This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

# WP3 "System Design Monitoring and Evaluation"

# Deliverable D3.4

# "Pilot system adapted reports"

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# 1. Preface

The scope of Deliverable D.3.4 is to draw up adapted proposals for smart grid operation – services for the **p**hoto**v**oltaic **C**ase **S**tudies (**PV-C.Ss)** of the EU Heroes project, taking into consideration information on financial cases and business models from WP4 and WP5. These proposals should be considered as a vehicle that facilitates the steady increase of renewable energy sources in traditional electric systems, as well as their transformation into smart grids.

Energy transactions between the output of the under-study **PV-C.Ss** and **L**ocal **D**istribution **N**etwork (**LDN**) are illustrated in the following figure. A PV-C.S can supply or absorb energy to/from the LDN serving the energy balance, as it is defined by the equilibrium of the produced PV power and PV-C.S's electricity consumption.

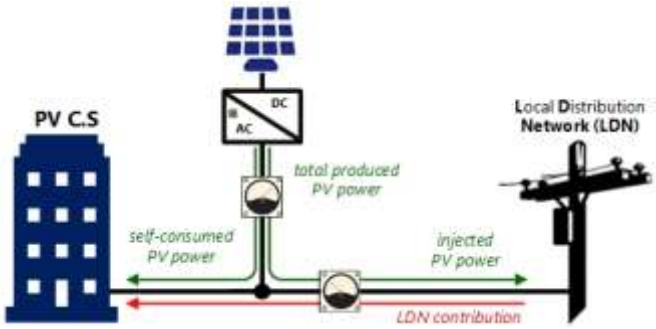


***Figure 1**: Energy transactions between the output of PVs, the under-study PV-C.S and the LDN*

Hereinafter and for the purposes of this document, the following definitions are used:

**Self-Consumption Index (S-C Index)** is defined as the ratio of the self-consumed PV energy (the part of the PV electricity that is locally consumed) to the total PVs Energy production (kWh).

$$\mathbf{S-C\ Index} = \frac{\text{self-consumed PV energy (kWh)}}{\text{total produced PV Energy (kWh)}}$$

**PVs Injection Index (PVI Index)** is defined as the ratio of the excess PV electricity that cannot be self-consumed immediately and therefore it is injected into the LDN (the part of the PV electricity that is not locally consumed) to the total PVs Energy production (kWh).

$$\mathbf{PVI\ Index} = \frac{\text{excess PV electricity that is injected into the LDN (kWh)}}{\text{total produced PV Energy (kWh)}}$$

**S-S Index** is defined as the ratio of the self-consumed PV energy to the total electrical energy consumption (kWh) of the PV-C.S, regardless if it serviced from the LDN, the PV plant or from both of them.

$$\mathbf{S-S\ Index} = \frac{\text{self-consumed PV energy (kWh)}}{\text{total electrical energy consumption of the PV-C.S (kWh)}}$$

**PVs Exploitation Index (PVE Index)** is defined as the ratio of the final AC energy output (kWh) of the PV plant to that of the "theoretical" AC energy output of the PV plant without the application of an external set point controller that limit PVs production (curtailed operation). As curtailed operation of a

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PV plant is considered the condition where the output of the PV inverters is limited due to external reasons such as inability of the local grid to receive the power or contractual agreement [IEC TS 61724-2:2016-10, Edition 1] The "theoretical" final AC energy output of a PV plant is calculated based on the total in-plane irradiance and a good estimation of the overall conversion efficiency (conversion of sunlight to AC power)of the PV plant.

$$\textbf{PVE Index} = \frac{\text{final AC energy output of the PV plant (kWh)}}{\text{"theoretical" AC energy output of the PV plant}}$$

**Typical daily profile** (**TD-Profile**) of the energy transactions between the the PV-C.Ss and LDN for each month of the reporting period. TD-Profiles illustrate the average (**AVG**) hourly values of the energy transactions mentioned in figure 1, for the total days in the month concerned. In more detail, Figure 1 illustrates the total produced PV power of a PV-C.S broken down by component (self-consumed PV power and injected PV power As far as power losses on the power lines between the output of the PV inverters, the PV-C.S and LDN are negligible, total produced PV power is equal to the sum of the self-consumed PV power and the injected PV power. This is a reasonable assumption for good and qualitative PV installations. Therefore, if two of the above-mentioned energy quantities are known the other can be computed. PV plant could be either within (e.g. many small residential PV systems) or outside (e.g. central PV plant) of PV-C.S's close geographical barriers.

General Remark I: The security and the ownership of electrical energy data raise questions concerning not only on the safety of the electric system against malicious attacks, but also on the privacy of the end users. PV-C.Ss' owners were asked to express their acceptance for publishing their processed energy data. So far, only seven owners (one from Greece, two from the Netherlands, one from Germany, one from Poland and two from Lithuania) expressed their agreement for making public their production and consumption data. Therefore, this report contains energy data solely from the afore mentioned 7 PV-C.Ss. The report will be updated on the 36th month. In this regard it has to be noted that the performance evaluation of each PV-C.S was carried out under D3.3, mainly by calculating specific monthly performance indices such as Final Yield Index, Self-Consumption Index, Self-Sufficiency Index, Capacity Utilisation Index, PVs Injection Index and PVs Exploitation Index.

General Remark II: The number of performance data reported for each PV-C.S depends on available data. Generally, data from PV case studies were available in different time scales (eg, minute time series, five-minute time series, quarter time series, half hour time series). Considering the needs and requirements of Work Packages 4 and 5, typical day profiles were deemed quite adequate for the development of new business models for community PV projects. These profiles correspond to the average day of each month, build upon average hourly values. I

General Remark III: All monitored power quantities are reported in the frame of a well-defined "**P**er-**u**nit (**pu**) system," with the nominal power of the installed PV system consisting

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the base value of the system. All the other power quantities are specified as multiples of the selected base value. It is recalled here that the main idea of a pu system is to absorb large differences in absolute values into base correlations. Therefore, the representation of the reported quantities become more uniform.

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# 2. Overview of the 11 PV case studies

Nowadays, **PV E**nergy **Co**mmunitie**s** (**PV ECOs**) are characterized by different degree of technological and operational maturity around Europe, as well as treated differently by national regulatory frameworks, energy market operators, players and investors.

Therefore, EU Heroes studies and analyses eleven (11) PV-C.Ss from 6.6kWp to 1.6MWp, focusing either on operational PV ECOs or on PV systems which might be an essential ingredient of current or future PV ECOs. More precisely, among the eleven (11) PV-C.Ss are two primary schools from Germany and UK, two multifunctional arts, education and/or entertainment centers from Greece and UK, one autonomous hybrid PV ECO from Greece, one industrial multi-RES Energy Community from Spain, two net metering PV household applications from Poland, and Lithuania, one feed in tariff PV system from Lithuania and two residential complex PV ECOs from the Netherlands. Next a very short description of each PV-C.S is taking place.

*The eleven (11) PV-C.Ss of EU Heroes Project*

## 2.1 Stavros Niarchos Foundation Cultural Center (SNFCC) PV-C.S (Greece)

SNFCC PV-C.S is a multifunctional arts, education and entertainment complex with a multi-storeyed parking building, several outbuildings, dining and coffee halls, whilst a photovoltaic canopy services part of its electricity needs. SNFCC has signed a self-consumption contract with the **D**istribution **N**etwork **O**perator (**DNO**) and therefore, under normal operating conditions, PV exports to the LDN should be minimized or reaching zero if possible. Additionally, in case of surplus produced PV energy, no payment measures are envisaged for compensation (e.g. predefined Feed-in Tariff or according to the value of the System Margin Price).

## 2.2 Iveron Monastery Autonomous Hybrid PV-C.S (Greece)

Iveron Monastery hosts about 100 people, whilst it features wood, stone and marble processing facilities, various farming activities, a restaurant and a museum. There is no connection to a central electric grid and thus lighting and electrical appliances are electrified by standalone diesel generators. A PV system was integrated into the existing diesel system in order to reduce the oil consumption. Energy storage systems were not installed in order to minimize the initial cost of the PV investment. In case there is an excess of produced PV energy, an external controller adjusts extremely quickly the MPPT operation of each inverter (reducing the produced PV energy). Therefore, PVs production falls under curtailed operation.

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### 2.3 Phoenix Centre Grid-connected PV-C.S (U.K.)

The Phoenix Centre is a community enterprise centre which is open Monday-Saturday and hosts a community café, affordable childcare services, a library and IT Suite, sports facilities, conference rooms, and a variety of other activities and events for the local community. The Phoenix Centre is connected to the LDN whilst a photovoltaic system services part of its electricity needs. The PV system was installed by local solar PV Cooperative which receives the Feed-in Tariff generation and deemed export (50% of generation) payments for the electricity generated and in exchange provides the Centre with free electricity

### 2.4 Ysgol y Bedol Grid-connected PV-C.S (U.K.)

Ysgol y Bedol is a large primary school owned by a local authority and run by a board of governors. Ysgol y Bedol is connected to the LDN whilst a photovoltaic system services part of its electricity needs. The PV system was installed by a local solar PV Cooperative which has entered into a Power Purchase Agreement with a licensed electricity supplier for payment of the electricity exported to the distribution network. In addition to income earned through the Power Purchase Agreement, the cooperative receives the Feed-in Tariff generation payments for the electricity generated. Any electricity used by Ysgol y Bedol, is used free of charge

### 2.5 Industrial multi-RES Factory microgrid (Spain)

Industrial multi-**R**enewable **E**nergy **S**ources (**RES)**-C.S is a full-scale industrial smart-grid that features a wind turbine, PVs, electrochemical energy storage system and several bidirectional charging points for electrical vehicles. The operation principle of the Industrial multi-RES-C.S is based on the self-consumption of RES. It is noted that Energy Storage systems' operation as well as electrical vehicles operation were omitted, because their setting up has not yet been fully completed.

### 2.6 Collegepark Zwijsen Grid Connected PV-C.S (The Netherlands)

Collegepark Zwijsen Grid Connected PV-C.S is a residential complex consisting of 115 apartments. Part of PV-C.S electrical needs are serviced by a PV system installed on roofs. Considering that this project is under construction, only a part of the PV system and apartments are in operation. All apartments of the Collegepark Zwijsen Grid Connected PV-C.S have balanced ventilation with energy recovery and an air-to-air heat pump and hot fill facilities for dish washer and washing machine. Owners were guaranteed a zero-energy bill for the first three years. Project has given experimental exemption of the Electricity Law. Batteries were not installed at the site and any electricity which is generated and is not used by the PV-C.S is exported onto the local distribution network.

### 2.7 Aardehuizen-Olst PV-C.S (The Netherlands)

Aardehuizen-Olst PV-C.S composed of 23 Zero Energy dwellings and a community centre that make optimal use of local existing waste materials, and natural resources, reducing notably the carbon footprint of the residents. A notable part of community's electrical needs is serviced by many small PV systems, installed mainly on roofs. The community is equipped with own water supply and sanitation and sewage system. All buildings are designed to minimize their heating needs, by focusing on the optimal use of thermal mass. Aardehuizen-Olst PV-C.S operates with experimental exemption from

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the Electricity law and therefore owners-union is allowed to supply electricity to their members and has balance responsibility, building upon solar PVs, Demand Side management and energy storage system. For the time being, all buildings are connected to the LDN, using it as a means for balancing the instantaneous differences between local consumption and generation.

### 2.8 Net-metering Passive Residence with PVs (Poland)

Passive Residence with PVs is a grid connected, net metering, rooftop PV installation which services the annual electrical needs of the residence. Although PVs power is for self-consumption use, the surplus of produced PV energy is allowed to be injected to the electrical grid without a fixed tariff. Instead, the regulatory framework gives prosumers the opportunity to receive up to 80% of the energy fed into the grid, without any charge.

### 2.9 Net-metering PV Residence (Lithuania)

Net-metering PV Residence covers its energy needs (including thermal needs) by exploiting the produced energy from a small PV system. PV system is connected to the LDN using the net-metering option. Rules of net-metering foresee that if not all electricity is consumed directly, surplus of electricity can be "fed" to the grid and returned/reused when customer has shortage. For that service consumer pays some fee to the grid operator, which is approved annually by the national agency for energy and prices control.

### 2.10 Feed-in tariff PV System (Lithuania)

This Feed-in tariff PV station was built by a private person. Purpose of this station was to get most of the possibilities of feed-in tariff system for commercial purposes. In order to compromise Feed-in tariff PV systems with PV community concept, it was decided to correlate the energy production of the under-study system with the electrical consumption of an hypothetical/theoretical **A**ggregated **H**ouseholds **C**ommunity (**AHC**) representing 30 households. In view of the specific exercise, the electricity consumption profile of the abovementioned community was calculated by using the national electricity consumption profile of a typical household, which serves heating energy needs with conventional fuels and not with electric power.

### 2.11 Grid-connected Primary school PV-C.S (Germany)

Grid-connected Primary school PV-C.S is connected to the LDN whilst a photovoltaic system services part of its electricity needs. The PV system is owned and run by a local energy cooperative. In order to have the system installed on the local school the energy cooperative is leasing the roof from the municipality. The grid connected PV system is set up in a way that some of the electricity that is being generated is consumed directly by the school itself and the surplus energy gets fed into the grid, receiving a feed-in tariff

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# 3. Typical Day profiles of the 7 PV-C.Ss

## 3.1. Net-metering Passive Residence with PVs in Dąbrowa Chotomowska (Poland)

The next five tables and figures present the typical daily profiles of the: a) Passive Residence total electrical power consumption, b) total produced PV Power, c) Self-consumed PV Power, d) Injected PV Power and e) Power fed by the LDN. A pu system was introduced with the nominal power of the installed PV system consisting the base value of the system (9.75 kW). All the other reported power quantities are specified as multiples of the selected base value.

| PV-C.S total electrical power consumption [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.101 | 0.119 | 0.143 | 0.076 | 0.052 | 0.089 | 0.062 | 0.058 | 0.067 | 0.065 | 0.071 | 0.103 |
| 1:00 | 0.055 | 0.060 | 0.091 | 0.066 | 0.037 | 0.043 | 0.049 | 0.051 | 0.049 | 0.034 | 0.037 | 0.048 |
| 2:00 | 0.060 | 0.046 | 0.077 | 0.057 | 0.029 | 0.029 | 0.047 | 0.037 | 0.048 | 0.030 | 0.033 | 0.036 |
| 3:00 | 0.048 | 0.046 | 0.080 | 0.060 | 0.029 | 0.032 | 0.040 | 0.041 | 0.042 | 0.028 | 0.032 | 0.035 |
| 4:00 | 0.051 | 0.046 | 0.084 | 0.058 | 0.027 | 0.035 | 0.038 | 0.032 | 0.040 | 0.027 | 0.033 | 0.033 |
| 5:00 | 0.050 | 0.054 | 0.084 | 0.060 | 0.031 | 0.032 | 0.039 | 0.039 | 0.045 | 0.027 | 0.034 | 0.033 |
| 6:00 | 0.121 | 0.180 | 0.182 | 0.116 | 0.056 | 0.042 | 0.054 | 0.056 | 0.066 | 0.077 | 0.110 | 0.116 |
| 7:00 | 0.151 | 0.284 | 0.247 | 0.121 | 0.085 | 0.118 | 0.078 | 0.089 | 0.124 | 0.156 | 0.171 | 0.151 |
| 8:00 | 0.192 | 0.293 | 0.285 | 0.100 | 0.070 | 0.103 | 0.090 | 0.098 | 0.089 | 0.123 | 0.186 | 0.170 |
| 9:00 | 0.189 | 0.272 | 0.231 | 0.073 | 0.058 | 0.089 | 0.086 | 0.092 | 0.103 | 0.090 | 0.169 | 0.166 |
| 10:00 | 0.167 | 0.296 | 0.202 | 0.071 | 0.075 | 0.097 | 0.090 | 0.090 | 0.071 | 0.100 | 0.138 | 0.157 |
| 11:00 | 0.139 | 0.248 | 0.149 | 0.072 | 0.061 | 0.070 | 0.107 | 0.090 | 0.094 | 0.083 | 0.141 | 0.154 |
| 12:00 | 0.135 | 0.219 | 0.138 | 0.054 | 0.050 | 0.084 | 0.095 | 0.080 | 0.086 | 0.081 | 0.085 | 0.117 |
| 13:00 | 0.126 | 0.208 | 0.142 | 0.057 | 0.061 | 0.079 | 0.096 | 0.089 | 0.090 | 0.058 | 0.097 | 0.128 |
| 14:00 | 0.138 | 0.178 | 0.121 | 0.058 | 0.061 | 0.079 | 0.114 | 0.085 | 0.076 | 0.058 | 0.109 | 0.138 |
| 15:00 | 0.131 | 0.204 | 0.126 | 0.044 | 0.057 | 0.071 | 0.097 | 0.087 | 0.129 | 0.073 | 0.108 | 0.130 |
| 16:00 | 0.161 | 0.195 | 0.120 | 0.056 | 0.062 | 0.093 | 0.104 | 0.080 | 0.121 | 0.056 | 0.108 | 0.113 |
| 17:00 | 0.157 | 0.218 | 0.141 | 0.052 | 0.064 | 0.080 | 0.105 | 0.087 | 0.096 | 0.075 | 0.121 | 0.138 |
| 18:00 | 0.169 | 0.257 | 0.188 | 0.087 | 0.077 | 0.080 | 0.104 | 0.119 | 0.094 | 0.117 | 0.150 | 0.157 |
| 19:00 | 0.189 | 0.274 | 0.218 | 0.114 | 0.103 | 0.088 | 0.120 | 0.127 | 0.105 | 0.137 | 0.179 | 0.136 |
| 20:00 | 0.189 | 0.280 | 0.262 | 0.130 | 0.105 | 0.123 | 0.132 | 0.092 | 0.146 | 0.169 | 0.166 | 0.146 |
| 21:00 | 0.201 | 0.336 | 0.291 | 0.152 | 0.131 | 0.129 | 0.132 | 0.125 | 0.145 | 0.210 | 0.235 | 0.166 |
| 22:00 | 0.213 | 0.280 | 0.293 | 0.159 | 0.144 | 0.174 | 0.130 | 0.105 | 0.110 | 0.144 | 0.182 | 0.159 |
| 23:00 | 0.181 | 0.238 | 0.208 | 0.098 | 0.090 | 0.104 | 0.096 | 0.059 | 0.085 | 0.090 | 0.131 | 0.160 |

***Table I**: Typical Daily Profile of total electrical consumption for the Passive Residence with PVs in Dąbrowa*

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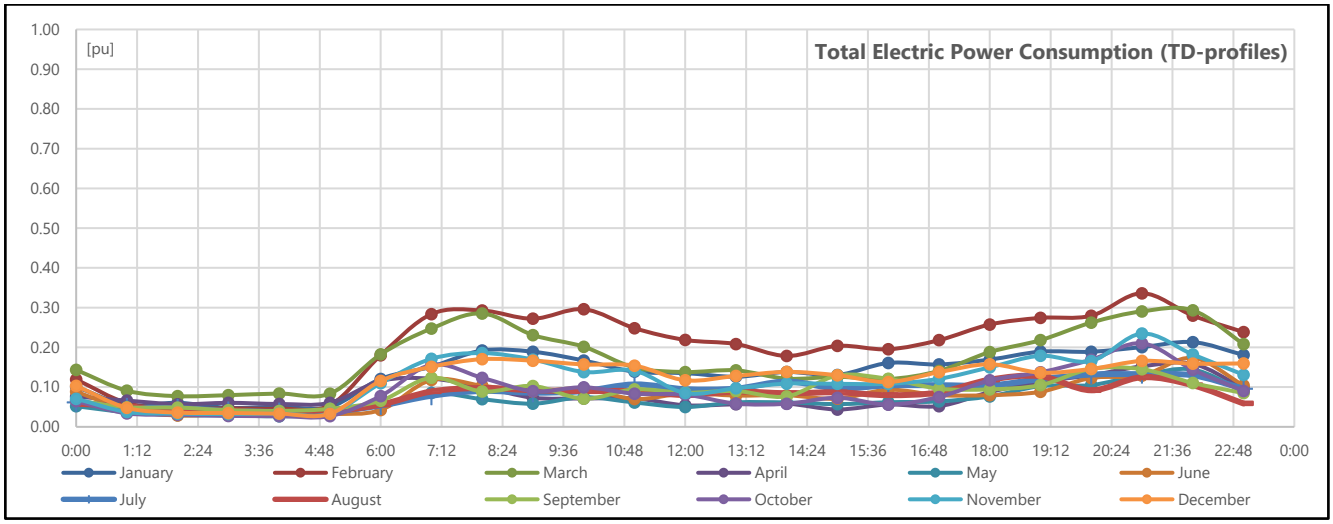


***Figure 1**: Typical Daily Profile of total electrical consumption for the Passive Residence with PVs in Dąbrowa*

| Total produced PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.011 | 0.001 | 0.011 | 0.020 | 0.019 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.070 | 0.024 | 0.070 | 0.074 | 0.077 | 0.046 | 0.013 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.025 | 0.207 | 0.143 | 0.207 | 0.200 | 0.187 | 0.161 | 0.120 | 0.012 | 0.003 | 0.000 |
| 8:00 | 0.010 | 0.107 | 0.374 | 0.310 | 0.374 | 0.329 | 0.316 | 0.320 | 0.278 | 0.071 | 0.030 | 0.008 |
| 9:00 | 0.053 | 0.166 | 0.509 | 0.466 | 0.509 | 0.444 | 0.439 | 0.446 | 0.390 | 0.142 | 0.066 | 0.034 |
| 10:00 | 0.096 | 0.213 | 0.617 | 0.566 | 0.617 | 0.512 | 0.478 | 0.519 | 0.490 | 0.190 | 0.097 | 0.055 |
| 11:00 | 0.120 | 0.232 | 0.652 | 0.671 | 0.652 | 0.546 | 0.531 | 0.526 | 0.514 | 0.229 | 0.115 | 0.081 |
| 12:00 | 0.130 | 0.219 | 0.661 | 0.649 | 0.661 | 0.564 | 0.566 | 0.540 | 0.514 | 0.242 | 0.132 | 0.098 |
| 13:00 | 0.119 | 0.218 | 0.613 | 0.644 | 0.613 | 0.537 | 0.540 | 0.469 | 0.501 | 0.223 | 0.100 | 0.076 |
| 14:00 | 0.061 | 0.139 | 0.525 | 0.597 | 0.525 | 0.493 | 0.474 | 0.437 | 0.411 | 0.208 | 0.049 | 0.036 |
| 15:00 | 0.016 | 0.082 | 0.455 | 0.453 | 0.455 | 0.371 | 0.367 | 0.356 | 0.318 | 0.140 | 0.011 | 0.006 |
| 16:00 | 0.000 | 0.019 | 0.330 | 0.313 | 0.330 | 0.306 | 0.265 | 0.255 | 0.186 | 0.069 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.001 | 0.176 | 0.147 | 0.176 | 0.185 | 0.144 | 0.135 | 0.073 | 0.016 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.063 | 0.046 | 0.063 | 0.081 | 0.067 | 0.044 | 0.013 | 0.000 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.028 | 0.011 | 0.028 | 0.046 | 0.034 | 0.013 | 0.000 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.006 | 0.000 | 0.006 | 0.017 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table II**: Typical Daily Profile of total produced PV Power for the Passive Residence with PVs in Dąbrowa*

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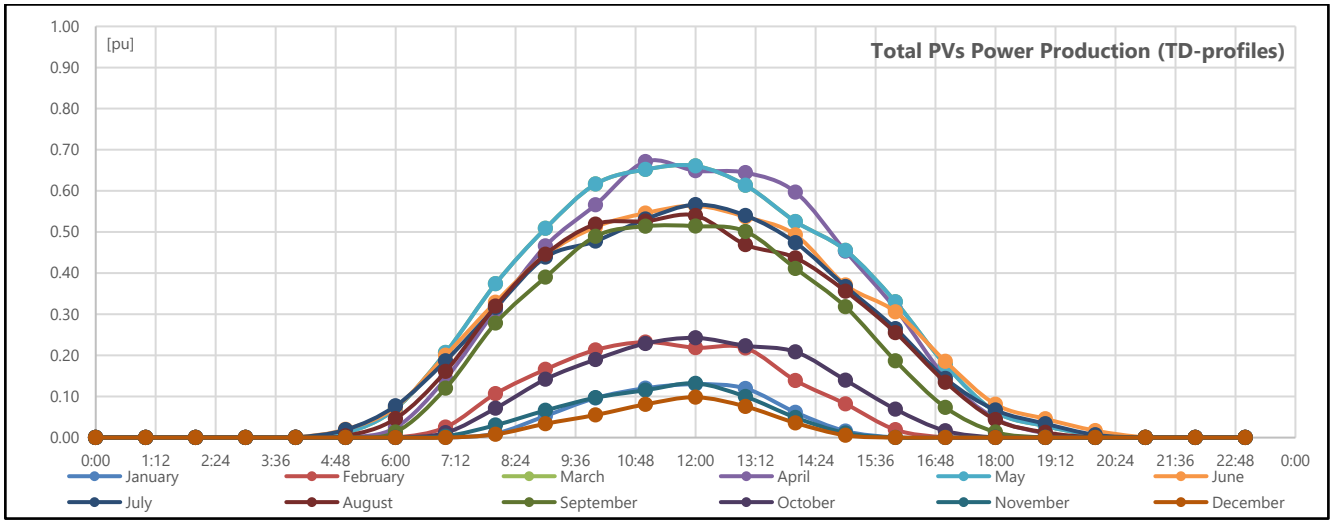



***Figure 2**: Typical Daily Profile of total produced PV Power for the Passive Residence with PVs in Dąbrowa*

| Self-consumed PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.010 | 0.001 | 0.010 | 0.017 | 0.017 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.032 | 0.018 | 0.032 | 0.034 | 0.040 | 0.029 | 0.011 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.024 | 0.062 | 0.056 | 0.062 | 0.089 | 0.065 | 0.073 | 0.075 | 0.010 | 0.003 | 0.000 |
| 8:00 | 0.010 | 0.085 | 0.061 | 0.080 | 0.061 | 0.091 | 0.082 | 0.089 | 0.081 | 0.042 | 0.028 | 0.008 |
| 9:00 | 0.042 | 0.124 | 0.058 | 0.062 | 0.058 | 0.080 | 0.079 | 0.082 | 0.087 | 0.053 | 0.053 | 0.029 |
| 10:00 | 0.071 | 0.142 | 0.074 | 0.059 | 0.074 | 0.089 | 0.085 | 0.086 | 0.066 | 0.058 | 0.050 | 0.047 |
| 11:00 | 0.075 | 0.137 | 0.061 | 0.063 | 0.061 | 0.069 | 0.104 | 0.088 | 0.090 | 0.054 | 0.052 | 0.056 |
| 12:00 | 0.072 | 0.121 | 0.050 | 0.044 | 0.050 | 0.083 | 0.092 | 0.077 | 0.081 | 0.047 | 0.042 | 0.054 |
| 13:00 | 0.065 | 0.112 | 0.059 | 0.046 | 0.059 | 0.075 | 0.092 | 0.086 | 0.088 | 0.035 | 0.040 | 0.043 |
| 14:00 | 0.042 | 0.087 | 0.059 | 0.046 | 0.059 | 0.074 | 0.109 | 0.078 | 0.074 | 0.039 | 0.025 | 0.025 |
| 15:00 | 0.013 | 0.065 | 0.055 | 0.041 | 0.055 | 0.068 | 0.085 | 0.084 | 0.110 | 0.042 | 0.009 | 0.005 |
| 16:00 | 0.000 | 0.017 | 0.057 | 0.047 | 0.057 | 0.087 | 0.098 | 0.075 | 0.095 | 0.024 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.001 | 0.053 | 0.038 | 0.053 | 0.068 | 0.082 | 0.071 | 0.051 | 0.011 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.038 | 0.031 | 0.038 | 0.050 | 0.053 | 0.039 | 0.013 | 0.000 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.025 | 0.010 | 0.025 | 0.036 | 0.032 | 0.012 | 0.000 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.006 | 0.000 | 0.006 | 0.016 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table III**: Typical Daily Profile of self-consumed PV Power for the Passive Residence with PVs in Dąbrowa*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

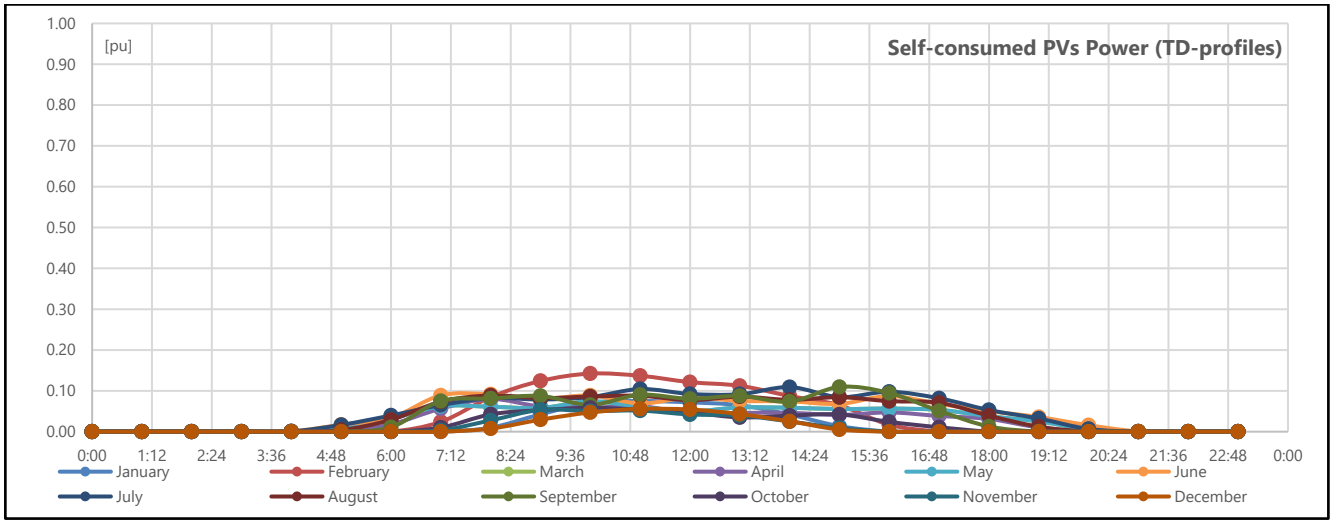



***Figure 3**: Typical Daily Profile of self-consumed PV Power for the Passive Residence with PVs in Dąbrowa*

| Injected PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.003 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.039 | 0.006 | 0.039 | 0.040 | 0.038 | 0.017 | 0.002 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.001 | 0.144 | 0.087 | 0.144 | 0.111 | 0.122 | 0.087 | 0.045 | 0.002 | 0.000 | 0.000 |
| 8:00 | 0.000 | 0.022 | 0.313 | 0.230 | 0.313 | 0.238 | 0.234 | 0.231 | 0.197 | 0.029 | 0.003 | 0.000 |
| 9:00 | 0.010 | 0.042 | 0.451 | 0.405 | 0.451 | 0.364 | 0.360 | 0.363 | 0.302 | 0.089 | 0.013 | 0.004 |
| 10:00 | 0.025 | 0.071 | 0.542 | 0.507 | 0.542 | 0.424 | 0.393 | 0.433 | 0.424 | 0.131 | 0.047 | 0.008 |
| 11:00 | 0.045 | 0.095 | 0.591 | 0.608 | 0.591 | 0.477 | 0.427 | 0.438 | 0.424 | 0.175 | 0.064 | 0.025 |
| 12:00 | 0.058 | 0.097 | 0.611 | 0.605 | 0.611 | 0.480 | 0.474 | 0.463 | 0.434 | 0.196 | 0.090 | 0.044 |
| 13:00 | 0.055 | 0.105 | 0.554 | 0.598 | 0.554 | 0.461 | 0.448 | 0.383 | 0.414 | 0.188 | 0.060 | 0.033 |
| 14:00 | 0.020 | 0.051 | 0.467 | 0.551 | 0.467 | 0.419 | 0.365 | 0.359 | 0.338 | 0.169 | 0.024 | 0.010 |
| 15:00 | 0.002 | 0.017 | 0.400 | 0.412 | 0.400 | 0.303 | 0.283 | 0.272 | 0.208 | 0.097 | 0.002 | 0.000 |
| 16:00 | 0.000 | 0.002 | 0.273 | 0.266 | 0.273 | 0.219 | 0.167 | 0.180 | 0.092 | 0.045 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.000 | 0.123 | 0.108 | 0.123 | 0.117 | 0.062 | 0.064 | 0.022 | 0.006 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.025 | 0.015 | 0.025 | 0.031 | 0.014 | 0.004 | 0.001 | 0.000 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.003 | 0.001 | 0.003 | 0.010 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table IV**: Typical Daily Profile of injected PV Power for the Passive Residence with PVs in Dąbrowa*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

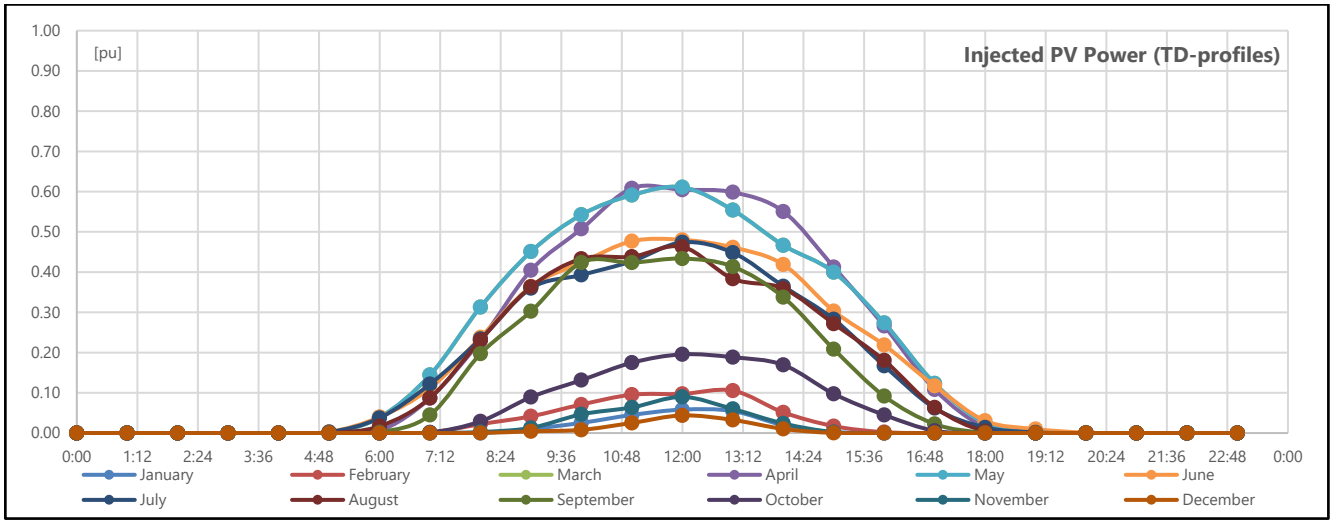



***Figure 4**: Typical Daily Profile of injected PV Power for the Passive Residence with PVs in Dąbrowa*

| Power fed by the LDN [kWh] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.101 | 0.119 | 0.052 | 0.076 | 0.052 | 0.089 | 0.062 | 0.058 | 0.067 | 0.065 | 0.071 | 0.103 |
| 1:00 | 0.055 | 0.060 | 0.037 | 0.066 | 0.037 | 0.043 | 0.049 | 0.051 | 0.049 | 0.034 | 0.037 | 0.048 |
| 2:00 | 0.060 | 0.046 | 0.029 | 0.057 | 0.029 | 0.029 | 0.047 | 0.037 | 0.048 | 0.030 | 0.033 | 0.036 |
| 3:00 | 0.048 | 0.046 | 0.029 | 0.060 | 0.029 | 0.032 | 0.040 | 0.041 | 0.042 | 0.028 | 0.032 | 0.035 |
| 4:00 | 0.051 | 0.046 | 0.026 | 0.058 | 0.026 | 0.034 | 0.037 | 0.032 | 0.040 | 0.027 | 0.033 | 0.033 |
| 5:00 | 0.050 | 0.054 | 0.021 | 0.060 | 0.021 | 0.015 | 0.022 | 0.035 | 0.045 | 0.027 | 0.034 | 0.033 |
| 6:00 | 0.121 | 0.180 | 0.025 | 0.097 | 0.025 | 0.009 | 0.014 | 0.027 | 0.055 | 0.077 | 0.110 | 0.116 |
| 7:00 | 0.151 | 0.260 | 0.023 | 0.065 | 0.023 | 0.029 | 0.013 | 0.015 | 0.049 | 0.146 | 0.168 | 0.151 |
| 8:00 | 0.182 | 0.208 | 0.009 | 0.020 | 0.009 | 0.012 | 0.008 | 0.009 | 0.008 | 0.081 | 0.158 | 0.163 |
| 9:00 | 0.146 | 0.148 | 0.000 | 0.012 | 0.000 | 0.010 | 0.007 | 0.010 | 0.015 | 0.037 | 0.116 | 0.137 |
| 10:00 | 0.096 | 0.154 | 0.000 | 0.013 | 0.000 | 0.008 | 0.005 | 0.004 | 0.005 | 0.041 | 0.088 | 0.110 |
| 11:00 | 0.064 | 0.111 | 0.001 | 0.009 | 0.001 | 0.001 | 0.002 | 0.002 | 0.004 | 0.030 | 0.090 | 0.098 |
| 12:00 | 0.063 | 0.097 | 0.000 | 0.010 | 0.000 | 0.001 | 0.002 | 0.003 | 0.005 | 0.034 | 0.043 | 0.063 |
| 13:00 | 0.061 | 0.096 | 0.002 | 0.011 | 0.002 | 0.003 | 0.005 | 0.003 | 0.003 | 0.024 | 0.057 | 0.085 |
| 14:00 | 0.096 | 0.091 | 0.003 | 0.012 | 0.003 | 0.005 | 0.005 | 0.007 | 0.003 | 0.019 | 0.084 | 0.113 |
| 15:00 | 0.117 | 0.139 | 0.002 | 0.003 | 0.002 | 0.003 | 0.012 | 0.002 | 0.020 | 0.031 | 0.099 | 0.125 |
| 16:00 | 0.160 | 0.178 | 0.005 | 0.009 | 0.005 | 0.006 | 0.006 | 0.005 | 0.026 | 0.032 | 0.108 | 0.113 |
| 17:00 | 0.157 | 0.217 | 0.011 | 0.014 | 0.011 | 0.012 | 0.023 | 0.016 | 0.045 | 0.064 | 0.121 | 0.138 |
| 18:00 | 0.169 | 0.257 | 0.039 | 0.056 | 0.039 | 0.029 | 0.051 | 0.079 | 0.082 | 0.117 | 0.150 | 0.157 |
| 19:00 | 0.189 | 0.274 | 0.078 | 0.103 | 0.078 | 0.052 | 0.088 | 0.115 | 0.105 | 0.137 | 0.179 | 0.136 |
| 20:00 | 0.189 | 0.280 | 0.099 | 0.130 | 0.099 | 0.107 | 0.125 | 0.092 | 0.146 | 0.169 | 0.166 | 0.146 |
| 21:00 | 0.201 | 0.336 | 0.131 | 0.152 | 0.131 | 0.128 | 0.132 | 0.125 | 0.145 | 0.210 | 0.235 | 0.166 |
| 22:00 | 0.213 | 0.280 | 0.144 | 0.159 | 0.144 | 0.174 | 0.130 | 0.105 | 0.110 | 0.144 | 0.182 | 0.159 |
| 23:00 | 0.181 | 0.238 | 0.090 | 0.098 | 0.090 | 0.104 | 0.096 | 0.059 | 0.085 | 0.090 | 0.131 | 0.160 |

***Table V**: Typical Daily Profile of power fed by the LDN for the Passive Residence with PVs in Dąbrowa*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

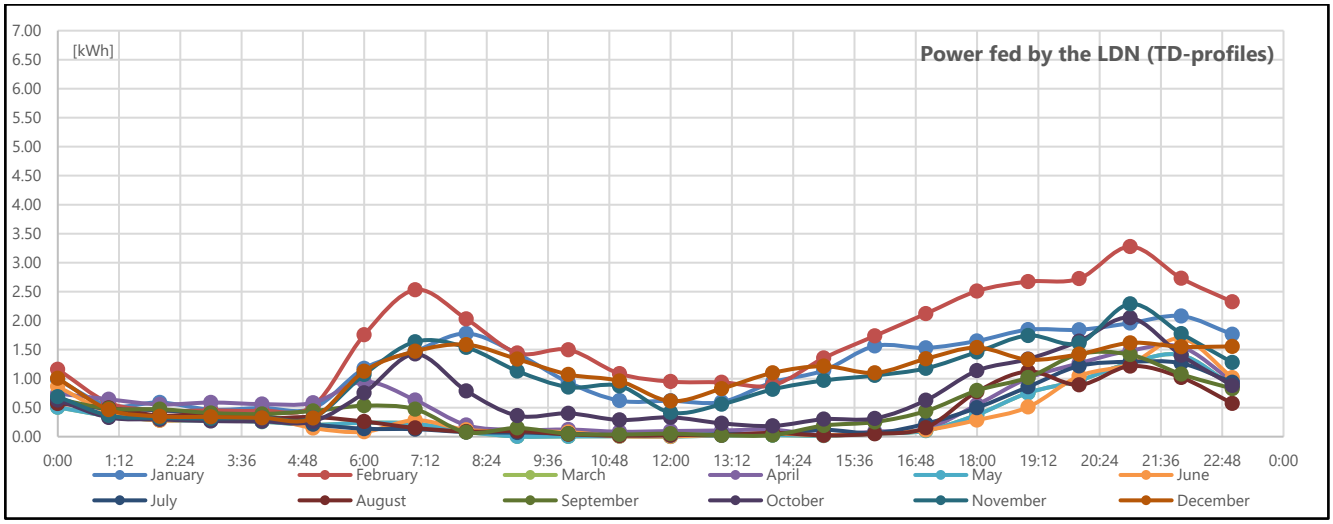
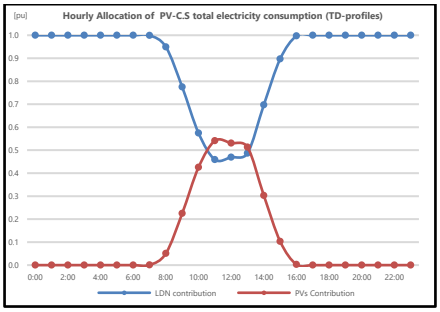
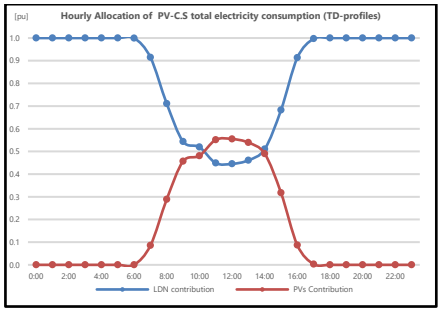



***Figure 5**: Typical Daily Profile of power fed by the LDN for the Passive Residence with PVs in Dąbrowa*

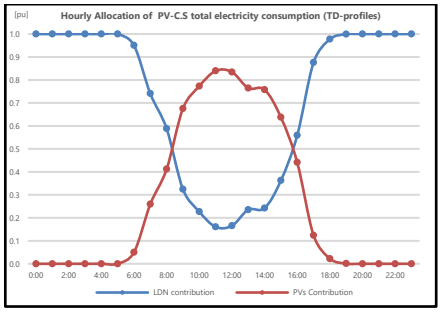
**Figures 6** illustrates the typical hourly allocation of PV-C.S's total power consumption for each month of the reporting period. Both LDN and PVs hourly contributions are divided with the corresponding hourly value of the PV-C.S total electrical power consumption and thus their sum is always equal to unit. After a careful analysis of **Figure 6** it is concluded that, even in the case where the energy transactions are considered as hourly values, there are time intervals (particularly during spring and summer) where the energy needs of the PV-C.S are serviced by PVs in high rates (almost around 100%).



