixed price of z cents/kWh

The net metering is calculated for a period of 1 year for:

- grid – prosumers (before the micro-grid),

and

- grid – micro-grid (after the micro-grid).

2 Calculations

In order to evaluate the Greek pilot from both the technical and economical points of view, the following software programs were used:

- the MS Excel for the economic evaluation and
- the MATLAB/Simulink for the technical evaluation.

Microsoft Excel is a spreadsheet developed by Microsoft. It features calculation, graphing tools, pivot tables, and a macro programming language called Visual Basic for Applications and it has been a very widely applied spreadsheet for these platforms. Excel forms part of the Microsoft Office suite of software.

MATLAB is a software package for high-performance computation. Combined with Simulink, it provides a de-facto industry standard for the analysis, modelling and visualizing of complex systems.

Simulink is a software package used for modeling, analyzing, and simulating a wide variety of dynamic systems. Simulink provides a graphical interface for constructing the models. It has a library of standard components, which makes block diagram representation easier and quicker.

3 Economical evaluation of the system

Many parameters influence the economic evaluation of a micro-grid: the resources potential, the cost of used renewable sources, the price of purchase for the electricity produced by these sources, the price of purchase for electricity from the main electrical grid, financial transactions etc.

3.1 Economical evaluation of system with MS Excel

Mega Evydrio Pilot - configuration without storage

Table 1: Present situation - Main grid

Building type	Consumer, Prosumer, Producer	Nbr	Committed power (kW)	PV System power (kWp)	Consumption (kWh/year)	PV System generation (kWh/year)	Self Consumption (net meetering) (kWh/year)	Electricity withdrawn from the grid (kWh/year)	Electricity fed into the grid (kWh/year)
Public	Consumer	4	32		13.815			13.815	
Domestic -Houses Permanently/Partially Inhabited	Consumer	295	1.224		1.687.729			1.687.729	
Commercial - Shops	Consumer	16	54		148.081			148.081	
Public Street Lighting (471 lamps)	Consumer	1	166		628.731			628.731	
Public (2 Public pumping stations)	Consumer	2	65		368.687			368.687	
Farming - Private pumping stations	Consumer	147	735		271.215			271.215	
Domestic- Houses with 10 kWp PV	Prosumer	4	20	40	27.555	51.369	12.239	15.316	39.129,76
Domestic- Houses with 5 kWp PV	Prosumer	1	5	5	6.889	6.421	2.768	4.121	3.653,11
Commercial -with 100 kWp PV	Producer	5		500		642.109			642.109,00
Total		475	2.301	545	3.152.700	699.899	15.007	3.137.693	684.891,87

Table 2: Future situation - Microgrid /energy community

Building type	Customers, Prosumers, Producers	Nbr	Committed power (kW)	PV System power (kWp)	Consumption (kWh/year)	PV System generation (kWh/year)	Self Consumption (kWh/year)	Electricity withdrawn (buy) from the microgrid (kWh/year)	Electricity fed into (sell) the microgrid (kWh/year)
Public	Consumer	3	24		10.361			10.361,25	
Domestic -Houses Permanently/Partially Inhabited	Consumer	220	850		1.171.077			1.171.076,98	
Commercial - Shops	Consumer	16	54		148.081			148.080,68	
Public Street Lighting (471 lamps)	Consumer	1	166		628.705			628.705,20	
Public (2 Public pumping stations)	Consumer	2	65		368.687			368.686,50	
Farming - Private pumping stations	Consumer	147	735		271.215			264.600,00	
Domestic- Houses with 10 kWp PV	Prosumer	4	20	40	27.555	51.369	12.239	15.315,76	39.129,72
Domestic- Houses with 5 kWp PV	Prosumer	1	5	5	6.889	6.421	2.768	4.120,71	3.653,11
Domestic- Houses with 2.25 kWp PV	Future prosun	75	374	169	516.652	216.711	164.734	351.918,00	51.977,47
Public with 9 kWp PV	Future prosun	1	8	9	3.454	11.558	1.682	1.771,99	9.876,20
Commercial -with 100 kWp PV	Producer	5		500		642.109	0		642.109,00
Total		475	2.301	723	3.152.675	928.168	181.422	2.964.637,07	746.745,50

Four different scenarios have been studied:

a) With batteries and 10% discount on electricity's price;

b) Without batteries and 10% discount on electricity's price;

c) Without private pumps and batteries and 10% discount on electricity's price;

d) Without private pumps and batteries maximum discount on electricity's price.

Table 3: Current electricity consumption and PV production Tariffs

Building type	Customers, Prosumers, Producers	buy / sell	Tariff (€cent/kWh)
Public	Consumer	buy	18,61
Domestic -Houses Permanently/Partially Inhabited	Consumer	buy	19,40
Commercial - Shops	Consumer	buy	18,61
Public Street Lighting	Consumer	buy	15,52
Pumping stations (public)	Consumer	buy	18,61
Farming - Private pumping stations	Consumer	buy	8,90
Domestic- Houses with PV on the roof	Prosumer	buy	19,40
Public with PV on the roof	Prosumer	buy	18,61
Domestic- Houses with PV on the roof	Prosumer		
Public with PV on the roof	Prosumer		
Commercial PV	Producer	sell	14,00

Table 4: Electricity prices for different types of consumers/producers

Building type	Customers, Prosumers, Producers	buy / sell	Tariff (€cent/kWh)
Domestic- Houses with PV on the roof	Prosumer	sell	10,00
Public with PV on the roof	Prosumer	sell	10,00
Commercial PV	Producer	sell	14,55

The micro-grid sells with a discount of 10% and buys at 0.1456 €/kWh.

Table 5: Net cash flow for scenario 3

Net Cash Flow (Year)	0	1	2	3	4	5	6	7	8	9	10	11	12
Net Capital Costs													
Capital Project Name	-62.049 €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
Total Capital	-62.049 €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
Operating and Maintenance Costs													
Cost 1 - OM		24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €
Cost 2		- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
Escalation of Costs		482 €	974 €	1.476 €	1.987 €	2.509 €	3.042 €	3.585 €	4.139 €	4.704 €	5.280 €	5.868 €	6.467 €
loan interest		6.361 €	6.206 €	6.040 €	5.863 €	5.672 €	5.469 €	5.251 €	5.019 €	4.769 €	4.503 €	4.217 €	3.912 €
loanPrincipal		2.217 €	2.372 €	2.538 €	2.716 €	2.906 €	3.109 €	3.327 €	3.560 €	3.809 €	4.075 €	4.361 €	4.666 €
Total Costs	- €	33.170 €	33.662 €	34.164 €	34.676 €	35.198 €	35.730 €	36.273 €	36.827 €	37.392 €	37.968 €	38.556 €	39.156 €
Revenue and Operating Benefits													
New Revenue		57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €
Benefit 1		- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
Benefit 2		- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
Escalation of Benefits		1.148 €	2.320 €	3.515 €	4.733 €	5.977 €	7.244 €	8.538 €	9.857 €	11.203 €	12.575 €	13.975 €	15.403 €
Total Benefits and Revenue	- €	58.570 €	59.742 €	60.937 €	62.155 €	63.398 €	64.666 €	65.960 €	67.279 €	68.624 €	69.997 €	71.397 €	72.825 €
Cash Flow Before Taxes	-62.049 €	25.400 €	26.079 €	26.773 €	27.480 €	28.201 €	28.936 €	29.687 €	30.452 €	31.233 €	32.029 €	32.841 €	33.669 €
Cumulative Cash Flow Before Taxes	-62.049 €	-36.649 €	-10.569 €	16.203 €	43.683 €	71.884 €	100.820 €	130.506 €	160.958 €	192.191 €	224.220 €	257.060 €	290.730 €
Income Tax Calculation													
Depreciation Expense		-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €
Operating Cost		-33.170 €	-33.662 €	-34.164 €	-34.676 €	-35.198 €	-35.730 €	-36.273 €	-36.827 €	-37.392 €	-37.968 €	-38.556 €	-39.156 €
Operating Benefits		58.570 €	59.742 €	60.937 €	62.155 €	63.398 €	64.666 €	65.960 €	67.279 €	68.624 €	69.997 €	71.397 €	72.825 €
Net Income Taxes	- €	5.729 €	5.899 €	6.073 €	6.249 €	6.430 €	6.614 €	6.801 €	6.992 €	7.188 €	7.387 €	7.590 €	7.797 €
Cash Flow After Taxes	-62.049 €	19.670 €	20.180 €	20.700 €	21.230 €	21.771 €	22.323 €	22.885 €	23.459 €	24.045 €	24.642 €	25.251 €	25.872 €
Cumulative Cash Flow After Taxes	-62.049 €	-42.378 €	-22.198 €	-1.498 €	19.732 €	41.503 €	63.826 €	86.711 €	110.171 €	134.215 €	158.857 €	184.109 €	209.981 €
Discounted Cash Flow (After Tax)	-62.049 €	18.213 €	17.301 €	16.432 €	15.605 €	14.817 €	14.067 €	13.353 €	12.674 €	12.028 €	11.414 €	10.830 €	10.274 €
Cumulative Discounted Cash Flow After T	-62.049 €	-43.835 €	-26.534 €	-10.102 €	5.503 €	20.320 €	34.387 €	47.740 €	60.415 €	72.443 €	83.857 €	94.687 €	104.961 €
Depreciation Expense													
Net Capital Costs	(62.048,55)												
Depreciation Expense		(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)
Depreciation		4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%
Payback Calculation													
Simple Cash Flow	62.049 €	19.670 €	20.180 €	20.700 €	21.230 €	21.771 €	22.323 €	22.885 €	23.459 €	24.045 €	24.642 €	25.251 €	25.872 €
Cumulative Simple Payback		19.670 €	39.850 €	60.550 €	81.780 €	103.552 €	125.874 €	148.760 €	172.219 €	196.264 €	220.906 €	246.157 €	272.029 €
Discounted Cash Flow	62.049 €	18.213 €	17.301 €	16.432 €	15.605 €	14.817 €	14.067 €	13.353 €	12.674 €	12.028 €	11.414 €	10.830 €	10.274 €
Cumulative Discounted Payback		18.213 €	35.514 €	51.947 €	67.551 €	82.368 €	96.436 €	109.789 €	122.463 €	134.492 €	145.906 €	156.736 €	167.010 €