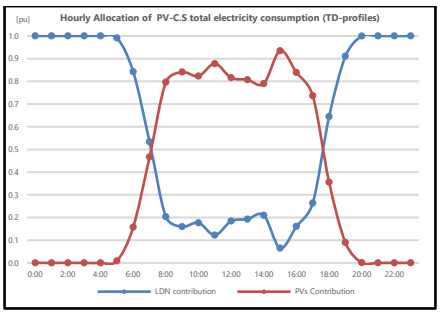

January



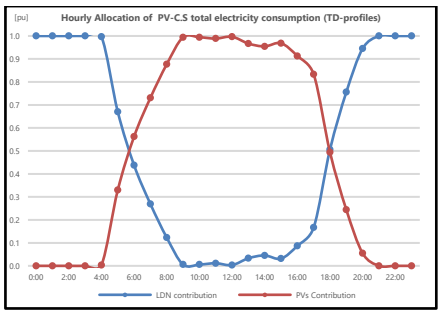

February



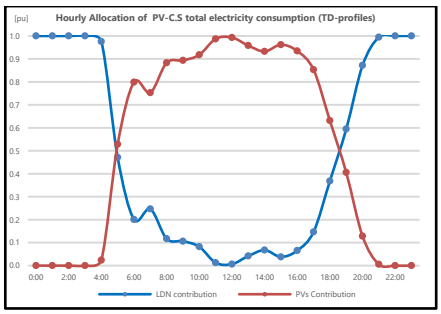

March




April




May




June

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

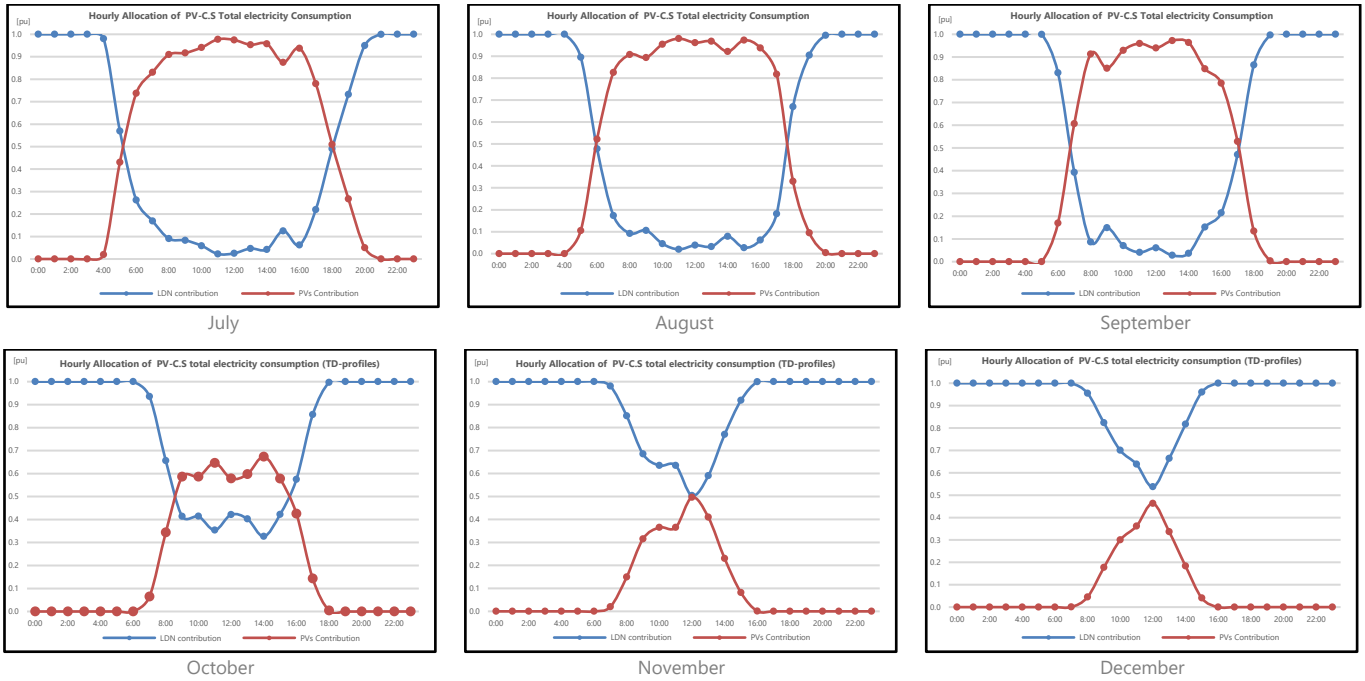
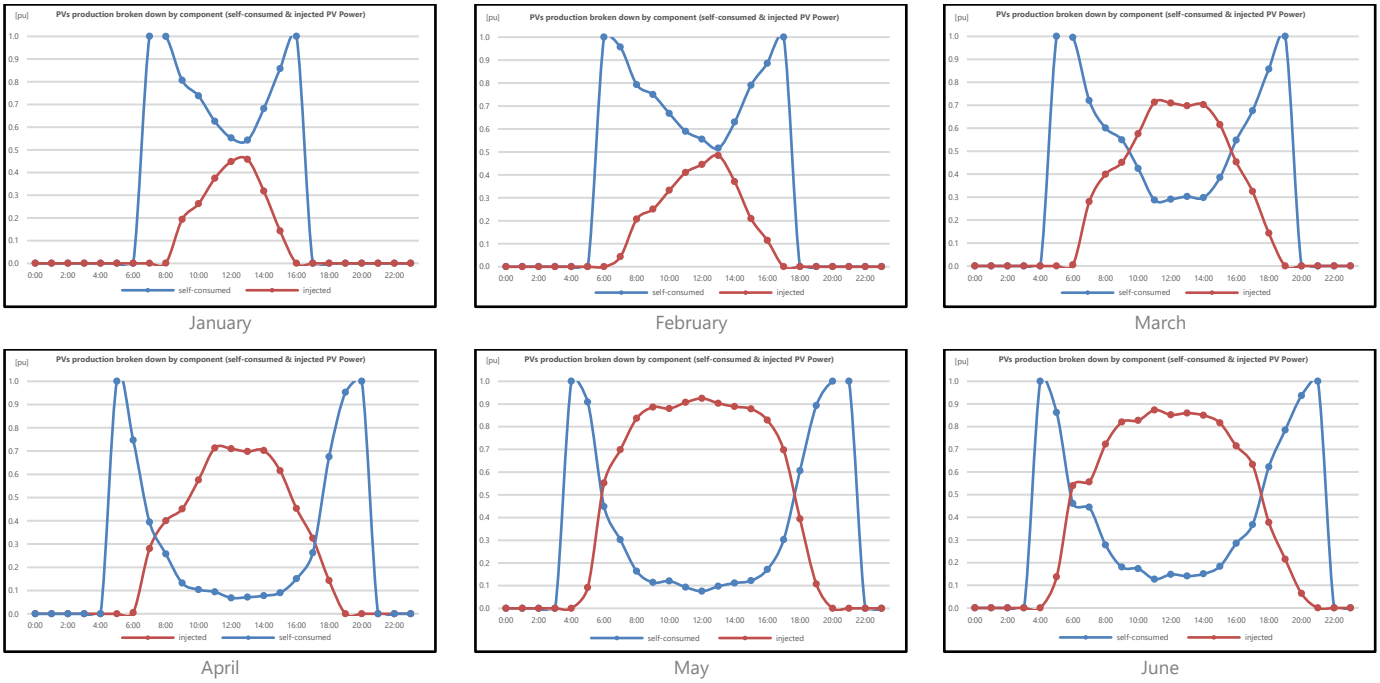
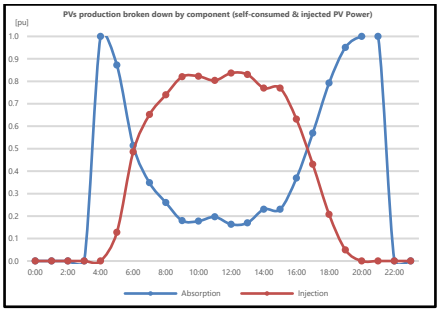



***Figure 6**: Hourly Allocation of PV-C.S total electricidal power consumption for each month of the reporting period (TD-profiles)*

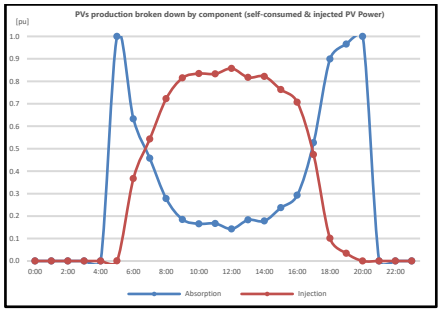
**Figures 7** illustrates the typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Power). Both components of hourly contributions are divided with the corresponding hourly value of the total PVs production and thus their sum is always equal to unit. After a careful analysis of **Figure 7** it is concluded that both PVs production components are comparable almost throughout the reported period.



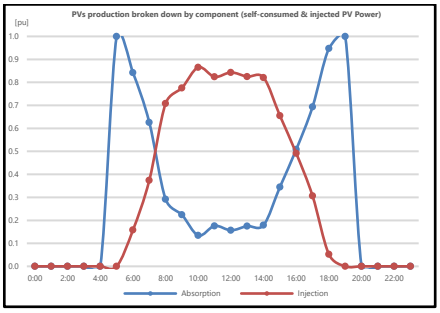
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805



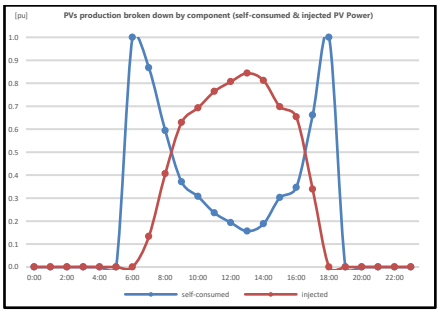

July



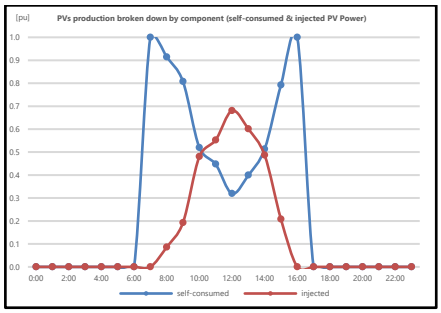

August



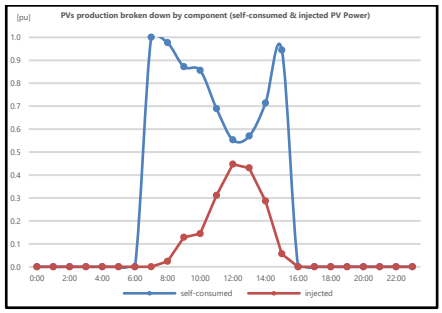

September




October




November




December

***Figure 7**: Typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Power)*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

## 3.2. Net-metering PV Residence in Bukciai (Lithuania)

The next five tables and figures present the typical daily profiles of the: a) PV Residence total electrical power consumption, b) total produced PV Power, c) Self-consumed PV Power, d) Injected PV Power and e) Power fed by the LDN. A pu system was introduced with the nominal power of the installed PV system consisting the base value of the system m (6.6 kW). All the other reported power quantities are specified as multiples of the selected base value.

| PV-C.S total electrical power consumption [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.086 | 0.176 | 0.178 | 0.077 | 0.059 | 0.043 | 0.042 | 0.049 | 0.044 | 0.147 | 0.125 | 0.133 |
| 1:00 | 0.058 | 0.089 | 0.140 | 0.055 | 0.041 | 0.036 | 0.033 | 0.035 | 0.035 | 0.050 | 0.055 | 0.070 |
| 2:00 | 0.122 | 0.068 | 0.178 | 0.053 | 0.063 | 0.054 | 0.047 | 0.050 | 0.062 | 0.102 | 0.114 | 0.145 |
| 3:00 | 0.153 | 0.068 | 0.184 | 0.112 | 0.130 | 0.095 | 0.126 | 0.154 | 0.118 | 0.105 | 0.128 | 0.173 |
| 4:00 | 0.375 | 0.068 | 0.413 | 0.163 | 0.164 | 0.079 | 0.100 | 0.095 | 0.067 | 0.101 | 0.221 | 0.361 |
| 5:00 | 0.498 | 0.080 | 0.518 | 0.395 | 0.145 | 0.062 | 0.053 | 0.062 | 0.120 | 0.329 | 0.411 | 0.558 |
| 6:00 | 0.713 | 0.266 | 0.756 | 0.473 | 0.173 | 0.089 | 0.057 | 0.072 | 0.141 | 0.531 | 0.624 | 0.824 |
| 7:00 | 0.419 | 0.419 | 0.384 | 0.332 | 0.099 | 0.054 | 0.055 | 0.057 | 0.109 | 0.414 | 0.428 | 0.525 |
| 8:00 | 0.194 | 0.432 | 0.274 | 0.177 | 0.071 | 0.062 | 0.050 | 0.045 | 0.093 | 0.271 | 0.246 | 0.275 |
| 9:00 | 0.204 | 0.402 | 0.236 | 0.117 | 0.143 | 0.108 | 0.084 | 0.091 | 0.071 | 0.229 | 0.225 | 0.267 |
| 10:00 | 0.195 | 0.437 | 0.286 | 0.152 | 0.173 | 0.131 | 0.109 | 0.135 | 0.069 | 0.175 | 0.189 | 0.237 |
| 11:00 | 0.248 | 0.367 | 0.220 | 0.136 | 0.146 | 0.103 | 0.081 | 0.115 | 0.064 | 0.151 | 0.197 | 0.273 |
| 12:00 | 0.205 | 0.323 | 0.167 | 0.103 | 0.118 | 0.253 | 0.180 | 0.250 | 0.206 | 0.116 | 0.157 | 0.222 |
| 13:00 | 0.182 | 0.308 | 0.134 | 0.091 | 0.083 | 0.205 | 0.177 | 0.257 | 0.170 | 0.123 | 0.151 | 0.205 |
| 14:00 | 0.206 | 0.263 | 0.168 | 0.068 | 0.085 | 0.159 | 0.145 | 0.190 | 0.101 | 0.093 | 0.144 | 0.214 |
| 15:00 | 0.352 | 0.301 | 0.224 | 0.059 | 0.075 | 0.099 | 0.153 | 0.130 | 0.082 | 0.107 | 0.215 | 0.344 |
| 16:00 | 0.502 | 0.288 | 0.474 | 0.151 | 0.144 | 0.127 | 0.166 | 0.095 | 0.086 | 0.162 | 0.312 | 0.495 |
| 17:00 | 0.561 | 0.322 | 0.596 | 0.264 | 0.158 | 0.156 | 0.179 | 0.080 | 0.084 | 0.232 | 0.380 | 0.574 |
| 18:00 | 0.600 | 0.380 | 0.586 | 0.204 | 0.122 | 0.093 | 0.162 | 0.106 | 0.090 | 0.231 | 0.396 | 0.607 |
| 19:00 | 0.607 | 0.405 | 0.607 | 0.177 | 0.139 | 0.064 | 0.113 | 0.094 | 0.093 | 0.227 | 0.397 | 0.611 |
| 20:00 | 0.553 | 0.413 | 0.594 | 0.191 | 0.110 | 0.060 | 0.112 | 0.091 | 0.104 | 0.242 | 0.382 | 0.571 |
| 21:00 | 0.605 | 0.497 | 0.483 | 0.238 | 0.163 | 0.059 | 0.123 | 0.085 | 0.111 | 0.246 | 0.407 | 0.617 |
| 22:00 | 0.514 | 0.414 | 0.361 | 0.131 | 0.179 | 0.060 | 0.074 | 0.079 | 0.059 | 0.134 | 0.300 | 0.494 |
| 23:00 | 0.225 | 0.352 | 0.218 | 0.178 | 0.090 | 0.058 | 0.050 | 0.063 | 0.054 | 0.115 | 0.165 | 0.239 |

***Table I**: Typical Daily Profile of total electrical consumption for the net-metering PV Residence in Bukciai*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

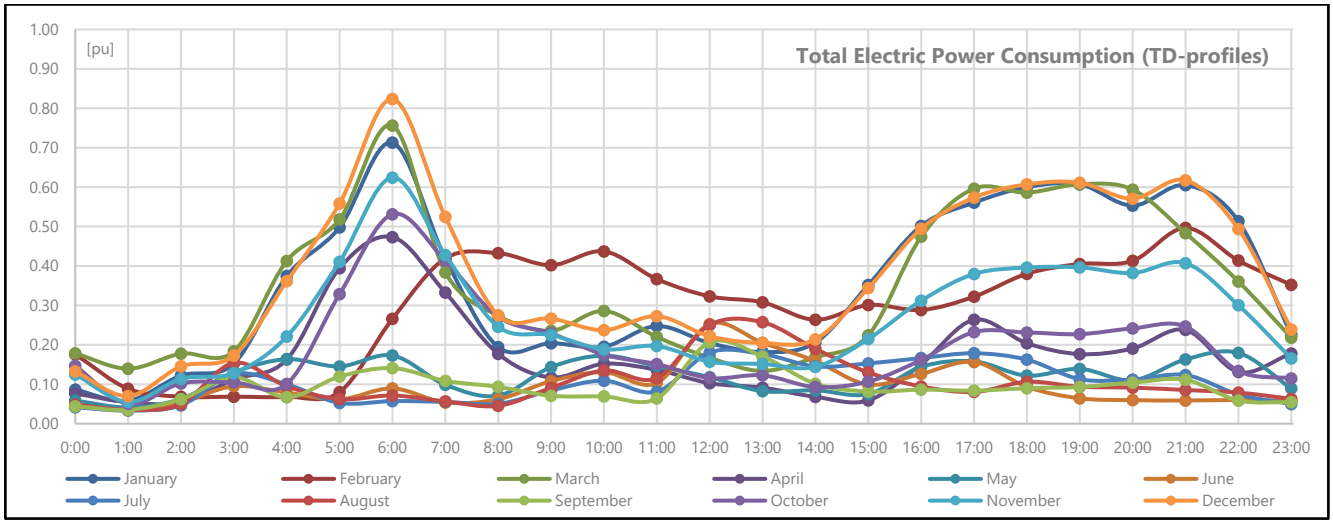



***Figure 1**: Typical Daily Profile of total electrical consumption for the net-metering PV Residence in Bukciai*

| Total produced PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.011 | 0.001 | 0.011 | 0.020 | 0.012 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.037 | 0.046 | 0.021 | 0.046 | 0.053 | 0.046 | 0.024 | 0.010 | 0.000 | 0.000 | 0.000 |
| 8:00 | 0.000 | 0.158 | 0.143 | 0.089 | 0.143 | 0.130 | 0.102 | 0.085 | 0.066 | 0.009 | 0.000 | 0.002 |
| 9:00 | 0.006 | 0.245 | 0.277 | 0.203 | 0.277 | 0.239 | 0.170 | 0.179 | 0.155 | 0.058 | 0.012 | 0.045 |
| 10:00 | 0.021 | 0.315 | 0.405 | 0.289 | 0.405 | 0.395 | 0.309 | 0.324 | 0.248 | 0.131 | 0.037 | 0.055 |
| 11:00 | 0.033 | 0.343 | 0.483 | 0.367 | 0.483 | 0.502 | 0.367 | 0.452 | 0.337 | 0.197 | 0.061 | 0.050 |
| 12:00 | 0.048 | 0.323 | 0.619 | 0.444 | 0.619 | 0.595 | 0.394 | 0.509 | 0.452 | 0.246 | 0.070 | 0.045 |
| 13:00 | 0.047 | 0.322 | 0.643 | 0.508 | 0.643 | 0.603 | 0.421 | 0.600 | 0.490 | 0.300 | 0.058 | 0.050 |
| 14:00 | 0.032 | 0.205 | 0.675 | 0.521 | 0.675 | 0.608 | 0.450 | 0.574 | 0.435 | 0.293 | 0.044 | 0.020 |
| 15:00 | 0.011 | 0.121 | 0.595 | 0.450 | 0.595 | 0.512 | 0.429 | 0.526 | 0.386 | 0.243 | 0.031 | 0.000 |
| 16:00 | 0.000 | 0.028 | 0.481 | 0.352 | 0.481 | 0.458 | 0.439 | 0.410 | 0.261 | 0.145 | 0.020 | 0.000 |
| 17:00 | 0.000 | 0.001 | 0.364 | 0.232 | 0.364 | 0.393 | 0.323 | 0.285 | 0.154 | 0.069 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.226 | 0.126 | 0.226 | 0.283 | 0.215 | 0.187 | 0.060 | 0.006 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.072 | 0.029 | 0.072 | 0.140 | 0.095 | 0.075 | 0.008 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.009 | 0.001 | 0.009 | 0.038 | 0.034 | 0.010 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table II**: Typical Daily Profile of total produced PV Power for the net-metering PV Residence in Bukciai*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

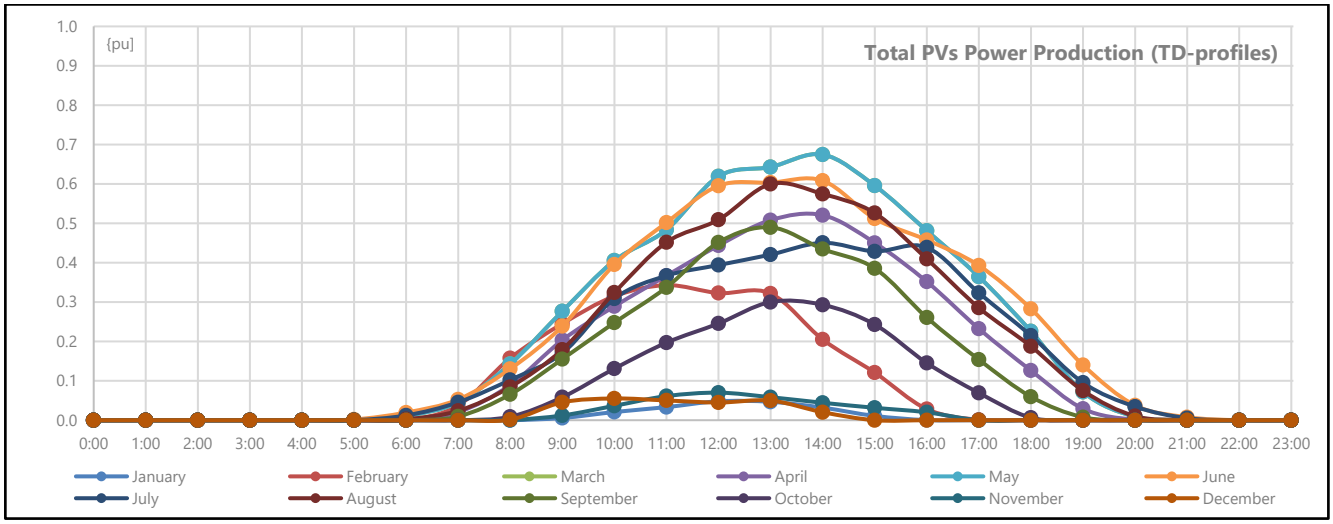



***Figure 2**: Typical Daily Profile of total produced PV Power for the net-metering PV Residence in Bukciai*

| Self-consumed PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.011 | 0.001 | 0.011 | 0.017 | 0.012 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.036 | 0.031 | 0.019 | 0.031 | 0.022 | 0.029 | 0.019 | 0.009 | 0.000 | 0.000 | 0.002 |
| 8:00 | 0.000 | 0.125 | 0.054 | 0.054 | 0.054 | 0.034 | 0.038 | 0.036 | 0.042 | 0.008 | 0.012 | 0.045 |
| 9:00 | 0.005 | 0.183 | 0.126 | 0.072 | 0.126 | 0.085 | 0.075 | 0.080 | 0.056 | 0.034 | 0.037 | 0.055 |
| 10:00 | 0.016 | 0.210 | 0.154 | 0.107 | 0.154 | 0.086 | 0.098 | 0.128 | 0.069 | 0.051 | 0.061 | 0.050 |
| 11:00 | 0.019 | 0.202 | 0.137 | 0.091 | 0.137 | 0.097 | 0.073 | 0.113 | 0.063 | 0.058 | 0.070 | 0.045 |
| 12:00 | 0.020 | 0.179 | 0.113 | 0.079 | 0.113 | 0.235 | 0.167 | 0.247 | 0.206 | 0.069 | 0.058 | 0.050 |
| 13:00 | 0.013 | 0.166 | 0.081 | 0.059 | 0.081 | 0.160 | 0.167 | 0.227 | 0.170 | 0.051 | 0.044 | 0.020 |
| 14:00 | 0.014 | 0.129 | 0.084 | 0.055 | 0.084 | 0.152 | 0.131 | 0.174 | 0.100 | 0.047 | 0.031 | 0.000 |
| 15:00 | 0.007 | 0.096 | 0.071 | 0.014 | 0.071 | 0.093 | 0.140 | 0.116 | 0.050 | 0.047 | 0.020 | 0.000 |
| 16:00 | 0.000 | 0.025 | 0.124 | 0.054 | 0.124 | 0.118 | 0.146 | 0.087 | 0.016 | 0.040 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.001 | 0.140 | 0.061 | 0.140 | 0.152 | 0.127 | 0.065 | 0.007 | 0.035 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.093 | 0.029 | 0.093 | 0.086 | 0.082 | 0.055 | 0.001 | 0.005 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.051 | 0.013 | 0.051 | 0.061 | 0.052 | 0.036 | 0.002 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.009 | 0.001 | 0.009 | 0.032 | 0.023 | 0.009 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table III**: Typical Daily Profile of self-consumed PV Power for the net-metering PV Residence in Bukciai*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

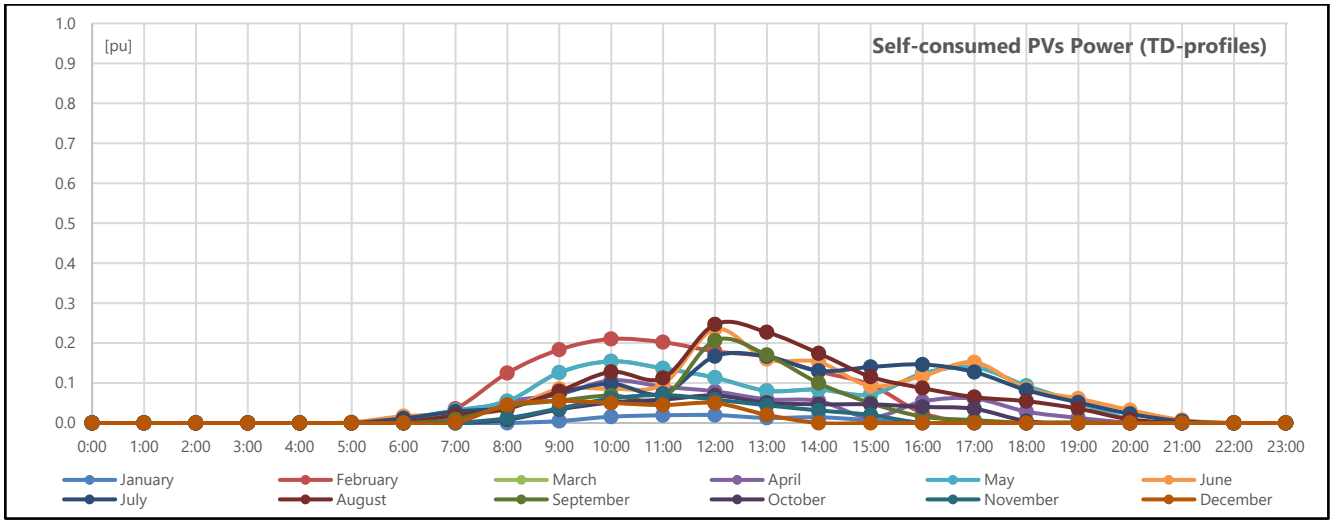



***Figure 3**: Typical Daily Profile of self-consumed PV Power for the net-metering PV Residence in Bukciai*

| Injected PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.002 | 0.014 | 0.001 | 0.014 | 0.031 | 0.017 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 |
| 8:00 | 0.000 | 0.033 | 0.089 | 0.035 | 0.089 | 0.096 | 0.064 | 0.048 | 0.023 | 0.001 | 0.000 | 0.000 |
| 9:00 | 0.001 | 0.061 | 0.151 | 0.132 | 0.151 | 0.153 | 0.096 | 0.100 | 0.099 | 0.024 | 0.000 | 0.000 |
| 10:00 | 0.005 | 0.105 | 0.251 | 0.182 | 0.251 | 0.310 | 0.210 | 0.196 | 0.179 | 0.080 | 0.000 | 0.000 |
| 11:00 | 0.014 | 0.141 | 0.347 | 0.276 | 0.347 | 0.405 | 0.294 | 0.339 | 0.274 | 0.138 | 0.000 | 0.000 |
| 12:00 | 0.028 | 0.144 | 0.506 | 0.364 | 0.506 | 0.360 | 0.227 | 0.262 | 0.245 | 0.177 | 0.000 | 0.000 |
| 13:00 | 0.034 | 0.156 | 0.562 | 0.449 | 0.562 | 0.444 | 0.254 | 0.373 | 0.319 | 0.249 | 0.000 | 0.000 |
| 14:00 | 0.018 | 0.076 | 0.591 | 0.465 | 0.591 | 0.456 | 0.320 | 0.400 | 0.335 | 0.246 | 0.000 | 0.000 |
| 15:00 | 0.004 | 0.025 | 0.524 | 0.437 | 0.524 | 0.419 | 0.289 | 0.410 | 0.336 | 0.196 | 0.000 | 0.000 |
| 16:00 | 0.000 | 0.003 | 0.357 | 0.298 | 0.357 | 0.340 | 0.292 | 0.322 | 0.245 | 0.105 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.000 | 0.225 | 0.171 | 0.225 | 0.241 | 0.196 | 0.221 | 0.147 | 0.034 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.133 | 0.098 | 0.133 | 0.197 | 0.132 | 0.133 | 0.059 | 0.002 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.020 | 0.016 | 0.020 | 0.079 | 0.044 | 0.039 | 0.006 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.012 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table IV**: Typical Daily Profile of injected PV Power for the net-metering PV Residence in Bukciai*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

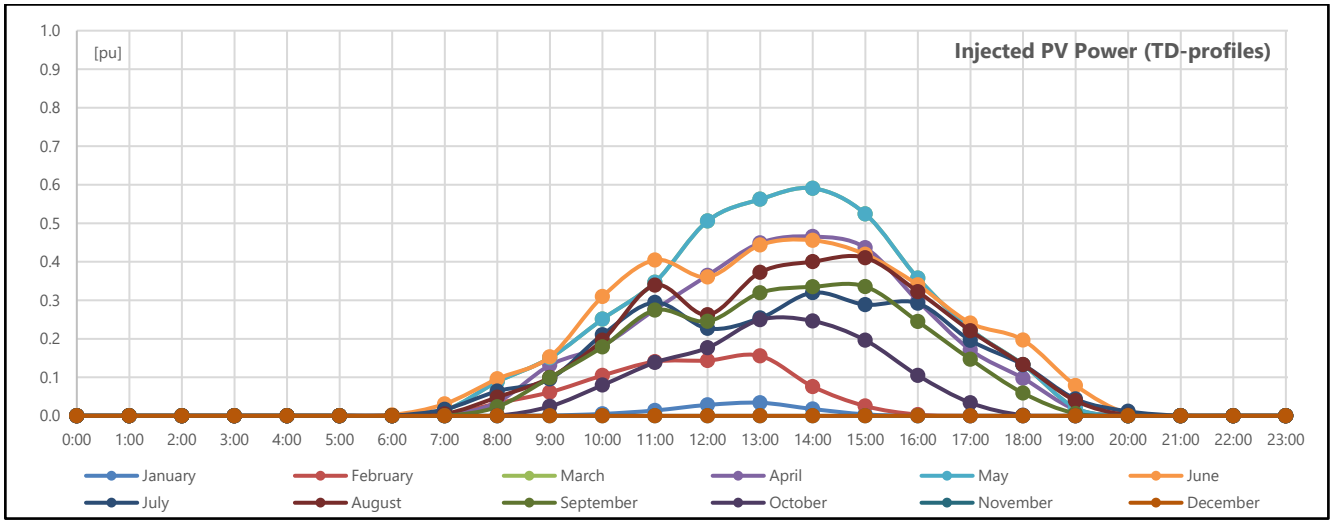



***Figure 4**: Typical Daily Profile of injected PV Power for the net-metering PV Residence in Bukciai*

| Power fed by the LDN [kWh] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.086 | 0.176 | 0.059 | 0.077 | 0.059 | 0.043 | 0.042 | 0.049 | 0.044 | 0.147 | 0.125 | 0.133 |
| 1:00 | 0.058 | 0.089 | 0.041 | 0.055 | 0.041 | 0.036 | 0.033 | 0.035 | 0.035 | 0.050 | 0.055 | 0.070 |
| 2:00 | 0.122 | 0.068 | 0.063 | 0.053 | 0.063 | 0.054 | 0.047 | 0.050 | 0.062 | 0.102 | 0.114 | 0.145 |
| 3:00 | 0.153 | 0.068 | 0.130 | 0.112 | 0.130 | 0.095 | 0.126 | 0.154 | 0.118 | 0.105 | 0.128 | 0.173 |
| 4:00 | 0.375 | 0.068 | 0.164 | 0.163 | 0.164 | 0.079 | 0.100 | 0.095 | 0.067 | 0.101 | 0.221 | 0.361 |
| 5:00 | 0.498 | 0.080 | 0.145 | 0.395 | 0.145 | 0.060 | 0.053 | 0.062 | 0.120 | 0.329 | 0.410 | 0.558 |
| 6:00 | 0.713 | 0.266 | 0.162 | 0.472 | 0.162 | 0.072 | 0.046 | 0.069 | 0.141 | 0.531 | 0.612 | 0.822 |
| 7:00 | 0.419 | 0.383 | 0.067 | 0.313 | 0.067 | 0.032 | 0.027 | 0.037 | 0.099 | 0.414 | 0.391 | 0.479 |
| 8:00 | 0.194 | 0.307 | 0.017 | 0.123 | 0.017 | 0.028 | 0.012 | 0.009 | 0.051 | 0.263 | 0.185 | 0.220 |
| 9:00 | 0.199 | 0.218 | 0.017 | 0.045 | 0.017 | 0.022 | 0.010 | 0.011 | 0.015 | 0.195 | 0.155 | 0.217 |
| 10:00 | 0.179 | 0.227 | 0.018 | 0.045 | 0.018 | 0.045 | 0.011 | 0.007 | 0.000 | 0.124 | 0.130 | 0.192 |
| 11:00 | 0.228 | 0.165 | 0.010 | 0.046 | 0.010 | 0.006 | 0.008 | 0.003 | 0.001 | 0.093 | 0.153 | 0.223 |
| 12:00 | 0.185 | 0.144 | 0.005 | 0.024 | 0.005 | 0.018 | 0.013 | 0.004 | 0.000 | 0.047 | 0.126 | 0.201 |
| 13:00 | 0.169 | 0.142 | 0.002 | 0.032 | 0.002 | 0.046 | 0.010 | 0.030 | 0.000 | 0.072 | 0.131 | 0.205 |
| 14:00 | 0.192 | 0.134 | 0.001 | 0.013 | 0.001 | 0.006 | 0.015 | 0.016 | 0.002 | 0.046 | 0.144 | 0.214 |
| 15:00 | 0.345 | 0.205 | 0.004 | 0.045 | 0.004 | 0.007 | 0.013 | 0.014 | 0.031 | 0.060 | 0.215 | 0.344 |
| 16:00 | 0.501 | 0.263 | 0.020 | 0.097 | 0.020 | 0.009 | 0.020 | 0.007 | 0.070 | 0.121 | 0.312 | 0.495 |
| 17:00 | 0.561 | 0.321 | 0.018 | 0.202 | 0.018 | 0.005 | 0.051 | 0.016 | 0.077 | 0.197 | 0.380 | 0.574 |
| 18:00 | 0.600 | 0.380 | 0.029 | 0.175 | 0.029 | 0.007 | 0.080 | 0.052 | 0.089 | 0.226 | 0.396 | 0.607 |
| 19:00 | 0.607 | 0.405 | 0.088 | 0.164 | 0.088 | 0.003 | 0.061 | 0.058 | 0.092 | 0.227 | 0.397 | 0.611 |
| 20:00 | 0.553 | 0.413 | 0.101 | 0.190 | 0.101 | 0.027 | 0.089 | 0.083 | 0.104 | 0.242 | 0.382 | 0.571 |
| 21:00 | 0.605 | 0.497 | 0.163 | 0.238 | 0.163 | 0.051 | 0.119 | 0.085 | 0.111 | 0.246 | 0.407 | 0.617 |
| 22:00 | 0.514 | 0.414 | 0.179 | 0.131 | 0.179 | 0.060 | 0.074 | 0.079 | 0.059 | 0.134 | 0.300 | 0.494 |
| 23:00 | 0.225 | 0.352 | 0.090 | 0.178 | 0.090 | 0.058 | 0.050 | 0.063 | 0.054 | 0.115 | 0.165 | 0.239 |

***Table V**: Typical Daily Profile of power fed by the LDN for the net-metering PV Residence in Bukciai*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

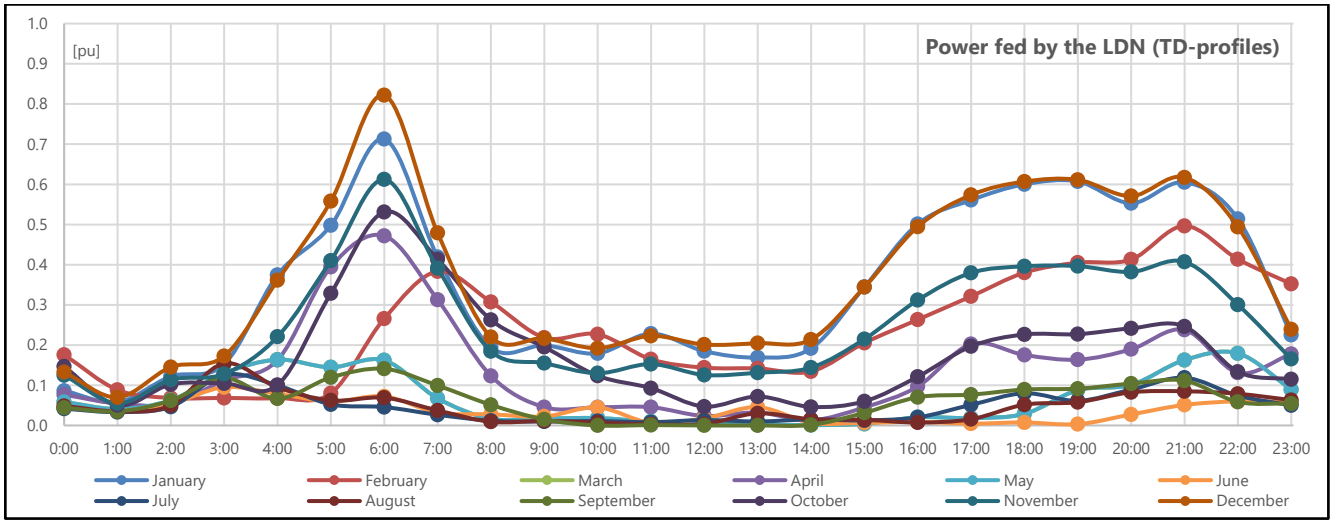
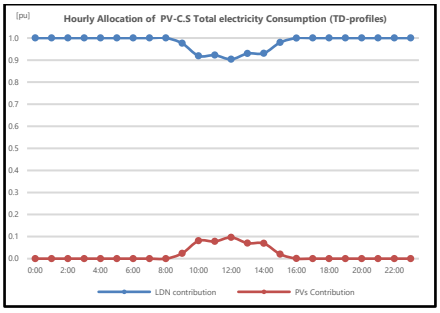
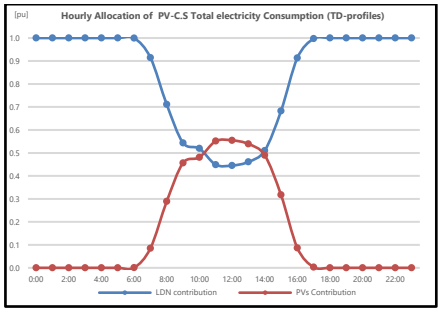



***Figure 5**: Typical Daily Profile of power fed by the LDN for the net-metering PV Residence in Bukciai*

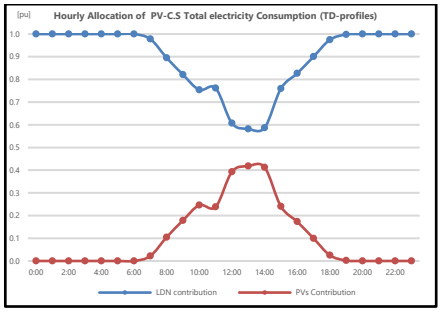
**Figures 6** illustrates the typical hourly allocation of PV-C.S's total power consumption for each month of the reporting period. Both LDN and PVs hourly contributions are divided with the corresponding hourly value of the PV-C.S total electrical power consumption and thus their sum is always equal to unit. After a careful analysis of **Figure 6** it is concluded that, even in the case where the energy transactions are considered as hourly values, there are time intervals (particularly during spring and summer) where the energy needs of the PV-C.S are serviced by PVs in high rates (almost around 100%).



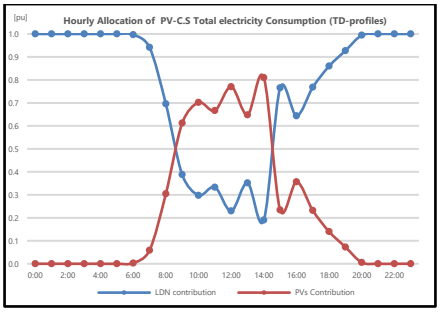

January



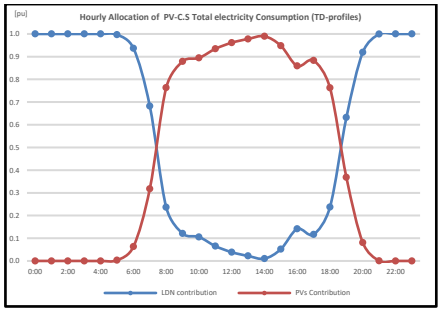

February



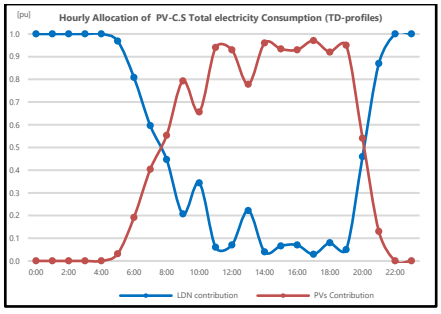

March




April




May




June

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

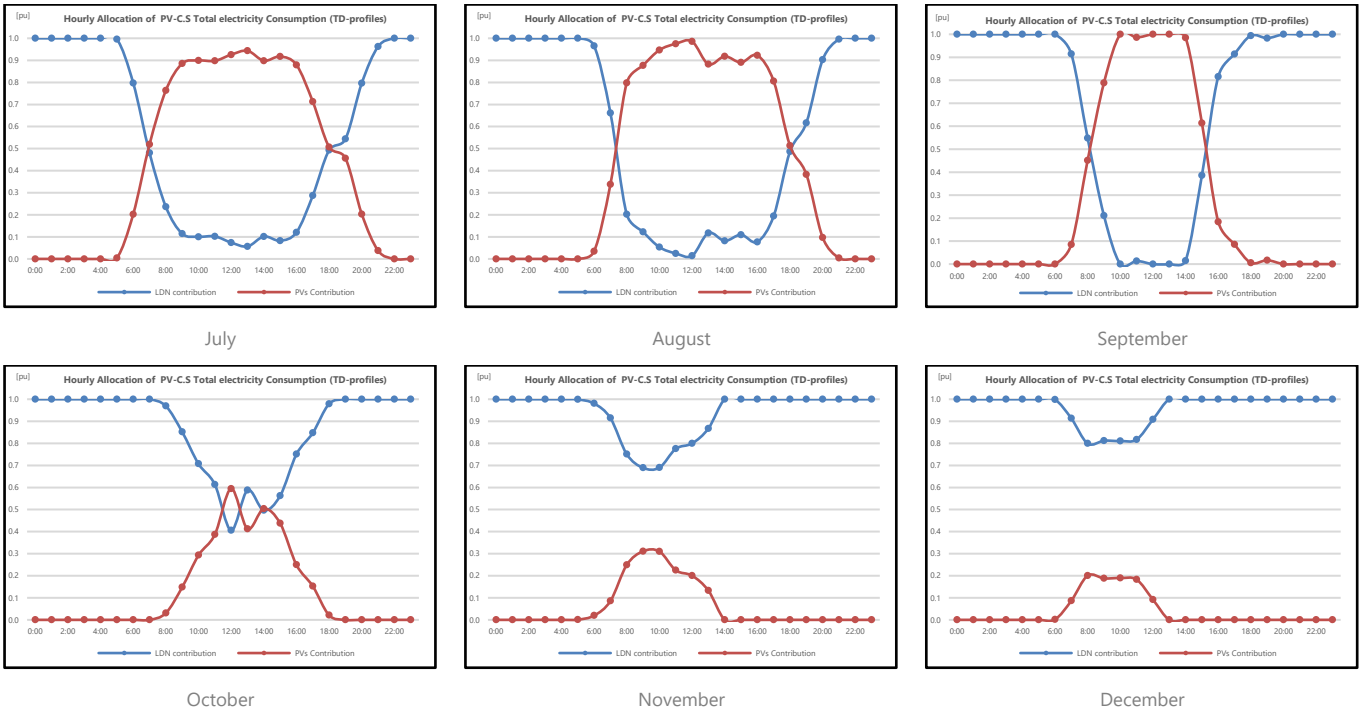
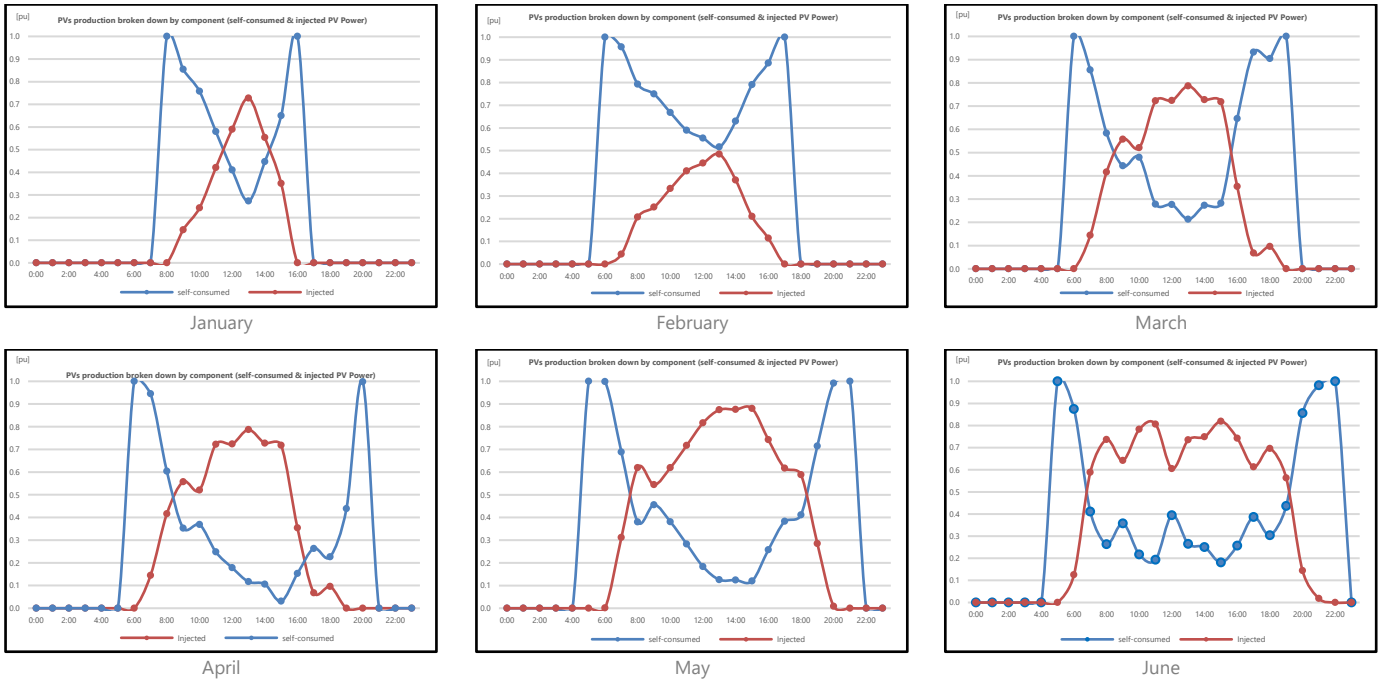



***Figure 6**: Hourly Allocation of PV-C.S total electricity consumption for each month of the reporting period (TD-profiles)*

**Figures 7** illustrates the typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Energy). Both components of hourly contributions are divided with the corresponding hourly value of the total PVs production and thus their sum is always equal to unit. After a careful analysis of **Figure 7** it is concluded that, the self-consumed PV Energy is considerably larger than the injected PV energy during winter and autumn, whilst both PVs production components are comparable during spring and summer.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

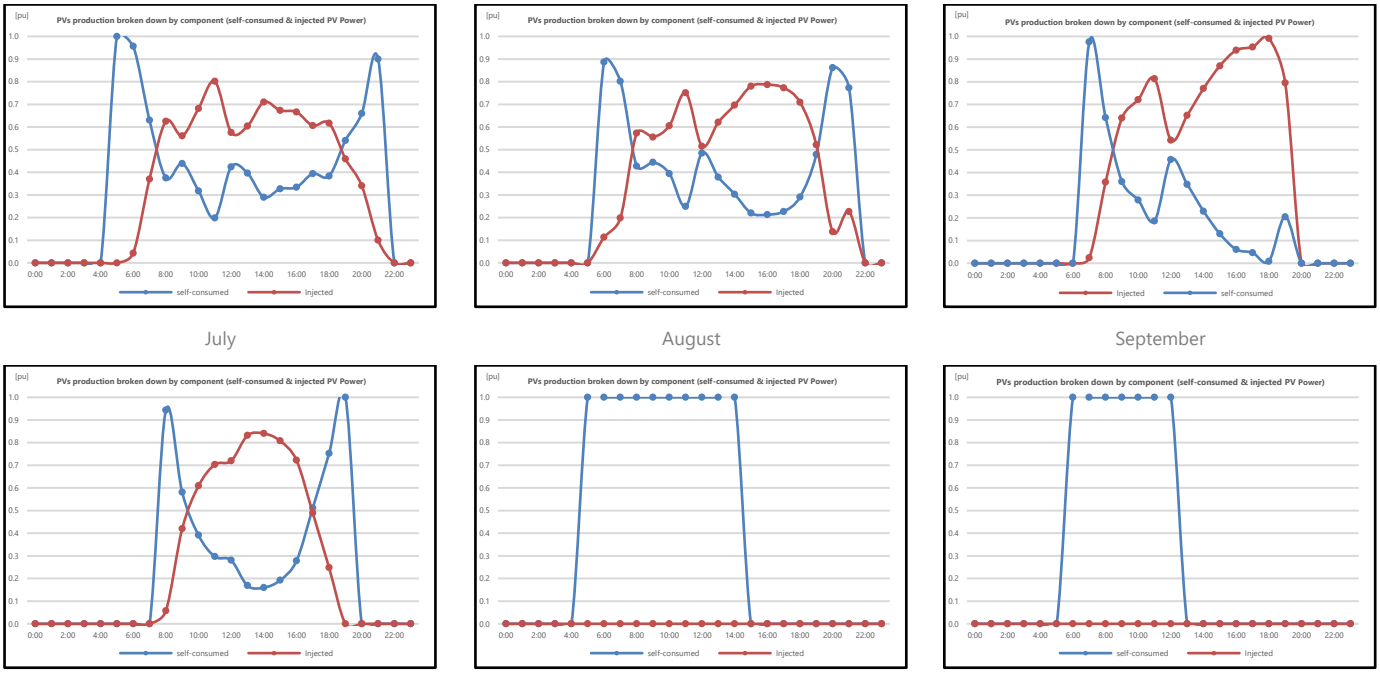



***Figure 7**: typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Power)*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

## 3.3. Aggregated Households Community with central PV System in Rudamina (Lithuania)

The next five tables and figures present the typical daily profiles of the: a) Rudamina theoretical AHC total electrical power consumption, b) total produced PV Power, c) Self-consumed PV Power, d) Injected PV Power and e) Power fed by the LDN. A pu system was introduced with the nominal power of the installed PV system consisting the base value of the system (30kW). All the other reported power quantities are specified as multiples of the selected base value.

| PV-C.S total electrical power consumption [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.187 | 0.222 | 0.184 | 0.205 | 0.190 | 0.194 | 0.185 | 0.177 | 0.198 | 0.178 | 0.170 | 0.189 |
| 1:00 | 0.163 | 0.192 | 0.159 | 0.171 | 0.156 | 0.159 | 0.152 | 0.147 | 0.166 | 0.152 | 0.150 | 0.163 |
| 2:00 | 0.149 | 0.171 | 0.144 | 0.149 | 0.137 | 0.138 | 0.132 | 0.130 | 0.145 | 0.138 | 0.139 | 0.147 |
| 3:00 | 0.141 | 0.159 | 0.137 | 0.137 | 0.129 | 0.127 | 0.122 | 0.121 | 0.135 | 0.131 | 0.134 | 0.139 |
| 4:00 | 0.138 | 0.154 | 0.130 | 0.131 | 0.125 | 0.123 | 0.117 | 0.117 | 0.129 | 0.132 | 0.133 | 0.135 |
| 5:00 | 0.138 | 0.153 | 0.137 | 0.130 | 0.125 | 0.117 | 0.114 | 0.117 | 0.133 | 0.130 | 0.140 | 0.136 |
| 6:00 | 0.149 | 0.160 | 0.150 | 0.137 | 0.129 | 0.123 | 0.115 | 0.122 | 0.135 | 0.142 | 0.165 | 0.147 |
| 7:00 | 0.182 | 0.187 | 0.185 | 0.154 | 0.164 | 0.152 | 0.138 | 0.141 | 0.160 | 0.183 | 0.197 | 0.180 |
| 8:00 | 0.206 | 0.218 | 0.203 | 0.176 | 0.191 | 0.179 | 0.162 | 0.166 | 0.192 | 0.207 | 0.215 | 0.206 |
| 9:00 | 0.211 | 0.229 | 0.216 | 0.197 | 0.203 | 0.197 | 0.183 | 0.189 | 0.210 | 0.212 | 0.219 | 0.214 |
| 10:00 | 0.218 | 0.240 | 0.223 | 0.211 | 0.209 | 0.208 | 0.199 | 0.203 | 0.215 | 0.219 | 0.223 | 0.222 |
| 11:00 | 0.224 | 0.249 | 0.223 | 0.217 | 0.207 | 0.211 | 0.205 | 0.207 | 0.220 | 0.221 | 0.224 | 0.229 |
| 12:00 | 0.227 | 0.252 | 0.223 | 0.218 | 0.206 | 0.212 | 0.207 | 0.209 | 0.220 | 0.220 | 0.225 | 0.232 |
| 13:00 | 0.226 | 0.252 | 0.220 | 0.217 | 0.203 | 0.211 | 0.205 | 0.207 | 0.220 | 0.218 | 0.224 | 0.231 |
| 14:00 | 0.227 | 0.250 | 0.221 | 0.215 | 0.204 | 0.212 | 0.205 | 0.207 | 0.219 | 0.219 | 0.225 | 0.232 |
| 15:00 | 0.225 | 0.248 | 0.218 | 0.212 | 0.201 | 0.207 | 0.200 | 0.203 | 0.218 | 0.217 | 0.227 | 0.232 |
| 16:00 | 0.228 | 0.247 | 0.218 | 0.209 | 0.200 | 0.206 | 0.198 | 0.202 | 0.217 | 0.218 | 0.242 | 0.240 |
| 17:00 | 0.248 | 0.252 | 0.224 | 0.210 | 0.202 | 0.208 | 0.199 | 0.204 | 0.220 | 0.224 | 0.277 | 0.273 |
| 18:00 | 0.285 | 0.272 | 0.236 | 0.215 | 0.210 | 0.214 | 0.203 | 0.208 | 0.228 | 0.240 | 0.297 | 0.291 |
| 19:00 | 0.294 | 0.301 | 0.264 | 0.223 | 0.219 | 0.221 | 0.209 | 0.214 | 0.249 | 0.269 | 0.296 | 0.293 |
| 20:00 | 0.288 | 0.320 | 0.289 | 0.232 | 0.224 | 0.224 | 0.211 | 0.217 | 0.284 | 0.295 | 0.286 | 0.286 |
| 21:00 | 0.276 | 0.315 | 0.288 | 0.247 | 0.228 | 0.225 | 0.212 | 0.225 | 0.292 | 0.285 | 0.268 | 0.274 |
| 22:00 | 0.253 | 0.295 | 0.265 | 0.253 | 0.239 | 0.224 | 0.214 | 0.240 | 0.273 | 0.258 | 0.237 | 0.254 |
| 23:00 | 0.220 | 0.262 | 0.223 | 0.242 | 0.232 | 0.221 | 0.215 | 0.219 | 0.238 | 0.217 | 0.200 | 0.222 |

***Table I**: Typical Daily Profile of total electrical consumption for the Rudamina theoretical AHC*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

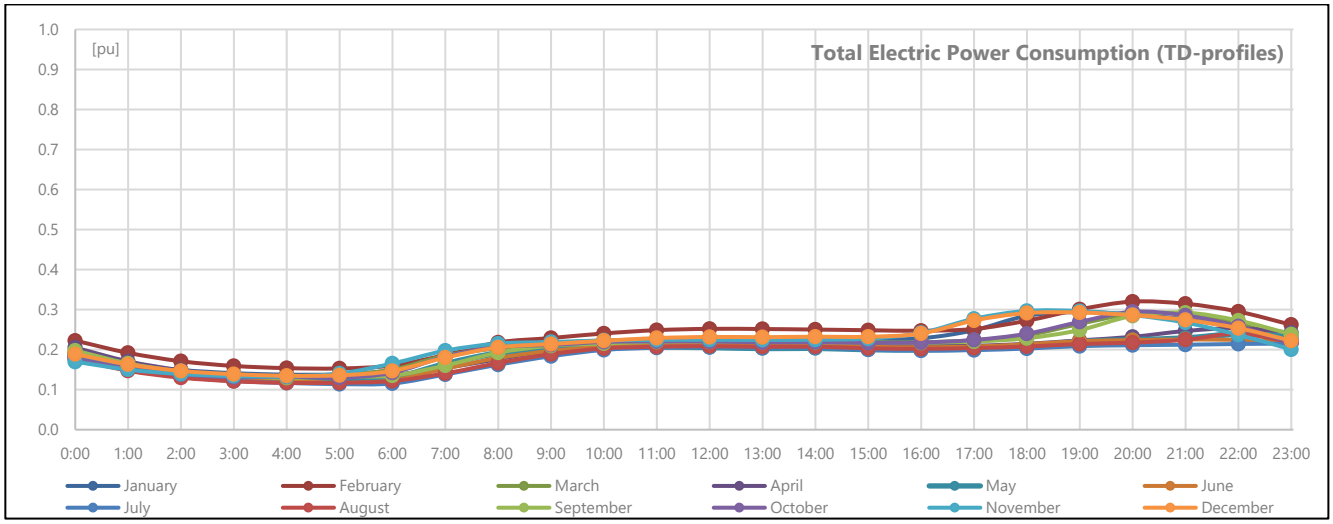



***Figure 1**: Typical Daily Profile of total electrical consumption for the Rudamina theoretical AHC*

| Total produced PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.000 |
| 7:00 | 0.003 | 0.033 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.024 | 0.003 |
| 8:00 | 0.090 | 0.069 | 0.087 | 0.000 | 0.087 | 0.098 | 0.049 | 0.027 | 0.000 | 0.032 | 0.055 | 0.083 |
| 9:00 | 0.139 | 0.151 | 0.248 | 0.090 | 0.248 | 0.226 | 0.157 | 0.170 | 0.045 | 0.148 | 0.084 | 0.101 |
| 10:00 | 0.141 | 0.182 | 0.424 | 0.234 | 0.424 | 0.369 | 0.262 | 0.334 | 0.169 | 0.269 | 0.102 | 0.076 |
| 11:00 | 0.142 | 0.190 | 0.540 | 0.379 | 0.540 | 0.484 | 0.339 | 0.465 | 0.302 | 0.357 | 0.113 | 0.089 |
| 12:00 | 0.120 | 0.170 | 0.625 | 0.501 | 0.625 | 0.521 | 0.381 | 0.517 | 0.404 | 0.419 | 0.099 | 0.060 |
| 13:00 | 0.082 | 0.138 | 0.677 | 0.570 | 0.677 | 0.553 | 0.337 | 0.573 | 0.445 | 0.395 | 0.075 | 0.046 |
| 14:00 | 0.034 | 0.093 | 0.690 | 0.589 | 0.690 | 0.560 | 0.352 | 0.536 | 0.457 | 0.346 | 0.035 | 0.000 |
| 15:00 | 0.000 | 0.061 | 0.648 | 0.563 | 0.648 | 0.517 | 0.371 | 0.488 | 0.453 | 0.284 | 0.000 | 0.000 |
| 16:00 | 0.000 | 0.023 | 0.564 | 0.502 | 0.564 | 0.462 | 0.352 | 0.433 | 0.417 | 0.172 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.000 | 0.484 | 0.404 | 0.484 | 0.394 | 0.302 | 0.337 | 0.370 | 0.069 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.360 | 0.287 | 0.360 | 0.308 | 0.227 | 0.243 | 0.228 | 0.000 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.195 | 0.177 | 0.195 | 0.196 | 0.138 | 0.122 | 0.106 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.020 | 0.066 | 0.020 | 0.070 | 0.042 | 0.005 | 0.009 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table II**: Typical Daily Profile of total produced PV Power for the Rudamina theoretical AHC*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

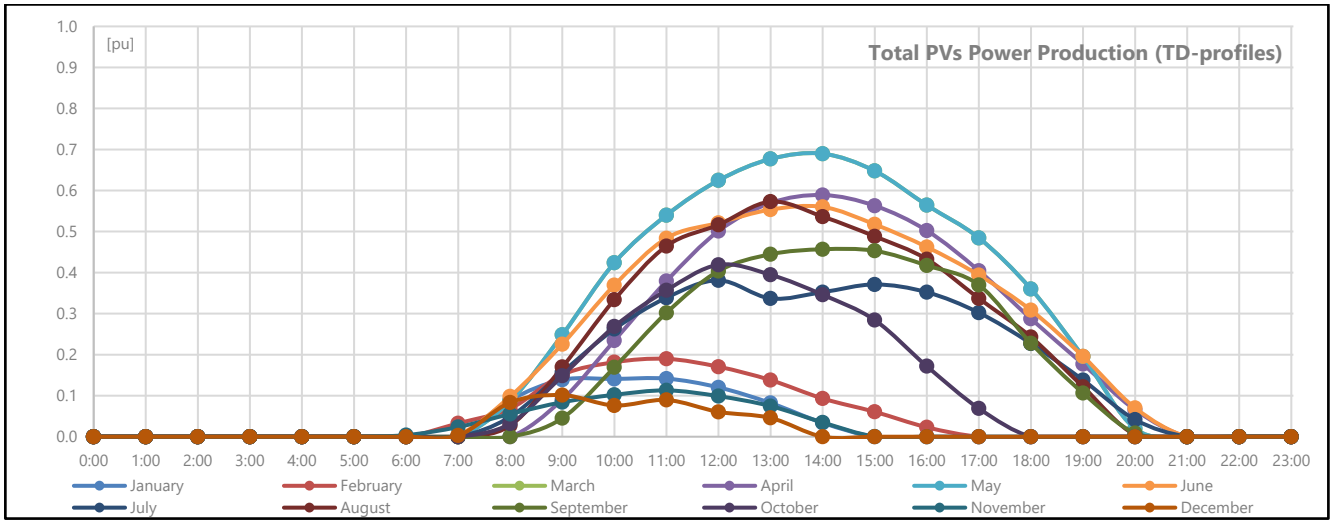



***Figure 2**: Typical Daily Profile of total produced PV Power for the Rudamina theoretical AHC*

| Self-consumed PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.000 |
| 7:00 | 0.003 | 0.033 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.024 | 0.003 |
| 8:00 | 0.089 | 0.069 | 0.083 | 0.000 | 0.083 | 0.098 | 0.049 | 0.027 | 0.000 | 0.031 | 0.051 | 0.082 |
| 9:00 | 0.100 | 0.123 | 0.172 | 0.087 | 0.172 | 0.173 | 0.137 | 0.147 | 0.045 | 0.105 | 0.075 | 0.086 |
| 10:00 | 0.103 | 0.135 | 0.190 | 0.158 | 0.190 | 0.203 | 0.183 | 0.178 | 0.135 | 0.148 | 0.094 | 0.062 |
| 11:00 | 0.104 | 0.138 | 0.194 | 0.179 | 0.194 | 0.209 | 0.197 | 0.200 | 0.181 | 0.157 | 0.093 | 0.075 |
| 12:00 | 0.099 | 0.128 | 0.198 | 0.193 | 0.198 | 0.210 | 0.198 | 0.208 | 0.188 | 0.166 | 0.082 | 0.058 |
| 13:00 | 0.080 | 0.111 | 0.197 | 0.194 | 0.197 | 0.208 | 0.185 | 0.204 | 0.197 | 0.163 | 0.071 | 0.046 |
| 14:00 | 0.034 | 0.078 | 0.195 | 0.196 | 0.195 | 0.212 | 0.179 | 0.202 | 0.207 | 0.158 | 0.035 | 0.000 |
| 15:00 | 0.000 | 0.059 | 0.192 | 0.196 | 0.192 | 0.200 | 0.177 | 0.197 | 0.205 | 0.139 | 0.000 | 0.000 |
| 16:00 | 0.000 | 0.023 | 0.186 | 0.188 | 0.186 | 0.192 | 0.178 | 0.189 | 0.207 | 0.116 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.000 | 0.192 | 0.183 | 0.192 | 0.184 | 0.170 | 0.180 | 0.205 | 0.069 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.200 | 0.173 | 0.200 | 0.197 | 0.158 | 0.160 | 0.172 | 0.000 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.181 | 0.143 | 0.181 | 0.180 | 0.131 | 0.119 | 0.105 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.020 | 0.066 | 0.020 | 0.070 | 0.042 | 0.005 | 0.009 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table III**: Typical Daily Profile of self-consumed PV Power for the Rudamina theoretical AHC*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

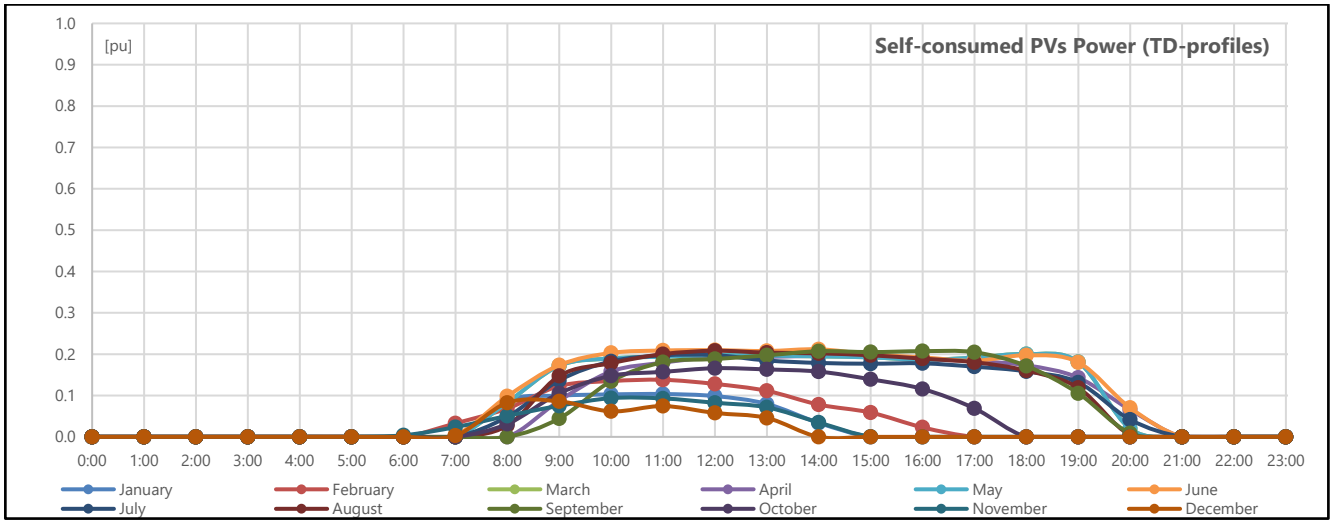



***Figure 3**: Typical Daily Profile of self-consumed PV Power for the Rudamina theoretical AHC*

| Injected PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 8:00 | 0.001 | 0.000 | 0.004 | 0.000 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.005 | 0.001 |
| 9:00 | 0.039 | 0.028 | 0.077 | 0.003 | 0.077 | 0.052 | 0.020 | 0.023 | 0.001 | 0.043 | 0.009 | 0.015 |
| 10:00 | 0.038 | 0.047 | 0.234 | 0.076 | 0.234 | 0.166 | 0.080 | 0.156 | 0.034 | 0.121 | 0.008 | 0.014 |
| 11:00 | 0.038 | 0.052 | 0.346 | 0.200 | 0.346 | 0.275 | 0.142 | 0.264 | 0.121 | 0.200 | 0.020 | 0.015 |
| 12:00 | 0.022 | 0.042 | 0.427 | 0.308 | 0.427 | 0.311 | 0.183 | 0.308 | 0.216 | 0.253 | 0.016 | 0.003 |
| 13:00 | 0.002 | 0.027 | 0.480 | 0.376 | 0.480 | 0.346 | 0.152 | 0.369 | 0.248 | 0.232 | 0.003 | 0.000 |
| 14:00 | 0.000 | 0.015 | 0.495 | 0.393 | 0.495 | 0.348 | 0.173 | 0.334 | 0.250 | 0.188 | 0.000 | 0.000 |
| 15:00 | 0.000 | 0.002 | 0.455 | 0.367 | 0.455 | 0.318 | 0.194 | 0.291 | 0.248 | 0.145 | 0.000 | 0.000 |
| 16:00 | 0.000 | 0.000 | 0.378 | 0.314 | 0.378 | 0.270 | 0.174 | 0.243 | 0.210 | 0.056 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.000 | 0.293 | 0.221 | 0.293 | 0.210 | 0.132 | 0.156 | 0.165 | 0.000 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.160 | 0.114 | 0.160 | 0.111 | 0.069 | 0.083 | 0.056 | 0.000 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.014 | 0.034 | 0.014 | 0.016 | 0.007 | 0.003 | 0.001 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table IV**: Typical Daily Profile of injected PV Power for the Rudamina theoretical AHC*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

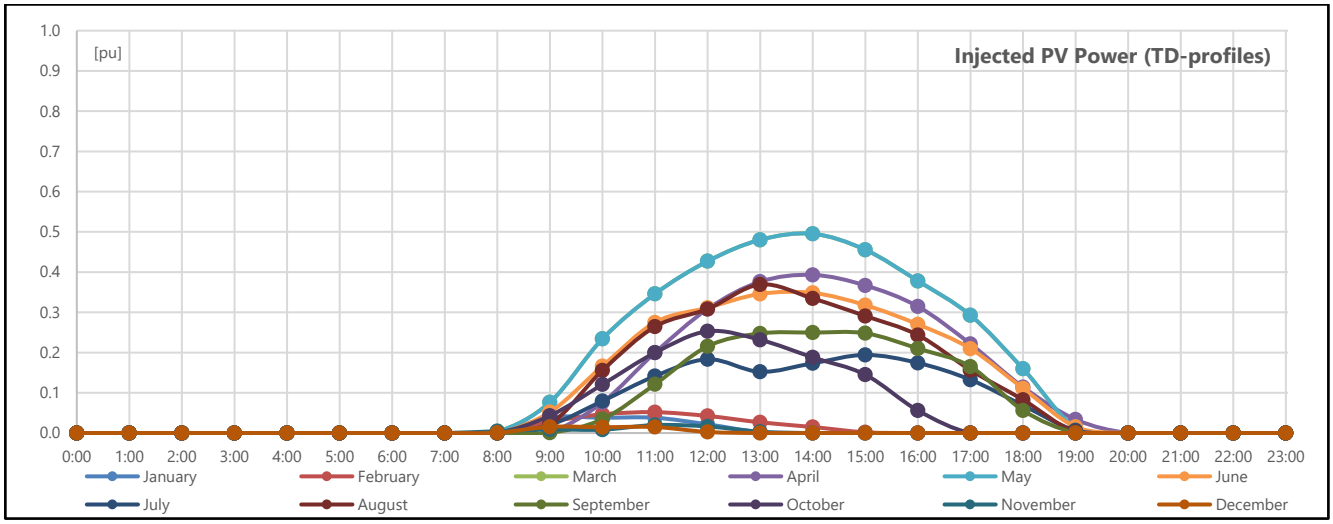



***Figure 4**: Typical Daily Profile of injected PV Power for the Rudamina theoretical AHC*

| Power fed by the LDN [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.187 | 0.222 | 0.190 | 0.205 | 0.190 | 0.194 | 0.185 | 0.177 | 0.198 | 0.178 | 0.170 | 0.189 |
| 1:00 | 0.163 | 0.192 | 0.156 | 0.171 | 0.156 | 0.159 | 0.152 | 0.147 | 0.166 | 0.152 | 0.150 | 0.163 |
| 2:00 | 0.149 | 0.171 | 0.137 | 0.149 | 0.137 | 0.138 | 0.132 | 0.130 | 0.145 | 0.138 | 0.139 | 0.147 |
| 3:00 | 0.141 | 0.159 | 0.129 | 0.137 | 0.129 | 0.127 | 0.122 | 0.121 | 0.135 | 0.131 | 0.134 | 0.139 |
| 4:00 | 0.138 | 0.154 | 0.125 | 0.131 | 0.125 | 0.123 | 0.117 | 0.117 | 0.129 | 0.132 | 0.133 | 0.135 |
| 5:00 | 0.138 | 0.153 | 0.125 | 0.130 | 0.125 | 0.117 | 0.114 | 0.117 | 0.133 | 0.130 | 0.140 | 0.136 |
| 6:00 | 0.149 | 0.160 | 0.129 | 0.137 | 0.129 | 0.123 | 0.115 | 0.122 | 0.135 | 0.142 | 0.162 | 0.147 |
| 7:00 | 0.179 | 0.154 | 0.164 | 0.154 | 0.164 | 0.148 | 0.138 | 0.141 | 0.160 | 0.183 | 0.174 | 0.177 |
| 8:00 | 0.118 | 0.149 | 0.108 | 0.176 | 0.108 | 0.081 | 0.114 | 0.139 | 0.192 | 0.175 | 0.164 | 0.123 |
| 9:00 | 0.111 | 0.106 | 0.031 | 0.110 | 0.031 | 0.023 | 0.047 | 0.041 | 0.165 | 0.106 | 0.144 | 0.128 |
| 10:00 | 0.115 | 0.106 | 0.019 | 0.052 | 0.019 | 0.005 | 0.017 | 0.025 | 0.081 | 0.071 | 0.129 | 0.160 |
| 11:00 | 0.120 | 0.111 | 0.013 | 0.037 | 0.013 | 0.002 | 0.008 | 0.007 | 0.039 | 0.063 | 0.131 | 0.154 |
| 12:00 | 0.129 | 0.124 | 0.008 | 0.025 | 0.008 | 0.003 | 0.009 | 0.000 | 0.032 | 0.054 | 0.142 | 0.174 |
| 13:00 | 0.147 | 0.140 | 0.007 | 0.023 | 0.007 | 0.004 | 0.020 | 0.003 | 0.022 | 0.055 | 0.153 | 0.185 |
| 14:00 | 0.193 | 0.172 | 0.009 | 0.019 | 0.009 | 0.000 | 0.026 | 0.005 | 0.011 | 0.061 | 0.190 | 0.232 |
| 15:00 | 0.225 | 0.190 | 0.008 | 0.016 | 0.008 | 0.008 | 0.023 | 0.006 | 0.013 | 0.078 | 0.227 | 0.232 |
| 16:00 | 0.228 | 0.224 | 0.014 | 0.021 | 0.014 | 0.014 | 0.020 | 0.013 | 0.010 | 0.102 | 0.242 | 0.240 |
| 17:00 | 0.248 | 0.252 | 0.011 | 0.027 | 0.011 | 0.024 | 0.029 | 0.024 | 0.015 | 0.155 | 0.277 | 0.273 |
| 18:00 | 0.285 | 0.272 | 0.009 | 0.041 | 0.009 | 0.016 | 0.044 | 0.047 | 0.057 | 0.240 | 0.297 | 0.291 |
| 19:00 | 0.294 | 0.301 | 0.038 | 0.080 | 0.038 | 0.041 | 0.077 | 0.095 | 0.144 | 0.269 | 0.296 | 0.293 |
| 20:00 | 0.288 | 0.320 | 0.204 | 0.167 | 0.204 | 0.153 | 0.169 | 0.213 | 0.275 | 0.295 | 0.286 | 0.286 |
| 21:00 | 0.276 | 0.315 | 0.228 | 0.247 | 0.228 | 0.225 | 0.212 | 0.225 | 0.292 | 0.285 | 0.268 | 0.274 |
| 22:00 | 0.253 | 0.295 | 0.239 | 0.253 | 0.239 | 0.224 | 0.214 | 0.240 | 0.273 | 0.258 | 0.237 | 0.254 |
| 23:00 | 0.220 | 0.262 | 0.232 | 0.242 | 0.232 | 0.221 | 0.215 | 0.219 | 0.238 | 0.217 | 0.200 | 0.222 |

***Table V**: Typical Daily Profile of power fed by the LDN for the Rudamina theoretical AHC*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

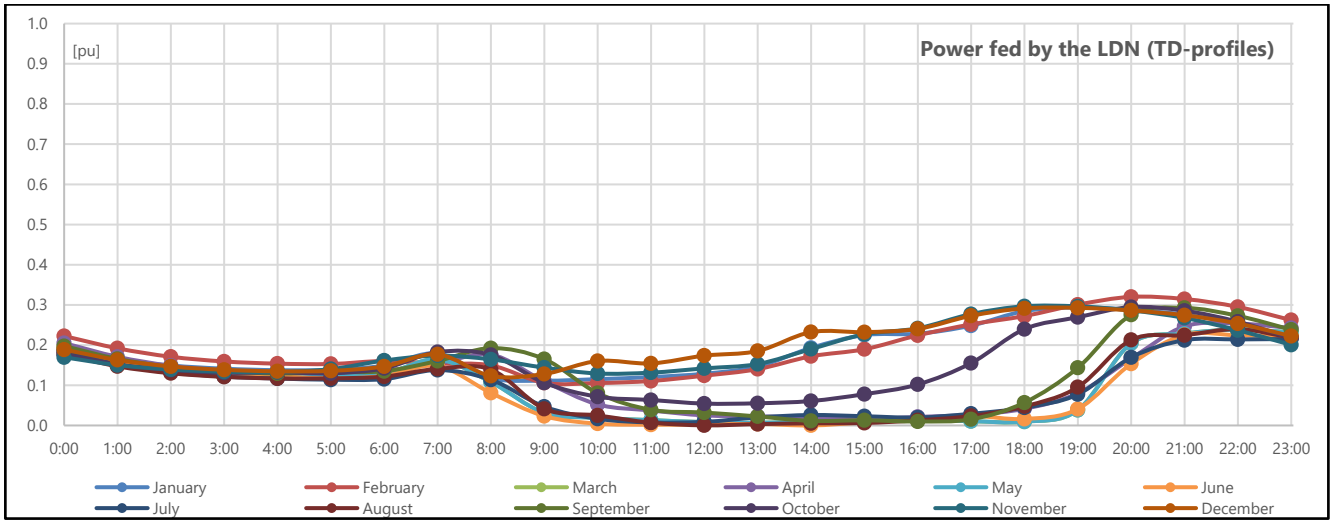
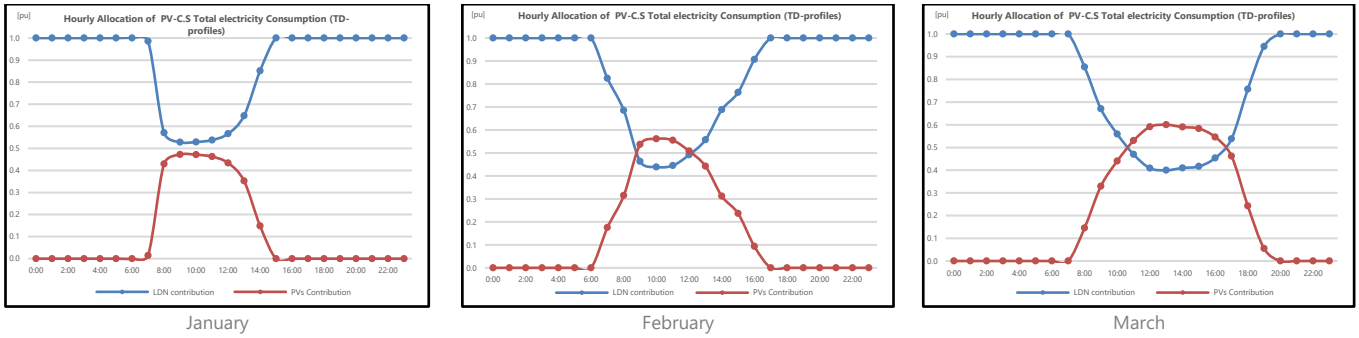



***Figure 5**: Typical Daily Profile of power fed by the LDN for the Rudamina theoretical AHC*

**Figures 6** illustrates the typical hourly allocation of AHC's total electricity consumption for twelve months. Both LDN and PVs hourly contributions are divided with the corresponding hourly value of the AHC total electrical consumption and thus their sum is always equal to unit. After a careful analysis of **Figure 6** it is concluded that, even in the case where the energy transactions are considered as hourly values, there are time intervals (particularly during spring and summer) where almost all energy needs of the AHC are serviced by PVs production. This is a notable load reduction for LDN, particular when the high penetration level of such AHCs comes into consideration.