Net Cash Flow (Year)	13	14	15	16	17	18	19	20	21	22	23	24	25	Totals
Net Capital Costs														
Capital Project Name	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	-62.049 €
Total Capital	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	-62.049 €
Operating and Maintenance Costs														
Cost 1 - OM	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	24.110 €	602.750 €
Cost 2	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
Escalation of Costs	7.079 €	7.703 €	8.339 €	8.988 €	9.650 €	10.325 €	11.014 €	11.716 €	12.433 €	13.164 €	13.909 €	14.669 €	15.445 €	184.946 €
loan interest	3.586 €	3.236 €	2.862 €	2.462 €	2.034 €	1.576 €	1.086 €	561 €	- €	- €	- €	- €	- €	80.687 €
loanPrincipal	4.993 €	5.342 €	5.716 €	6.116 €	6.544 €	7.002 €	7.493 €	8.017 €	- €	- €	- €	- €	- €	90.878 €
Total Costs	39.767 €	40.391 €	41.027 €	41.676 €	42.338 €	43.013 €	43.702 €	44.404 €	36.543 €	37.274 €	38.019 €	38.779 €	39.555 €	959.260 €
Revenue and Operating Benefits														
New Revenue	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	57.422 €	1.435.546 €
Benefit 1	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
Benefit 2	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
Escalation of Benefits	16.859 €	18.345 €	19.860 €	21.406 €	22.983 €	24.591 €	26.231 €	27.904 €	29.611 €	31.351 €	33.127 €	34.938 €	36.785 €	440.478 €
Total Benefits and Revenue	74.281 €	75.767 €	77.282 €	78.828 €	80.404 €	82.013 €	83.653 €	85.326 €	87.032 €	88.773 €	90.548 €	92.359 €	94.207 €	1.876.024 €
Cash Flow Before Taxes	34.514 €	35.376 €	36.255 €	37.152 €	38.066 €	38.999 €	39.951 €	40.921 €	50.490 €	51.499 €	52.529 €	53.580 €	54.652 €	854.715 €
Cumulative Cash Flow Before Taxes	325.244 €	360.620 €	396.875 €	434.027 €	472.093 €	511.092 €	551.043 €	591.965 €	642.454 €	693.954 €	746.483 €	800.063 €	854.715 €	
Income Tax Calculation														
Depreciation Expense	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-2.482 €	-62.049 €
Operating Cost	-39.767 €	-40.391 €	-41.027 €	-41.676 €	-42.338 €	-43.013 €	-43.702 €	-44.404 €	-36.543 €	-37.274 €	-38.019 €	-38.779 €	-39.555 €	-959.260 €
Operating Benefits	74.281 €	75.767 €	77.282 €	78.828 €	80.404 €	82.013 €	83.653 €	85.326 €	87.032 €	88.773 €	90.548 €	92.359 €	94.207 €	1.876.024 €
Net Income Taxes	8.008 €	8.224 €	8.443 €	8.667 €	8.896 €	9.129 €	9.367 €	9.610 €	12.002 €	12.254 €	12.512 €	12.775 €	13.042 €	213.679 €
Cash Flow After Taxes	26.506 €	27.153 €	27.812 €	28.484 €	29.170 €	29.870 €	30.584 €	31.312 €	38.488 €	39.245 €	40.018 €	40.805 €	41.609 €	641.036 €
Cumulative Cash Flow After Taxes	236.487 €	263.640 €	291.451 €	319.936 €	349.106 €	378.976 €	409.560 €	440.871 €	479.359 €	518.604 €	558.621 €	599.427 €	641.036 €	
Discounted Cash Flow (After Tax)	9.746 €	9.244 €	8.767 €	8.314 €	7.884 €	7.475 €	7.087 €	6.718 €	7.646 €	7.219 €	6.816 €	6.435 €	6.076 €	204.388 €
Cumulative Discounted Cash Flow After T	114.708 €	123.952 €	132.719 €	141.034 €	148.918 €	156.392 €	163.479 €	170.197 €	177.843 €	185.061 €	191.877 €	198.312 €	204.388 €	
Depreciation Expense														
Net Capital Costs														(62.048,55)
Depreciation Expense	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(2.481,94)	(62.048,55)
Depreciation	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	
Payback Calculation														
Simple Cash Flow	26.506 €	27.153 €	27.812 €	28.484 €	29.170 €	29.870 €	30.584 €	31.312 €	38.488 €	39.245 €	40.018 €	40.805 €	41.609 €	703.085 €
Cumulative Simple Payback	298.536 €	325.688 €	353.500 €	381.984 €	411.155 €	441.024 €	471.608 €	502.920 €	541.407 €	580.652 €	620.670 €	661.475 €	703.085 €	7.981.317 €
														- €
Discounted Cash Flow	9.746 €	9.244 €	8.767 €	8.314 €	7.884 €	7.475 €	7.087 €	6.718 €	7.646 €	7.219 €	6.816 €	6.435 €	6.076 €	266.436 €
Cumulative Discounted Payback	176.756 €	186.001 €	194.768 €	203.082 €	210.966 €	218.441 €	225.528 €	232.245 €	239.891 €	247.110 €	253.926 €	260.361 €	266.436 €	4.103.937 €
														-

3.1.1 With batteries and 10% discount

In the first scenario the case of the micro-grid with a total installed capacity of 722.75 kWp PV, of which 177.75 kWp are new installations and 545.00 kWp are old, was studied. It is going to be bought batteries of 200 kWh and the micro-grid is going to sell electricity to the different types of consumers with a 10% discount from the existing tariff for each category.

The producers will sell the energy to the micro-grid at the price of 14.55 euro cents / kWh.

The prosumers will sell the surplus energy at 10 euro cents / kWh in a net metering basis during the period of one year. It must be noticed that before the micro-grid, the prosumers could not sell the surplus energy, they had to give it to the grid without any profit.

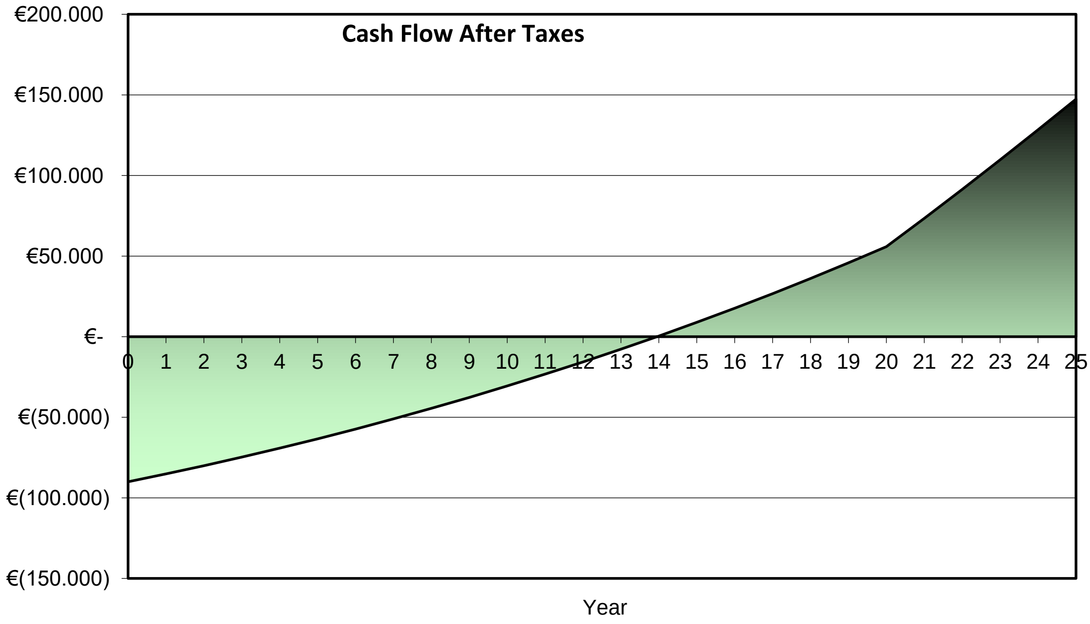

Figure 1: Cash flow after taxes for scenario 1

In this scenario the micro-grid – "Energy Community" earns 39,124 Euros/year and the economic results are presented in tables 6 and 7.

Table 6: Business Case Results for scenario 1

Net present value (NPV) of Cash Flow	- 9,285 € negative
Internal Rate of Return (IRR)	7.0% lower than discount rate (8.0 %)
Simple Payback period	13 Years 11 Months
Discounted Payback	25 Years 1 Months

Table 7: Capital Expenditures (CAPEX) financing for scenario 1

Total CAPEX	342,926.50 €	
Equity	90,048.55 €	26%
Grants	150,000.00 €	44%
Loans	102,877.95 €	30%
- interest on loan	7.00%	
- loan term (years)	20 years	

A positive net present value indicates that the projected earnings generated by a project or investment exceed the anticipated costs. It is further assumed that an investment with a positive NPV will be profitable, and an investment with a negative NPV will result in a net loss.