January | February | March

April | May | June 2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

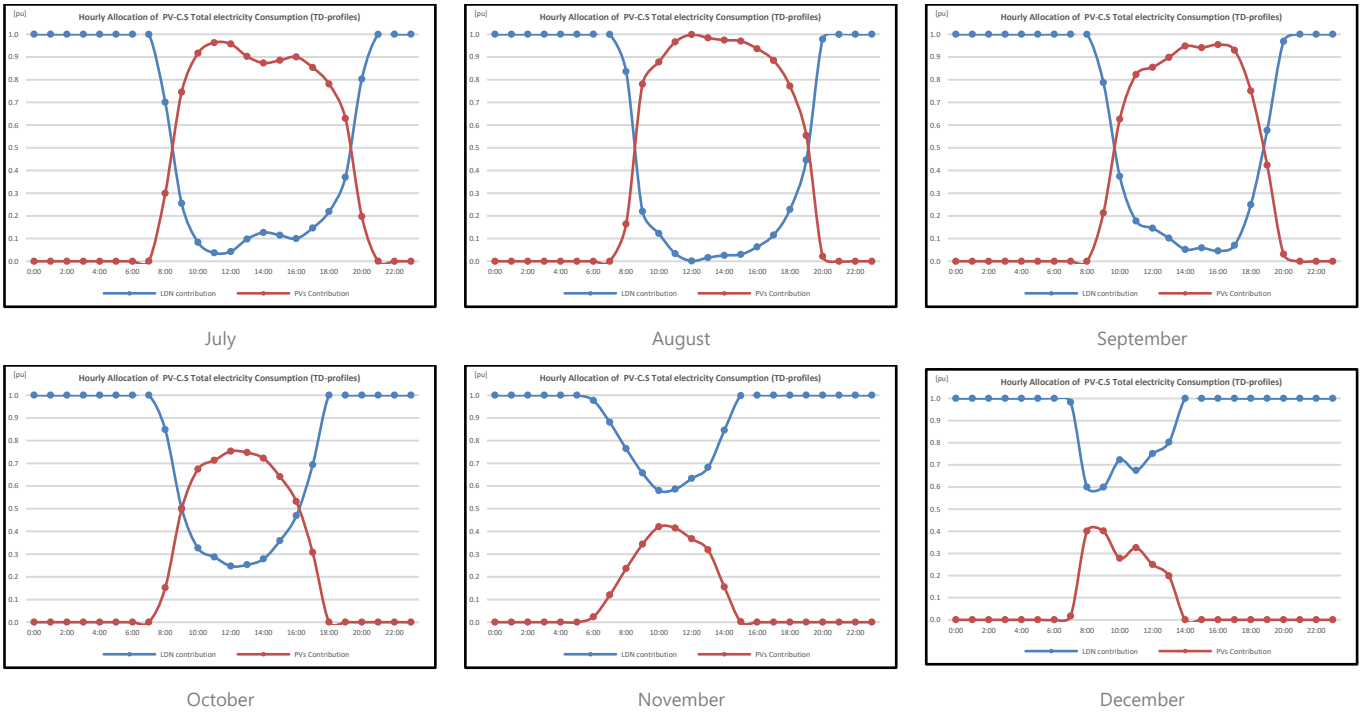
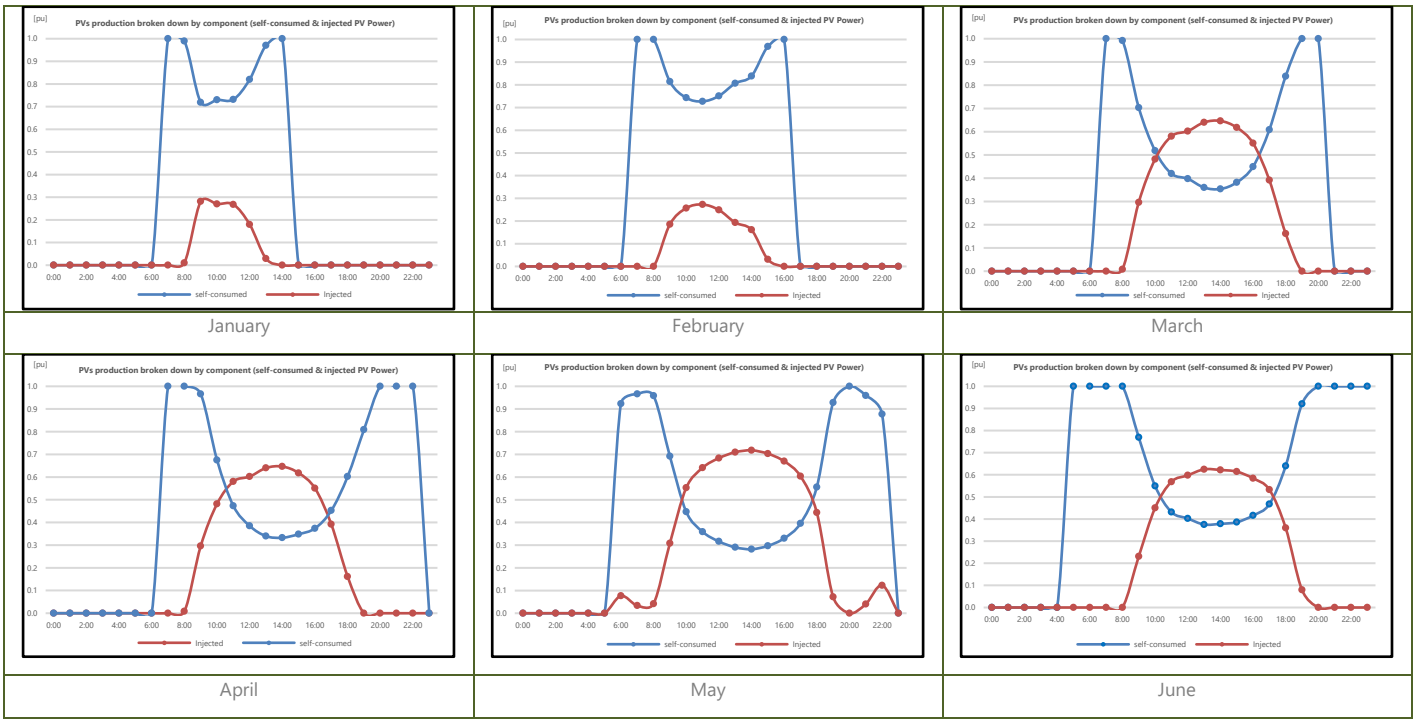



***Figure 6**: Hourly Allocation of AHC total electricity consumption for each month of the reporting period (TD-profiles)*

In more detail, the total generation of an electrical power system is continuously adjusted to limit the frequency variation within an acceptable range. Therefore, the event of a remarkable load reduction (due to a significant match of the on-site demand of AHCs with local production from RES), may affect the scheduled operation of conventional power plants, pushing them to reduce their power output very close to their lower technical operational limits. Such a situation will also jeopardize exchanges through the interconnection line.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

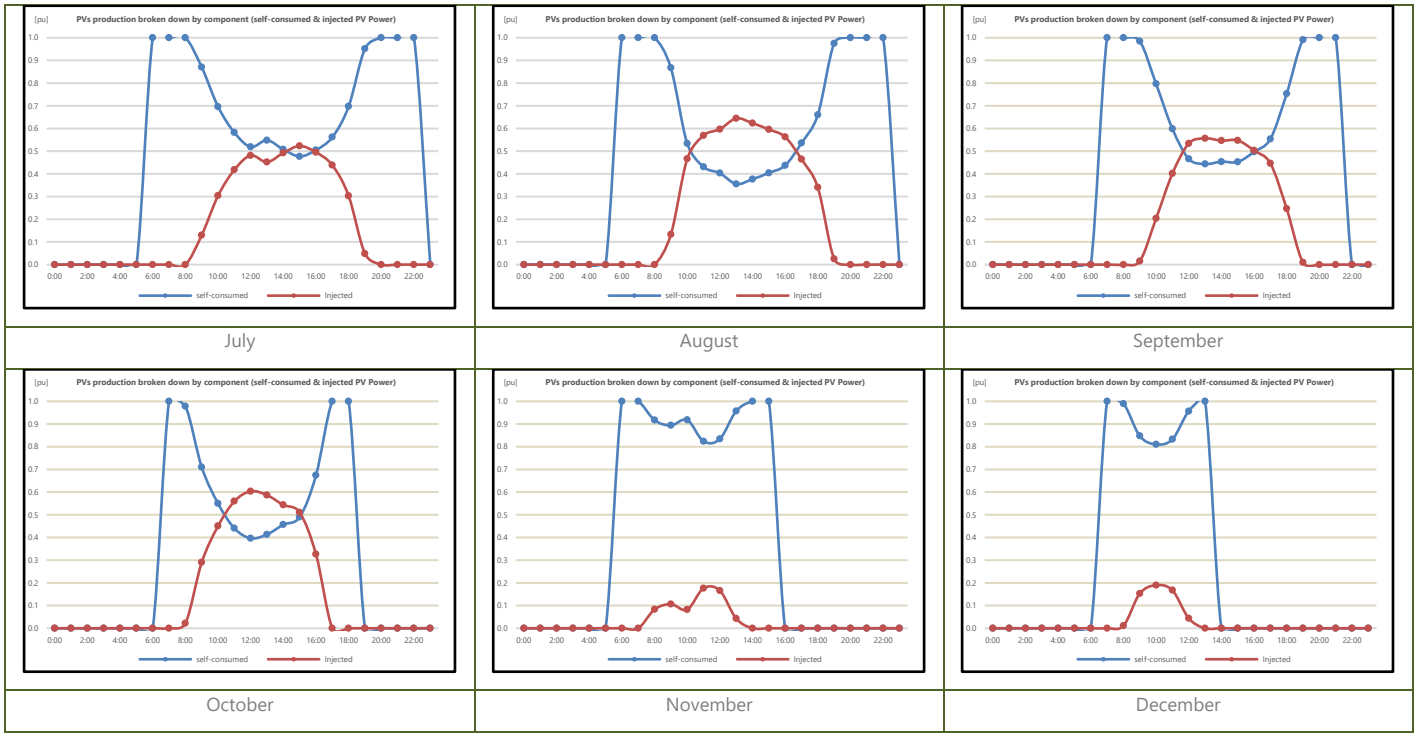



***Figure 7**: typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Power)*

**Figures 7** illustrates the typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Energy). Both components of hourly contributions are divided with the corresponding hourly value of the total PVs production and thus their sum is always equal to unit. After a careful analysis of **Figure 7** it is concluded that, both PVs production components are comparable at least for eight months.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

## 3.4. Collegepark Zwijsen Grid Connected PV-C.S (The Netherlands)

The next five tables and figures present the typical daily profiles of the: a) Collegepark Zwijsen PV-C.S total electrical power consumption, b) total produced PV Power, c) Self-consumed PV Power, d) Injected PV Power and e) Power fed by the LDN. A pu system was introduced with the nominal power of the installed PV system consisting the base value of the system. Considering that the Collegepark Zwijsen complex is under development, PVs installed capacity is increasing accordingly to the number of apartments that have been sold. Therefore, PVs capacity was 25kW for October and November, 37.3 KW for December, January and February, 40KW for March, 45KW for April and 60kW from May to September. All the other reported power quantities are specified as multiples of the selected base value.

| PV-C.S total electrical power consumption [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.097 | 0.084 | 0.145 | 0.070 | 0.064 | 0.075 | 0.083 | 0.081 | 0.082 | 0.110 | 0.131 | 0.098 |
| 1:00 | 0.073 | 0.067 | 0.117 | 0.061 | 0.055 | 0.066 | 0.071 | 0.069 | 0.068 | 0.092 | 0.100 | 0.073 |
| 2:00 | 0.064 | 0.061 | 0.107 | 0.058 | 0.052 | 0.062 | 0.066 | 0.064 | 0.062 | 0.087 | 0.088 | 0.064 |
| 3:00 | 0.061 | 0.058 | 0.105 | 0.057 | 0.052 | 0.061 | 0.064 | 0.062 | 0.061 | 0.085 | 0.084 | 0.060 |
| 4:00 | 0.061 | 0.059 | 0.108 | 0.060 | 0.053 | 0.062 | 0.063 | 0.062 | 0.061 | 0.087 | 0.084 | 0.060 |
| 5:00 | 0.064 | 0.065 | 0.124 | 0.070 | 0.060 | 0.072 | 0.066 | 0.065 | 0.067 | 0.102 | 0.089 | 0.063 |
| 6:00 | 0.080 | 0.085 | 0.164 | 0.093 | 0.078 | 0.093 | 0.077 | 0.076 | 0.086 | 0.140 | 0.115 | 0.077 |
| 7:00 | 0.110 | 0.115 | 0.211 | 0.116 | 0.098 | 0.114 | 0.095 | 0.092 | 0.106 | 0.171 | 0.160 | 0.105 |
| 8:00 | 0.140 | 0.136 | 0.247 | 0.133 | 0.113 | 0.129 | 0.115 | 0.112 | 0.123 | 0.193 | 0.190 | 0.132 |
| 9:00 | 0.154 | 0.150 | 0.266 | 0.139 | 0.118 | 0.134 | 0.125 | 0.125 | 0.133 | 0.205 | 0.210 | 0.153 |
| 10:00 | 0.158 | 0.153 | 0.269 | 0.141 | 0.119 | 0.135 | 0.129 | 0.126 | 0.135 | 0.203 | 0.213 | 0.161 |
| 11:00 | 0.161 | 0.156 | 0.271 | 0.141 | 0.119 | 0.136 | 0.131 | 0.128 | 0.136 | 0.207 | 0.214 | 0.165 |
| 12:00 | 0.161 | 0.155 | 0.267 | 0.138 | 0.116 | 0.132 | 0.128 | 0.127 | 0.134 | 0.205 | 0.218 | 0.165 |
| 13:00 | 0.157 | 0.150 | 0.258 | 0.131 | 0.112 | 0.128 | 0.123 | 0.121 | 0.130 | 0.197 | 0.213 | 0.160 |
| 14:00 | 0.154 | 0.145 | 0.249 | 0.126 | 0.110 | 0.125 | 0.120 | 0.116 | 0.126 | 0.191 | 0.208 | 0.158 |
| 15:00 | 0.155 | 0.144 | 0.251 | 0.130 | 0.113 | 0.129 | 0.120 | 0.118 | 0.129 | 0.197 | 0.209 | 0.159 |
| 16:00 | 0.183 | 0.162 | 0.285 | 0.153 | 0.131 | 0.149 | 0.136 | 0.134 | 0.149 | 0.236 | 0.245 | 0.189 |
| 17:00 | 0.231 | 0.204 | 0.338 | 0.166 | 0.141 | 0.160 | 0.149 | 0.149 | 0.166 | 0.277 | 0.322 | 0.238 |
| 18:00 | 0.243 | 0.229 | 0.376 | 0.172 | 0.143 | 0.162 | 0.152 | 0.153 | 0.177 | 0.313 | 0.344 | 0.247 |
| 19:00 | 0.240 | 0.232 | 0.404 | 0.173 | 0.138 | 0.153 | 0.148 | 0.151 | 0.191 | 0.320 | 0.345 | 0.246 |
| 20:00 | 0.217 | 0.210 | 0.373 | 0.176 | 0.137 | 0.145 | 0.141 | 0.153 | 0.187 | 0.293 | 0.317 | 0.229 |
| 21:00 | 0.194 | 0.188 | 0.330 | 0.163 | 0.137 | 0.147 | 0.145 | 0.155 | 0.173 | 0.260 | 0.284 | 0.206 |
| 22:00 | 0.165 | 0.159 | 0.274 | 0.129 | 0.114 | 0.130 | 0.133 | 0.135 | 0.143 | 0.209 | 0.247 | 0.182 |
| 23:00 | 0.126 | 0.118 | 0.202 | 0.092 | 0.083 | 0.098 | 0.103 | 0.102 | 0.105 | 0.150 | 0.187 | 0.141 |

***Table I**: Typical Daily Profile of total electrical consumption for the Collegepark Zwijsen PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

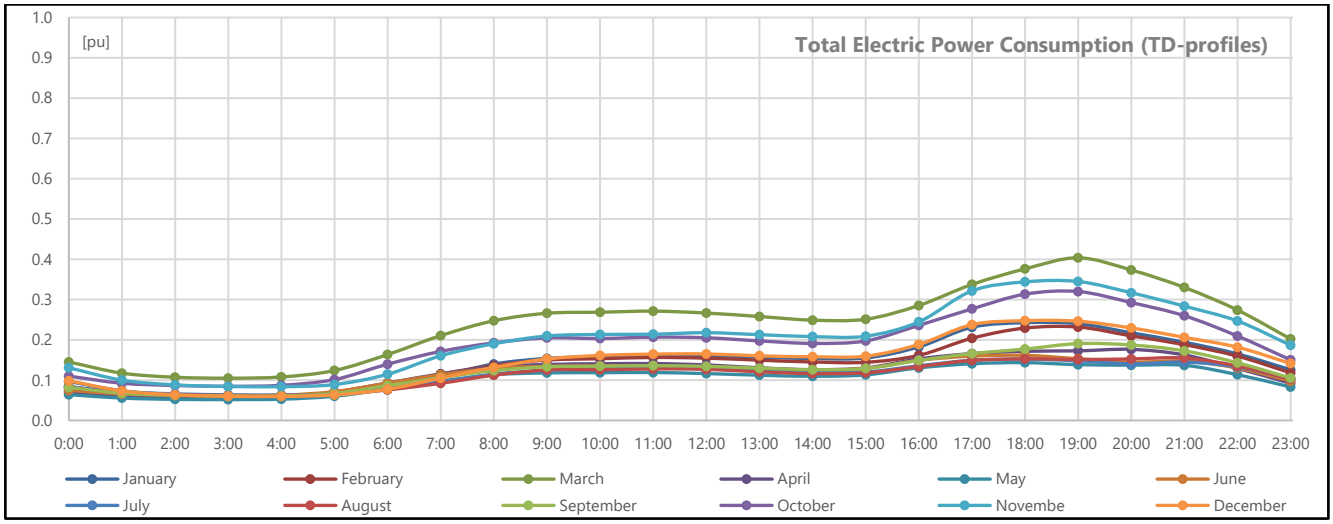



***Figure 1**: Typical Daily Profile of total electrical consumption for the Collegepark Zwijsen PV-C.S*

| Total produced PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.001 | 0.000 | 0.066 | 0.000 | 0.000 | 0.001 | 0.014 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.001 | 0.000 | 0.149 | 0.001 | 0.019 | 0.019 | 0.057 | 0.032 | 0.006 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.001 | 0.000 | 0.227 | 0.020 | 0.061 | 0.059 | 0.147 | 0.109 | 0.049 | 0.004 | 0.000 | 0.000 |
| 8:00 | 0.001 | 0.017 | 0.273 | 0.100 | 0.146 | 0.133 | 0.290 | 0.225 | 0.140 | 0.026 | 0.013 | 0.000 |
| 9:00 | 0.008 | 0.078 | 0.310 | 0.202 | 0.261 | 0.243 | 0.420 | 0.316 | 0.248 | 0.104 | 0.073 | 0.007 |
| 10:00 | 0.028 | 0.139 | 0.319 | 0.293 | 0.365 | 0.320 | 0.516 | 0.396 | 0.330 | 0.199 | 0.140 | 0.031 |
| 11:00 | 0.062 | 0.215 | 0.276 | 0.355 | 0.454 | 0.399 | 0.566 | 0.421 | 0.397 | 0.269 | 0.193 | 0.058 |
| 12:00 | 0.079 | 0.263 | 0.223 | 0.382 | 0.520 | 0.445 | 0.591 | 0.444 | 0.402 | 0.355 | 0.219 | 0.062 |
| 13:00 | 0.082 | 0.253 | 0.184 | 0.426 | 0.515 | 0.444 | 0.551 | 0.430 | 0.405 | 0.338 | 0.187 | 0.059 |
| 14:00 | 0.065 | 0.219 | 0.127 | 0.413 | 0.491 | 0.424 | 0.484 | 0.354 | 0.333 | 0.272 | 0.138 | 0.035 |
| 15:00 | 0.034 | 0.163 | 0.056 | 0.356 | 0.437 | 0.384 | 0.401 | 0.297 | 0.240 | 0.212 | 0.062 | 0.017 |
| 16:00 | 0.007 | 0.069 | 0.010 | 0.308 | 0.368 | 0.328 | 0.306 | 0.205 | 0.133 | 0.133 | 0.011 | 0.005 |
| 17:00 | 0.001 | 0.014 | 0.000 | 0.206 | 0.267 | 0.259 | 0.177 | 0.113 | 0.049 | 0.059 | 0.000 | 0.000 |
| 18:00 | 0.001 | 0.000 | 0.000 | 0.113 | 0.160 | 0.153 | 0.088 | 0.051 | 0.011 | 0.016 | 0.000 | 0.000 |
| 19:00 | 0.001 | 0.000 | 0.000 | 0.046 | 0.079 | 0.083 | 0.038 | 0.011 | 0.000 | 0.002 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.000 | 0.004 | 0.031 | 0.035 | 0.008 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.012 | 0.008 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table II**: Typical Daily Profile of total produced PV Power for the Collegepark Zwijsen PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

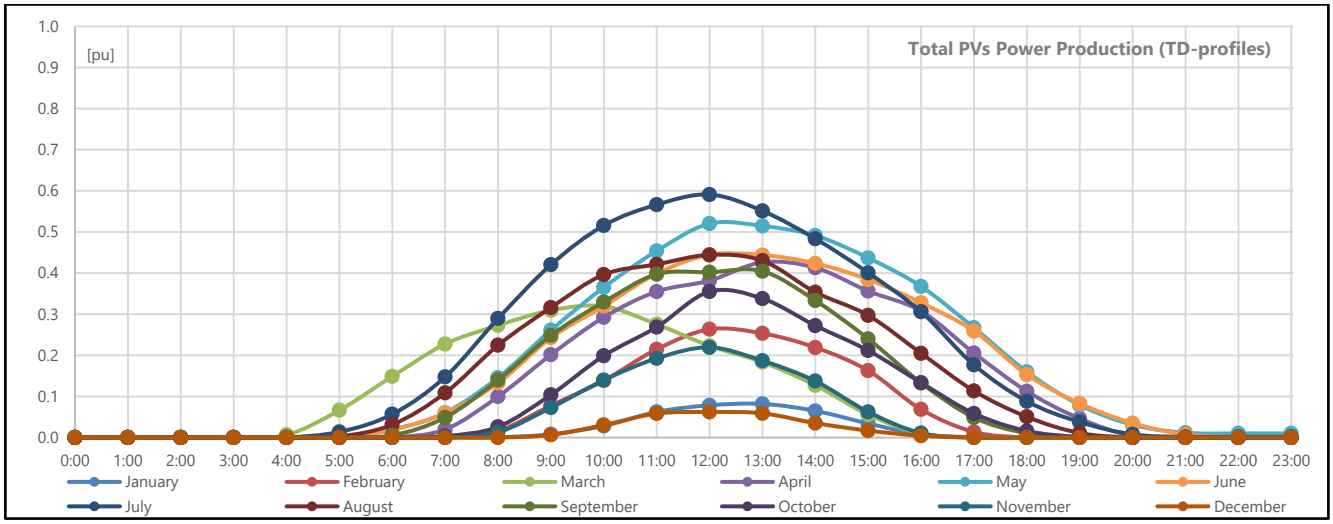



***Figure 2**: Typical Daily Profile of total produced PV Power for the Collegepark Zwijsen PV-C.S*

| Self-consumed PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.013 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.001 | 0.000 | 0.023 | 0.001 | 0.015 | 0.019 | 0.053 | 0.031 | 0.006 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.001 | 0.000 | 0.086 | 0.020 | 0.057 | 0.059 | 0.090 | 0.079 | 0.047 | 0.004 | 0.000 | 0.000 |
| 8:00 | 0.001 | 0.017 | 0.141 | 0.083 | 0.094 | 0.097 | 0.114 | 0.109 | 0.104 | 0.026 | 0.013 | 0.000 |
| 9:00 | 0.008 | 0.074 | 0.162 | 0.118 | 0.108 | 0.116 | 0.123 | 0.122 | 0.125 | 0.096 | 0.070 | 0.007 |
| 10:00 | 0.028 | 0.107 | 0.171 | 0.131 | 0.114 | 0.128 | 0.127 | 0.121 | 0.125 | 0.147 | 0.112 | 0.031 |
| 11:00 | 0.060 | 0.123 | 0.172 | 0.133 | 0.115 | 0.130 | 0.131 | 0.126 | 0.130 | 0.163 | 0.133 | 0.054 |
| 12:00 | 0.075 | 0.126 | 0.171 | 0.128 | 0.114 | 0.127 | 0.127 | 0.121 | 0.125 | 0.178 | 0.144 | 0.054 |
| 13:00 | 0.073 | 0.120 | 0.165 | 0.126 | 0.110 | 0.125 | 0.123 | 0.116 | 0.125 | 0.165 | 0.137 | 0.054 |
| 14:00 | 0.063 | 0.121 | 0.164 | 0.120 | 0.109 | 0.122 | 0.119 | 0.113 | 0.120 | 0.149 | 0.111 | 0.035 |
| 15:00 | 0.034 | 0.111 | 0.166 | 0.125 | 0.110 | 0.126 | 0.120 | 0.115 | 0.120 | 0.138 | 0.062 | 0.017 |
| 16:00 | 0.007 | 0.067 | 0.186 | 0.142 | 0.124 | 0.145 | 0.134 | 0.120 | 0.111 | 0.118 | 0.011 | 0.005 |
| 17:00 | 0.001 | 0.014 | 0.203 | 0.138 | 0.135 | 0.145 | 0.138 | 0.105 | 0.049 | 0.059 | 0.000 | 0.000 |
| 18:00 | 0.001 | 0.000 | 0.190 | 0.106 | 0.127 | 0.124 | 0.088 | 0.051 | 0.011 | 0.016 | 0.000 | 0.000 |
| 19:00 | 0.001 | 0.000 | 0.110 | 0.046 | 0.073 | 0.083 | 0.038 | 0.011 | 0.000 | 0.002 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.038 | 0.004 | 0.025 | 0.035 | 0.008 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.009 | 0.000 | 0.006 | 0.008 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.005 | 0.000 | 0.004 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.004 | 0.000 | 0.003 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table III**: Typical Daily Profile of self-consumed PV Power for the Collegepark Zwijsen PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

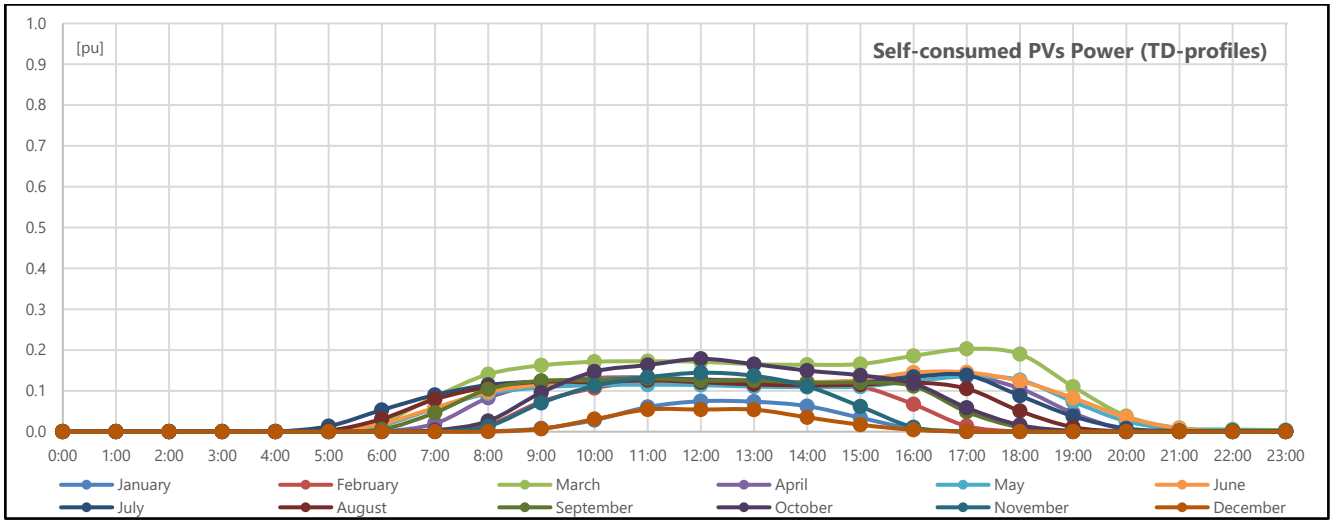



***Figure 3**: Typical Daily Profile of self-consumed PV Power for the Collegepark Zwijsen PV-C.S*

| Injected PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.000 | 0.004 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.000 | 0.020 | 0.000 | 0.004 | 0.001 | 0.058 | 0.029 | 0.002 | 0.000 | 0.000 | 0.000 |
| 8:00 | 0.000 | 0.000 | 0.035 | 0.017 | 0.052 | 0.035 | 0.175 | 0.116 | 0.036 | 0.000 | 0.000 | 0.000 |
| 9:00 | 0.000 | 0.004 | 0.056 | 0.084 | 0.153 | 0.127 | 0.298 | 0.194 | 0.124 | 0.008 | 0.002 | 0.000 |
| 10:00 | 0.000 | 0.032 | 0.067 | 0.161 | 0.251 | 0.192 | 0.389 | 0.275 | 0.204 | 0.052 | 0.027 | 0.000 |
| 11:00 | 0.002 | 0.092 | 0.028 | 0.222 | 0.339 | 0.269 | 0.435 | 0.295 | 0.267 | 0.106 | 0.060 | 0.004 |
| 12:00 | 0.004 | 0.138 | 0.107 | 0.254 | 0.406 | 0.318 | 0.464 | 0.323 | 0.277 | 0.177 | 0.075 | 0.008 |
| 13:00 | 0.009 | 0.134 | 0.119 | 0.300 | 0.404 | 0.319 | 0.428 | 0.314 | 0.279 | 0.173 | 0.050 | 0.005 |
| 14:00 | 0.002 | 0.098 | 0.091 | 0.293 | 0.382 | 0.302 | 0.365 | 0.240 | 0.213 | 0.123 | 0.026 | 0.000 |
| 15:00 | 0.000 | 0.052 | 0.043 | 0.231 | 0.326 | 0.258 | 0.281 | 0.182 | 0.120 | 0.074 | 0.001 | 0.000 |
| 16:00 | 0.000 | 0.002 | 0.006 | 0.166 | 0.244 | 0.183 | 0.172 | 0.085 | 0.022 | 0.016 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.000 | 0.000 | 0.068 | 0.132 | 0.114 | 0.038 | 0.008 | 0.000 | 0.000 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.000 | 0.007 | 0.034 | 0.029 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.000 | 0.001 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table IV**: Typical Daily Profile of injected PV Power for the Collegepark Zwijsen PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

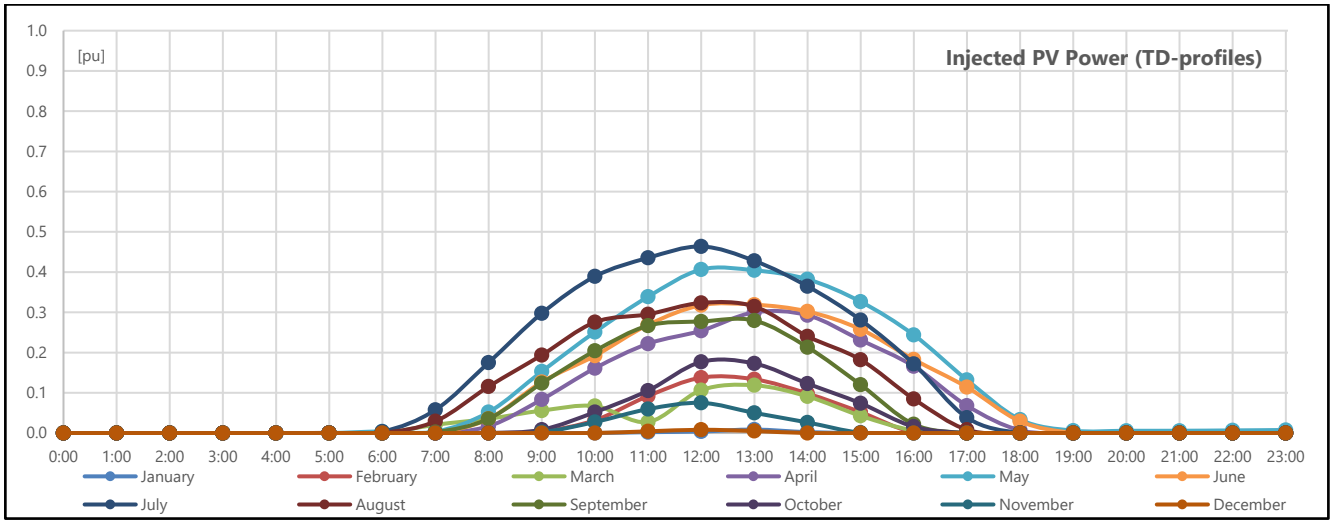



***Figure 4**: Typical Daily Profile of injected PV Power for the Collegepark Zwijsen PV-C.S*

| Power fed by the LDN [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.097 | 0.084 | 0.145 | 0.070 | 0.053 | 0.075 | 0.083 | 0.081 | 0.082 | 0.110 | 0.131 | 0.098 |
| 1:00 | 0.073 | 0.067 | 0.117 | 0.061 | 0.055 | 0.066 | 0.071 | 0.069 | 0.068 | 0.092 | 0.100 | 0.073 |
| 2:00 | 0.064 | 0.061 | 0.107 | 0.058 | 0.052 | 0.062 | 0.066 | 0.064 | 0.062 | 0.087 | 0.088 | 0.064 |
| 3:00 | 0.061 | 0.058 | 0.105 | 0.057 | 0.052 | 0.061 | 0.064 | 0.062 | 0.061 | 0.085 | 0.084 | 0.060 |
| 4:00 | 0.061 | 0.059 | 0.101 | 0.060 | 0.053 | 0.062 | 0.063 | 0.062 | 0.061 | 0.087 | 0.084 | 0.060 |
| 5:00 | 0.063 | 0.065 | 0.057 | 0.070 | 0.060 | 0.071 | 0.052 | 0.063 | 0.067 | 0.102 | 0.089 | 0.063 |
| 6:00 | 0.079 | 0.085 | 0.015 | 0.092 | 0.063 | 0.073 | 0.023 | 0.045 | 0.081 | 0.140 | 0.115 | 0.077 |
| 7:00 | 0.109 | 0.115 | 0.004 | 0.096 | 0.041 | 0.055 | 0.006 | 0.013 | 0.060 | 0.168 | 0.160 | 0.105 |
| 8:00 | 0.139 | 0.120 | 0.010 | 0.050 | 0.020 | 0.032 | 0.000 | 0.003 | 0.019 | 0.166 | 0.177 | 0.132 |
| 9:00 | 0.146 | 0.076 | 0.012 | 0.021 | 0.010 | 0.018 | 0.002 | 0.003 | 0.009 | 0.109 | 0.139 | 0.146 |
| 10:00 | 0.130 | 0.046 | 0.016 | 0.009 | 0.004 | 0.008 | 0.002 | 0.005 | 0.009 | 0.056 | 0.101 | 0.131 |
| 11:00 | 0.101 | 0.034 | 0.023 | 0.008 | 0.004 | 0.006 | 0.000 | 0.002 | 0.005 | 0.044 | 0.081 | 0.110 |
| 12:00 | 0.086 | 0.029 | 0.150 | 0.010 | 0.002 | 0.005 | 0.001 | 0.006 | 0.009 | 0.027 | 0.073 | 0.111 |
| 13:00 | 0.084 | 0.030 | 0.193 | 0.004 | 0.002 | 0.003 | 0.000 | 0.005 | 0.005 | 0.032 | 0.076 | 0.106 |
| 14:00 | 0.091 | 0.024 | 0.213 | 0.006 | 0.000 | 0.003 | 0.001 | 0.003 | 0.006 | 0.042 | 0.097 | 0.123 |
| 15:00 | 0.121 | 0.033 | 0.238 | 0.005 | 0.003 | 0.003 | 0.000 | 0.003 | 0.009 | 0.059 | 0.147 | 0.143 |
| 16:00 | 0.175 | 0.095 | 0.282 | 0.011 | 0.007 | 0.004 | 0.002 | 0.013 | 0.038 | 0.118 | 0.234 | 0.184 |
| 17:00 | 0.230 | 0.190 | 0.338 | 0.028 | 0.006 | 0.014 | 0.011 | 0.044 | 0.117 | 0.218 | 0.321 | 0.238 |
| 18:00 | 0.242 | 0.229 | 0.376 | 0.066 | 0.017 | 0.038 | 0.064 | 0.102 | 0.167 | 0.297 | 0.344 | 0.247 |
| 19:00 | 0.239 | 0.232 | 0.404 | 0.127 | 0.065 | 0.071 | 0.110 | 0.140 | 0.191 | 0.318 | 0.345 | 0.246 |
| 20:00 | 0.217 | 0.210 | 0.373 | 0.172 | 0.112 | 0.110 | 0.133 | 0.152 | 0.187 | 0.293 | 0.317 | 0.229 |
| 21:00 | 0.194 | 0.188 | 0.330 | 0.163 | 0.131 | 0.140 | 0.143 | 0.155 | 0.173 | 0.260 | 0.284 | 0.206 |
| 22:00 | 0.165 | 0.159 | 0.274 | 0.129 | 0.110 | 0.130 | 0.131 | 0.135 | 0.143 | 0.209 | 0.247 | 0.182 |
| 23:00 | 0.126 | 0.118 | 0.202 | 0.000 | 0.080 | 0.098 | 0.101 | 0.102 | 0.105 | 0.150 | 0.187 | 0.141 |

***Table V**: Typical Daily Profile of power fed by the LDN for the Collegepark Zwijsen PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

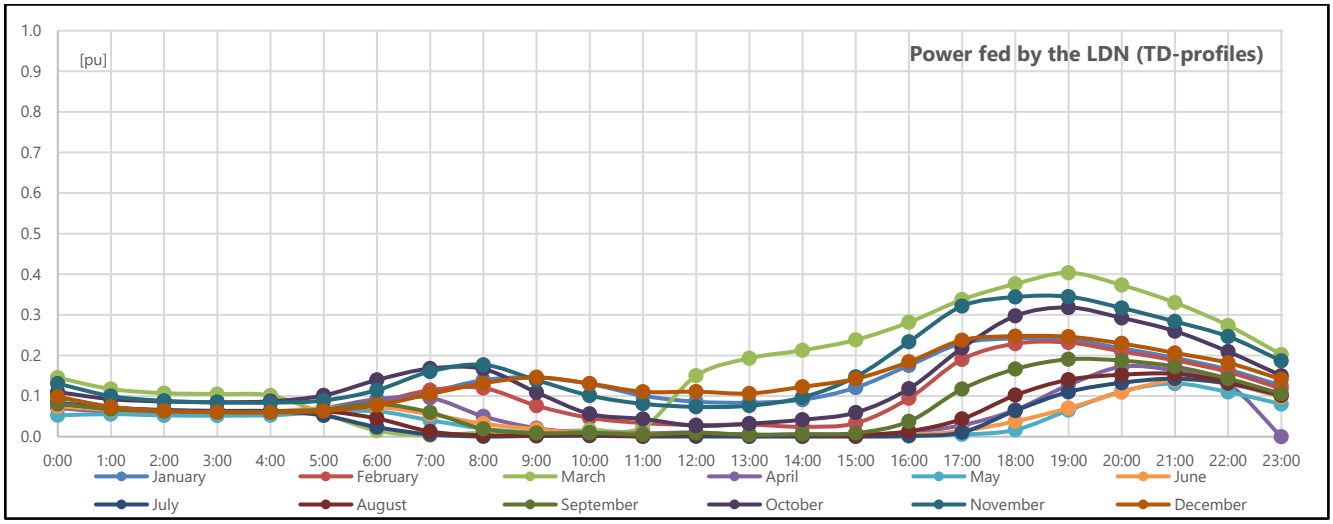
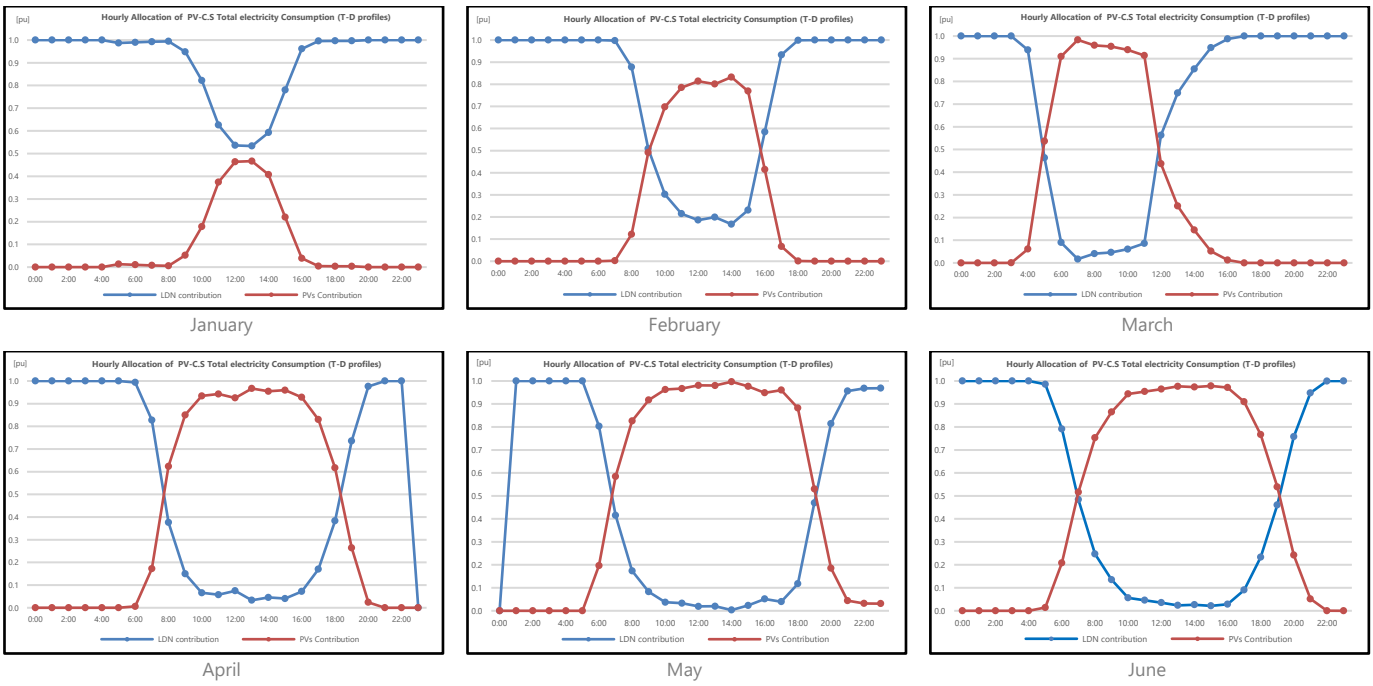



***Figure 5**: Typical Daily Profile of power fed by the LDN for the Collegepark Zwijsen PV-C.S*

**Figures 6** illustrates the typical hourly allocation of PV-C.S's total electricity consumption for each month of the reporting period. Both LDN and PVs hourly contributions are divided with the corresponding hourly value of the PV-C.S total electrical consumption and thus their sum is always equal to unit. After a careful analysis of **Figure 6** it is concluded that, even in the case where the energy transactions are considered as hourly values, there are time intervals (particularly during spring and summer) where the energy needs of the PV-C.S are serviced by PVs in high rates (almost around 100%). This is a remarkable load reduction for LDN, particular when the high penetration level of such PV-C.Ss comes into consideration.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

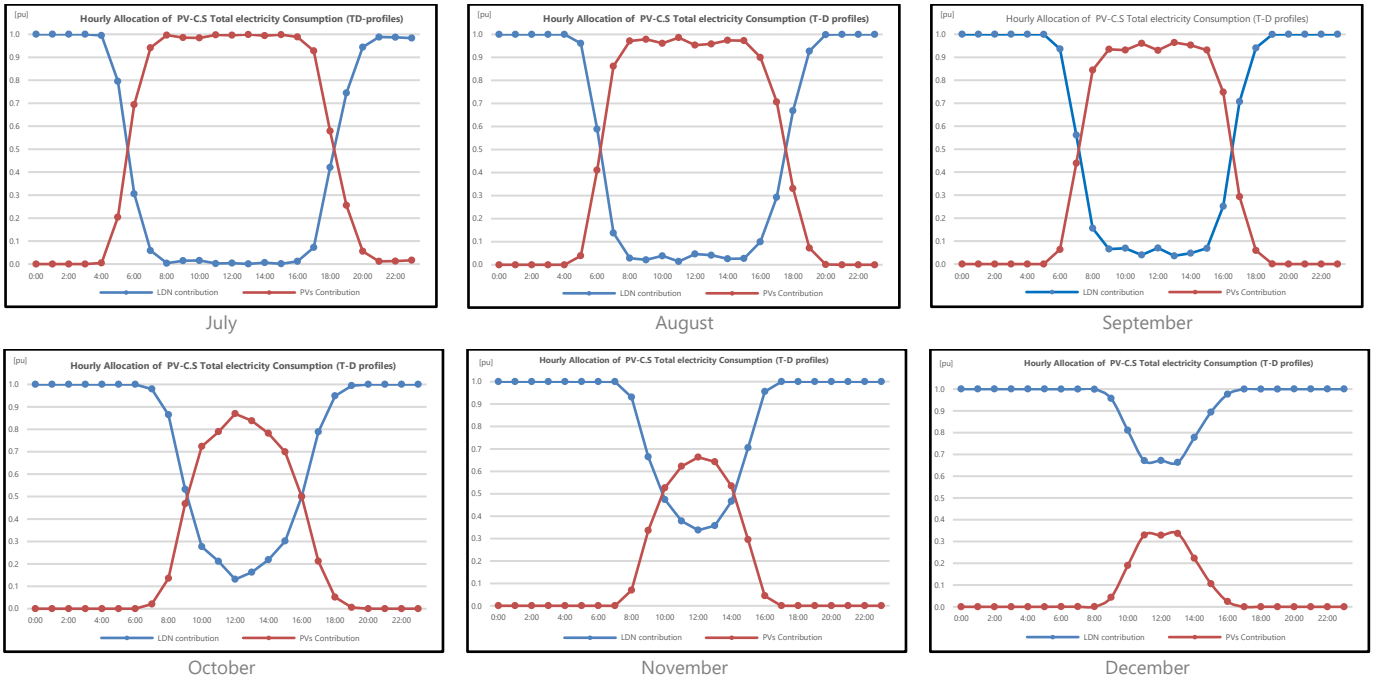
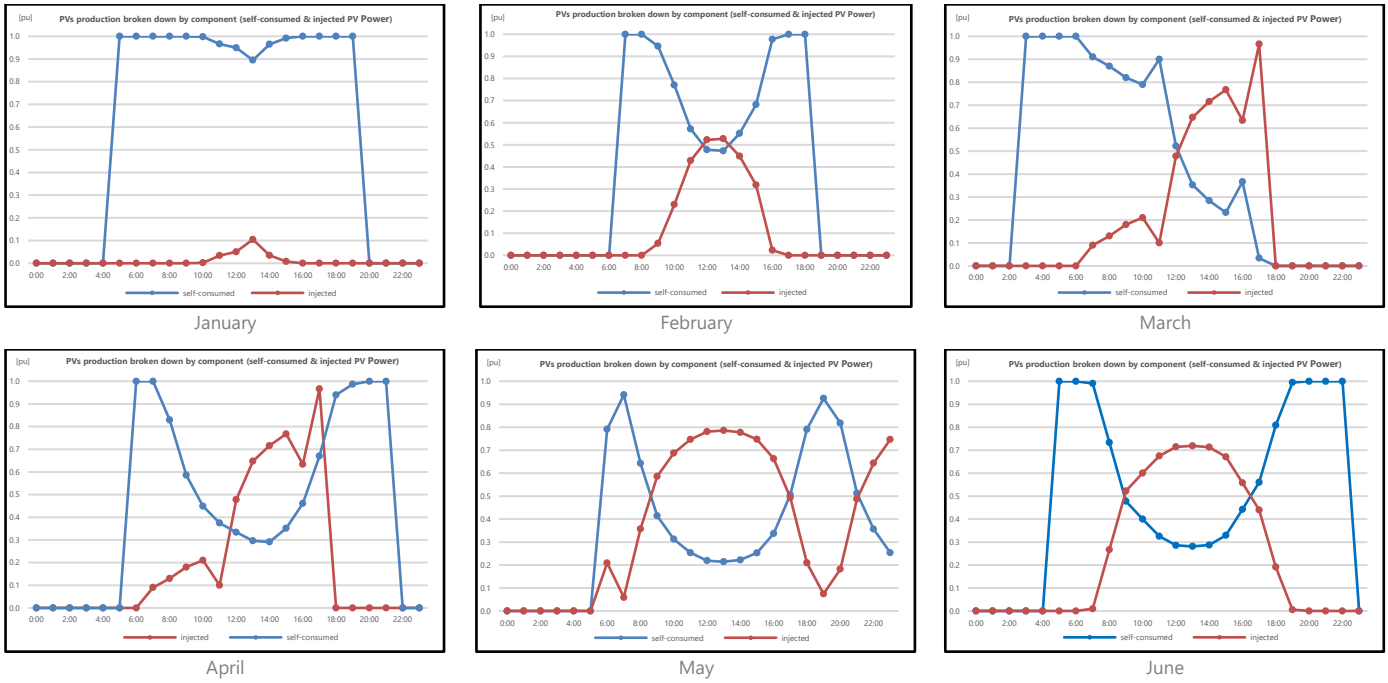



***Figure 6**: Hourly Allocation of PV-C.S total electricity consumption for each month of the reporting period (TD-profiles)*

In more detail, the total generation of an electrical power system is continuously adjusted to limit the frequency variation within an acceptable range. Therefore, the event of a remarkable load reduction (due to a significant match of the on-site demand of PV-C.Ss with local production from RES), may affect the scheduled operation of conventional power plants, pushing them to reduce their power output very close to their lower technical operational limits. Such a situation will also jeopardize exchanges through the interconnection line.



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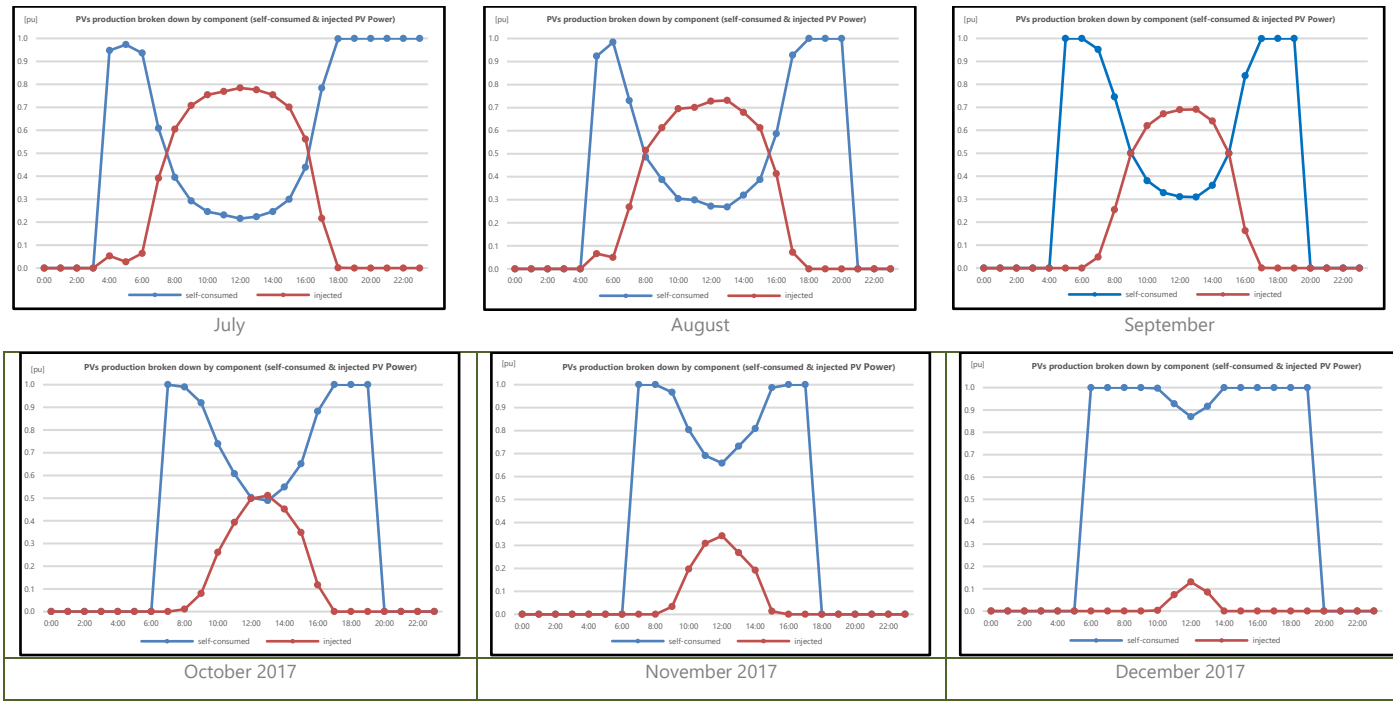



***Figure 7**: typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Power)*

**Figures 7** illustrates the typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Energy). Both components of hourly contributions are divided with the corresponding hourly value of the total PVs production and thus their sum is always equal to unit. After a careful analysis of **Figure 7** it is concluded that, the self-consumed PV Energy is considerably larger than the injected PV energy during winter and autumn, whilst both PVs production components are comparable during spring and summer.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

## 3.5. Aardehuizen-Olst Grid Connected PV-C.S (The Netherlands)

The next five tables and figures present the typical daily profiles of the: a) Aardehuizen-Olst PV-C.S total electrical power consumption, b) total produced PV Power, c) Self-consumed PV Power, d) Injected PV Power and e) Power fed by the LDN. A pu system was introduced with the nominal power of the installed PV system consisting the base value of the system (69.18kW). All the other reported power quantities are specified as multiples of the selected base value.

| PV-C.S total electrical power consumption [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.086 | 0.101 | 0.069 | 0.060 | 0.044 | 0.048 | 0.051 | 0.043 | 0.048 | 0.066 | 0.111 | 0.121 |
| 1:00 | 0.094 | 0.050 | 0.070 | 0.053 | 0.033 | 0.039 | 0.044 | 0.039 | 0.039 | 0.058 | 0.052 | 0.062 |
| 2:00 | 0.070 | 0.047 | 0.042 | 0.039 | 0.039 | 0.037 | 0.047 | 0.049 | 0.037 | 0.038 | 0.034 | 0.051 |
| 3:00 | 0.040 | 0.049 | 0.038 | 0.035 | 0.047 | 0.052 | 0.047 | 0.053 | 0.052 | 0.041 | 0.032 | 0.053 |
| 4:00 | 0.039 | 0.057 | 0.051 | 0.042 | 0.043 | 0.047 | 0.044 | 0.043 | 0.047 | 0.050 | 0.032 | 0.055 |
| 5:00 | 0.050 | 0.046 | 0.058 | 0.062 | 0.037 | 0.054 | 0.046 | 0.042 | 0.054 | 0.051 | 0.033 | 0.041 |
| 6:00 | 0.067 | 0.050 | 0.134 | 0.208 | 0.123 | 0.180 | 0.142 | 0.090 | 0.180 | 0.183 | 0.040 | 0.048 |
| 7:00 | 0.228 | 0.256 | 0.242 | 0.239 | 0.102 | 0.189 | 0.208 | 0.124 | 0.189 | 0.204 | 0.192 | 0.172 |
| 8:00 | 0.255 | 0.229 | 0.213 | 0.249 | 0.115 | 0.138 | 0.307 | 0.209 | 0.138 | 0.234 | 0.284 | 0.232 |
| 9:00 | 0.291 | 0.225 | 0.165 | 0.190 | 0.131 | 0.184 | 0.348 | 0.248 | 0.184 | 0.257 | 0.318 | 0.235 |
| 10:00 | 0.206 | 0.198 | 0.191 | 0.147 | 0.117 | 0.153 | 0.259 | 0.220 | 0.153 | 0.197 | 0.331 | 0.213 |
| 11:00 | 0.214 | 0.148 | 0.131 | 0.142 | 0.122 | 0.101 | 0.231 | 0.215 | 0.101 | 0.177 | 0.328 | 0.187 |
| 12:00 | 0.176 | 0.137 | 0.134 | 0.151 | 0.123 | 0.128 | 0.172 | 0.177 | 0.128 | 0.203 | 0.337 | 0.172 |
| 13:00 | 0.167 | 0.127 | 0.144 | 0.143 | 0.093 | 0.137 | 0.148 | 0.156 | 0.137 | 0.184 | 0.267 | 0.179 |
| 14:00 | 0.175 | 0.139 | 0.139 | 0.141 | 0.068 | 0.101 | 0.113 | 0.119 | 0.101 | 0.129 | 0.241 | 0.163 |
| 15:00 | 0.166 | 0.116 | 0.124 | 0.121 | 0.087 | 0.152 | 0.104 | 0.111 | 0.152 | 0.124 | 0.238 | 0.181 |
| 16:00 | 0.191 | 0.167 | 0.212 | 0.316 | 0.280 | 0.281 | 0.111 | 0.114 | 0.281 | 0.330 | 0.264 | 0.179 |
| 17:00 | 0.503 | 0.458 | 0.395 | 0.335 | 0.383 | 0.333 | 0.121 | 0.122 | 0.333 | 0.479 | 0.350 | 0.460 |
| 18:00 | 0.552 | 0.520 | 0.445 | 0.264 | 0.180 | 0.213 | 0.114 | 0.104 | 0.213 | 0.353 | 0.396 | 0.471 |
| 19:00 | 0.493 | 0.446 | 0.461 | 0.351 | 0.219 | 0.243 | 0.107 | 0.095 | 0.243 | 0.416 | 0.289 | 0.442 |
| 20:00 | 0.450 | 0.451 | 0.402 | 0.237 | 0.200 | 0.228 | 0.061 | 0.054 | 0.228 | 0.391 | 0.238 | 0.448 |
| 21:00 | 0.340 | 0.357 | 0.295 | 0.123 | 0.129 | 0.141 | 0.049 | 0.041 | 0.141 | 0.208 | 0.212 | 0.374 |
| 22:00 | 0.193 | 0.169 | 0.101 | 0.086 | 0.094 | 0.093 | 0.066 | 0.057 | 0.093 | 0.122 | 0.188 | 0.245 |
| 23:00 | 0.124 | 0.109 | 0.081 | 0.066 | 0.049 | 0.056 | 0.057 | 0.050 | 0.056 | 0.068 | 0.148 | 0.185 |

***Table I**: Typical Daily Profile of total electrical consumption for the Aardehuizen-Olst PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

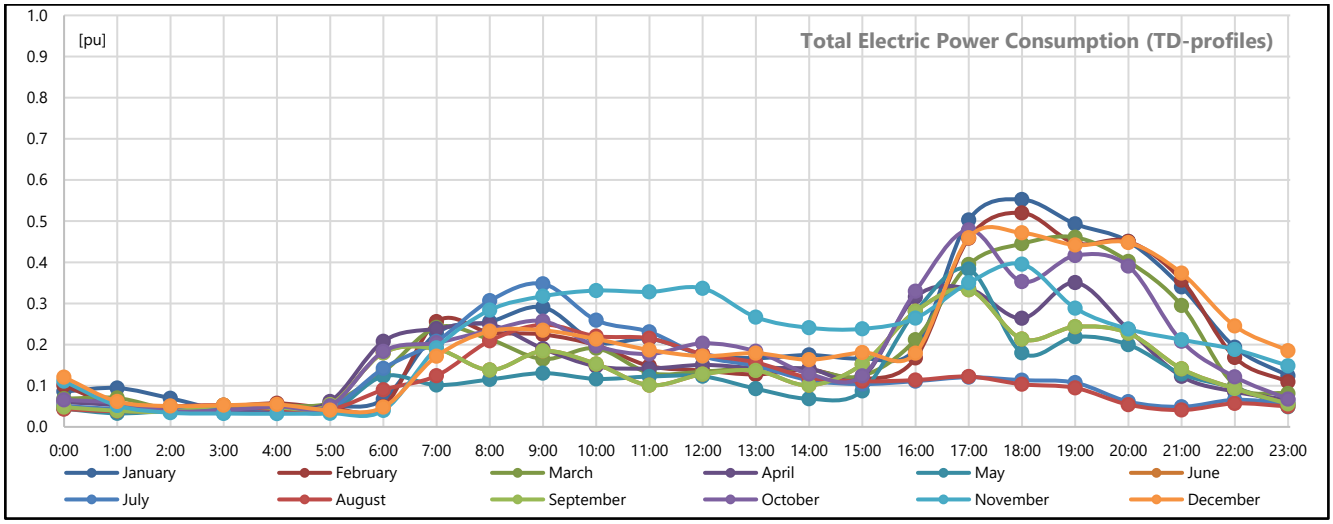



***Figure 1**: Typical Daily Profile of total electrical consumption for the Aardehuizen-Olst PV-C.S*

| Total produced PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.010 | 0.001 | 0.010 | 0.016 | 0.000 | 0.000 | 0.016 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.049 | 0.016 | 0.049 | 0.054 | 0.011 | 0.002 | 0.054 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.000 | 0.152 | 0.079 | 0.152 | 0.138 | 0.047 | 0.021 | 0.138 | 0.006 | 0.000 | 0.000 |
| 8:00 | 0.000 | 0.017 | 0.287 | 0.174 | 0.287 | 0.236 | 0.156 | 0.098 | 0.236 | 0.043 | 0.011 | 0.000 |
| 9:00 | 0.010 | 0.091 | 0.432 | 0.272 | 0.432 | 0.327 | 0.294 | 0.218 | 0.327 | 0.121 | 0.051 | 0.006 |
| 10:00 | 0.039 | 0.207 | 0.512 | 0.361 | 0.512 | 0.404 | 0.421 | 0.328 | 0.404 | 0.199 | 0.104 | 0.021 |
| 11:00 | 0.076 | 0.306 | 0.575 | 0.421 | 0.575 | 0.429 | 0.520 | 0.439 | 0.429 | 0.260 | 0.112 | 0.046 |
| 12:00 | 0.102 | 0.343 | 0.589 | 0.418 | 0.589 | 0.441 | 0.584 | 0.458 | 0.441 | 0.268 | 0.140 | 0.061 |
| 13:00 | 0.106 | 0.344 | 0.603 | 0.437 | 0.603 | 0.465 | 0.584 | 0.460 | 0.465 | 0.258 | 0.167 | 0.054 |
| 14:00 | 0.087 | 0.310 | 0.552 | 0.405 | 0.552 | 0.468 | 0.595 | 0.441 | 0.468 | 0.214 | 0.075 | 0.040 |
| 15:00 | 0.049 | 0.238 | 0.481 | 0.347 | 0.481 | 0.404 | 0.576 | 0.406 | 0.404 | 0.153 | 0.035 | 0.023 |
| 16:00 | 0.017 | 0.124 | 0.386 | 0.286 | 0.386 | 0.329 | 0.483 | 0.332 | 0.329 | 0.070 | 0.004 | 0.005 |
| 17:00 | 0.002 | 0.035 | 0.269 | 0.183 | 0.269 | 0.243 | 0.413 | 0.277 | 0.243 | 0.019 | 0.001 | 0.000 |
| 18:00 | 0.000 | 0.002 | 0.139 | 0.083 | 0.139 | 0.152 | 0.303 | 0.197 | 0.152 | 0.001 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.048 | 0.017 | 0.048 | 0.063 | 0.182 | 0.108 | 0.063 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.009 | 0.001 | 0.009 | 0.020 | 0.068 | 0.029 | 0.020 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.016 | 0.003 | 0.002 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table II**: Typical Daily Profile of total produced PV Power for the Aardehuizen-Olst PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

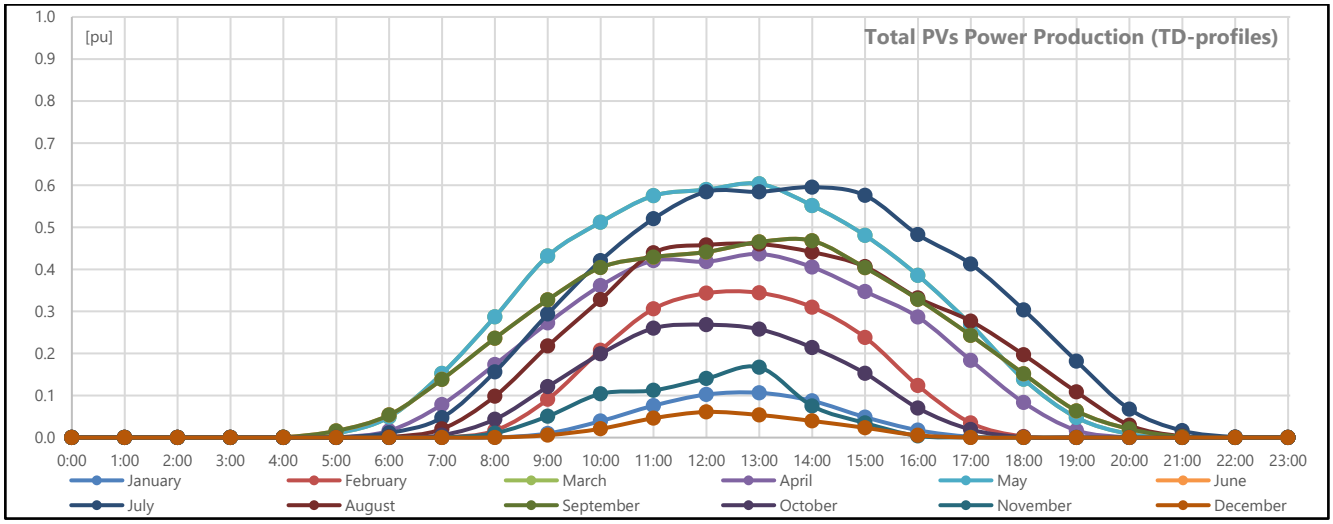



***Figure 2**: Typical Daily Profile of total produced PV Power for the Aardehuizen-Olst PV-C.S*

| Self-consumed PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.010 | 0.001 | 0.010 | 0.015 | 0.000 | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.035 | 0.015 | 0.035 | 0.042 | 0.011 | 0.002 | 0.042 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.000 | 0.066 | 0.057 | 0.066 | 0.082 | 0.047 | 0.021 | 0.082 | 0.005 | 0.000 | 0.000 |
| 8:00 | 0.000 | 0.002 | 0.094 | 0.097 | 0.094 | 0.108 | 0.155 | 0.094 | 0.108 | 0.039 | 0.011 | 0.000 |
| 9:00 | 0.010 | 0.023 | 0.119 | 0.094 | 0.119 | 0.138 | 0.259 | 0.188 | 0.138 | 0.081 | 0.051 | 0.006 |
| 10:00 | 0.036 | 0.104 | 0.113 | 0.098 | 0.113 | 0.129 | 0.230 | 0.194 | 0.129 | 0.111 | 0.104 | 0.019 |
| 11:00 | 0.057 | 0.136 | 0.120 | 0.128 | 0.120 | 0.095 | 0.214 | 0.200 | 0.095 | 0.117 | 0.112 | 0.039 |
| 12:00 | 0.078 | 0.125 | 0.109 | 0.133 | 0.109 | 0.115 | 0.165 | 0.158 | 0.115 | 0.129 | 0.140 | 0.047 |
| 13:00 | 0.074 | 0.124 | 0.091 | 0.114 | 0.091 | 0.119 | 0.139 | 0.136 | 0.119 | 0.110 | 0.149 | 0.045 |
| 14:00 | 0.064 | 0.131 | 0.066 | 0.117 | 0.066 | 0.097 | 0.111 | 0.105 | 0.097 | 0.082 | 0.075 | 0.034 |
| 15:00 | 0.041 | 0.108 | 0.083 | 0.099 | 0.083 | 0.117 | 0.096 | 0.090 | 0.117 | 0.071 | 0.035 | 0.023 |
| 16:00 | 0.016 | 0.059 | 0.159 | 0.163 | 0.159 | 0.146 | 0.099 | 0.090 | 0.146 | 0.054 | 0.004 | 0.005 |
| 17:00 | 0.002 | 0.006 | 0.176 | 0.129 | 0.176 | 0.146 | 0.113 | 0.099 | 0.146 | 0.018 | 0.001 | 0.000 |
| 18:00 | 0.000 | 0.002 | 0.086 | 0.067 | 0.086 | 0.087 | 0.109 | 0.098 | 0.087 | 0.001 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.045 | 0.017 | 0.045 | 0.053 | 0.101 | 0.080 | 0.053 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.009 | 0.001 | 0.009 | 0.020 | 0.042 | 0.024 | 0.020 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.013 | 0.003 | 0.002 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table III**: Typical Daily Profile of self-consumed PV Power for the Aardehuizen-Olst PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

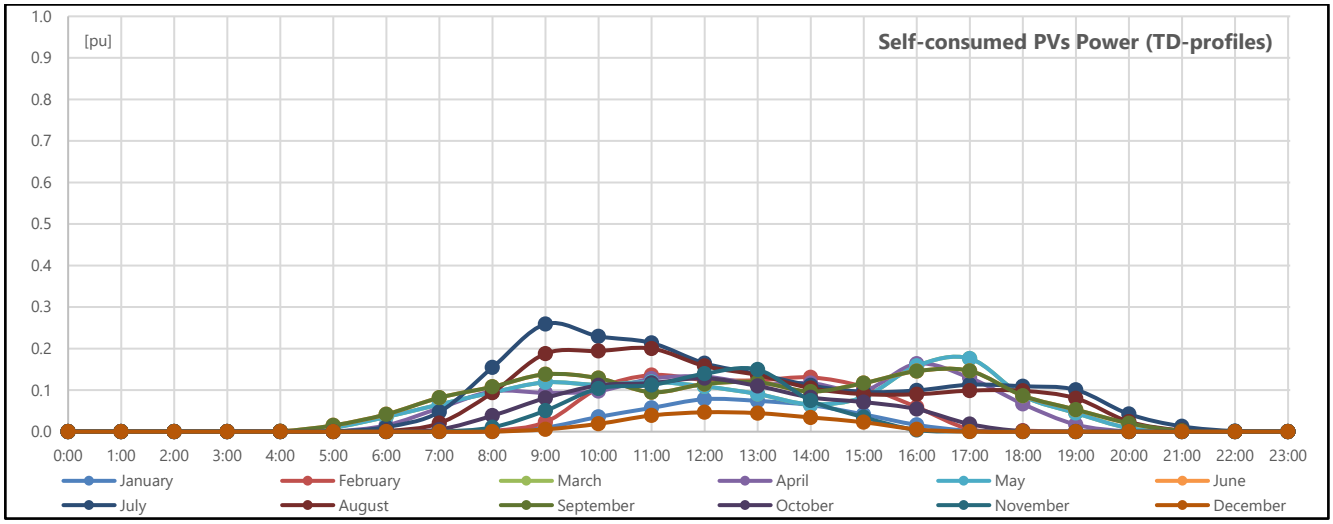



***Figure 3**: Typical Daily Profile of self-consumed PV Power for the Aardehuizen-Olst PV-C.S*

| Injected PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 5:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| 6:00 | 0.000 | 0.000 | 0.013 | 0.001 | 0.013 | 0.012 | 0.000 | 0.000 | 0.012 | 0.000 | 0.000 | 0.000 |
| 7:00 | 0.000 | 0.000 | 0.087 | 0.022 | 0.087 | 0.057 | 0.000 | 0.000 | 0.057 | 0.001 | 0.000 | 0.000 |
| 8:00 | 0.000 | 0.015 | 0.193 | 0.077 | 0.193 | 0.128 | 0.002 | 0.004 | 0.128 | 0.005 | 0.000 | 0.000 |
| 9:00 | 0.000 | 0.068 | 0.313 | 0.179 | 0.313 | 0.189 | 0.035 | 0.030 | 0.189 | 0.040 | 0.000 | 0.000 |
| 10:00 | 0.004 | 0.103 | 0.399 | 0.263 | 0.399 | 0.276 | 0.191 | 0.134 | 0.276 | 0.088 | 0.000 | 0.002 |
| 11:00 | 0.019 | 0.170 | 0.455 | 0.293 | 0.455 | 0.334 | 0.307 | 0.239 | 0.334 | 0.143 | 0.000 | 0.007 |
| 12:00 | 0.024 | 0.219 | 0.480 | 0.286 | 0.480 | 0.327 | 0.420 | 0.300 | 0.327 | 0.139 | 0.001 | 0.014 |
| 13:00 | 0.032 | 0.220 | 0.512 | 0.322 | 0.512 | 0.346 | 0.445 | 0.324 | 0.346 | 0.148 | 0.018 | 0.009 |
| 14:00 | 0.023 | 0.179 | 0.486 | 0.288 | 0.486 | 0.371 | 0.484 | 0.336 | 0.371 | 0.131 | 0.000 | 0.005 |
| 15:00 | 0.007 | 0.130 | 0.397 | 0.248 | 0.397 | 0.287 | 0.480 | 0.316 | 0.287 | 0.082 | 0.000 | 0.001 |
| 16:00 | 0.001 | 0.065 | 0.227 | 0.123 | 0.227 | 0.183 | 0.383 | 0.242 | 0.183 | 0.016 | 0.000 | 0.000 |
| 17:00 | 0.000 | 0.029 | 0.093 | 0.054 | 0.093 | 0.097 | 0.299 | 0.178 | 0.097 | 0.001 | 0.000 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.052 | 0.017 | 0.052 | 0.065 | 0.194 | 0.098 | 0.065 | 0.000 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.003 | 0.000 | 0.003 | 0.010 | 0.081 | 0.028 | 0.010 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.025 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table IV**: Typical Daily Profile of injected PV Power for the Aardehuizen-Olst PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

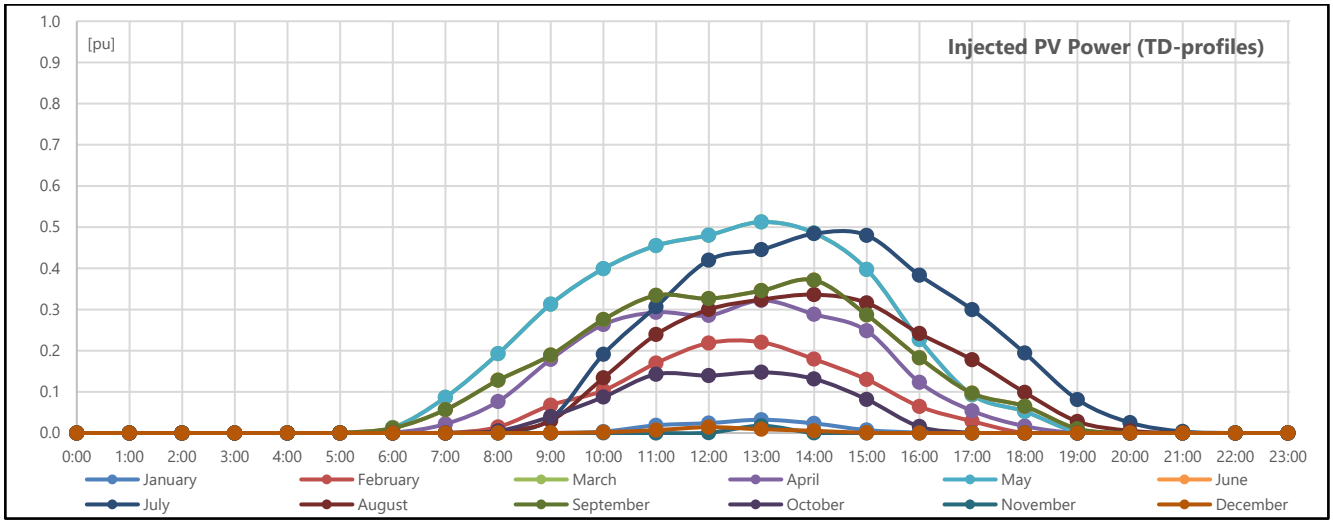



***Figure 4**: Typical Daily Profile of injected PV Power for the Aardehuizen-Olst PV-C.S*

| Power fed by the LDN [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 0:00 | 0.086 | 0.101 | 0.044 | 0.060 | 0.044 | 0.048 | 0.051 | 0.043 | 0.048 | 0.066 | 0.111 | 0.121 |
| 1:00 | 0.094 | 0.050 | 0.033 | 0.053 | 0.033 | 0.039 | 0.044 | 0.039 | 0.039 | 0.058 | 0.052 | 0.062 |
| 2:00 | 0.070 | 0.047 | 0.039 | 0.039 | 0.039 | 0.037 | 0.047 | 0.049 | 0.037 | 0.038 | 0.034 | 0.051 |
| 3:00 | 0.040 | 0.049 | 0.047 | 0.035 | 0.047 | 0.052 | 0.047 | 0.053 | 0.052 | 0.041 | 0.032 | 0.053 |
| 4:00 | 0.039 | 0.057 | 0.043 | 0.042 | 0.043 | 0.046 | 0.044 | 0.043 | 0.046 | 0.050 | 0.032 | 0.055 |
| 5:00 | 0.050 | 0.046 | 0.028 | 0.061 | 0.028 | 0.039 | 0.046 | 0.042 | 0.039 | 0.051 | 0.033 | 0.041 |
| 6:00 | 0.067 | 0.050 | 0.088 | 0.193 | 0.088 | 0.138 | 0.131 | 0.089 | 0.138 | 0.183 | 0.040 | 0.048 |
| 7:00 | 0.228 | 0.255 | 0.036 | 0.182 | 0.036 | 0.108 | 0.160 | 0.104 | 0.108 | 0.199 | 0.191 | 0.172 |
| 8:00 | 0.255 | 0.227 | 0.021 | 0.152 | 0.021 | 0.030 | 0.152 | 0.115 | 0.030 | 0.196 | 0.273 | 0.232 |
| 9:00 | 0.281 | 0.201 | 0.012 | 0.097 | 0.012 | 0.046 | 0.089 | 0.060 | 0.046 | 0.176 | 0.267 | 0.229 |
| 10:00 | 0.171 | 0.094 | 0.004 | 0.050 | 0.004 | 0.024 | 0.030 | 0.026 | 0.024 | 0.085 | 0.227 | 0.195 |
| 11:00 | 0.157 | 0.012 | 0.003 | 0.014 | 0.003 | 0.006 | 0.017 | 0.015 | 0.006 | 0.060 | 0.216 | 0.148 |
| 12:00 | 0.098 | 0.012 | 0.014 | 0.018 | 0.014 | 0.013 | 0.007 | 0.019 | 0.013 | 0.074 | 0.197 | 0.125 |
| 13:00 | 0.093 | 0.004 | 0.002 | 0.029 | 0.002 | 0.018 | 0.009 | 0.020 | 0.018 | 0.074 | 0.117 | 0.135 |
| 14:00 | 0.111 | 0.008 | 0.002 | 0.025 | 0.002 | 0.005 | 0.002 | 0.015 | 0.005 | 0.046 | 0.166 | 0.129 |
| 15:00 | 0.125 | 0.008 | 0.004 | 0.022 | 0.004 | 0.035 | 0.008 | 0.020 | 0.035 | 0.053 | 0.203 | 0.158 |
| 16:00 | 0.174 | 0.108 | 0.121 | 0.152 | 0.121 | 0.135 | 0.012 | 0.024 | 0.135 | 0.275 | 0.260 | 0.174 |
| 17:00 | 0.501 | 0.452 | 0.207 | 0.206 | 0.207 | 0.187 | 0.008 | 0.024 | 0.187 | 0.460 | 0.350 | 0.460 |
| 18:00 | 0.552 | 0.518 | 0.094 | 0.197 | 0.094 | 0.127 | 0.004 | 0.005 | 0.127 | 0.352 | 0.396 | 0.471 |
| 19:00 | 0.493 | 0.446 | 0.174 | 0.334 | 0.174 | 0.190 | 0.007 | 0.015 | 0.190 | 0.416 | 0.289 | 0.442 |
| 20:00 | 0.450 | 0.451 | 0.191 | 0.236 | 0.191 | 0.208 | 0.019 | 0.030 | 0.208 | 0.391 | 0.238 | 0.448 |
| 21:00 | 0.340 | 0.357 | 0.128 | 0.123 | 0.128 | 0.139 | 0.036 | 0.038 | 0.139 | 0.208 | 0.212 | 0.374 |
| 22:00 | 0.193 | 0.169 | 0.094 | 0.086 | 0.094 | 0.093 | 0.064 | 0.057 | 0.093 | 0.122 | 0.188 | 0.245 |
| 23:00 | 0.124 | 0.109 | 0.049 | 0.066 | 0.049 | 0.056 | 0.057 | 0.050 | 0.056 | 0.068 | 0.148 | 0.185 |

***Table V**: Typical Daily Profile of power fed by the LDN for the Aardehuizen-Olst PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

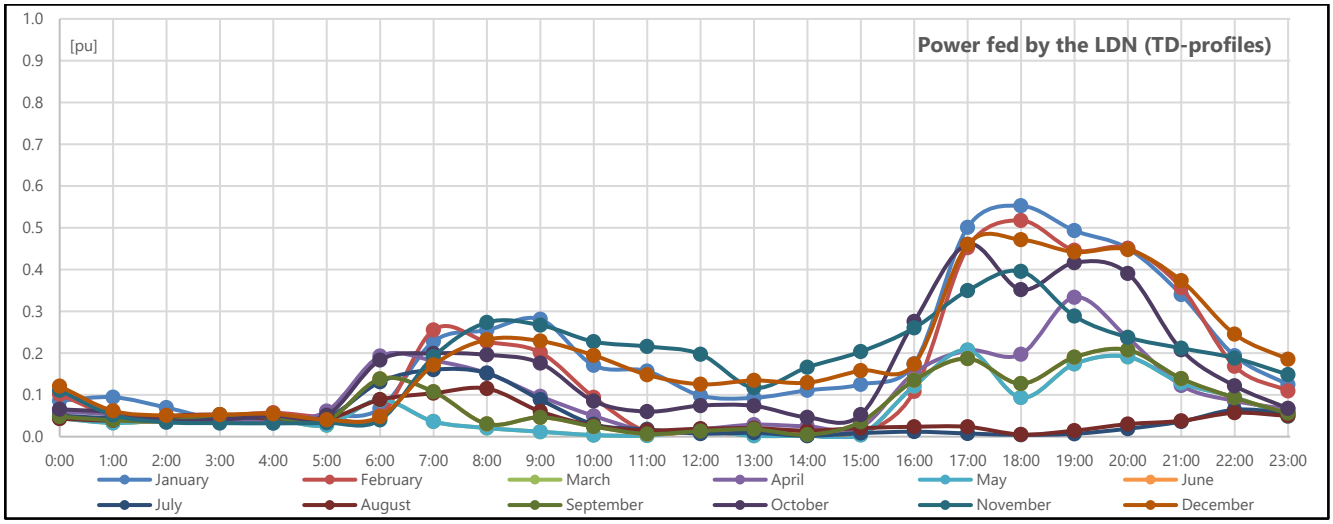
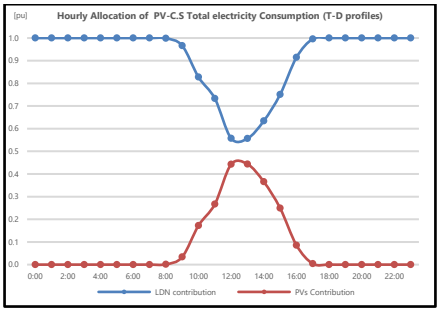
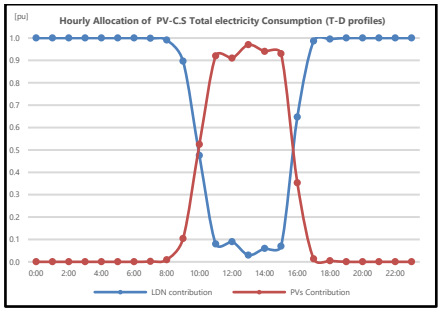



***Figure 5**: Typical Daily Profile of power fed by the LDN for the Aardehuizen-Olst PV-C.S*

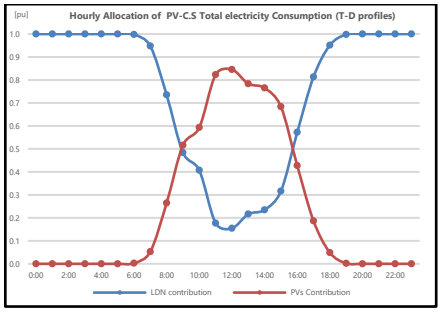
**Figures 6** illustrates the typical hourly allocation of PV-C.S's total electricity consumption for twelve months. Both LDN and PVs hourly contributions are divided with the corresponding hourly value of the PV-C.S total electrical consumption and thus their sum is always equal to unit. After a careful analysis of **Figure 6** it is concluded that, even in the case where the energy transactions are considered as hourly values, there are time intervals (particularly during spring and summer) where the energy needs of the PV-C.S are serviced by PVs in high rates (almost around 100%). This is a remarkable load reduction for LDN, particular when the high penetration level of such PV-C.Ss comes into consideration.