On the other hand, an investment will be profitable if the internal rate of return (IRR) is higher than the discount rate. In this scenario the net present value (NPV) of Cash Flow is negative and the internal rate of return (IRR) is lower than the discount rate (7.00 < 8.00). This means that the investment is not profitable.

3.1.2 Without batteries and 10% discount

The second scenario is the same with the 1st scenario but without the batteries.

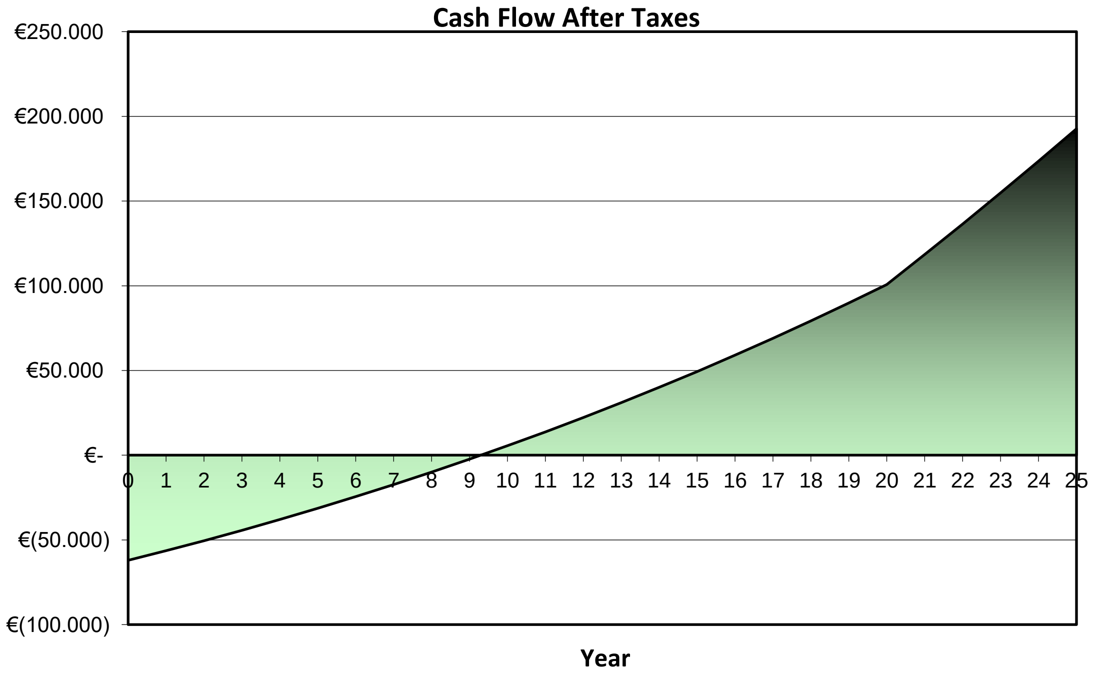

Figure 2: Cash flow after taxes for scenario 2

In this scenario the micro-grid – “Energy Community” earns 39,124 Euros/year and the economic results are presented in tables 8 and 9.

Table 8: Business Case Results for scenario 2

NPV of Cash Flow	26,976
IRR	11.7%
Simple Payback period	9 Years 4 Months
Discounted Payback	15 Years 7 Months

Table 9: CAPEX financing for scenario 2

Total CAPEX	302,926.50 €	
Equity	62,048.55 €	20%
Grants	150,000.00 €	50%
Loans	90,877.95 €	30%
- interest on loan	7.00%	
- loan term (years)	20 years	

Here, the net present value (NPV) of Cash Flow is positive and the internal rate of return (IRR) is higher than the discount rate (11.7 > 8.00). This means that the investment is profitable.

3.1.3 Without private pumps and batteries and 10% discount

The third scenario is the same with the scenario Nr 1, but without the batteries and the 147 private pumps for irrigation. These pumps consume electricity from the main grid in a very low tariff much lower than the tariff in which the micro-grid is going to buy electricity from the main grid.

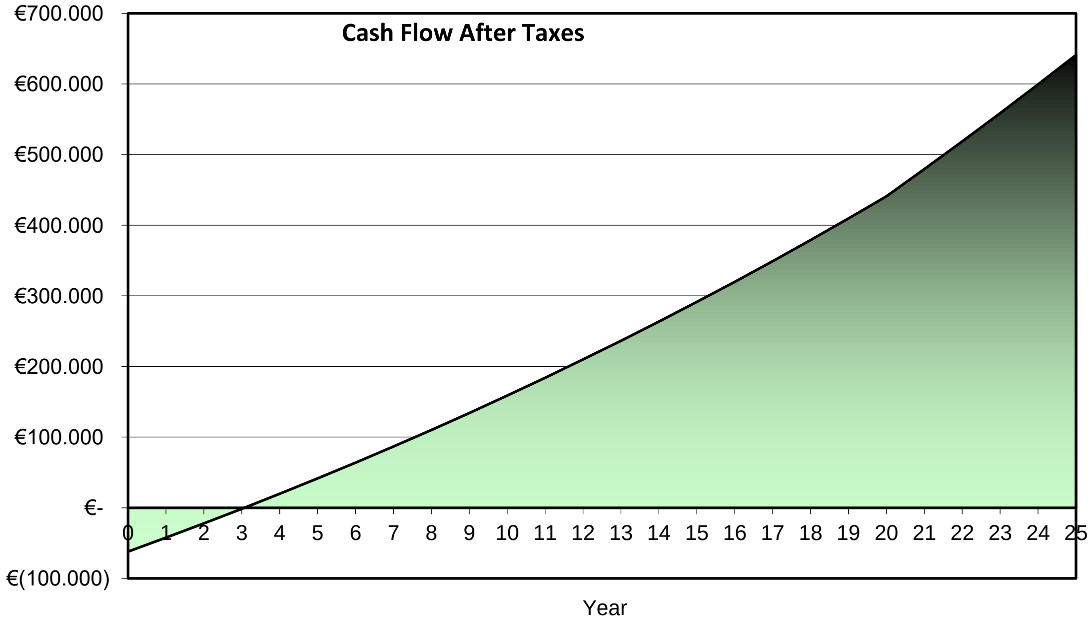

Figure 3: Cash flow after taxes for scenario 3

In this scenario the micro-grid – "Energy Community" will earn 57,422 Euros/year and the economic results of the activity are presented in tables 10 and 11.

Table 10: Business Case Results for scenario 3

NPV of Cash Flow	204,388
IRR	34.2%
Simple Payback period	3 Years 1 Months
Discounted Payback	3 Years 8 Months

Table 11: CAPEX financing for scenario 3

Total CAPEX	302,926.50 €	
Equity	62,048.55 €	20%
Grants	150,000.00 €	50%
Loans	90,877.95 €	30%
- interest on loan	7.00%	
- loan term (years)	20 years	

In this scenario the net present value (NPV) of Cash Flow is positive and the internal rate of return (IRR) is much higher than the discount rate (34.2 > 8.00), which means that the investment is very profitable.

3.1.4 Without private pumps and batteries and maximum discount

In the last - fourth - scenario again the batteries and the 147 private pumps for irrigation are not taken into consideration. Now the micro-grid is going to sell electricity to the different types of consumers with a x% discount from the existing tariff for each category.

After a number of tests made, it was found that the maximum accepted tariff discount is 14.2%. This is the maximum discount where the investment will be still profitable.

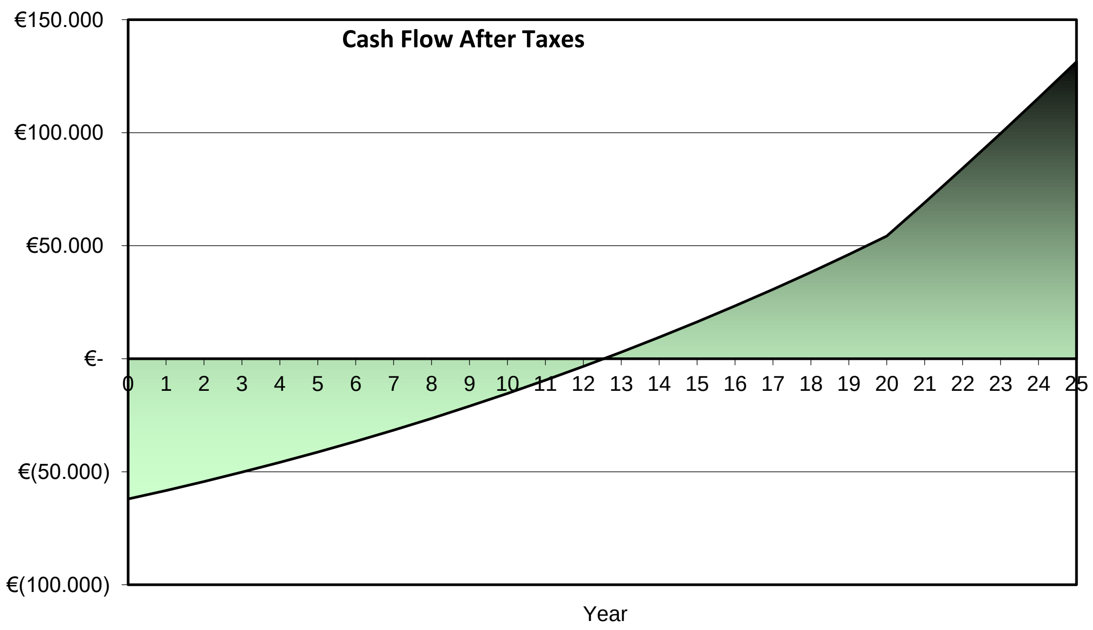

Figure 4: Cash flow after taxes for scenario 4

In this (last examined) scenario the micro-grid – "Energy Community" earns 36,622 Euros /year, and the economic results are presented in tables 12 and 13.

Table 12: Business Case Results for scenario 4

NPV of Cash Flow	2,720
IRR	8.4%
Simple Payback period	12 Years 7 Months
Discounted Payback	23 Years 10 Months

Table 13: CAPEX financing for scenario 4

Total CAPEX	302,926.50 €	
Equity	62,048.55 €	20%
Grants	150,000.00 €	50%
Loans	90,877.95 €	30%
- interest on loan	7.00%	
- loan term (years)	20 years	

In this scenario the net present value (NPV) of Cash Flow is positive and the internal rate of return (IRR) is slightly higher than the discount rate (8.40 > 8.00). This means that the investment is still profitable.

4 System's introduction in MATLAB

The electric consumption of the Greek pilot is defined in the MATLAB program. Some of the assumptions that have been taken into account are the following:

- Simulation period: from January 1st to December 31st
- Maximum consumption: 1,486.00 kW
- Total installed PV capacity: 722.75 kWp
- 10 different groups of consumers/producers:
  - Group01: 5 houses with existing PV panels on their roof with a total installed capacity of 45 kWp
  - Group02: 75 houses with new PV panels on their roof with a total installed capacity of 168.75 kWp
  - Group03: 170 houses without any production
  - Group04: 16 shops without any production
  - Group05: 3 Public buildings without any production
  - Group06: 1 Public building with new PV panels on its roof with a total installed capacity of 9 kWp
  - Group07: 5 PV parks of total installed capacity of 500 kWp (5*100kWp)
  - Group08: The street-lighting load as a bulk load
  - Group09: The public pumping stations for potable water circulation as one bulk load
  - Group10: The private pumping stations for irrigation as one bulk load
- Four (4) different scenarios studied:
  - Scenario01: Without any storage available
  - Scenario02: With a storage facility of 500 kWh / 1.5 MW (limited storage)
  - Scenario03: With a storage facility of 5 MWh / 1.5 MW (unlimited storage)
  - Scenario04: Unlimited storage (scenario03) with additional installed PV parks of 1000 kWp, increasing the total installed capacity of Group07 to 1500 kWp.

The model developed in MATLAB/Simulink is shown in Figure 5, while the details of Groups01-02 and Group06 are shown in Figures 2 and 3, and Figure 7 respectively.

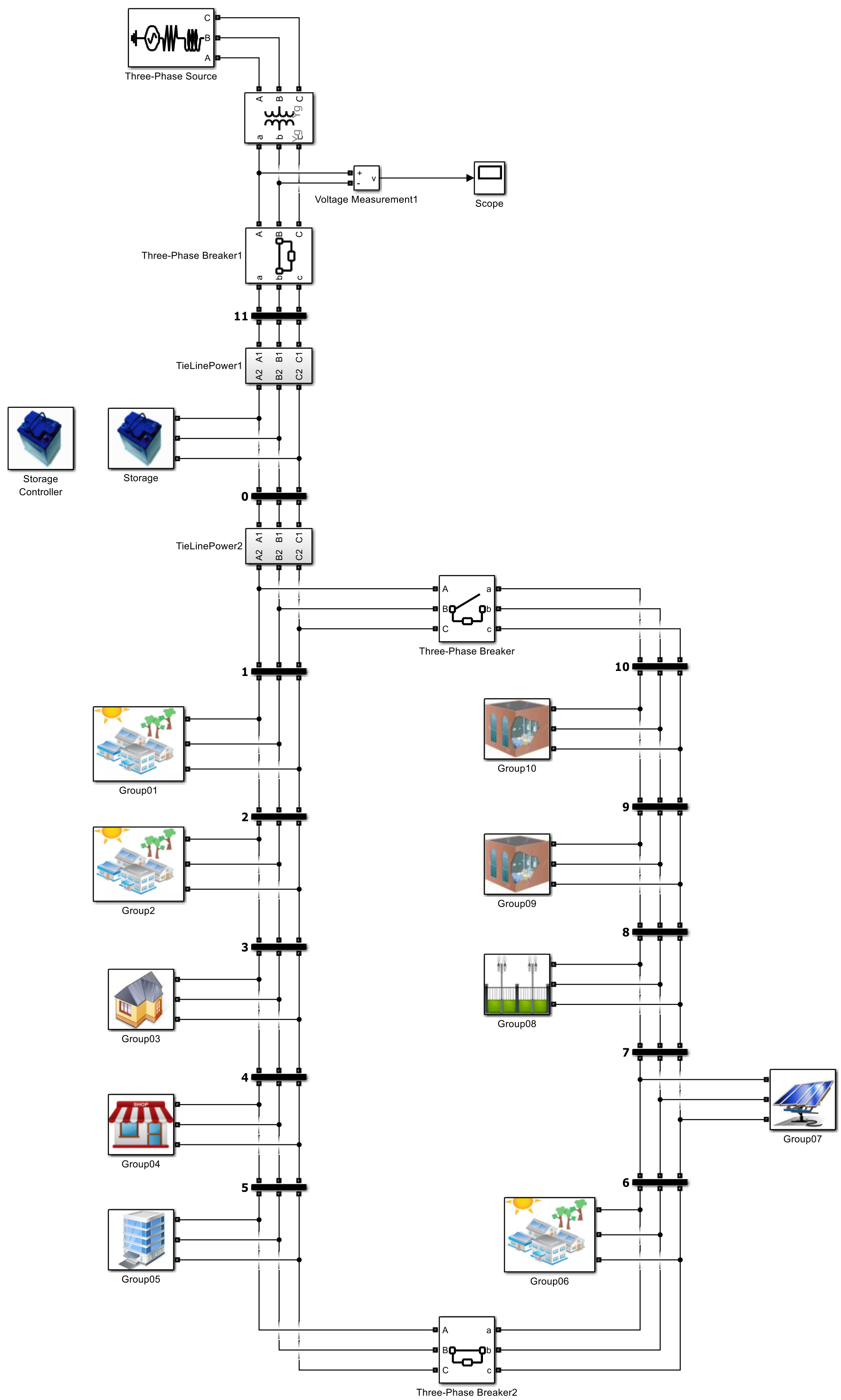

Figure 5: Diagram of the pilot micro-grid in MATLAB/Simulink

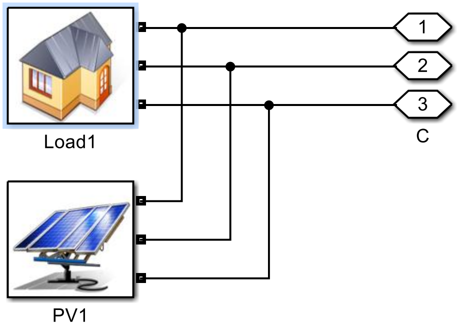

Figure 6: Detail of Group01 and Group02

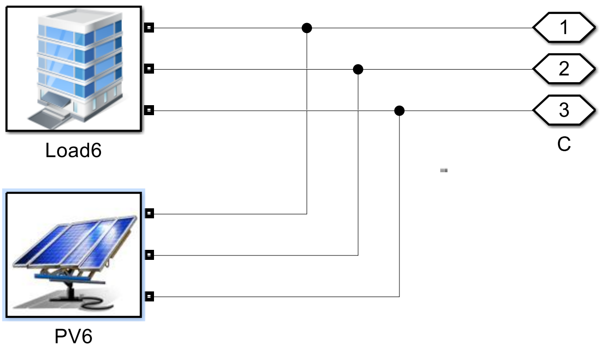

Figure 7: Detail of Group06

5 Data inputs

The data used as input include the average power consumption per type of consumer (i.e. household, public building, shop, street-lighting, private pumping station, public pumping station) with an interval of 15 minutes for approximately 365 days (1/1/2018-31/12/2018). Likewise, the production input data include the average power production of 15 minutes interval, per installed kWp in the area of Mega Evydrio. A fraction of these data is shown in the following Table 14 and 15 respectively.

Table 14: Load input data

TIME	Public buildings (W)	Houses (W)	Shops (W)	Pumps public total est. (W)	Pumps private total est. (W)	Municipal Lighting est. (W)
1/5/2018 0:00	216	779	1001	65000	0	165691
1/5/2018 0:15	201	703	1106	65000	0	165691
1/5/2018 0:30	171	537	1120	65000	0	165691
1/5/2018 0:45	226	560	986	65000	0	165691
1/5/2018 1:00	224	461	1119	0	0	165691
1/5/2018 1:15	169	523	1234	0	0	165691

1/5/2018 1:30	194	509	1243	0	0	165691
1/5/2018 1:45	200	447	763	0	0	165691
1/5/2018 2:00	228	473	869	0	0	165691
1/5/2018 2:15	195	514	795	0	0	165691
1/5/2018 2:30	170	511	625	0	0	165691
1/5/2018 2:45	225	495	675	0	0	165691
1/5/2018 3:00	204	555	571	0	0	165691

Table 15: PV production data input

Time	Mean power (for 1 kWp) per 15'
	W
1/5/18 4:15	0.00
1/5/18 4:30	0.00
1/5/18 4:45	0.00
1/5/18 5:00	0.00
1/5/18 5:15	0.00
1/5/18 5:30	0.05
1/5/18 5:45	4.78
1/5/18 6:00	16.84
1/5/18 6:15	28.94
1/5/18 6:30	52.01

6 Results

Following the aforementioned four scenarios (see Section 3), different approaches for the strategy of the Mega Evydrio micro-grid functioning were examined, as it is described in more detail in the following paragraphs.