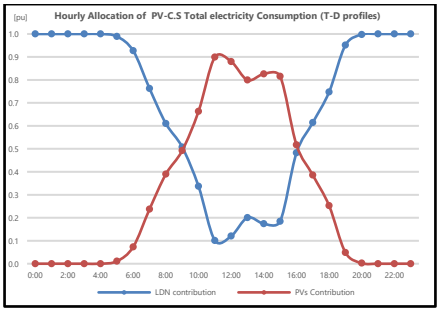

January



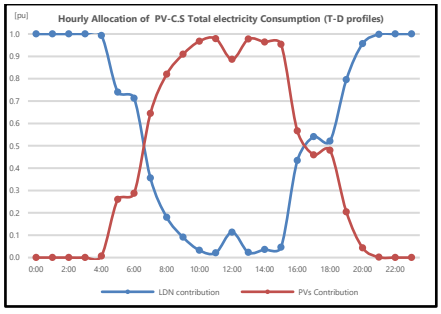

February



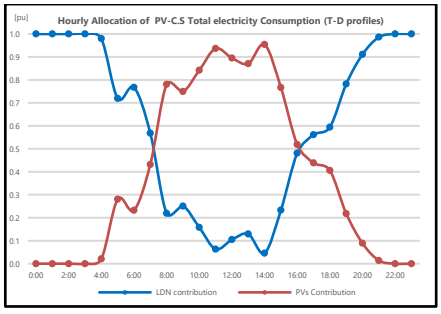

March




April

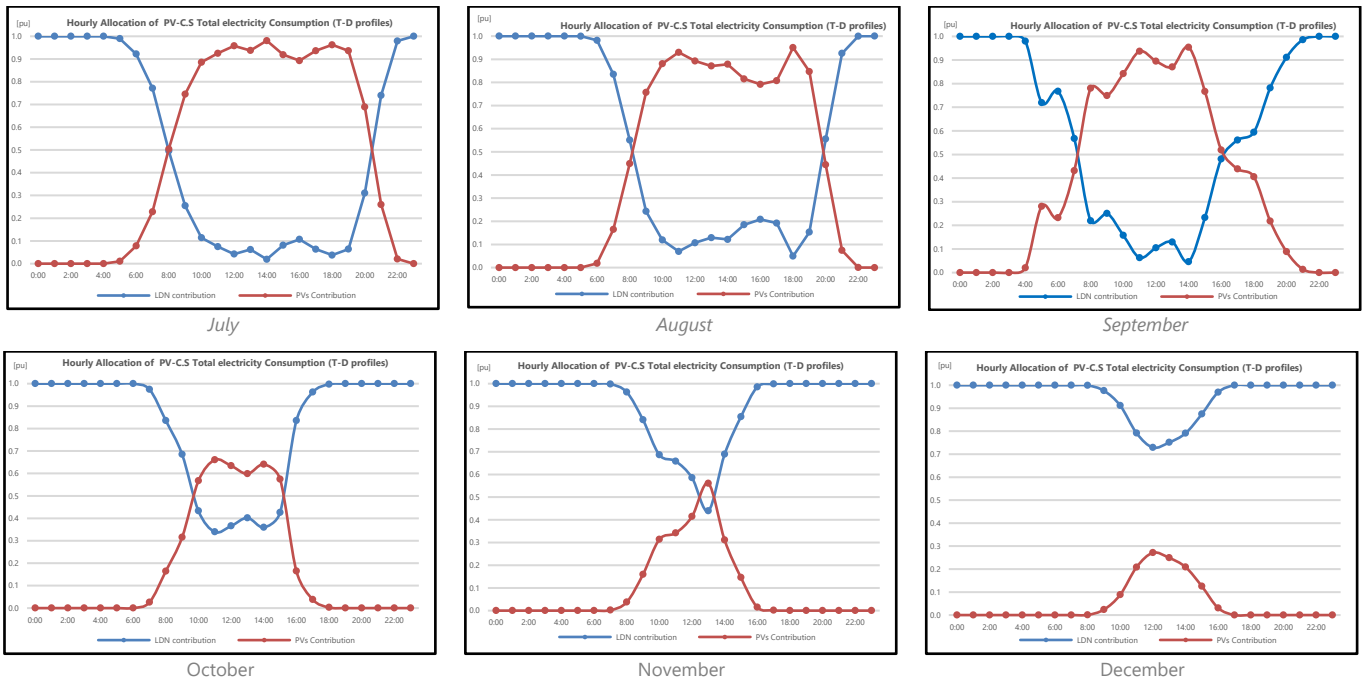



May




June

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

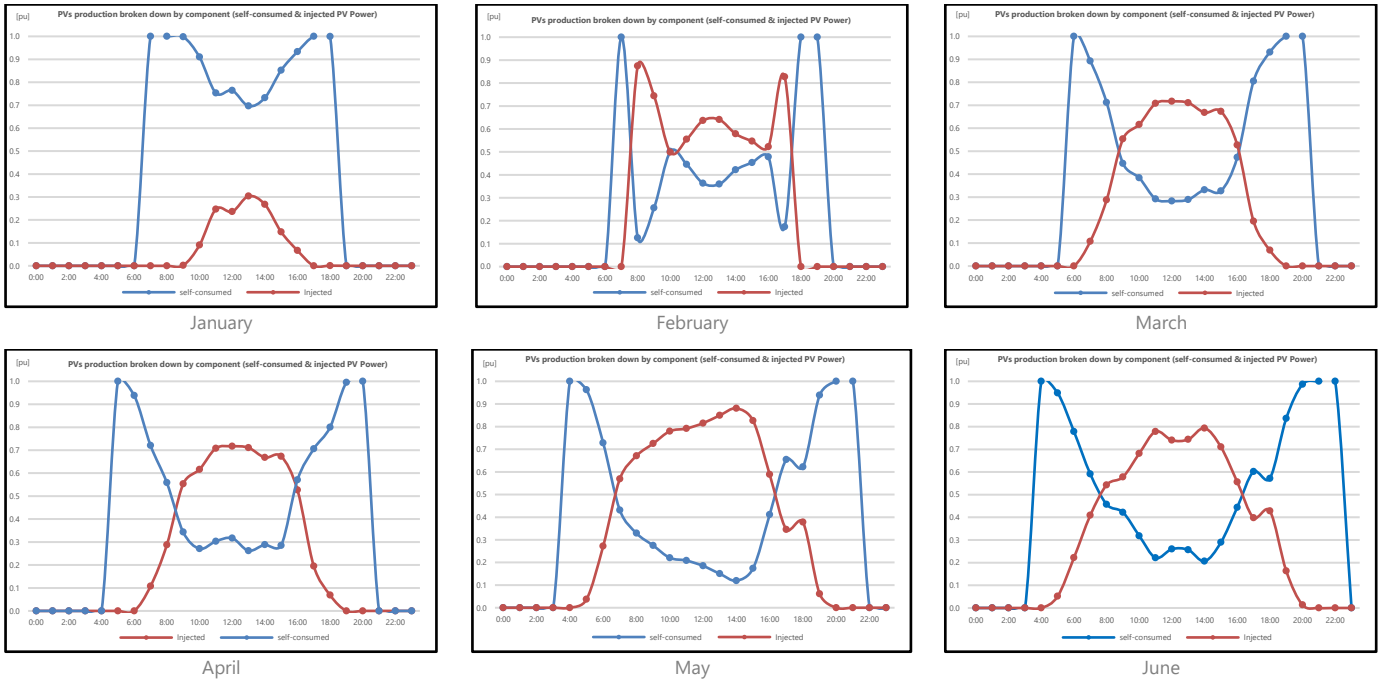



July | August | September

October | November | December

***Figure 6**: Hourly Allocation of PV-C.S total electricity consumption for each month of the reporting period (TD-profiles)*

In more detail, the total generation of an electrical power system is continuously adjusted to limit the frequency variation within an acceptable range. Therefore, the event of a remarkable load reduction (due to a significant match of the on-site demand of PV-C.Ss with local production from RES), may affect the scheduled operation of conventional power plants, pushing them to reduce their power output very close to their lower technical operational limits. Such a situation will also jeopardize exchanges through the interconnection line.




January | February | March

April | May | June

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

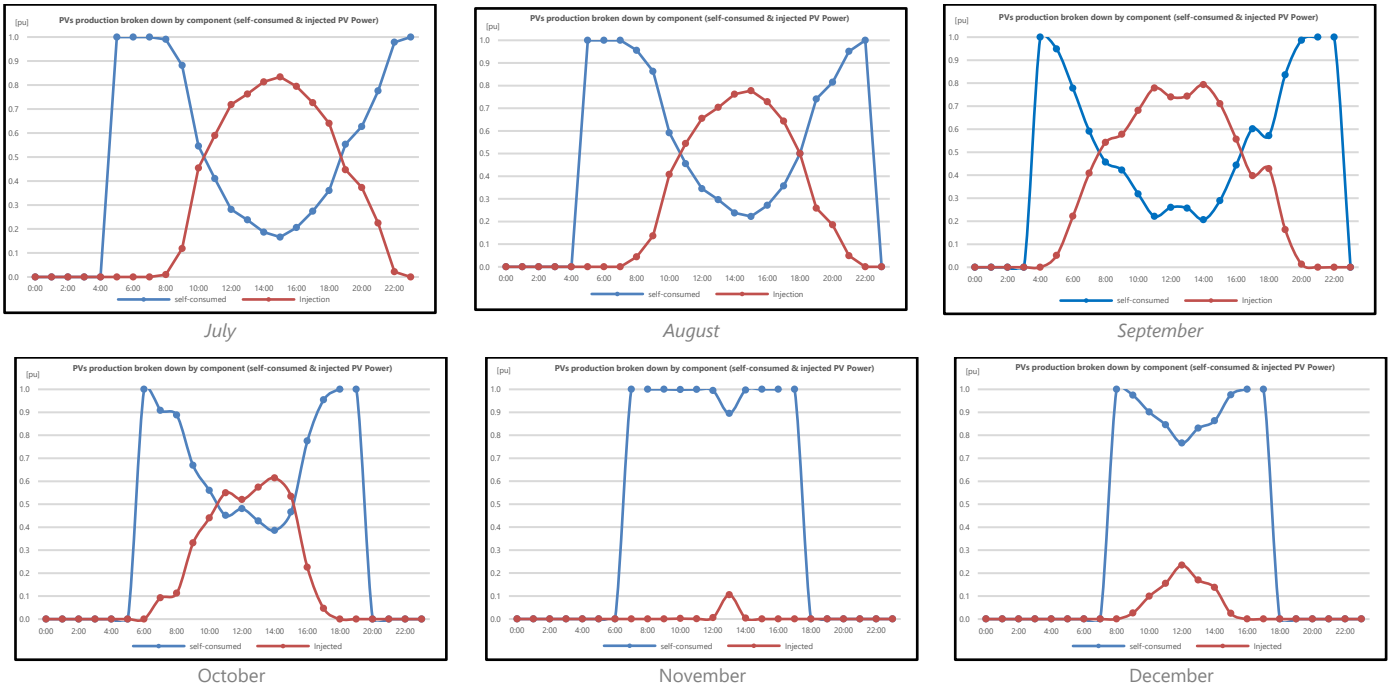



***Figure 7**: typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Power)*

**Figures 7** illustrates the typical day profiles of the total PVs production broken down by component (self-consumed & injected PV Energy). Both components of hourly contributions are divided with the corresponding hourly value of the total PVs production and thus their sum is always equal to unit. After a careful analysis of **Figure 7** it is concluded that, both PVs production components are comparable during spring and summer.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

## 3.6. Iveron Monastery Autonomous Hybrid PV-C.S (Greece)

The next three tables and figures present the typical daily profiles of the: a) Iveron Monastery PV-C.S total electrical power consumption, b) produced PV Power and c) Power fed by the LDN (diesel generator). A pu system was introduced with the nominal power of the installed PV system consisting the base value of the system (60.84kW). All the other reported power quantities are specified as multiples of the selected base value. In the end of February 2018, the capacity of PV system was upgraded to 83kWp. Therefore, the base value for March, April and May is 83kWp

| PV-C.S total electrical power consumption [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 6:00 | 0.88 | 0.85 | 0.57 | 0.37 | 0.39 | 0.88 | 0.81 | 0.73 | 0.61 | 1.01 | 1.03 | 0.87 |
| 7:00 | 0.90 | 1.04 | 0.75 | 0.44 | 0.49 | 1.09 | 1.02 | 1.00 | 0.91 | 0.96 | 1.08 | 1.00 |
| 8:00 | 1.02 | 1.13 | 0.79 | 0.45 | 0.48 | 1.18 | 1.14 | 1.06 | 1.05 | 0.92 | 0.99 | 1.01 |
| 9:00 | 0.98 | 1.04 | 0.78 | 0.55 | 0.60 | 1.28 | 1.18 | 1.04 | 1.16 | 1.03 | 1.06 | 1.01 |
| 10:00 | 0.95 | 0.99 | 0.77 | 0.55 | 0.61 | 1.22 | 1.13 | 1.08 | 1.03 | 1.15 | 1.17 | 0.99 |
| 11:00 | 1.04 | 1.10 | 0.82 | 0.63 | 0.72 | 1.22 | 1.24 | 1.12 | 0.99 | 1.10 | 1.19 | 0.99 |
| 12:00 | 1.01 | 1.03 | 0.75 | 0.60 | 0.67 | 1.17 | 1.17 | 1.11 | 1.00 | 1.10 | 1.15 | 1.00 |
| 13:00 | 0.92 | 0.95 | 0.69 | 0.52 | 0.63 | 1.07 | 1.07 | 1.06 | 1.00 | 1.19 | 1.23 | 0.95 |
| 14:00 | 1.08 | 1.17 | 0.76 | 0.60 | 0.68 | 0.99 | 1.28 | 1.19 | 0.98 | 1.20 | 1.27 | 1.13 |
| 15:00 | 1.13 | 1.13 | 0.74 | 0.55 | 0.71 | 1.19 | 1.11 | 1.13 | 1.15 | 1.16 | 1.18 | 1.05 |
| 16:00 | 1.01 | 1.06 | 0.76 | 0.57 | 0.70 | 0.94 | 1.15 | 1.18 | 0.92 | 1.03 | 1.01 | 1.04 |
| 17:00 | 0.88 | 0.88 | 0.67 | 0.67 | 0.68 | 0.99 | 1.02 | 1.05 | 0.90 | 0.83 | 0.88 | 0.92 |
| 18:00 | 0.84 | 0.87 | 0.62 | 0.59 | 0.56 | 0.76 | 0.96 | 0.99 | 0.79 | 0.72 | 0.77 | 0.83 |
| 19:00 | 0.72 | 0.81 | 0.60 | 0.47 | 0.46 | 0.79 | 0.72 | 0.72 | 0.81 | 0.70 | 0.73 | 0.74 |
| 20:00 | 0.68 | 0.78 | 0.58 | 0.41 | 0.39 | 0.64 | 0.66 | 0.66 | 0.65 | 0.68 | 0.70 | 0.70 |
| 21:00 | 0.66 | 0.75 | 0.56 | 0.41 | 0.39 | 0.59 | 0.63 | 0.63 | 0.61 | 0.66 | 0.67 | 0.69 |
| 22:00 | 0.66 | 0.74 | 0.54 | 0.43 | 0.39 | 0.60 | 0.86 | 0.85 | 0.59 | 0.63 | 0.70 | 0.64 |
| 23:00 | 0.61 | 0.72 | 0.52 | 0.40 | 0.38 | 0.60 | 0.99 | 0.85 | 0.52 | 0.79 | 0.81 | 0.59 |

***Table I**: Typical Daily Profile of total electrical consumption for the Iveron Monastery PV-C.S*

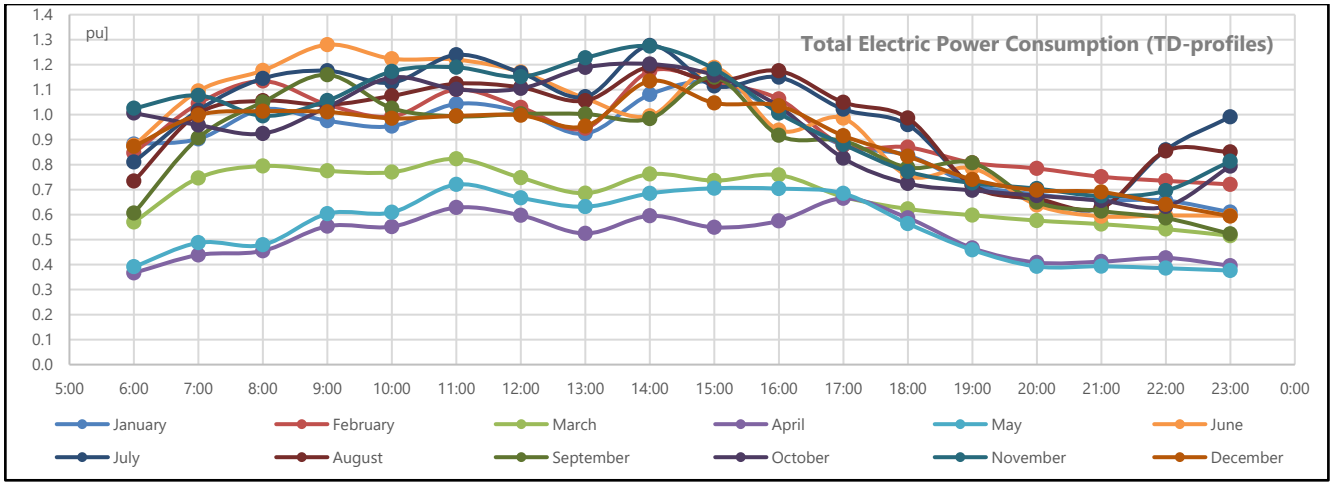



***Figure 1**: Typical Daily Profile of total electrical consumption for the Iveron Monastery PV-C.S*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

| Produced PV Power [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 6:00 | 0.000 | 0.000 | 0.002 | 0.001 | 0.008 | 0.015 | 0.007 | 0.002 | 0.000 | 0.004 | 0.000 | 0.000 |
| 7:00 | 0.001 | 0.002 | 0.046 | 0.031 | 0.056 | 0.073 | 0.049 | 0.034 | 0.014 | 0.104 | 0.012 | 0.002 |
| 8:00 | 0.036 | 0.046 | 0.170 | 0.166 | 0.191 | 0.216 | 0.186 | 0.165 | 0.116 | 0.296 | 0.093 | 0.060 |
| 9:00 | 0.163 | 0.106 | 0.266 | 0.298 | 0.322 | 0.385 | 0.364 | 0.359 | 0.296 | 0.454 | 0.218 | 0.216 |
| 10:00 | 0.255 | 0.146 | 0.296 | 0.290 | 0.335 | 0.504 | 0.504 | 0.514 | 0.422 | 0.574 | 0.296 | 0.357 |
| 11:00 | 0.329 | 0.164 | 0.314 | 0.353 | 0.443 | 0.626 | 0.626 | 0.616 | 0.521 | 0.551 | 0.316 | 0.372 |
| 12:00 | 0.375 | 0.170 | 0.285 | 0.357 | 0.417 | 0.618 | 0.649 | 0.666 | 0.544 | 0.508 | 0.305 | 0.390 |
| 13:00 | 0.345 | 0.174 | 0.266 | 0.257 | 0.353 | 0.589 | 0.640 | 0.667 | 0.481 | 0.547 | 0.267 | 0.353 |
| 14:00 | 0.317 | 0.177 | 0.306 | 0.332 | 0.412 | 0.607 | 0.674 | 0.679 | 0.490 | 0.456 | 0.248 | 0.307 |
| 15:00 | 0.236 | 0.165 | 0.281 | 0.281 | 0.391 | 0.581 | 0.615 | 0.656 | 0.468 | 0.311 | 0.140 | 0.130 |
| 16:00 | 0.035 | 0.083 | 0.217 | 0.289 | 0.362 | 0.475 | 0.531 | 0.560 | 0.381 | 0.154 | 0.020 | 0.014 |
| 17:00 | 0.003 | 0.011 | 0.078 | 0.251 | 0.275 | 0.354 | 0.374 | 0.374 | 0.233 | 0.011 | 0.001 | 0.000 |
| 18:00 | 0.000 | 0.000 | 0.010 | 0.137 | 0.150 | 0.163 | 0.184 | 0.164 | 0.074 | 0.000 | 0.000 | 0.000 |
| 19:00 | 0.000 | 0.000 | 0.000 | 0.024 | 0.042 | 0.048 | 0.046 | 0.033 | 0.006 | 0.000 | 0.000 | 0.000 |
| 20:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.008 | 0.008 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 |
| 21:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23:00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

***Table II**: Typical Daily Profile of produced PV Power for the Iveron Monastery PV-C*

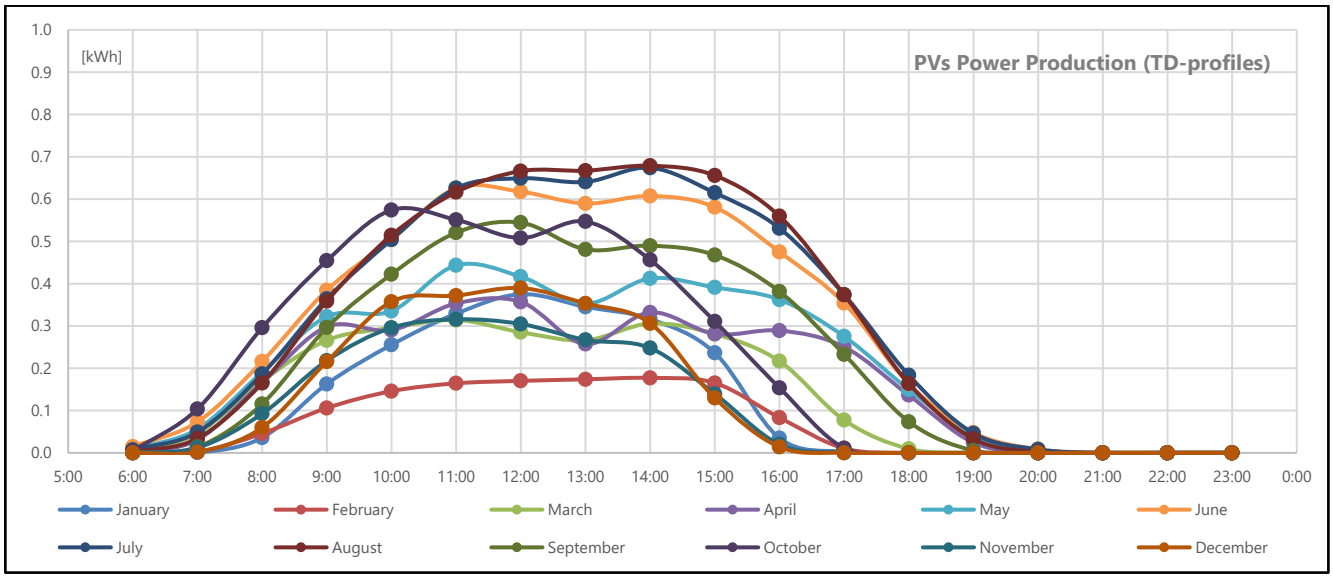



***Figure 2**: Typical Daily Profile of produced PV Power for the Iveron Monastery PV-C*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764805

| Power fed by the LDN [pu] (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| 6:00 | 0.882 | 0.847 | 0.568 | 0.366 | 0.383 | 0.862 | 0.803 | 0.733 | 0.606 | 1.002 | 1.025 | 0.873 |
| 7:00 | 0.902 | 1.042 | 0.701 | 0.407 | 0.431 | 1.021 | 0.968 | 0.970 | 0.893 | 0.854 | 1.065 | 0.996 |
| 8:00 | 0.986 | 1.088 | 0.624 | 0.289 | 0.288 | 0.960 | 0.958 | 0.890 | 0.935 | 0.628 | 0.902 | 0.953 |
| 9:00 | 0.813 | 0.934 | 0.509 | 0.255 | 0.282 | 0.895 | 0.811 | 0.681 | 0.863 | 0.576 | 0.838 | 0.795 |
| 10:00 | 0.698 | 0.847 | 0.474 | 0.262 | 0.274 | 0.719 | 0.624 | 0.561 | 0.604 | 0.575 | 0.877 | 0.628 |
| 11:00 | 0.714 | 0.936 | 0.509 | 0.275 | 0.277 | 0.594 | 0.614 | 0.507 | 0.473 | 0.550 | 0.874 | 0.623 |
| 12:00 | 0.637 | 0.858 | 0.462 | 0.240 | 0.251 | 0.553 | 0.518 | 0.443 | 0.458 | 0.597 | 0.847 | 0.608 |
| 13:00 | 0.579 | 0.771 | 0.419 | 0.267 | 0.279 | 0.476 | 0.431 | 0.388 | 0.521 | 0.641 | 0.960 | 0.601 |
| 14:00 | 0.764 | 0.996 | 0.456 | 0.263 | 0.272 | 0.387 | 0.602 | 0.513 | 0.494 | 0.746 | 1.026 | 0.828 |
| 15:00 | 0.893 | 0.962 | 0.455 | 0.268 | 0.314 | 0.608 | 0.500 | 0.477 | 0.682 | 0.847 | 1.043 | 0.917 |
| 16:00 | 0.978 | 0.979 | 0.541 | 0.285 | 0.342 | 0.463 | 0.619 | 0.615 | 0.536 | 0.879 | 0.985 | 1.021 |
| 17:00 | 0.874 | 0.866 | 0.593 | 0.414 | 0.409 | 0.631 | 0.647 | 0.675 | 0.662 | 0.814 | 0.880 | 0.915 |
| 18:00 | 0.838 | 0.870 | 0.613 | 0.450 | 0.414 | 0.592 | 0.776 | 0.822 | 0.715 | 0.725 | 0.773 | 0.833 |
| 19:00 | 0.720 | 0.807 | 0.597 | 0.442 | 0.417 | 0.738 | 0.673 | 0.682 | 0.801 | 0.697 | 0.726 | 0.741 |
| 20:00 | 0.681 | 0.785 | 0.576 | 0.408 | 0.389 | 0.630 | 0.652 | 0.662 | 0.649 | 0.676 | 0.704 | 0.697 |
| 21:00 | 0.659 | 0.751 | 0.562 | 0.412 | 0.393 | 0.593 | 0.627 | 0.627 | 0.614 | 0.656 | 0.675 | 0.690 |
| 22:00 | 0.656 | 0.735 | 0.542 | 0.427 | 0.386 | 0.597 | 0.859 | 0.855 | 0.586 | 0.632 | 0.695 | 0.641 |
| 23:00 | 0.610 | 0.721 | 0.515 | 0.395 | 0.376 | 0.595 | 0.991 | 0.851 | 0.523 | 0.794 | 0.814 | 0.594 |

***Table III**: Typical Daily Profile of power fed by the LDN (Diesel Generators) for the Iveron Monastery PV-C.S*

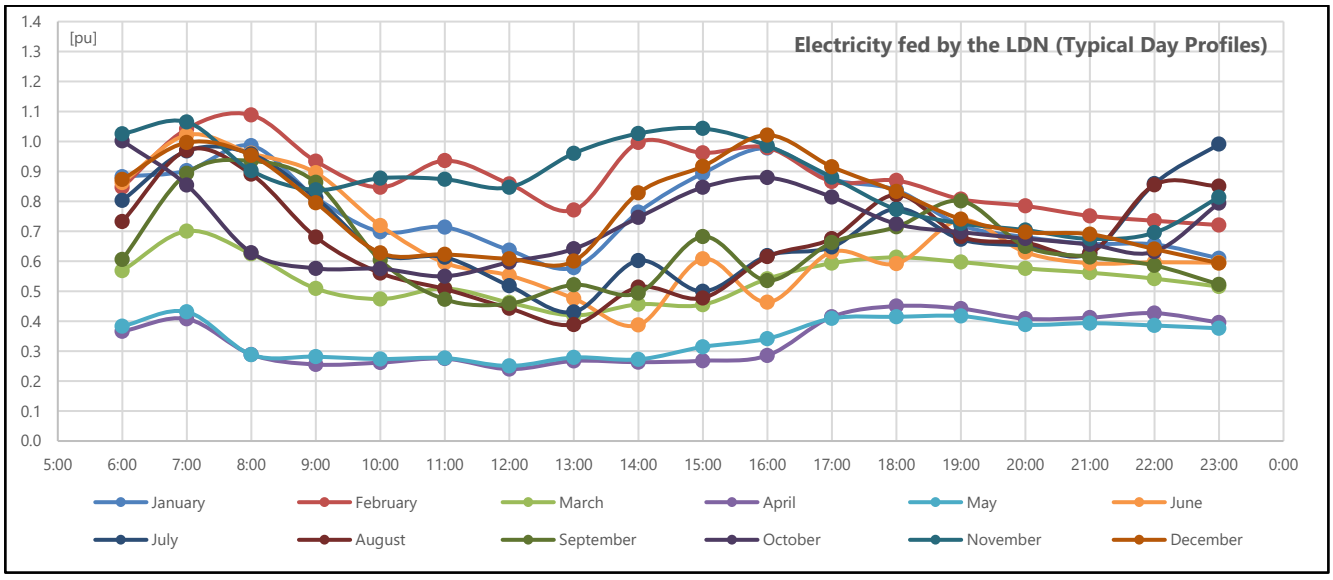



***Figure 3**: Typical Daily Profile of power fed by the LDN (Diesel Generators) for the Iveron Monastery PV-C.S*

**Figures 4** illustrates the typical hourly allocation of PV-C.S's total electricity consumption for each month of the reporting period. Both LDN and PVs hourly contributions are divided with the corresponding hourly value of the PV-C.S's total electrical consumption and thus their sum is always equal to unit. After a careful analysis of **Figure 4** it is concluded that, the application of an external set point controller that

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limits PVs production (curtailed operation), as well as the absence of an energy storage system, limits PVs contribution at 65% at the very most.

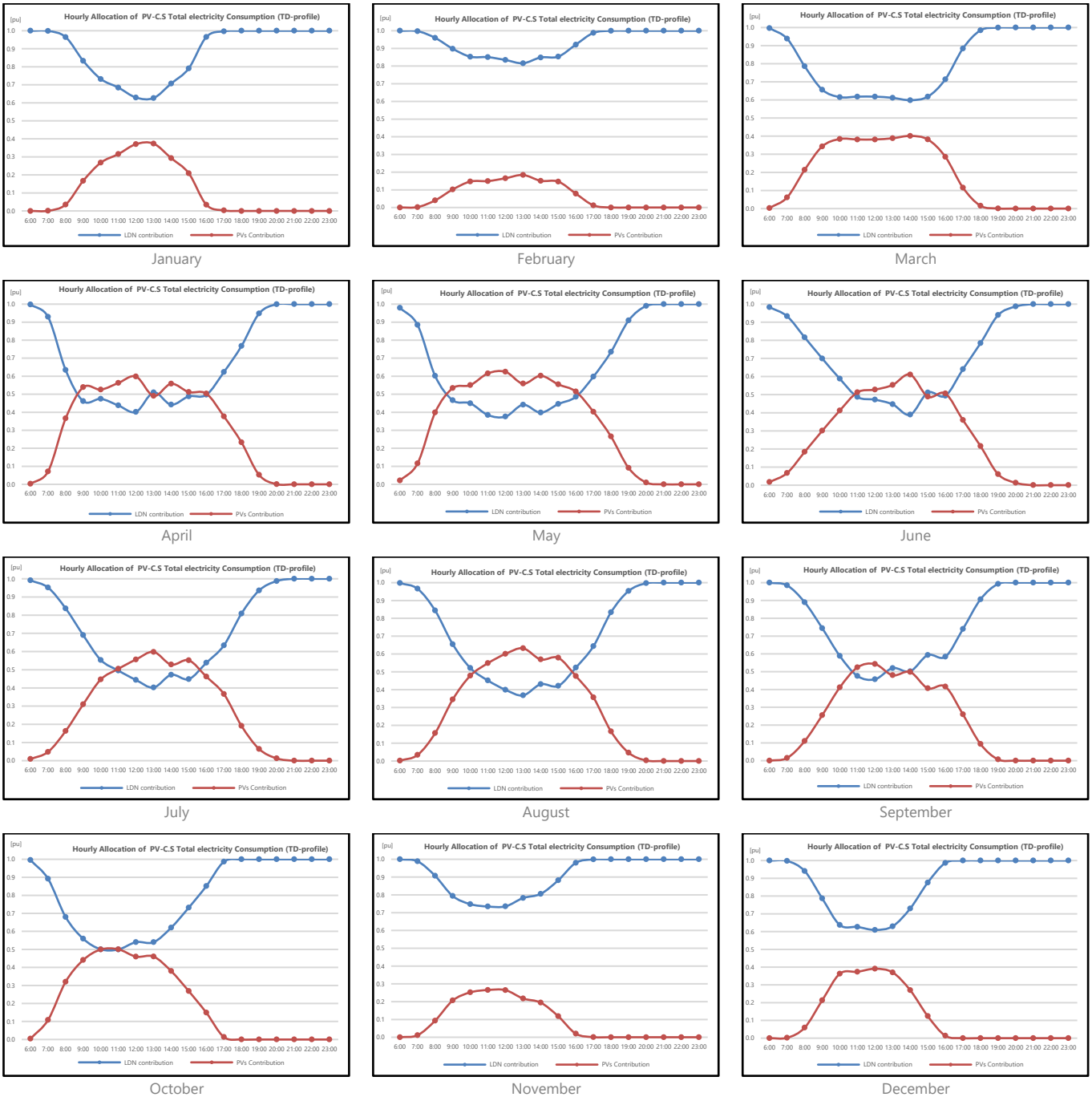


***Figure 4**: Hourly Allocation of PV-C.S total electricity consumption for each month of the reporting period (TD-profiles)*

Considering that energy storage systems and battery inverters were not installed (in order to minimize the initial cost of the PV investment) an external controller monitors the diesel generator to ensure that it is always operating at least at a predefined minimum power level to prolong its service life. In case there is an excess of produced PV energy, the controller adjusts extremely quickly the MPPT operation of each inverter (reducing the produced PV energy). Therefore, PVs production falls under curtailed operation.

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Indeed, the annual PVs production amount to 89% of the theoretical optimum. Next Table presents the values of PVs Exploitation Index for the typical day of each month as well as the corresponding amount of the unexploited PV Energy.

| PVs curtailed operation (Typical Day profiles) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| PVE [%] | 89.82 | 92.87 | 86.13 | 84.68 | 84.03 | 93.18 | 92.62 | 89.63 | 87.54 | 90.4 | 96.77 | 91.29 |

***Table IV**: Values of PVs Exploitation Index for the typical day of each month, for the Iveron Monastery PV-C.S*

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## 3.7. Primary school of Warthausen Grid Connected PV-C.S (Germany)

In the case of Warthausen Grid Connected PV-C.S,there are no detail energy measurements but only cumulative monthly values. **Table I** presents the monthly values of the energy transactions between the output of the PV inverters, the Warthausen PV-C.S and the LDN for each month of the reporting period

| | PV-C.S total electrical consumption [kWh] | Total produced PV Energy [kWh] | Self-consumed PV Energy [kWh] | Injected PV Energy [kWh] | Electricity fed by the LDN [kWh] |
|---|---|---|---|---|---|
| January | 6.100 | 0.640 | 0.640 | 0.000 | 5.460 |
| February | 5.000 | 3.360 | 2.100 | 1.260 | 2.900 |
| March | 6.100 | 7.850 | 2.100 | 5.750 | 4.000 |
| April | 4.900 | 7.810 | 2.100 | 5.710 | 2.800 |
| May | 4.900 | 10.470 | 2.100 | 8.370 | 2.800 |
| June | 4.000 | 10.950 | 2.100 | 8.850 | 1.900 |
| July | 3.500 | 9.880 | 2.100 | 7.780 | 1.400 |
| August | 3.500 | 9.620 | 1.500 | 8.120 | 2.000 |
| September | 4.500 | 7.150 | 2.100 | 5.050 | 2.400 |
| October | 4.900 | 6.140 | 2.100 | 4.040 | 2.800 |
| November | 6.200 | 2.100 | 2.100 | 0.000 | 4.100 |
| December | 6.300 | 1.310 | 1.000 | 0.310 | 5.300 |
| AVG monthly value | 4.992 | 6.440 | 1.837 | 4.603 | 3.155 |
| Yearly | 59.900 | 77.280 | 22.040 | 55.240 | 37.860 |

***Table I**: monthly energy transactions between the output of the PV inverters, the Warthausen Grid PV-C.S and LDN*

**Figure 1** illustrates Warthausen PV-C.S monthly energy balance, as it is defined by the equilibrium of the PV-C.S total electrical consumption, the self-consumed PV energy and the electricity fed by the LDN.

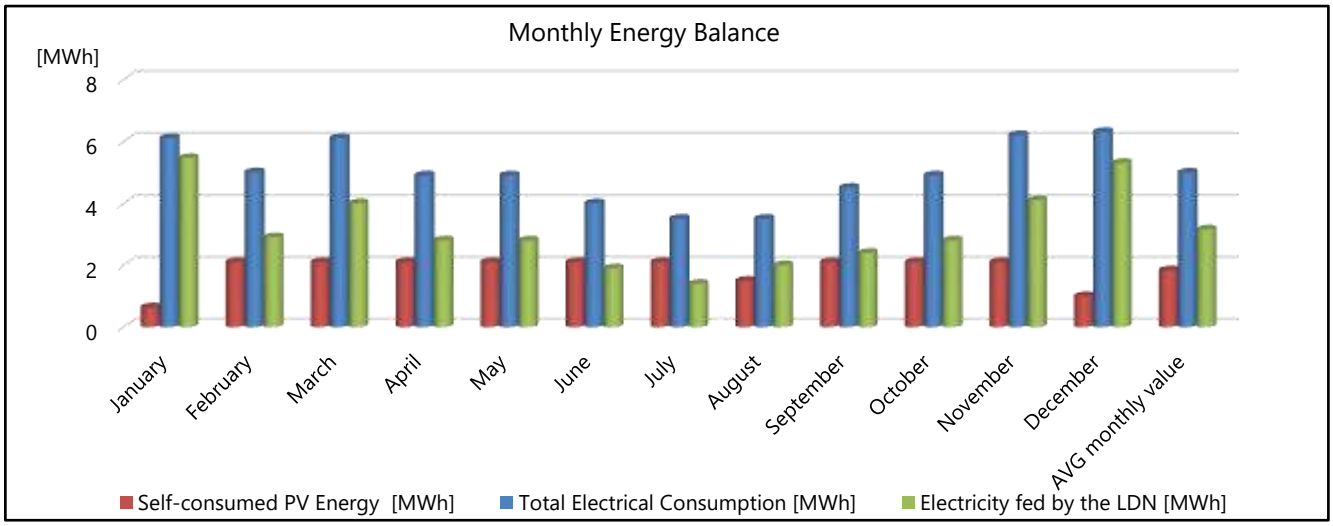


***Figure 1**: Warthausen PV-C.S monthly energy balance*

**Table II** presents the monthly values of the Final Yield Index, Self-Consumption Index, Self-Sufficiency Index, Capacity Utilisation Index and PVs Injection Index for the case of Warthausen PV-C.S and for each month of the reporting period. PVs Exploitation Index was omitted because Warthausen PV-C.S does not fall under curtailed operation.

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| | FY Index [kWh/kWp] | S-C Index [%] | S-S Index [%] | CU Index [%] | PVI Index [%] |
|---|---|---|---|---|---|
| January | 8.448 | 100.000 | 10.492 | 1.173 | 0.000 |
| February | 44.351 | 62.500 | 42.000 | 5.961 | 37.500 |
| March | 103.617 | 26.752 | 34.426 | 13.927 | 73.248 |
| April | 103.089 | 26.889 | 42.857 | 14.318 | 73.111 |
| May | 138.200 | 20.057 | 42.857 | 18.575 | 79.943 |
| June | 144.535 | 19.178 | 52.500 | 20.074 | 80.822 |
| July | 130.412 | 21.255 | 60.000 | 17.528 | 78.745 |
| August | 126.980 | 15.593 | 42.857 | 17.067 | 84.407 |
| September | 94.377 | 29.371 | 46.667 | 14.044 | 70.629 |
| October | 81.045 | 34.202 | 42.857 | 10.893 | 65.798 |
| November | 27.719 | 100.000 | 33.871 | 3.850 | 0.000 |
| December | 17.291 | 76.336 | 15.873 | 2.324 | 23.664 |
| Annual value | 1020.063 | 28.520 | 36.795 | 15.134 | 71.480 |

***Table II**: monthly values of the Final Yield Index, Self-Consumption Index, Self-Sufficiency Index, Capacity Utilisation Index and PVs Injection Index for the case of Warthausen PV-C.S*

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## 3.8. Conclusions

Most of the case studies analysed above represent residential applications that produce part or all of their electrical needs by installing small scale decentralized PV systems. Indeed, net metering and energy community schemes around Europe permit household owners/users to self-produce their own clean/green energy.

Based on the findings and considerations of the above paragraphs, it is concluded that the maximum hourly value of the produced PV power (for all PV case studies) is at most equal to 70% of the contracted PV capacity. This conclusion has been reached after giving careful consideration to the curves that depict the Typical Daily Profile of total produced PV Power for each PV case study. Additionally, according to the curves that illustrate the Typical Daily Profile of total electrical consumption for each PV case study, the maximum value of under study building's power consumption is usually less than 60% of the contracted PV capacity. In this context is noted that the maximum values of PVs production and buildings consumption take place at different times, whilst the power consumption varies between 5 and 35 % of the contracted PV capacity at the time intervals where the maximum PV production is exploited. As a result, significant amounts of PV energy are injected into the electricity grid. This finding is confirmed by studying both the curves that present the Typical Daily Profile of injected PV power into the electricity grid (for each PV case study), and the Typical day profiles of the total PVs production, broken down by component (self-consumed & injected PV Power). This is a very important outcome of interest to the electrical grid and will become more crucial as the electricity generation will shift from few and large classical dispatchable units to many smaller intermittent RES.

Additionally, by studying the curves that illustrate the Hourly Allocation of PV-C.Ss total electrical power consumption during the course of a calendar year, it is concluded that there are time intervals where the energy needs of all PV-C.Ss are covered by PVs in high rates (almost around 100%). This happens particularly during spring and summer. This is a remarkable load reduction for LDN, particular when high penetration level of such PV-C.Ss comes into consideration. The results of this specific situation are made more understandable by considering the operation of electrical power systems. In more detail, the total generation of an electrical power system is continuously adjusted to limit the frequency variation within an acceptable range. Therefore, the event of a remarkable load reduction (due to a significant match of the on-site demand of PV-C.Ss with local production from RES), may affect the scheduled operation of conventional power plants, pushing them to reduce their power output very close to their lower technical operational limits. Such a situation will also jeopardize exchanges through the interconnection line.

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# 4. Selection of smart grid operation – services

During the last decades, thousand MWs of RES power plants have been connected to the power networks throughout Europe, either at transmission or distribution level, in order to mitigate climate change and to facilitate EU objectives for sustainable renewable energy supply. Grid-connected PV systems constitute an important representative of RES at electrical distribution networks because these systems can be installed even in densely populated areas. However, PVs' variable and stochastic nature jeopardizes the operation of traditional electric systems, violating frequently the scheduled operation of thermal and hydro generators as well as the exchanges through interconnections. To avoid a generalized system collapse, as well as to maintain voltage and frequency within well-defined windows, new electricity network architectures in combination with smart monitoring and communication technologies are entering into the limelight. These new sophisticated network architectures are called smart grids.

The main scope of smart grids is to enable consumers and producers to participate to grid management and to improve the operation of the entire energy production, transmission and distribution chain, in reliable and economic terms. To achieve these objectives, smart grids a) offset the energy demand with growing RES investments, b) motivate consumers to modify their electrical consumption profile c) stabilise the production of intermittent RES by utilising energy storage systems, and d) facilitate bidirectional flows of power across transmission and distribution chain. Therefore, the lack of flexibility in power generation and energy demand (which are the most critical issues in traditional electric systems) are treated in an appropriate manner. **Figure 1** presents a generic scheme of the physical connection between the potential components of a smart low voltage distribution network, as well as the interactions among all components by introducing smart meters, local and central smart controllers and telecommunication infrastructures. Smart metering devices, controllers and communication devices are used to facilitate bidirectional information and energy flows across the entire energy production, transmission and distribution chain, and to adjust the energy production from all available dispatchable or non-dispatchable generation sources to the varying load demand.

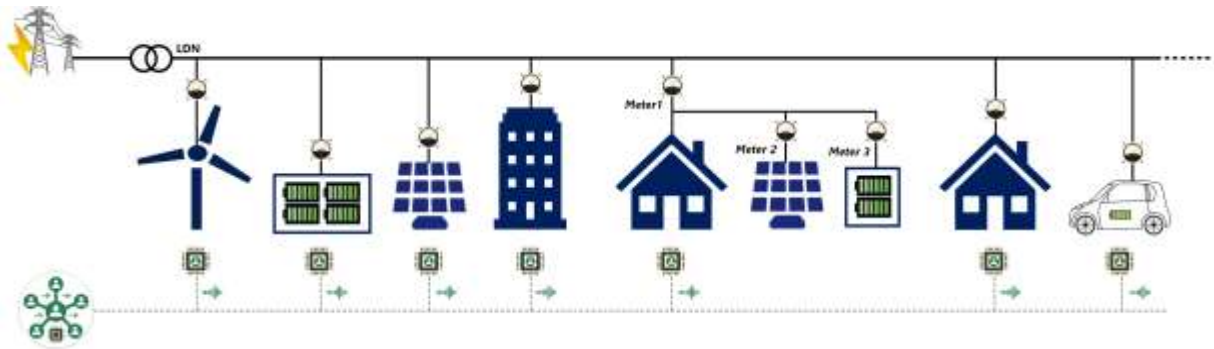


***Figure 1**: Generic scheme of smart low voltage distribution network*

Considering the energy profile of consumers / producers (prosumers) from the 11 PV case studies of EU Heroes projects, their Common Coupling Point (all PV-C.Ss are connected at distribution level) and the outcomes from WP4 and WP5, we conclude that **D**emand **R**esponse (**D-R**) and **E**nergy **S**torage **S**ystems (**E.S**$^2$) seem to be the most appropriate smart-grid services that can be implemented on the above mentioned case studies.

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Demand Response is a valuable tool whose capabilities could have a potential impact on demand profile either by reducing or shifting consumers' electricity usage during peak periods or by motivating consumers to modify their electrical consumption profile according to RES availability. Thus, D-R offer flexibility on electrical system operation. Consumers are remunerated either for their D-R availability (following contracted time-based rates and critical peak rebates) or for the procurement of the service (following variable peak pricing or real-time pricing and time-of-use pricing). Sometimes, D-R includes the direct control of air conditioner or heat pump units as well as water heaters (from aggregators) during periods of peak demand or peak RES production. Considering that the energy consumption profiles of the 11 PV-C.Ss are provided in the form of a single aggregated energy value, the EU Heroes consortium does not have a detailed picture of electricity consumption components and thus the impacts from the application of a DR scheme cannot be quantified.

Grid connected E.S$^2$ are regarded as an important component of smart grids, because they are able to provide flexibility to electricity networks. For example, E.S$^2$ can enable market participants to provide ancillary services such as frequency control, load following and ramping support, or can contribute to flexibility by reducing demand peaks and/or RES power production peaks. Additionally, E.S$^2$ can improve the operation of distribution networks by providing ancillary services such as voltage regulation or congestion management (either due to power system's physical or operational limitations). Hereinafter and for segregation purposes, E.S$^2$ that are installed in distribution networks will be referred to as **D**istributed **E**nergy **S**torage **S**ystems (**D.E.S$^2$**).

Up to now, ancillary services from E.S$^2$ have been considered solely on large-scale energy storage systems that are usually connected to high voltage transmission networks, whilst, small D.E.S$^2$ (up to a few tens of KWhs) are foreseen in order to increase the self-consumption rate of low voltage level RES prosumers (improving in some case the profitability of PV systems' owners).

Considering the 11 PV-C.Ss of the EU Heroes project, as well as the outcomes from WP4 and WP5, next we are going to focus on D.E.S$^2$. In more detail, D.E.S$^2$ are regarded to be either behind the meter (in the case of single households) or behind the Common Coupling Point (in the case of building complex or energy communities of very limited geographical area). In both cases, D.E.S$^2$ will be used not only to increase the self-consumption of locally generated clean electricity, but also to provide ancillary services to distribution networks. In this way, peaks in energy transactions between PV-C.Ss and grid can be reduced and the profitability of PVs' owners can be increased by maximizing the self-utilization of locally generated clean electricity. Moreover D.E.S$^{2'}$ owners are remunerated for the procurement of ancillary service (congestion management), resulting in an extra decrease in the electricity bills. Regarding DNOs, small energy storage systems could be a means to avoid (or postpone) the expensive grid investments, to increase flexibility and to reduce risks. Analytically, D.E.S$^2$ can provide auxiliary services such as mitigation of grid congestion and appeasement of transformers and lines thermal overload. Additionally, D.E.S$^2$ may absorb PV energy either from local produced PV energy or from neighbouring PV investments (without storage facilities) at midday hours with high irradiation and low electric load and inject it back to the grid at hours with electrical energy demand.

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Although in the recent past D.E.S$^2$ were not economically profitable for private users, today a general interest in local green electricity is driving many people to invest in small storage systems. Indeed, nowadays, both markets (large-scale E.S$^2$ at high voltage transmission networks and small D.E.S$^2$) are developed rather dynamically, due to decreasing costs of Lithium-ion batteries. It should be noted that Bloomberg's Energy Finance (BNEF) ninth Battery Price Survey states that prices of lithium-ion batteries fell 85% from 2010 to 2018, reaching the price of 176$/ kWh (wholesale price). Additionally, according to the same Survey, the cost of E.S$^2$ is expected to fall roughly 52% through 2030 (reaching the price of 85$/ kWh).

Next, in order to evaluate the results of the proposed smart grid services on the part of PV-C.Ss' owners, we consider the following assumptions:

- Under Net-Metering scheme, prosumers avoid all the charges (such as competitive charges, transmission and distribution grid charges, $CO_2$ emissions fees) for the electricity that they self-produce and consume simultaneously (self-utilisation), with the sole exception of the social services fees. The excess electricity injected into the grid can be used at a later time to offset (compensate) consumption during times when PV generation is absent or not sufficient. The excess energy (which is injected into the grid) is compensated with consumed energy; however, only competitive charges are subject to the compensation. The next Table summarizes the electricity tariffs for the EU Heroes' PV-C.Ss. It is recalled here that the total tariff for electricity energy supply is calculated by adding both competitive and regulated charges. Social services fees are not taken into account.

| Electricity tariffs without VAT | Greece | Poland | Lithuania | Netherlands | Germany |
|---|---|---|---|---|---|
| Competitive Charges (Power procurement) | 0.11058 | 0.11 | 0.10 | 0.13 | 0.13 |
| Regulated Charges (transmission and distribution grid charges, CO2 emissions fees) | ~40% of the competitive charges | ~30% of the competitive charges | ~30% of the competitive charges | ~50% of the competitive charges | ~50% of the competitive charges |

***Table I**: Electricity tariffs without VAT for the PV-C.Ss of EU Heroes project*

- Based on the abovementioned Battery Price Survey, the price of lithium-ion batteries will be considered at 100€ per kWh, a value which is significantly lower than current spot market prices (which are in the range of 300-400 € per kWh).
- The capital expenditure (CAPEX) of small PV systems ranges from 800 to 1200€/kWp (without VAT), around Europe, depending mainly on the installed capacity of the plants and PV modules' technology (mainstream or high efficiency modules, BIPV products, etc). It is noted that today CAPEX prices are significantly lower than those at the time the PV-C.Ss were implemented. For the sole purpose of this report, CAPEX is regarded to 1000€/kWp (including exclusive procurement, transportation and construction costs) for all the PV-C.Ss. Additionally, for simplicity, the Operating Expenses (OPEX) of the PV-C.Ss will be ignored.

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- The proposed capacities of D.E.S2 are not deriving from the application of cost function, and therefore may not be optimal.On the contrary, the proposals should be considered as a vehicle for the development of new business models that facilitates the steady increase of renewable energy sources in distribution level, as well as the transformation of traditional electric systems into smart grids. For the calculation of the optimal D.E.S$^2$ capacity, a well-defined market for ancillary services at distribution level (e.g. with predefined remuneration tariffs for time-based services, critical peak rebates, variable peak pricing, real-time pricing and time-of-use pricing) is needed. Instead, this report attempts to identify, through a simplified procedure, a single remuneration tariff for the procurement of ancillary services at the distribution level that will make D.E.S$^2$ sustainable investments.

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## 4.1. Net-metering Passive Residence with PVs in Dąbrowa Chotomowska (Poland)

**Table I** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices. According to these data the annual value of PVs Self-Consumed Energy amounts to 25.15%, whilst the corresponding value of PVs Injected Energy amounts to 74.85%. It is recalled here that, the second component of Total Produced PV Energy injected into the grid, can be used at a later time to compensate PV-C.S's consumption during times when PV generation is absent or not sufficient (accounting treatment).

| Current situation (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 32.30 | 5.90 | 3.81 | 2.10 | 28.49 | 64.49 | 35.51 |
| 2 | 47.13 | 13.84 | 8.93 | 4.92 | 38.20 | 64.48 | 35.52 |
| 3 | 40.02 | 27.13 | 10.71 | 16.41 | 29.30 | 39.49 | 60.51 |
| 4 | 19.42 | 49.16 | 6.26 | 42.89 | 13.16 | 12.74 | 87.26 |
| 5 | 15.74 | 51.65 | 7.41 | 44.24 | 8.33 | 14.34 | 85.66 |
| 6 | 19.14 | 46.07 | 10.03 | 36.04 | 9.11 | 21.77 | 78.23 |
| 7 | 20.51 | 43.98 | 10.93 | 33.05 | 9.58 | 24.86 | 75.14 |
| 8 | 18.58 | 41.63 | 9.50 | 32.13 | 9.08 | 22.82 | 77.18 |
| 9 | 20.69 | 37.27 | 8.98 | 28.29 | 11.71 | 24.09 | 75.91 |
| 10 | 20.58 | 15.04 | 4.05 | 10.99 | 16.52 | 26.94 | 73.06 |
| 11 | 27.55 | 5.88 | 2.95 | 2.94 | 24.60 | 50.09 | 49.91 |
| 12 | 28.18 | 3.82 | 2.61 | 1.21 | 25.57 | 68.27 | 31.73 |

***Table I**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar (Current Situation)*

Considering the data from the table above, we conclude that PV-C.S' total Electrical Energy Consumption amounts to 9377kWh, whilst the PV-C.S self-produces and consumes simultaneously 2616kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 1118€. Following the capital expenditure value of 1000€/kWp (as discussed in section 4), the total cost of this PV investment amounts to 9750€ and therefore, a period of 105 months is required to recoup the investment.

Next, we are going to study a new scenario, called "**scenario I**", by introducing a small Li-ion D.E.S$^2$ to the current PV-C.S. In order to select the appropriate capacity of the D.E.S$^2$ we draw valuable information from **Figure 1**. In more detail, **Figure 1** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Days of twelve calendar months. After a careful assessment of these curves, we conclude that self-consumed PV Energy can be significantly increased by storing 10kWh of generated PV energy (at midday hours with high irradiation) and use them at a later time to compensate consumption during hours where PV generation is not sufficient or absent. Thus, the self-consumed PV Energy becomes comparable to the Total Electrical Energy Consumption of the PV-C.S.

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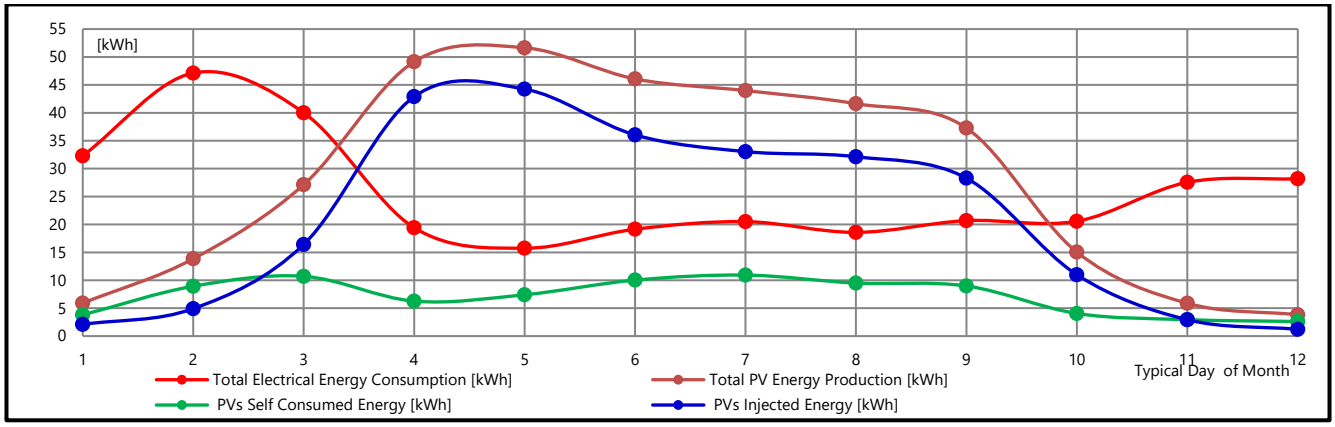


***Figure 1**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Days of twelve calendar months **(current situation)***

Considering that the **d**epth **o**f **d**ischarge (**DOD**) of an electrochemical storage system reflects its performance and protects batteries from over-discharge (improving so their life expectancy) we select the nominal capacity of the Li-ion D.E.S$^2$ to be equal to 12.5kWh and its useful capacity equal to 10 kWh (DOD≤80%).

**Table II** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of Self-Consumption, and PVs Injection Indices after the addition of the proposed Li-ion D.E.S$^2$ of 12.55kWh (nominal capacity) . According to these data the annual value of PVs self-consumed energy amounts to 50.7%, whilst the corresponding value of PVs injected Energy amounts to 48.14%.

| "Scenario I": addition of 12.5kWh Li-ion D.E.S$^2$ with 10kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 32.30 | 5.90 | 5.90 | 0.00 | 26.40 | 100.00 | 0.00 |
| 2 | 47.13 | 13.84 | 13.84 | 0.00 | 33.28 | 100.00 | 0.00 |
| 3 | 40.02 | 27.13 | 20.71 | 6.41 | 19.30 | 76.36 | 23.64 |
| 4 | 19.42 | 49.16 | 16.26 | 32.89 | 3.16 | 33.09 | 66.91 |
| 5 | 15.74 | 51.65 | 15.74 | 34.24 | 0.00 | 30.48 | 66.30 |
| 6 | 19.14 | 46.07 | 19.14 | 26.04 | 0.00 | 41.55 | 56.52 |
| 7 | 20.51 | 43.98 | 20.51 | 23.05 | 0.00 | 46.64 | 52.41 |
| 8 | 18.58 | 41.63 | 18.58 | 22.13 | 0.00 | 44.62 | 53.16 |
| 9 | 20.69 | 37.27 | 18.98 | 18.29 | 1.71 | 50.92 | 49.08 |
| 10 | 20.58 | 15.04 | 14.05 | 0.99 | 6.52 | 93.41 | 6.59 |
| 11 | 27.55 | 5.88 | 5.88 | 0.00 | 21.67 | 100.00 | 0.00 |
| 12 | 28.18 | 3.82 | 3.82 | 0.00 | 24.36 | 100.00 | 0.00 |

***Table II**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**Scenario I**")*

By studying the data from **Table II**, we conclude that in "**scenario I**" the PV-C.S self-produces and consumes simultaneously 5275kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to

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1305€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement and installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 11000€.

**Figure 2** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy), after the addition of the proposed 12.5kWh Li-ion D.E.S$^2$ and for the Typical Days of twelve calendar months.

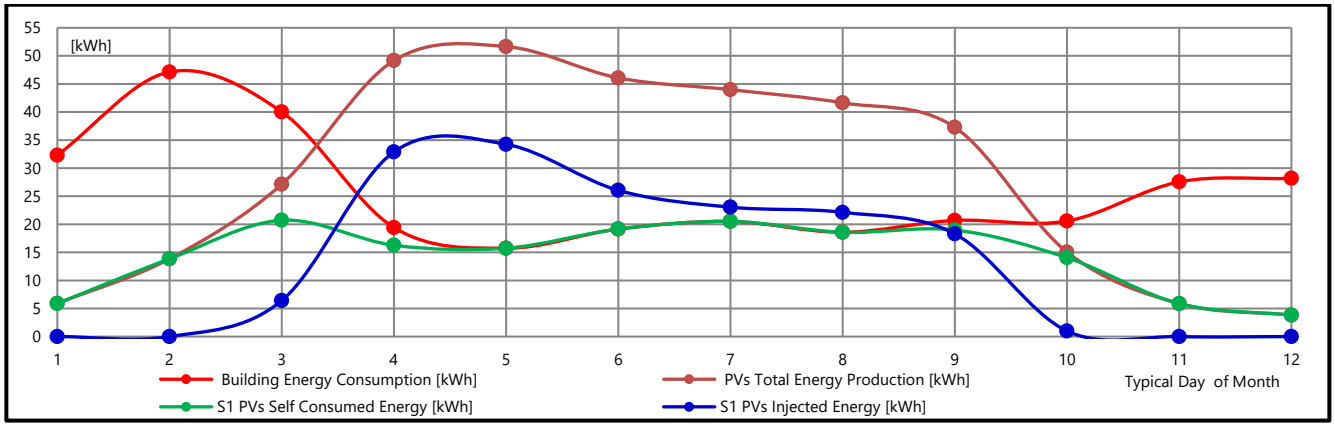


***Figure 2**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components after the addition of 12.5kWh Li-ion D.E.S$^2$ and for the Typical Days of twelve calendar months ("**scenario I**")*

At this point, it should be noted that the increase of 2659kWh of PVs Self-Consumed Energy (compared to the initial situation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.1. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload). Additionally, the proposed Li-ion D.E.S$^2$ of 12.5kWh (nominal capacity) is not fully utilized during January, February, November and December due to the low solar energy potential of these months. Thus, 872 kWhs of the D.E.S$^2$ remain unexploited. **Table III** presents the unexploited kWhs of Li-ion D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources. This service could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 44€ per year for the PV-C.S owners will result.

There is another very interesting point in this scenario. By introducing the D.E.S$^2$ of 12.5kWh (nominal capacity), we can store not only all the energy needed to meet the day-to-day energy needs of the PV-C.S (for the period from May to August) but even more. This is technically feasible due to the high solar energy potential of these months and the low energy demand of the PV-C.S. Considering that these KWhs are stored during midday hours (under high irradiation) it is concluded that they contribute to the mitigation of grid congestion. Therefore, these amounts of stored PV energy should be remunerated by the DNOs. This conclusion is clear by studying the data (at typical day level) set out in **Table IV**.

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| "Scenario I": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 7.90 | 245.01 |
| 2 | 5.08 | 142.32 |
| 3 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 |
| 7 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 |
| 9 | 0.00 | 0.00 |
| 10 | 0.00 | 0.00 |
| 11 | 7.06 | 211.93 |
| 12 | 8.79 | 272.38 |

***Table III**: Unexploited kWhs of the proposed D.E.S$^2$ of 12.5kWh nominal capacity and 10kWh useful capacity, either at Typical Day or Monthly level ("**Scenario I**")*

In more detail the difference between the Total Produced PV Energy and the sum of the PVs Self Consumed Energy and PVs Injected Energy, corresponds to kWhs that contribute to mitigation of congestion. **Table VI** presents the kWhs that contribute to mitigation of congestion either at Typical Day or Monthly level. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional very small benefit of about 6€ per year for the PV-C.S owners will result. Taking into account both ancillary services a period of 97 months is required to recoup the PV system and the D.E.S2 together.

| "Scenario I": kWhs that contribute to mitigation of congestion (Typical Days and Monthly values) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| Typical Day of Month [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 1.67 | 0.89 | 0.42 | 0.92 | 0.00 | 0.00 | 0.00 | 0.00 |
| Monthly Values [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 51.71 | 26.59 | 13.01 | 28.56 | 0.00 | 0.00 | 0.00 | 0.00 |

***Table IV**: kWhs that contribute to mitigation of congestion (Typical Days and Monthly values)*

Next, we are going to study a second scenario, named "**scenario II**", by introducing a second bigger, D.E.S$^2$ (18.75kWh nominal capacity and 15kWh useful capacity) to the current PV-C.S. **Table V** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices after the addition of the new Li-ion D.E.S$^2$ of 18.75kWh. According to these data the annual value of PVs self-consumed energy amounts to 53.89%, whilst the corresponding value of PVs injected Energy amounts to 37.56%.

By studying the data from **Table V**, we conclude that in "**scenario II**" the PV-C.S self-produces and consumes simultaneously 5607kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 1232€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement

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and installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 11625€.

| "Scenario II": addition of 25kWh Li-ion D.E.S$^2$ with 20kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total produced PV Energy [kWh] | PVs Self Consumed Energy [kWh] | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 32.30 | 5.90 | 5.90 | 0.00 | 26.40 | 100.00 | 0.00 |
| 2 | 47.13 | 13.84 | 13.84 | 0.00 | 33.28 | 100.00 | 0.00 |
| 3 | 40.02 | 27.13 | 25.71 | 1.41 | 14.30 | 94.79 | 5.21 |
| 4 | 19.42 | 49.16 | 19.42 | 27.89 | 0.00 | 39.51 | 56.74 |
| 5 | 15.74 | 51.65 | 15.74 | 29.24 | 0.00 | 30.48 | 56.62 |
| 6 | 19.14 | 46.07 | 19.14 | 21.04 | 0.00 | 41.55 | 45.67 |
| 7 | 20.51 | 43.98 | 20.51 | 18.05 | 0.00 | 46.64 | 41.04 |
| 8 | 18.58 | 41.63 | 18.58 | 17.13 | 0.00 | 44.62 | 41.15 |
| 9 | 20.69 | 37.27 | 20.69 | 13.29 | 0.00 | 55.51 | 35.66 |
| 10 | 20.58 | 15.04 | 15.04 | 0.00 | 5.53 | 100.00 | 0.00 |
| 11 | 27.55 | 5.88 | 5.88 | 0.00 | 21.67 | 100.00 | 0.00 |
| 12 | 28.18 | 3.82 | 3.82 | 0.00 | 24.36 | 100.00 | 0.00 |

***Table V**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**scenario II**")*

At this point, it should be noted that the increase of 2990kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.1. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload). Additionally, the proposed Li-ion D.E.S$^2$ of 18.75kWh (nominal capacity) is not fully utilized from January, to February and from October to December due to the low solar energy potential of these months. Thus, 1596 kWhs of the D.E.S$^2$ remain unexploited. **Table VI** presents the unexploited kWhs of the proposed D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources and therefore could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 80€ per year for the PV-C.S owners will result.

By introducing the D.E.S$^2$ of 18.75kWh (nominal capacity), we can store not only all the energy needed to meet the day-to-day energy needs of the PV-C.S (for the period from April to September) but even more. This is technically feasible due to the high solar energy potential of these months and the low energy demand of the PV-C.S. Considering that these KWhs are stored during midday hours (under high irradiation) it is concluded that they contribute to the mitigation of grid congestion. Therefore, these amounts of stored PV energy should be remunerated by the DNOs. This conclusion is clear by studying the data (at typical day level) set out in **Table V**. In more detail the difference between the Total Produced PV Energy and the sum of the PVs Self Consumed Energy and PVs Injected Energy, corresponds to kWhs that contribute to mitigation of congestion

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| "Scenario II": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 12.90 | *400.01* |
| 2 | 10.08 | *282.32* |
| 3 | 0.00 | *0.00* |
| 4 | 0.00 | *0.00* |
| 5 | 0.00 | *0.00* |
| 6 | 0.00 | *0.00* |
| 7 | 0.00 | *0.00* |
| 8 | 0.00 | *0.00* |
| 9 | 0.00 | *0.00* |
| 10 | 4.01 | *124.29* |
| 11 | 12.06 | *361.93* |
| 12 | 13.79 | *427.38* |

***Table VI**: Unexploited kWhs of the proposed D.E.S$^2$ of 18.75kWh nominal capacity and 15kWh useful capacity, either at Typical Day or Monthly level ("**Scenario II**")*

**Table VII** presents the kWhs that contribute to mitigation of congestion either at Typical Day or Monthly level. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 44€ per year for the PV-C.S owners will result. Taking into account both ancillary services a period of 103 months is required to recoup the PV system and the D.E.S$^2$ together.

| "Scenario II": kWhs that contribute to mitigation of congestion (Typical Days and Monthly values) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| Typical Day of Month [kWh] | 0.00 | 0.00 | 0.00 | 1.84 | 6.67 | 5.89 | 5.42 | 5.92 | 3.29 | 0.00 | 0.00 | 0.00 |
| Monthly Values [kWh] | 0.00 | 0.00 | 0.00 | 55.23 | 206.71 | 176.59 | 168.01 | 183.56 | 98.77 | 0.00 | 0.00 | 0.00 |

***Table VII**: kWhs that contribute to mitigation of congestion (Typical Days and Monthly values)*

Last but not least, **Figures 3** and **4** present the S-C and uncontrolled PVI indices of the PV-C.S for the typical day of twelve calendar months for: the Current Situation and the two hypothetical Scenarios (**Scenario I** and **Scenario II**). According to the data presented in this figure, it is concluded that D.E.S$^2$ can: a) maximize the self-utilization of locally generated clean electricity and b) contribute to the flexibility by reducing RES power production peaks.

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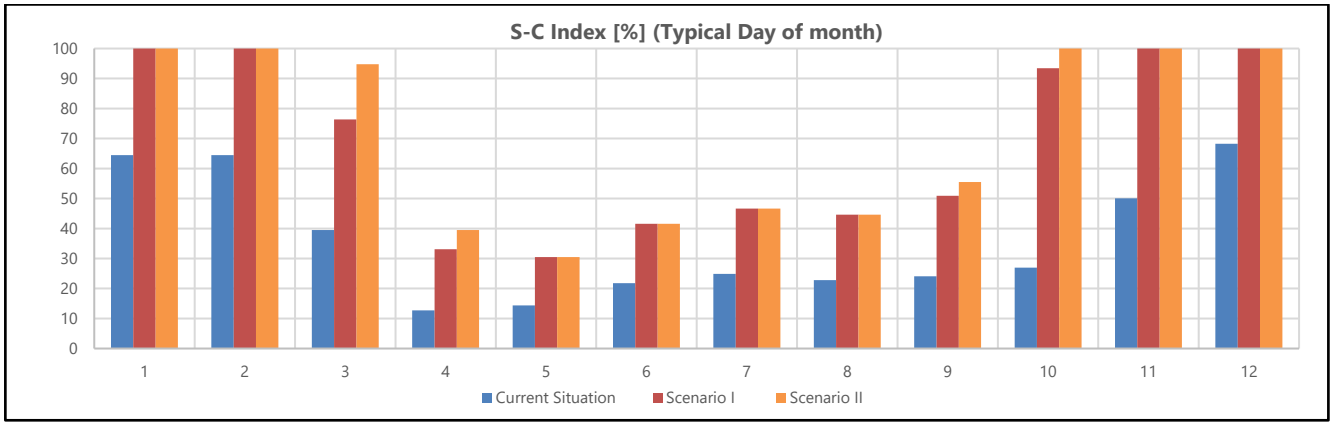


***Figure 3**: S-C Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 12.5kWh nominal capacity and b) 18.75kWh nominal*

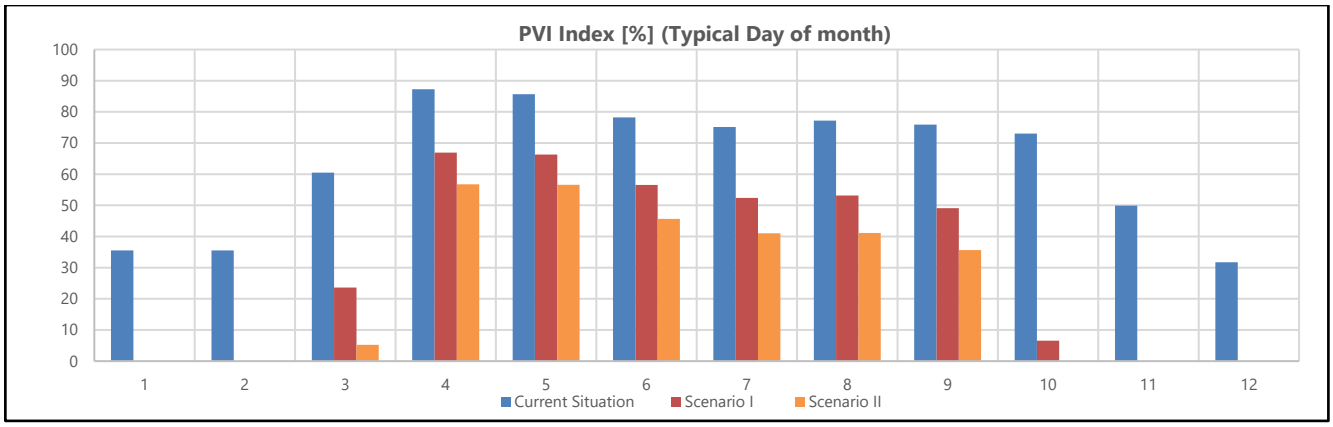


***Figure 4**: Uncontrolled PVI Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 12.5kWh nominal capacity and b) 18.75kWh nominal capacity*

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## 4.2. Net-metering PV Residence in Bukciai (Lithuania)

**Table I** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices. According to these data the annual value of PVs Self-Consumed Energy amounts to 30.72%, whilst the corresponding value of PVs Injected Energy amounts to 69.28%. It is recalled here that, the second component of Total Produced PV Energy injected into the grid, can be used at a later time to compensate PV-C.S's consumption during times when PV generation is absent or not sufficient (accounting treatment).

| Current situation (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 55.28 | 1.30 | 0.62 | 0.68 | 54.66 | 47.57 | 52.43 |
| 2 | 67.78 | 0.05 | 0.05 | 0.00 | 67.73 | 99.03 | 0.97 |
| 3 | 55.31 | 10.86 | 3.99 | 6.87 | 51.32 | 36.77 | 63.23 |
| 4 | 27.04 | 23.98 | 4.68 | 19.30 | 22.36 | 19.51 | 80.49 |
| 5 | 18.96 | 33.33 | 8.45 | 24.88 | 10.51 | 25.35 | 74.65 |
| 6 | 15.24 | 32.85 | 10.14 | 22.71 | 5.10 | 30.87 | 69.13 |
| 7 | 16.32 | 25.16 | 9.00 | 16.15 | 7.32 | 35.79 | 64.21 |
| 8 | 16.37 | 28.01 | 9.20 | 18.81 | 7.18 | 32.83 | 67.17 |
| 9 | 14.74 | 20.19 | 5.56 | 14.63 | 9.18 | 27.53 | 72.47 |
| 10 | 30.57 | 11.21 | 2.94 | 8.27 | 27.63 | 26.24 | 73.76 |
| 11 | 42.03 | 2.21 | 2.21 | 0.00 | 39.82 | 100.00 | 0.00 |
| 12 | 59.61 | 1.77 | 1.77 | 0.00 | 57.85 | 100.00 | 0.00 |

***Table I**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar (Current Situation)*

Considering the data from the table above, we conclude that PV-C.S' total Electrical Energy Consumption amounts to 12694kWh, whilst the PV-C.S self-produces and consumes simultaneously 1794kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 638€. Following the capital expenditure value of 1000€/kWp (as discussed in section 4), the total cost of this PV investment amounts to 6600€ and therefore, a period of 124 months is required to recoup the investment.

Next, we are going to study a new scenario, called "**scenario I**", by introducing a small Li-ion D.E.S$^2$ to the current PV-C.S. In order to select the appropriate capacity of the D.E.S$^2$ we draw valuable information from **Figure 1**. In more detail, **Figure 1** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Days of twelve calendar months. After a careful assessment of these curves, we conclude that self-consumed PV Energy can be increased in a significant way by storing 5kWh of generated PV energy (at midday hours with high irradiation) and use them at a later time to compensate consumption during hours where PV generation is not sufficient or absent. Thus, the self-consumed PV Energy becomes comparable to the Total Electrical Energy Consumption of the PV-C.S.

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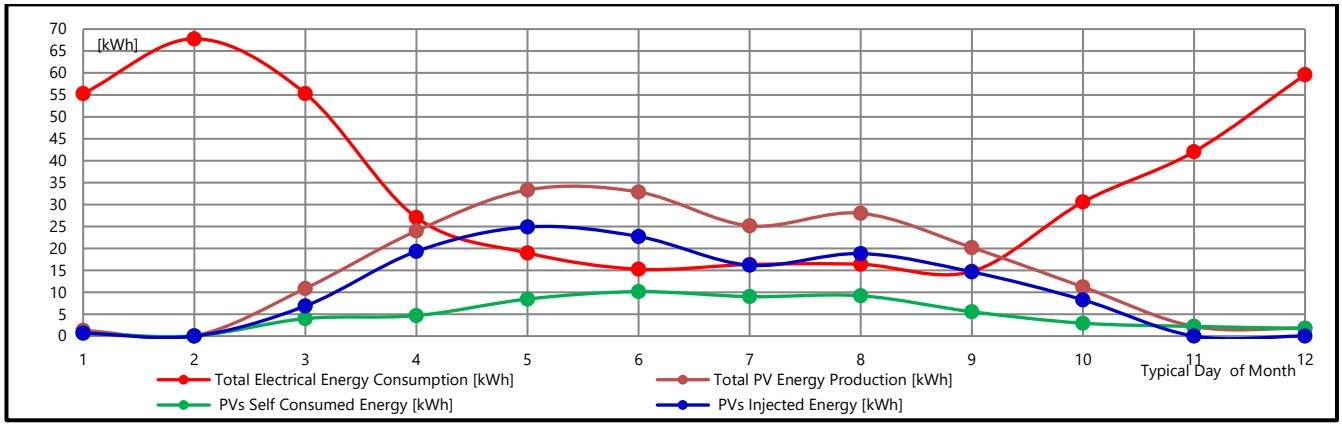


***Figure 1**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Day of twelve calendar months **(current situation)***

Considering that the DOD value of an electrochemical storage system reflects its performance and protects batteries from over-discharge (improving so their life expectancy) we select the nominal capacity of the Li-ion D.E.S[2] to be equal to 6.25kWh and its useful capacity equal to 5 kWh (DOD≤80%).

**Table II** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of Self-Consumption, and PVs Injection Indices after the addition of the proposed Li-ion D.E.S[2] of 6.25kWh (nominal capacity) . According to these data the annual value of PVs self-consumed energy amounts to 52.07%, whilst the corresponding value of PVs injected Energy amounts to 47.93%.

| "Scenario I": addition of 6.25kWh Li-ion D.E.S[2] with 5kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 55.28 | 1.30 | 1.30 | 0.00 | 53.98 | 100.00 | 0.00 |
| 2 | 67.78 | 0.05 | 0.05 | 0.00 | 67.73 | 100.00 | 0.00 |
| 3 | 55.31 | 10.86 | 8.99 | 1.87 | 46.32 | 82.80 | 17.20 |
| 4 | 27.04 | 23.98 | 9.68 | 14.30 | 17.36 | 40.36 | 59.64 |
| 5 | 18.96 | 33.33 | 13.45 | 19.88 | 5.51 | 40.35 | 59.65 |
| 6 | 15.24 | 32.85 | 15.14 | 17.71 | 0.10 | 46.09 | 53.91 |
| 7 | 16.32 | 25.16 | 14.00 | 11.15 | 2.32 | 55.66 | 44.34 |
| 8 | 16.37 | 28.01 | 14.20 | 13.81 | 2.18 | 50.68 | 49.32 |
| 9 | 14.74 | 20.19 | 10.56 | 9.63 | 4.18 | 52.29 | 47.71 |
| 10 | 30.57 | 11.21 | 7.94 | 3.27 | 22.63 | 70.86 | 29.14 |
| 11 | 42.03 | 2.21 | 2.21 | 0.00 | 39.82 | 100.00 | 0.00 |
| 12 | 59.61 | 1.77 | 1.77 | 0.00 | 57.85 | 100.00 | 0.00 |

***Table II**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**Scenario I**")*

By studying the data from **Table II**, we conclude that in "**scenario I**" the PV-C.S self-produces and consumes simultaneously 3040kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 675€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement and

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installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 7225€.