6.1 Scenario 01 - No storage available

Due to the nature of the load and renewable generation from PVs, the peak load and peak production do not coincide. Thus there are intervals with excess of renewable generation and intervals with excess load demand. During the first type of intervals the surplus of production is provided to the network, while during the second type of intervals the micro-grid demand is fulfilled by power from the network

The results are shown in the following figures:

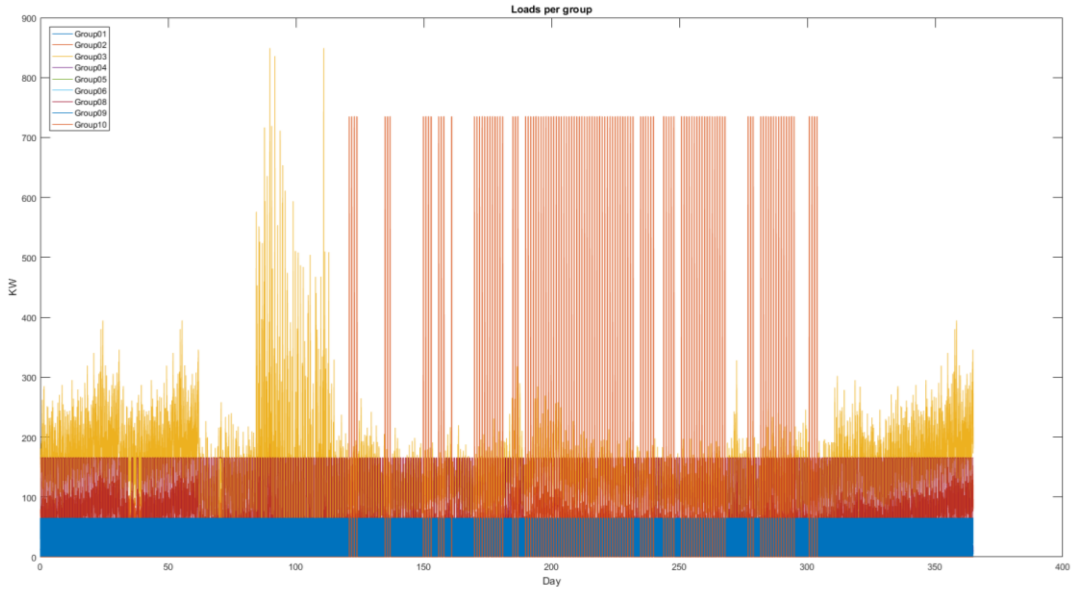

Figure 8: Scenario 01 - Loads per group of consumers

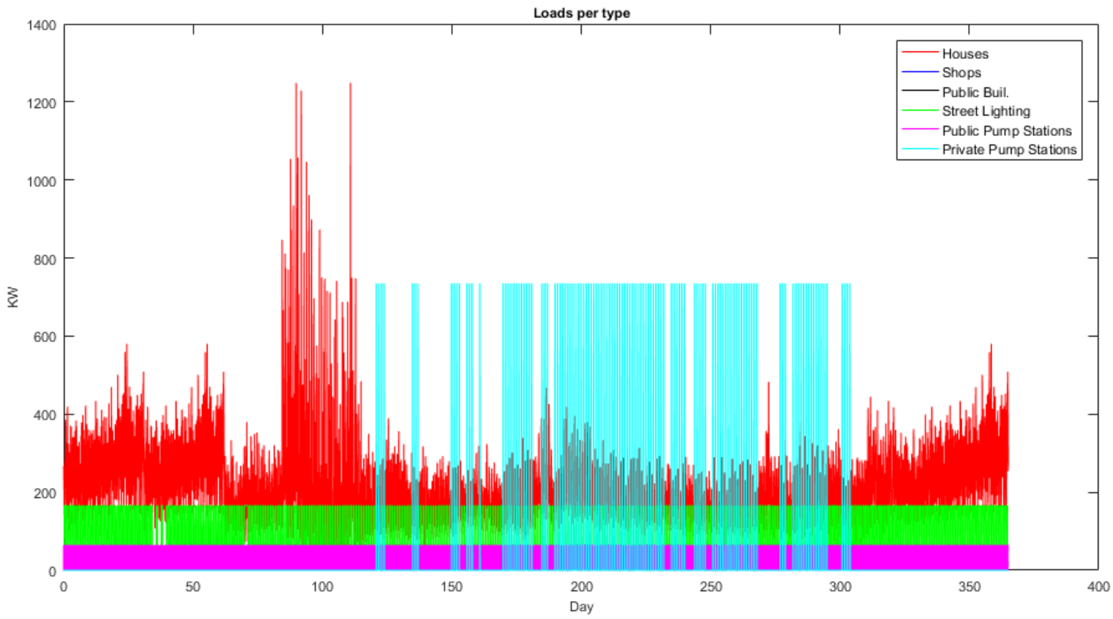

Figure 9: Scenario 01 - Load per type of consumer

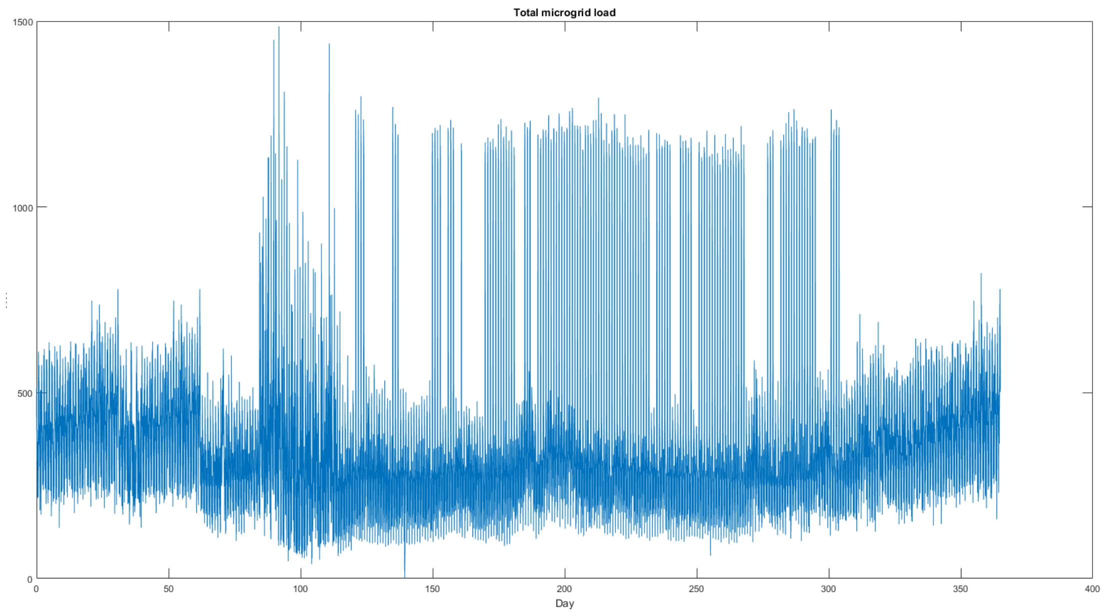

Figure 10: Scenario 01 - Total micro-grid load

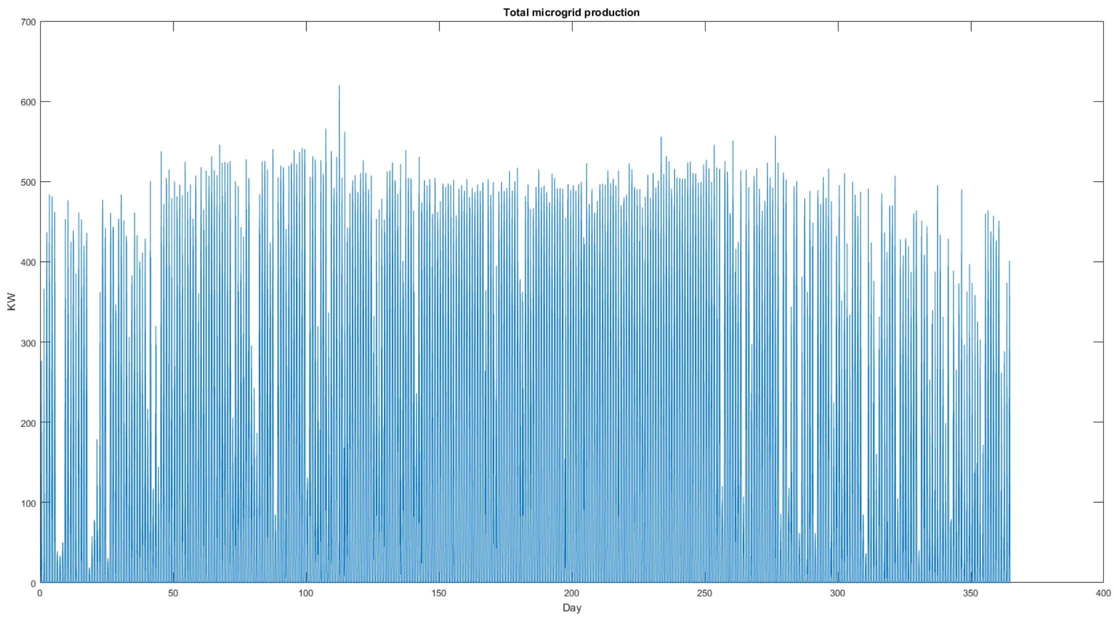

Figure 11: Scenario 01 - Total micro-grid production

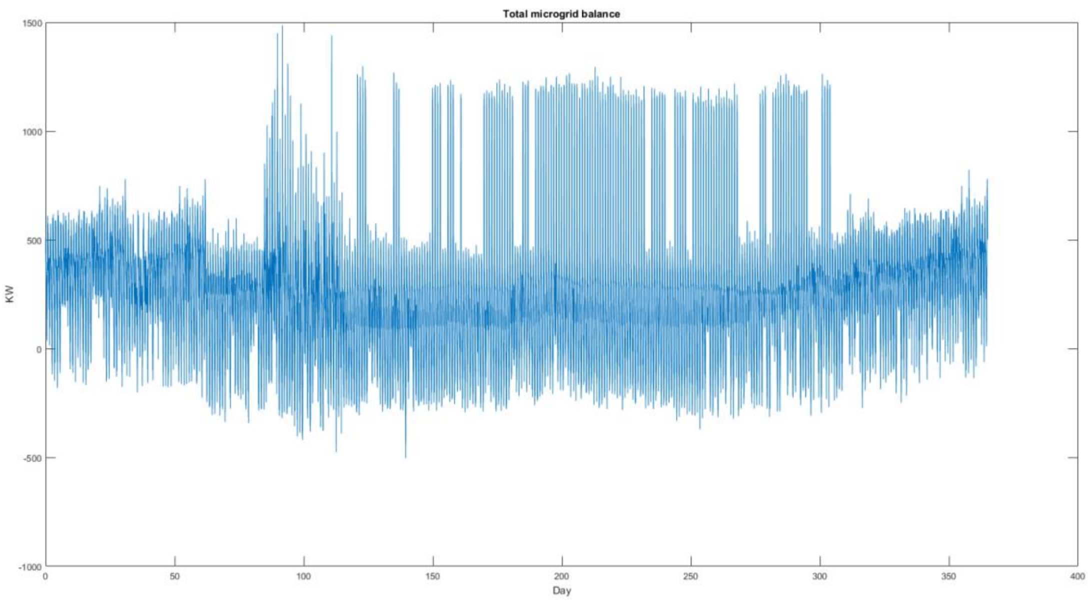

Figure 12: Scenario 01 – Micro-grid balance

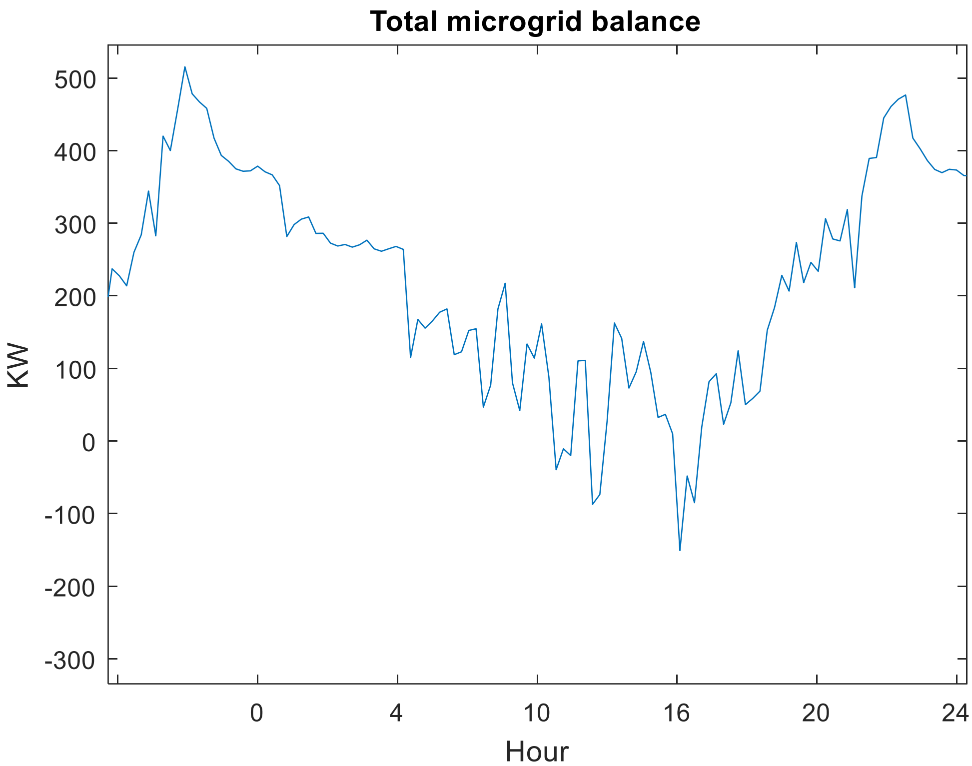

Figure 13: Scenario 01 – Micro-grid balance (9th day detail)

As it can be seen in **Figure 12** and

Figure 13, where the power balancing of the micro-grid is shown, there is a large amount of power provided to the network from the micro-grid during the daytime (when the generation from PVs is maximized), which could be used from the micro-grid during the peak load times (which occur at hours without PV production) if there is a storage system. This is the subject of the rest scenarios.

6.2 Scenario 02 – 500 kWh storage available

In this scenario, a storage system is considered to be installed at bus 0 (see Figure 5), which is the point of connection of the micro-grid and the network. The storage available considered is a concentrated 500 kWh / 1.3 MW storage device, e.g. a Lithium battery container.

In Scenario Nr 2 the battery selected represents a relatively small amount of total needs, while a practically unlimited storage available respectively, with the available RES capacity in mind, is considered in scenario 03. The choice of a 500 kWh battery has been made in order to have lower costs than in the case of a larger one.

The results are shown in the following figures.

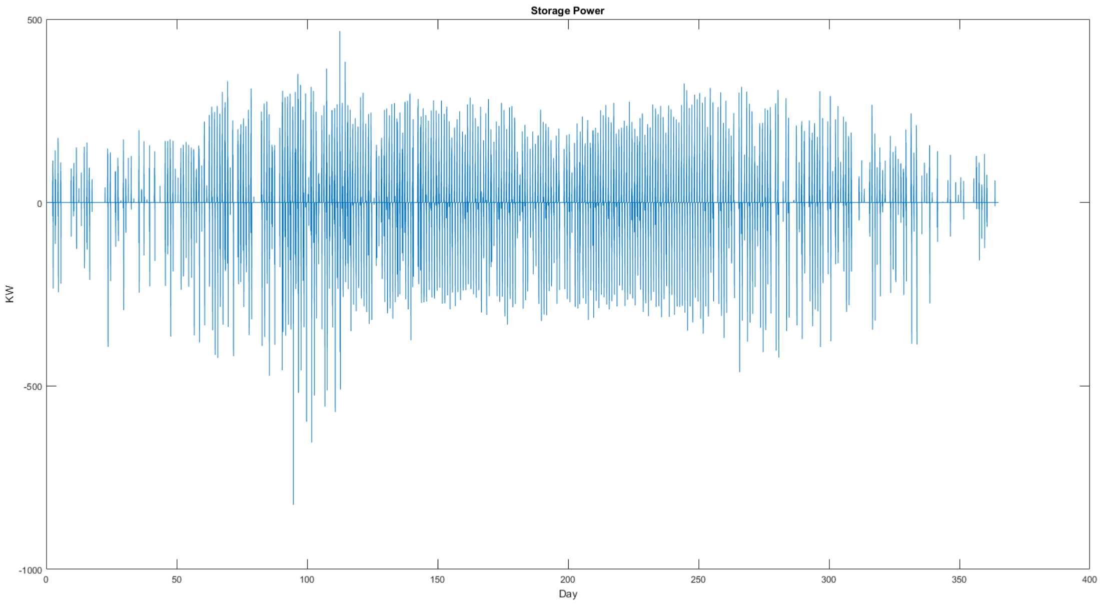

Figure 14: Scenario 02 – Storage power

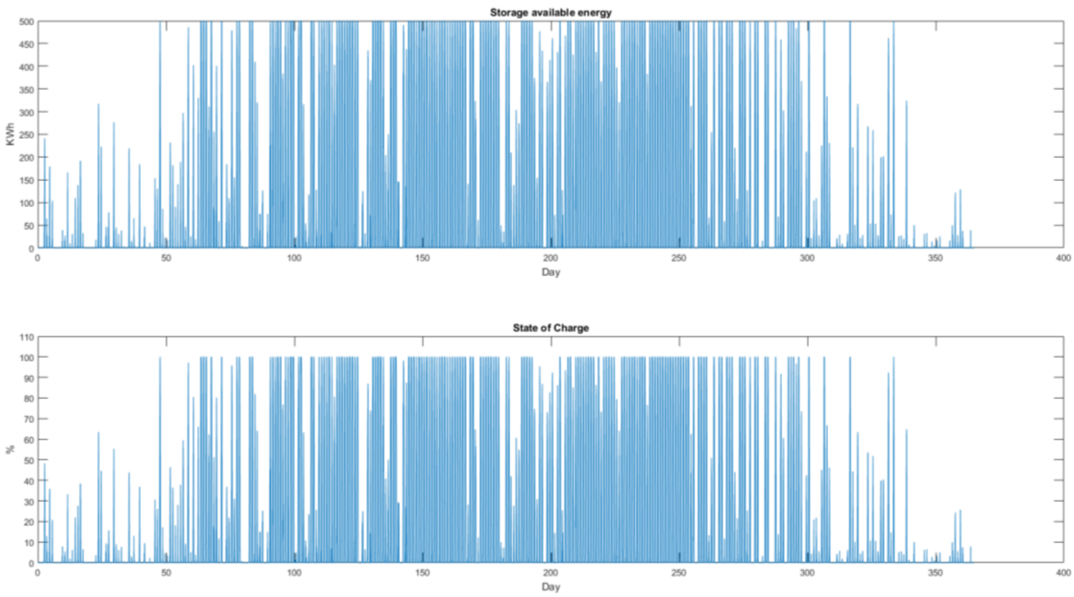

Figure 15: Scenario 02 – Storage available energy

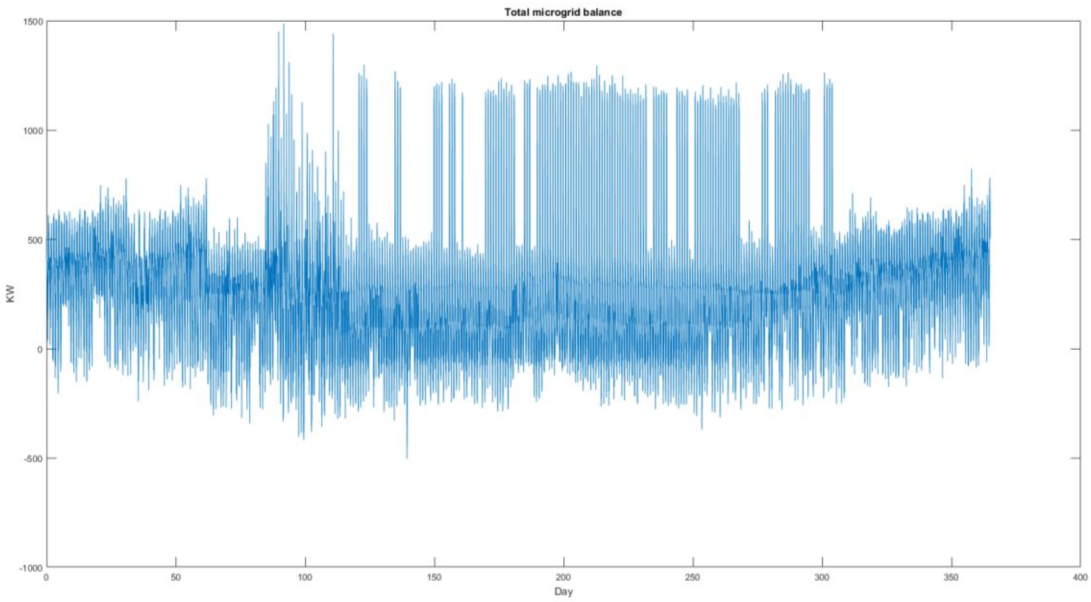

Figure 16: Scenario 02 – Total micro-grid balance

The total PV production is the same as in Scenario 01. The total micro-grid load is the one shown in Figure 10 plus the one of the storage shown in Figure 14. It must be noted that positive values in Figure 14 correspond to charging mode, i.e. it acts as a load for the micro-grid, while negative values correspond to discharging mode.

As it can be seen from Figure 16, where the total balance of the micro-grid is shown, there is still surplus during daytime that is provided to the network, as well as lack of available own power during night-time. This is due to the relative small storage capacity for the characteristics of the PV production, i.e. high production during daytime and zero to little production all the other hours. This can be seen also in **Figure 15**, where the available storage capacity is shown.

It is clear that the production from PV during the day is still larger than the one that can be stored or consumed, while the need for supply during the night hours is greater than the one already stored.

6.3 Scenario 03 – 5 MWh storage available

It is the same in nature as with scenario 02, but with practically unlimited storage in comparison with the PV production, in order to use all available local RES electricity generation.

In this case the storage is able to store all available energy, as shown in Figure 17, with the state of charge (SoC) reaching only 25% during the day. Even though storage is available to efficiently store any excess power, there is no enough local production for the micro-grid to cover all daily needs/loads, especially during night. This is the subject of Scenario 04, where additional PV capacity is added in order to cover the daily needs of the load.

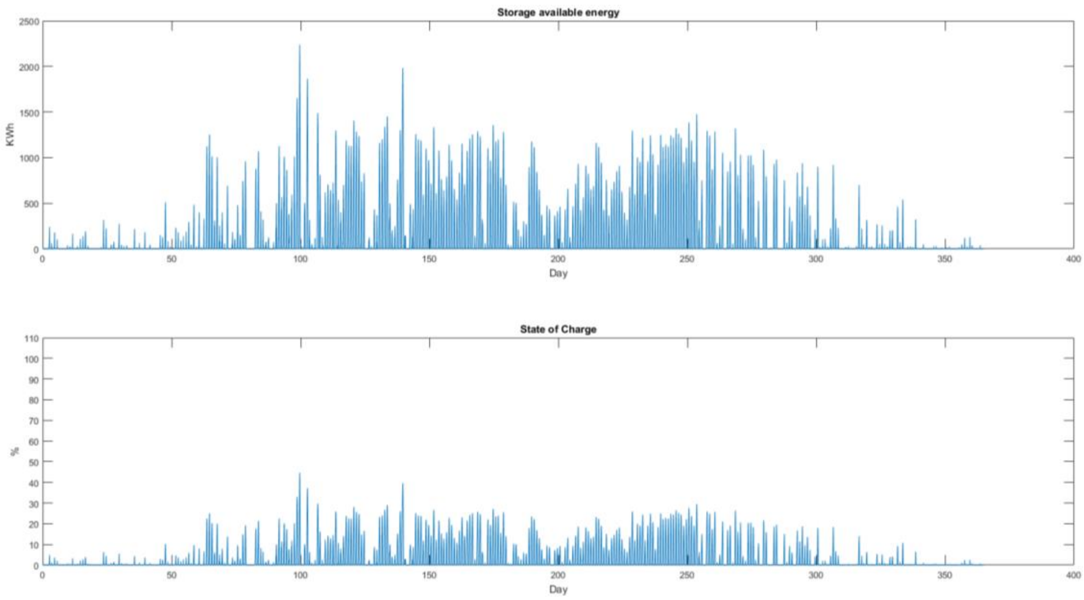

Figure 17: Scenario 03 – Battery state of Charge

6.4 Scenario 04 – 5 MWh storage available with additional 1000 kWp PV

In this scenario, the total installed capacity of Group07, i.e. the PV parks, is increased by 1000 kWp, reaching a total of 1500 kWp. There is also an available storage of 5 MWh.

The storage state of charge in this case is shown in Figure 18. It is evident from this figure that, during daytimes with sufficient luminosity, the battery with the local production from the PVs is sufficient to cover all load needs.

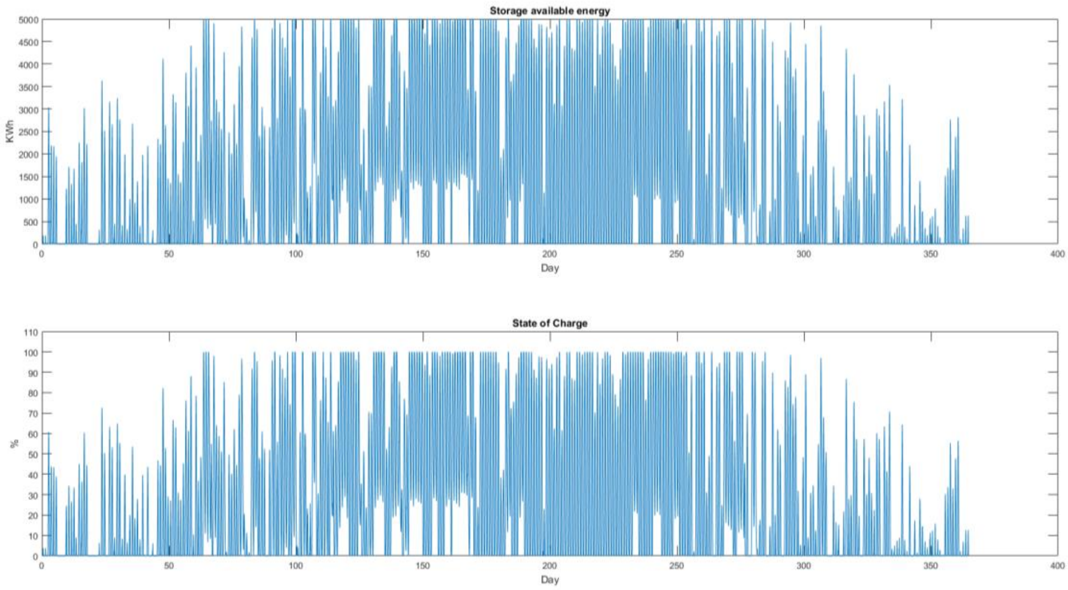

Figure 18: Scenario 04 – Battery state of Charge

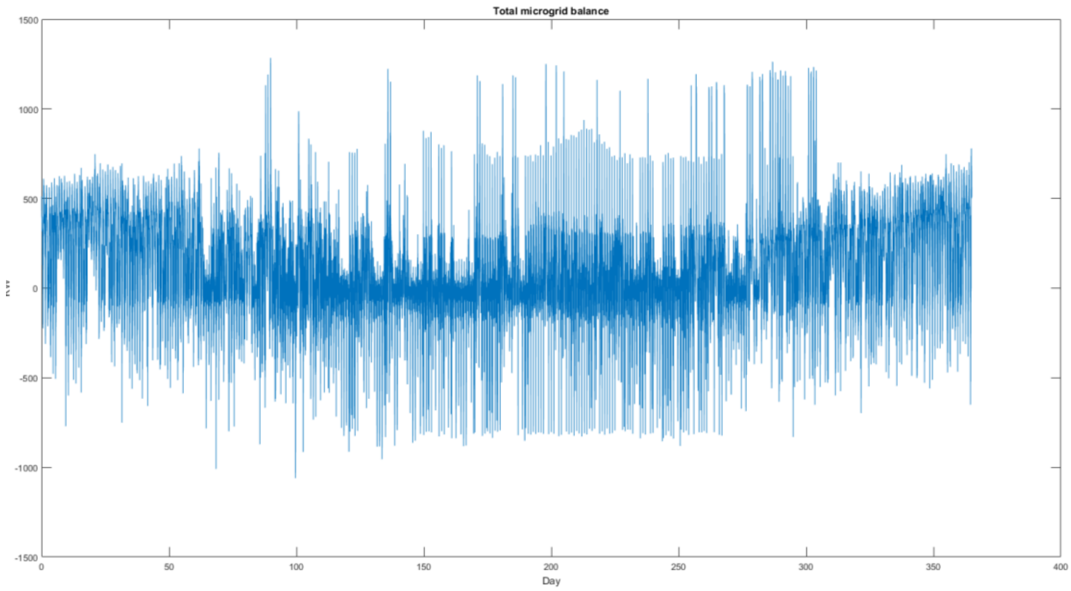

Figure 19: Scenario 04 - Microgrid balance

6.5 Conclusions

Since the data availability is for a month and a half, the conclusions are in a draft stage. From these preliminary results, it is clear that the dependency of the micro-grid only in PV production is insufficient for covering its autonomous operation since, in this case, the amount of installed PVs and storage capacity required is very large, especially if it is taken into account the fact that the data cover a period with large PV production, which is expected to be significant smaller during the other periods of the year (autumn, winter).

Thus, in a later stage, new/other RES technologies, e.g. wind and/or biomass, should be used to assess the performance of the micro-grid.

7 Financing methods - Support schemes

There are several possibilities to finance the proposed micro-grid. The new development law, and the bank loans (especially the loan from the "Consignment Deposits and Loans Fund") are two of them and they are described in annex 1 of this document.

In order to be financial viable the pilot micro-grid, the scheme of **net metering** is going to be used, as the feed-in tariff scheme that was promoted through a guaranteed feed-in tariff was stopped in the end of 2015.

The relevant law for Net-Metering is presented in annex 2 of this document.

8 Conclusions

- The green community of Mega Evydrio does not consume instantly all its renewable energy production.
- The fact that all the renewable energy produced in each moment is not consumed directly causes that it is useful to have an Energy Storage System. But from the economic point of view, for an energy storage system to be profit we should increase renewable generation power.
- In one year, the renewable energy production will avoid the emission of **560,520 kg CO_2**.
- To be protected against disconnection from the grid, the Greek pilot will need a continuous power from an Energy Storage System of **1,500 kW**. *(From the file "3.1 Balance 15 minutes.xlsx", it was noticed that the maximum electricity demand for the grid occurs at 2/4/2018 19:15; that time the consumption was 1,486,218 watts and the production was 0 watts.)*
- To be able to do net balance with the grid, it is necessary to increase the renewable power: **1700 kWp** of PV generation have to be added. Then the total installed PV power will be **2422.75 kWp**.
- Solar energy production is higher (9h–18h) in the time that the consumption is lower but the price of electricity is high.
- Solar energy production is lower in winter, like the electricity demand, because heating systems are based on diesel. On the other hand, there is a high solar production between May and October. The consumption is higher in summer time because of cooling building electricity consumption systems.

Annex 1 Financing methods

A) The new development law

The Development Law foresees support in form of a subsidy for CHP plants, small-scale hydro-power plants, and self-production using other RES (art.9 par.7 and par.8 Law No.4399/2016).

Eligible technologies
CHP, small-scale hydro-power and other RES are eligible (art.9 par. 7 and 8 Law No.4399/2016). RES projects are eligible for support, subject to the following limitations (art. 11, par.3, sub-par.2h and 2z Law No. 4399/2016).

Amount
To be eligible for support, minimum investment should amount to (art.5 par.3 Law No. 4399/2016) for social cooperatives/ cooperatives: € 50,000

RES for self-consumption can make up to 15% of eligible regional support. Regional support maximum is stipulated in the Regional Support Map (C (2014) 2642/7.5.2014), which is approved by the European Commission and is available at: http://ec.europa.eu/competition/state_aid/cases/252063/252063_1547272_57_2.pdf. Support for RES used for self-consumption only is also foreseen (art.7 par.8 Law No.4399/2016).

The Development Law alternatively offers the following types of support (art. 10 Law No. 4399/2016):
1. Subsidies
2. Leasing subsidies
3. Subsidies for the creation of new jobs

Addressees
Entitled party. All enterprises based in Greece or having a branch in Greece at the moment of the entry into force of the Development Law are eligible for this support scheme as long as they fall under the following categories:
1) private enterprises
2) commercial companies
3) cooperatives and
4) social cooperatives (art. 6 Law No. 4399/2016)

State
Own contribution amounts to 25% of total investment cost (art.5 par.1 Law No.4399/2016)

B) Loans from the Consignment Deposits and Loans Fund

Banks and financial institutions may offer so-called “golden” or “green” funds addressed to capital markets. Such funds are financed from accounts, which attract lower interest rates.

The margin consented by the lower interest rate is passed on by the bank to the investor in the form of discount rates. Furthermore, institutional banks offer soft loans and special facilities.

Consignment Deposits and Loans Fund

There is a new integrated financing scheme from the Consignment Deposits and Loans Fund in cooperation with the Centre for Renewable Energy Sources and Saving (CRES) for electricity production mainly from local authorities with important benefits.

The Consignment Deposits and Loans Fund, took the initiative for the development of a financial the programme, with the aim of producing electricity in municipal facilities of local authorities of "a" or "b" grade, but also more generally, on premises of Public Entities (universities, hospitals, etc.), through the installation of photovoltaic power plants with net-metering.

Respectively, the CRES is going to provide the necessary technical support for the program, the evaluation of the submitted proposals and the measurement and verification of the electricity production and performance of photovoltaic station.

The loans of this financing scheme have a maturity of up to twelve (12) years with fixed or floating rate, at the option of the borrower. The interested parties have the possibility to apply for financing either for the entire budget of the project or for part of it.

Annex 2 Net-metering

Net-Metering

Net-Metering (Law No.3468/2006 amended by Law No.4203/2013)

The net metering process is described in FEK B' 3583/2014. Furthermore, "virtual net metering" was introduced in 2016 (art. 2 par. Law No. 3428/2006). Especially city/regional councils, schools, universities, farmers and farming associations will be allowed to develop PV and wind power projects of up to 500 kWp, if installations are located at a considerable distance from the place of the actual power consumption (art.14A par.4 Law No.3468/2006). A new but very similar (virtual) net metering scheme has been introduced in 2017.

Eligible technologies

PV plants connected to the grid are eligible (art.14A Law No.3468/2006).

For the interconnected system: PV plants <20kW or 50% of the agreed capacity consumption (PV Capacity ≤0.5 x Sum of the agreed power consumption (kVA). For non-profit legal person this could reach up to 100%. (art. 1 par.2 FEK B' 3583/2014 and art.1 par.2 Min. Res./F1/175067).

Max. capacity limits for each PV plant are defined for the Interconnected system the 500kWp

Amount

Primarily, the electricity produced by an installation or plant is offset with self-consumed energy. Any surplus electricity is fed into the grid without any obligation for remuneration. Apart from that, PV installed on public buildings in the context of the EU funded programmes can receive up to 20% of the value of the total annual electricity production (art.14A par.4 Law No.3468/2006).

Addressees

Entitled party**.** Natural persons or legal persons governed by public or private law that they own/ rent the space in which the RES plants are installed (art. 14a par.1 Law No.3468/2006 and art.3 par.1a Min. Res. /F1/oik.175067). For PV (and other RES) virtual net-metering non-profit legal persons are only entitled (art.3 par.1a Min. Res. /F1/oik.175067 and art. 14a par.1 Law No.3468/2006).

Obligated party. The persons obligated are the grid operators (art. 2 par. 1 in conjunction with art. 12 par. 1 Law No. 3468/2006).

Procedure

Process flow

Net metering process follows an annual cycle. Each time the electricity retailer issues an electricity bill, the electricity fed into grid and the electricity consumed has to be measured. If the difference is positive, meaning that more electricity is produced and fed into the grid than consumed, this surplus is credited to the next electricity bill. However, any surpluses after the end of the year will not be disbursed by the electricity retailer to the self-producing electricity consumer and will be annulled. If the difference is negative, i.e. more electricity was consumed than produced, and then the plant/ installation operator is obliged to pay the difference (art.2. FEK B’ 3583/2014).

The new PV (virtual) net metering scheme follows an identical process. However, it follows a three-year cycle, while there is a liquidation procedure, when the PV plant operator switches to another electricity retailer (art.4 Min. Res./F1/oik.175067).

Distribution of costs

Distribution mechanism

No costs are incurred for the State (art.2 FEK B’ 3583/2014). However, it should be noted that the new PV (virtual) net metering scheme foresees how the surplus of electricity is introduced as an accounting record in the “Special Account for RES and CHP” (art.6 Min. Res. F1/oik.175067).