**Figure 2** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy), after the addition of the proposed 6.25kWh Li-ion D.E.S$^2$ and for the Typical Day of twelve calendar months.

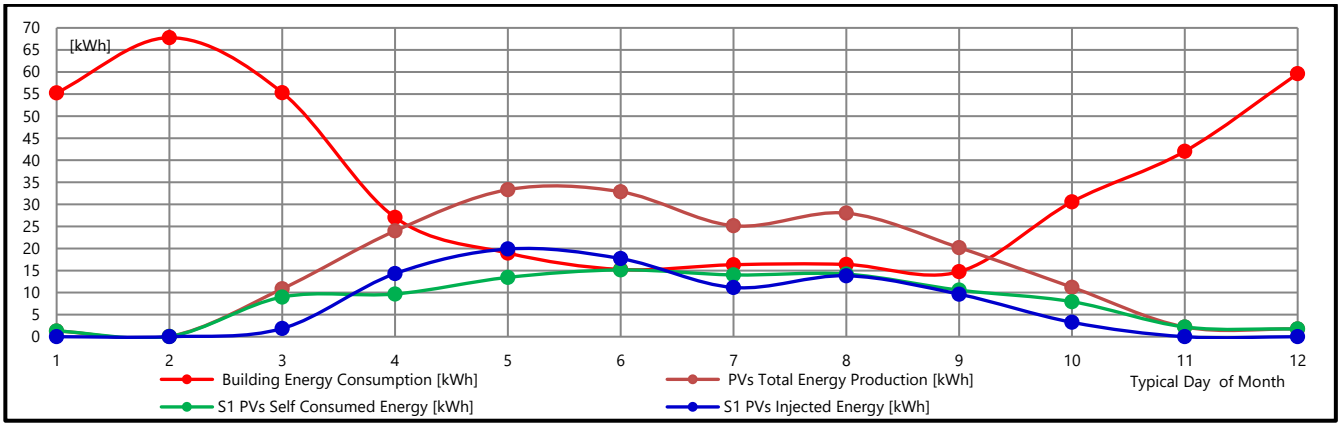


***Figure 2**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components after the addition of 6.25kWh Li-ion D.E.S$^2$ and for the Typical Days of twelve calendar months ("**scenario I**")*

At this point, it should be noted that the increase of 1246kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.2. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload).

| "Scenario I": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 4.32 | *133.79* |
| 2 | 5.00 | *139.99* |
| 3 | 0.00 | *0.00* |
| 4 | 0.00 | *0.00* |
| 5 | 0.00 | *0.00* |
| 6 | 0.00 | *0.00* |
| 7 | 0.00 | *0.00* |
| 8 | 0.00 | *0.00* |
| 9 | 0.00 | *0.00* |
| 10 | 0.00 | *0.00* |
| 11 | 5.00 | *150.00* |
| 12 | 5.00 | *155.00* |

***Table III**: Unexploited kWhs of the proposed D.E.S$^2$ of 6.25kWh nominal capacity and 5kWh useful capacity, either at Typical Day or Monthly level ("**Scenario I**")*

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Additionally, the proposed Li-ion D.E.S$^2$ of 6.25kWh (nominal capacity) is not fully utilized during January, February, November and December due to the low solar energy potential of these months. Thus, 579 kWhs of the D.E.S$^2$ remain unexploited. **Table III** presents the unexploited kWhs of Li-ion D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources. This service could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 29€ per year for the PV-C.S owners will result. Therefore, a period of roughly 123 months is required to recoup the PV system and the D.E.S$^2$ together.

Next, we are going to study a second scenario, named "**scenario II**", by introducing a second bigger, D.E.S$^2$ (10kWh nominal capacity and 8kWh useful capacity) to the current PV-C.S. **Table IV** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices after the addition of the new Li-ion D.E.S$^2$ of 10kWh. According to these data the annual value of PVs self-consumed energy amounts to 61.76%, whilst the corresponding value of PVs injected Energy amounts to 35.95%.

| "Scenario II": addition of 10kWh Li-ion D.E.S² with 10kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total produced PV Energy [kWh] | PVs Self Consumed Energy [kWh] | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 55.28 | 1.30 | 1.30 | 0.00 | 53.98 | 100.00 | 0.00 |
| 2 | 67.78 | 0.05 | 0.05 | 0.00 | 67.73 | 100.00 | 0.00 |
| 3 | 55.31 | 10.86 | 10.86 | 0.00 | 44.45 | 100.00 | 0.00 |
| 4 | 27.04 | 23.98 | 12.68 | 11.30 | 14.36 | 52.86 | 47.14 |
| 5 | 18.96 | 33.33 | 16.45 | 16.88 | 2.51 | 49.35 | 50.65 |
| 6 | 15.24 | 32.85 | 15.24 | 14.71 | 0.00 | 46.40 | 44.78 |
| 7 | 16.32 | 25.16 | 16.32 | 8.15 | 0.00 | 64.87 | 32.41 |
| 8 | 16.37 | 28.01 | 16.37 | 10.81 | 0.00 | 58.46 | 38.61 |
| 9 | 14.74 | 20.19 | 13.56 | 6.63 | 1.18 | 67.15 | 32.85 |
| 10 | 30.57 | 11.21 | 10.94 | 0.27 | 19.63 | 97.63 | 2.37 |
| 11 | 42.03 | 2.21 | 2.21 | 0.00 | 39.82 | 100.00 | 0.00 |
| 12 | 59.61 | 1.77 | 1.77 | 0.00 | 57.85 | 100.00 | 0.00 |

***Table IV**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**scenario II**")*

By studying the data from **Table IV**, we conclude that in "**scenario II**" the PV-C.S self-produces and consumes simultaneously 3606kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 679€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement and installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 7600€.

At this point, it should be noted that the increase of 1812kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.2. Thus, the

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increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload). Additionally, the proposed Li-ion D.E.S$^2$ of 10kWh (nominal capacity) is not fully utilized from January, to March and from November to December due to the low solar energy potential of these months. Thus, 974 kWhs of the D.E.S$^2$ remain unexploited. **Table V** presents the unexploited kWhs of the proposed D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources and therefore could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 49€ per year for the PV-C.S owners will result.

| "Scenario II": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 7.32 | 226.79 |
| 2 | 8.00 | 223.99 |
| 3 | 1.13 | 35.10 |
| 4 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 |
| 7 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 |
| 9 | 0.00 | 0.00 |
| 10 | 0.00 | 0.00 |
| 11 | 8.00 | 240.00 |
| 12 | 8.00 | 248.00 |

***Table V**: Unexploited kWhs of the proposed D.E.S$^2$ of 10kWh nominal capacity and 8kWh useful capacity, either at Typical Day or Monthly level ("**Scenario II**")*

By introducing the D.E.S$^2$ of 10kWh (nominal capacity), we can store not only all the energy needed to meet the day-to-day energy needs of the PV-C.S (for the period from June to August) but even more. This is technically feasible due to the high solar energy potential of these months and the low energy demand of the PV-C.S. Considering that these KWhs are stored during midday hours (under high irradiation) it is concluded that they contribute to the mitigation of grid congestion. Therefore, these amounts of stored PV energy should be remunerated by the DNOs. This conclusion is clear by studying the data (at typical day level) set out in **Table IV**. In more detail the difference between the Total Produced PV Energy and the sum of the PVs Self Consumed Energy and PVs Injected Energy, corresponds to kWhs that contribute to mitigation of congestion **Table VI** presents the kWhs that contribute to mitigation of congestion either at Typical Day or Monthly level. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 7€ per year for the PV-C.S owners will result. Considering both ancillary services a period of 124 months is required to recoup the PV system and the D.E.S$^2$ together.

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| "Scenario II": kWhs that contribute to mitigation of congestion (Typical Days and Monthly values) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| Typical Day of Month [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.90 | 0.68 | 0.82 | 0.00 | 0.00 | 0.00 | 0.00 |
| Monthly Values [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 86.98 | 21.16 | 25.49 | 0.00 | 0.00 | 0.00 | 0.00 |

***Table VI**: kWhs that contribute to mitigation of congestion (Typical Days and Monthly values)*

Last but not least, **Figures 3** and **4** present the S-C and uncontrolled PVI indices of the PV-C.S for the typical day of twelve calendar months for: the Current Situation and the two hypothetical Scenarios (**Scenario I** and **Scenario II**). According to the data presented in this figure, it is concluded that D.E.S$^2$ can: a) maximize the self-utilization of locally generated clean electricity and b) contribute to the flexibility by reducing RES power production peaks.

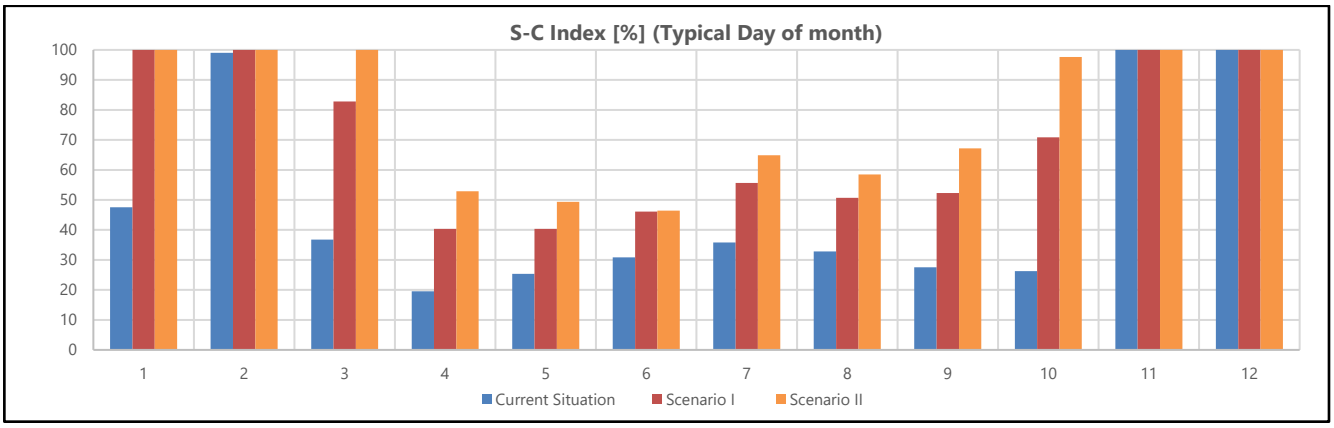


***Figure 3**: S-C Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 6.25kWh nominal capacity and b) 10kWh nominal*

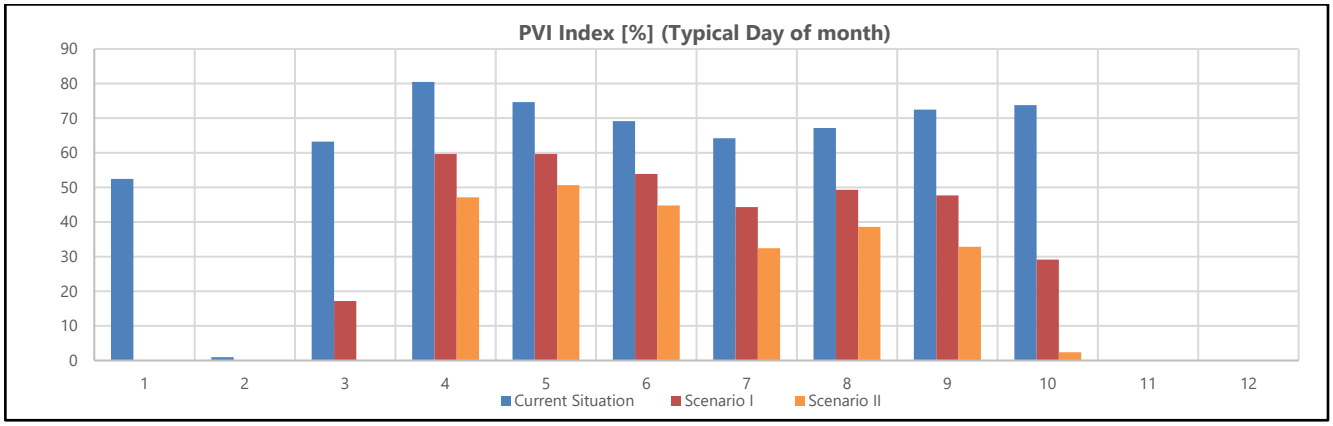


***Figure 4**: Uncontrolled PVI Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 6.25kWh nominal capacity and b) 10kWh nominal capacity*

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## 4.3. Aggregated Households Community with central PV System in Rudamina (Lithuania)

**Table I** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices. According to these data the annual value of PVs Self-Consumed Energy amounts to 51.09%, whilst the corresponding value of PVs Injected Energy amounts to 48.91%. It is recalled here that, although the second component of Total Produced PV Energy injected into the grid, can be used at a later time to compensate PV-C.S's consumption during times when PV generation is absent or not sufficient (accounting treatment).

| Current situation (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 153.29 | 22.47 | 18.28 | 4.20 | 135.01 | 81.33 | 18.67 |
| 2 | 168.18 | 33.25 | 26.88 | 6.37 | 141.29 | 80.84 | 19.16 |
| 3 | 149.64 | 75.57 | 33.97 | 41.60 | 115.67 | 44.95 | 55.05 |
| 4 | 141.36 | 130.90 | 58.68 | 72.22 | 82.67 | 44.83 | 55.17 |
| 5 | 166.86 | 166.86 | 65.98 | 100.88 | 100.88 | 39.54 | 60.46 |
| 6 | 135.61 | 142.92 | 70.24 | 72.69 | 65.37 | 49.14 | 50.86 |
| 7 | 129.21 | 99.28 | 59.47 | 39.81 | 69.73 | 59.90 | 40.10 |
| 8 | 131.92 | 127.45 | 60.53 | 66.92 | 71.39 | 47.49 | 52.51 |
| 9 | 147.68 | 102.14 | 55.67 | 46.48 | 92.01 | 54.50 | 45.50 |
| 10 | 147.95 | 74.70 | 37.57 | 37.13 | 110.38 | 50.30 | 49.70 |
| 11 | 153.61 | 17.71 | 15.87 | 1.84 | 137.74 | 89.61 | 10.39 |
| 12 | 155.20 | 13.79 | 12.34 | 1.45 | 142.86 | 89.46 | 10.54 |

***Table I**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar (Current Situation)*

Considering the data from the table above, we conclude that PV-C.S' total Electrical Energy Consumption amounts to 54112kWh, whilst the PV-C.S self-produces and consumes simultaneously 15699kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 3543€. Following the capital expenditure value of 1000€/kWp (as discussed in section 4), the total cost of this PV investment amounts to 30000€ and therefore, a period of 102 months is required to recoup the investment.

Next, we are going to study a new scenario, called "**scenario I**", by introducing a small Li-ion D.E.S$^2$ to the current PV-C.S. In order to select the appropriate capacity of the D.E.S$^2$ we draw valuable information from **Figure 1**. In more detail, **Figure 1** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Day of twelve calendar months. After a careful assessment of these curves, we conclude that self-consumed PV Energy can be increased in a significant way by storing 40kWh of generated PV energy (at midday hours with high irradiation) and use them at a later time to compensate consumption during hours where PV generation is not sufficient or absent. Thus, the self-consumed PV Energy becomes comparable to the Total Electrical Energy Consumption of the PV-C.S.

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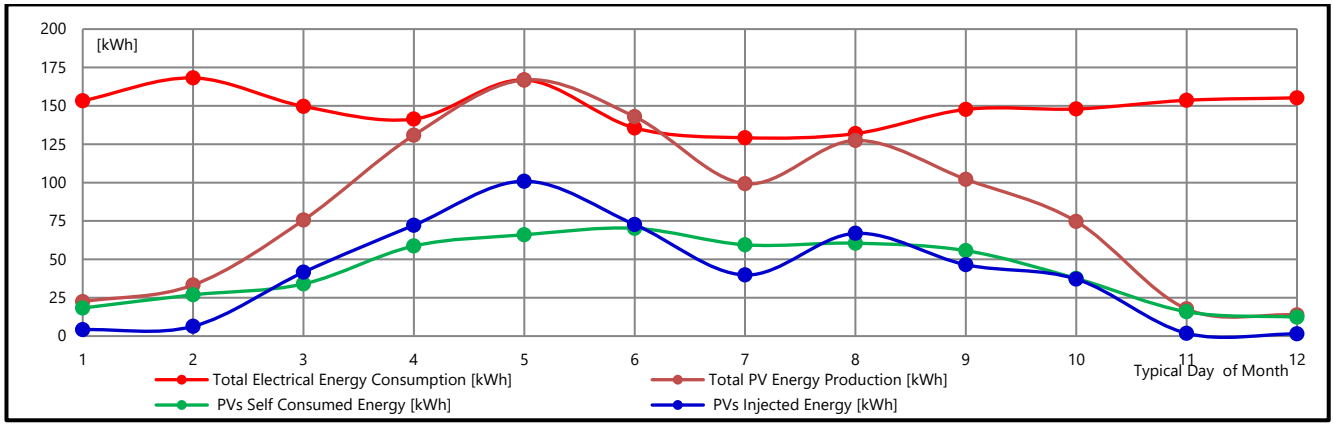


***Figure 1**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Day of twelve calendar months **(current situation)***

Considering that the DOD value of an electrochemical storage system reflects its performance and protects batteries from over-discharge (improving so their life expectancy) we select the nominal capacity of the Li-ion D.E.S$^2$ to be equal to 50kWh and its useful capacity equal to 40 kWh (DOD≤80%).

**Table II** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of Self-Consumption, and PVs Injection Indices after the addition of the proposed Li-ion D.E.S$^2$ of 50kWh (nominal capacity) . According to these data the annual value of PVs self-consumed energy amounts to 84.01%, whilst the corresponding value of PVs injected Energy amounts to 15.99%.

| "Scenario I": addition of 50kWh Li-ion D.E.S$^2$ with 10kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 153.29 | 22.47 | 22.47 | 0.00 | 130.82 | 100.00 | 0.00 |
| 2 | 168.18 | 33.25 | 33.25 | 0.00 | 134.92 | 100.00 | 0.00 |
| 3 | 149.64 | 75.57 | 73.97 | 1.60 | 75.67 | 97.89 | 2.11 |
| 4 | 141.36 | 130.90 | 98.68 | 32.22 | 42.67 | 75.39 | 24.61 |
| 5 | 166.86 | 166.86 | 105.98 | 60.88 | 60.88 | 63.52 | 36.48 |
| 6 | 135.61 | 142.92 | 110.24 | 32.69 | 25.37 | 77.13 | 22.87 |
| 7 | 129.21 | 99.28 | 99.28 | 0.00 | 29.93 | 100.00 | 0.00 |
| 8 | 131.92 | 127.45 | 100.53 | 26.92 | 31.39 | 78.87 | 21.13 |
| 9 | 147.68 | 102.14 | 95.67 | 6.48 | 52.01 | 93.66 | 6.34 |
| 10 | 147.95 | 74.70 | 74.70 | 0.00 | 73.25 | 100.00 | 0.00 |
| 11 | 153.61 | 17.71 | 17.71 | 0.00 | 135.90 | 100.00 | 0.00 |
| 12 | 155.20 | 13.79 | 13.79 | 0.00 | 141.41 | 100.00 | 0.00 |

***Table II**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**Scenario I**")*

By studying the data from **Table II**, we conclude that in "**scenario I**" the PV-C.S self-produces and consumes simultaneously 25812kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 3847€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement

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and installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 35000€.

**Figure 2** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy), after the addition of the proposed 50kWh Li-ion D.E.S$^2$ and for the Typical Day of twelve calendar months.

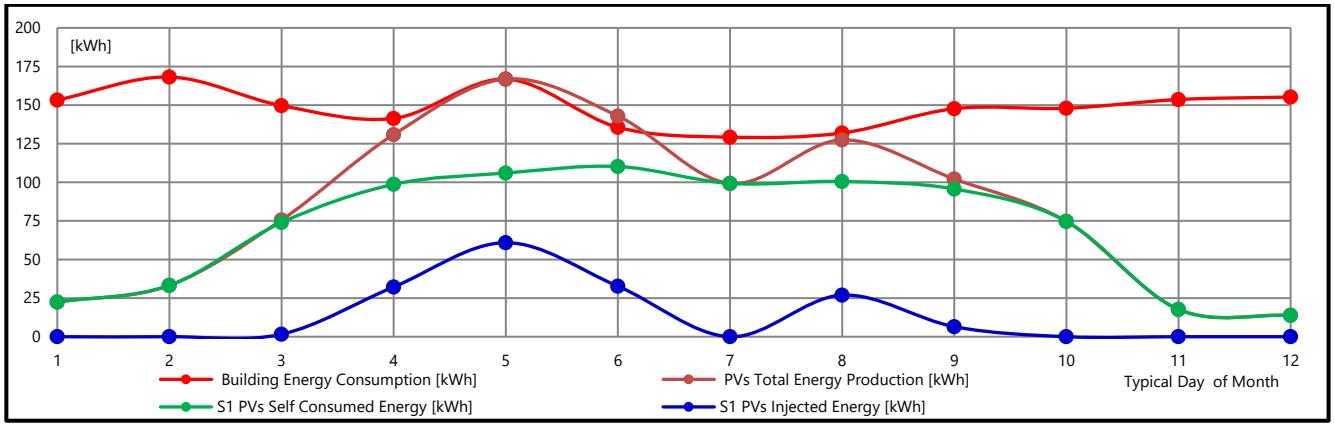


***Figure 2**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components after the addition of 50kWh Li-ion D.E.S$^2$ and for the Typical Day of twelve calendar months ("**scenario I**")*

At this point, it should be noted that the increase of 10113kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.3. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload).

| "Scenario I": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 35.80 | *1109.90* |
| 2 | 33.63 | *941.64* |
| 3 | 0.00 | *0.00* |
| 4 | 0.00 | *0.00* |
| 5 | 0.00 | *0.00* |
| 6 | 0.00 | *0.00* |
| 7 | 0.19 | *6.00* |
| 8 | 0.00 | *0.00* |
| 9 | 0.00 | *0.00* |
| 10 | 2.87 | *89.00* |
| 11 | 38.16 | *1144.80* |
| 12 | 38.55 | *1194.95* |

***Table III**: Unexploited kWhs of the proposed D.E.S$^2$ of 50kWh nominal capacity and 40kWh useful capacity, either at Typical Day or Monthly level ("**Scenario I**")*

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Additionally, the proposed Li-ion D.E.S$^2$ of 50kWh (nominal capacity) is not fully utilized during January, February, October, November and December due to the low solar energy potential of these months. Thus, 4486 kWhs of the D.E.S$^2$ remain unexploited. **Table III** presents the unexploited kWhs of Li-ion D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources. This service could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 224€ per year for the PV-C.S owners will result. Therefore, a period of 103 months is required to recoup the PV system and the D.E.S$^2$ together.

Next, we are going to study a second scenario, named "**scenario II**", by introducing a second bigger, D.E.S$^2$ (100kWh nominal capacity and 80kWh useful capacity) to the current PV-C.S. **Table IV** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices after the addition of the new Li-ion D.E.S$^2$ of 100kWh. According to these data the annual value of PVs self-consumed energy amounts to 97.18%, whilst the corresponding value of PVs injected Energy amounts to 2.11%.

| "Scenario II": addition of 100kWh Li-ion D.E.S$^2$ with 10kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total produced PV Energy [kWh] | PVs Self Consumed Energy [kWh] | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 153.29 | 22.47 | 22.47 | 0.00 | 130.82 | 100.00 | 0.00 |
| 2 | 168.18 | 33.25 | 33.25 | 0.00 | 134.92 | 100.00 | 0.00 |
| 3 | 149.64 | 75.57 | 75.57 | 0.00 | 74.07 | 100.00 | 0.00 |
| 4 | 141.36 | 130.90 | 130.90 | 0.00 | 10.45 | 100.00 | 0.00 |
| 5 | 166.86 | 166.86 | 145.98 | 20.88 | 20.88 | 87.49 | 12.51 |
| 6 | 135.61 | 142.92 | 135.61 | 0.00 | 0.00 | 94.88 | 0.00 |
| 7 | 129.21 | 99.28 | 99.28 | 0.00 | 29.93 | 100.00 | 0.00 |
| 8 | 131.92 | 127.45 | 127.45 | 0.00 | 4.47 | 100.00 | 0.00 |
| 9 | 147.68 | 102.14 | 102.14 | 0.00 | 45.54 | 100.00 | 0.00 |
| 10 | 147.95 | 74.70 | 74.70 | 0.00 | 73.25 | 100.00 | 0.00 |
| 11 | 153.61 | 17.71 | 17.71 | 0.00 | 135.90 | 100.00 | 0.00 |
| 12 | 155.20 | 13.79 | 13.79 | 0.00 | 141.41 | 100.00 | 0.00 |

***Table IV**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**scenario II**")*

By studying the data from **Table IV**, we conclude that in "**scenario II**" the PV-C.S self-produces and consumes simultaneously 29859kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 3946€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement and installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 40000€.

At this point, it should be noted that the increase of 14160kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.3. Thus, the

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increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload). Additionally, the proposed Li-ion D.E.S$^2$ of 100kWh (nominal capacity) is not fully utilized due to the small size of the installed PV system. Thus, 14821 kWhs of the D.E.S$^2$ remain unexploited. **Table V** presents the unexploited kWhs of the proposed D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources and therefore could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 741€ per year for the PV-C.S owners will result.

| "Scenario II": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 75.80 | 2349.90 |
| 2 | 73.63 | 2061.64 |
| 3 | 38.40 | 1190.48 |
| 4 | 7.78 | 233.40 |
| 5 | 0.00 | 0.00 |
| 6 | 7.31 | 219.38 |
| 7 | 40.19 | 1246.00 |
| 8 | 13.08 | 405.34 |
| 9 | 33.52 | 1005.68 |
| 10 | 42.87 | 1329.00 |
| 11 | 78.16 | 2344.80 |
| 12 | 78.55 | 2434.95 |

***Table V**: Unexploited kWhs of the proposed D.E.S$^2$ of 100kWh nominal capacity and 80kWh useful capacity, either at Typical Day or Monthly level ("**Scenario II**")*

By introducing the D.E.S$^2$ of 100Wh (nominal capacity), we can store not only all the energy needed to meet the day-to-day energy needs of the PV-C.S (for the period of June) but even more. This is technically feasible due to the high solar energy potential of these months and the low energy demand of the PV-C.S. Considering that these KWhs are stored during midday hours (under high irradiation) it is concluded that they contribute to the mitigation of grid congestion. Therefore, these amounts of stored PV energy should be remunerated by the DNOs. This conclusion is clear by studying the data (at typical day level) set out in **Table IV**. In more detail the difference between the Total Produced PV Energy and the sum of the PVs Self Consumed Energy and PVs Injected Energy, corresponds to kWhs that contribute to mitigation of congestion **Table VI** presents the kWhs that contribute to mitigation of congestion either at Typical Day or Monthly level. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 11€ per year for the PV-C.S owners will result. Considering both ancillary services a period of 102 months is required to recoup the PV system and the D.E.S$^2$ together.

| "Scenario II": kWhs that contribute to mitigation of congestion (Typical Days and Monthly values) |
|---|

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| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Typical Day of Month [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Monthly Values [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 219.52 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

***Table VI**: kWhs that contribute to mitigation of congestion (Typical Days and Monthly values)*

Last but not least, **Figures 3** and **4** present the S-C and uncontrolled PVI indices of the PV-C.S for the typical day of twelve calendar months for: the Current Situation and the two hypothetical Scenarios (**Scenario I** and **Scenario II**). According to the data presented in this figure, it is concluded that D.E.S$^2$ can: a) maximize the self-utilization of locally generated clean electricity and b) contribute to the flexibility by reducing RES power production peaks.

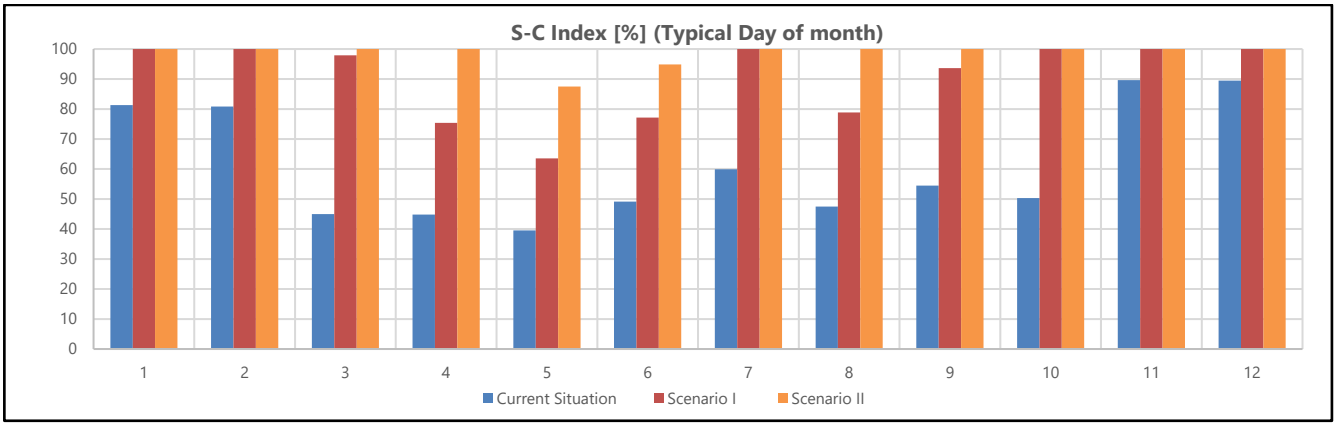


***Figure 3**: S-C Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 50kWh nominal capacity and b) 100kWh nominal*

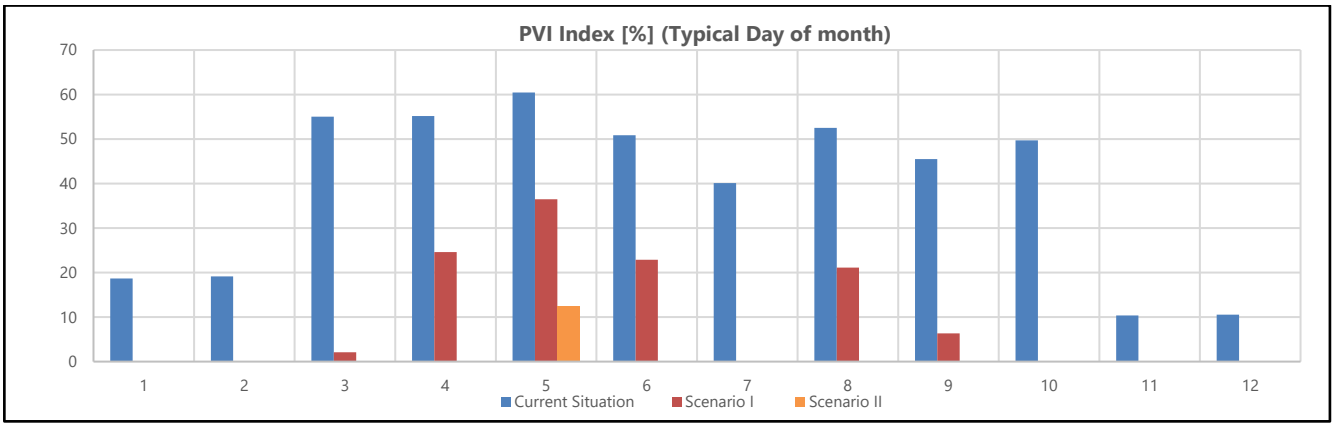


***Figure 4**: Uncontrolled PVI Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 50kWh nominal capacity and b) 100kWh nominal capacity*

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## 4.4. Collegepark Zwijsen Grid Connected PV-C.S (The Netherlands)

**Table I** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices. According to these data the annual value of PVs Self-Consumed Energy amounts to 43.99%, whilst the corresponding value of PVs Injected Energy amounts to 56%. It is recalled here that, although the second component of Total Produced PV Energy injected into the grid, can be used at a later time to compensate PV-C.S's consumption during times when PV generation is absent or not sufficient (accounting treatment).

| Current situation (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 128.65 | 14.13 | 13.48 | 0.65 | 115.13 | 95.43 | 4.57 |
| 2 | 122.54 | 53.32 | 32.75 | 20.54 | 89.79 | 61.42 | 38.51 |
| 3 | 229.61 | 89.03 | 69.00 | 20.06 | 160.65 | 77.50 | 22.54 |
| 4 | 129.90 | 145.03 | 63.90 | 81.13 | 66.00 | 44.06 | 55.94 |
| 5 | 147.32 | 256.06 | 86.65 | 169.42 | 60.68 | 33.84 | 66.16 |
| 6 | 167.80 | 224.17 | 95.33 | 128.83 | 72.47 | 42.53 | 57.47 |
| 7 | 160.90 | 280.06 | 93.71 | 186.35 | 67.23 | 33.46 | 66.54 |
| 8 | 160.58 | 204.42 | 80.65 | 123.77 | 79.94 | 39.45 | 60.55 |
| 9 | 175.80 | 164.53 | 71.83 | 92.67 | 103.93 | 43.66 | 56.32 |
| 10 | 113.26 | 49.71 | 31.52 | 18.19 | 81.74 | 63.40 | 36.60 |
| 11 | 120.33 | 25.90 | 19.83 | 6.03 | 100.50 | 76.58 | 23.29 |
| 12 | 131.77 | 10.23 | 9.58 | 0.65 | 122.19 | 93.69 | 6.31 |

***Table I**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar (Current Situation)*

Considering the data from the table above, we conclude that PV-C.S' total Electrical Energy Consumption amounts to 54481kWh, whilst the PV-C.S self-produces and consumes simultaneously 20366kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 7342€. Collegepark Zwijsen is an ongoing project and therefore PVs' capacity as well as the total electricity capacity depend on the number of apartments sold. Thus, it is impossible to calculate the total cost of this PV investment and the corresponding depreciation period.

Next, we are going to study a new scenario, called "**scenario I**", by introducing a small Li-ion D.E.S$^2$ to the current PV-C.S. In order to select the appropriate capacity of the D.E.S$^2$ we draw valuable information from **Figure 1**. In more detail, **Figure 1** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Day of twelve calendar months. After a careful assessment of these curves, we conclude that self-consumed PV Energy can be increased in a significant way by storing 50kWh of generated PV energy (at midday hours with high irradiation) and use them at a later time to compensate consumption during hours where PV generation is not sufficient or absent. Thus, the self-consumed PV Energy becomes comparable to the Total Electrical Energy Consumption of the PV-C.S.

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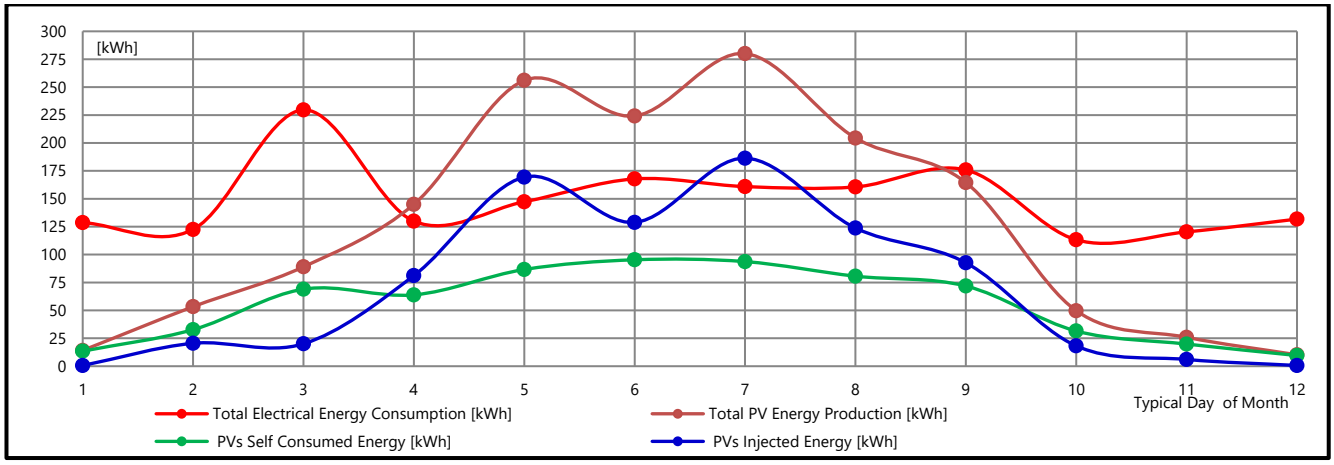


***Figure 1**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Day of twelve calendar months **(current situation)***

Considering that the DOD value of an electrochemical storage system reflects its performance and protects batteries from over-discharge (improving so their life expectancy) we select the nominal capacity of the Li-ion D.E.S$^2$ to be equal to 62.5kWh and its useful capacity equal to 50 kWh (DOD≤80%).

**Table II** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of Self-Consumption, and PVs Injection Indices after the addition of the proposed Li-ion D.E.S$^2$ of 62.5kWh (nominal capacity) . According to these data the annual value of PVs self-consumed energy amounts to 68.04%, whilst the corresponding value of PVs injected Energy amounts to 31.96%.

| **"Scenario I": addition of 62.5kWh Li-ion D.E.S$^2$ with 50kWh useful capacity (Typical Day of month)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 128.65 | 14.13 | 14.13 | 0.00 | 114.52 | 100.00 | 0.00 |
| 2 | 122.54 | 53.32 | 53.32 | 0.00 | 69.21 | 100.00 | 0.00 |
| 3 | 229.61 | 89.03 | 89.03 | 0.00 | 140.58 | 100.00 | 0.00 |
| 4 | 129.90 | 145.03 | 113.90 | 31.13 | 16.00 | 78.53 | 21.47 |
| 5 | 147.32 | 256.06 | 136.65 | 119.42 | 10.68 | 53.36 | 46.64 |
| 6 | 167.80 | 224.17 | 145.33 | 78.83 | 22.47 | 64.83 | 35.17 |
| 7 | 160.90 | 280.06 | 143.71 | 136.35 | 17.19 | 51.31 | 48.69 |
| 8 | 160.58 | 204.42 | 130.65 | 73.77 | 29.94 | 63.91 | 36.09 |
| 9 | 175.80 | 164.53 | 121.83 | 42.67 | 53.97 | 74.05 | 25.93 |
| 10 | 113.26 | 49.71 | 49.71 | 0.00 | 63.55 | 100.00 | 0.00 |
| 11 | 120.33 | 25.90 | 25.90 | 0.00 | 94.43 | 100.00 | 0.00 |
| 12 | 131.77 | 10.23 | 10.23 | 0.00 | 121.55 | 100.00 | 0.00 |

***Table II**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**Scenario I**")*

By studying the data from **Table II**, we conclude that in "**scenario I**" the PV-C.S self-produces and consumes simultaneously 31499kWh. Taking into account the tariffs of Competitive Charges and

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Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 8066€.

**Figure 2** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy), after the addition of the proposed 62.5kWh Li-ion D.E.S$^2$ and for the Typical Day of twelve calendar months.

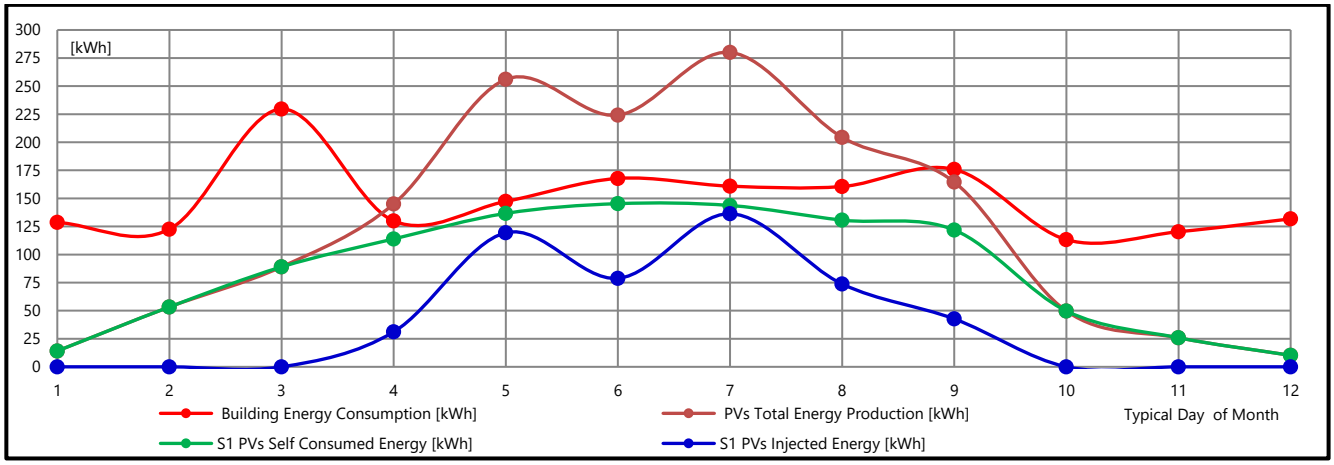


***Figure 2**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components after the addition of 62.5kWh Li-ion D.E.S$^2$ and for the Typical Day of twelve calendar months ("**scenario I**")*

At this point, it should be noted that the increase of 11133kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.3. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload).

| "Scenario I": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 49.35 | *1530.00* |
| 2 | 29.46 | *825.00* |
| 3 | 29.94 | *928.00* |
| 4 | 0.00 | *0.00* |
| 5 | 0.00 | *0.00* |
| 6 | 0.00 | *0.00* |
| 7 | 0.00 | *0.00* |
| 8 | 0.00 | *0.00* |
| 9 | 0.00 | *0.00* |
| 10 | 31.81 | *986.00* |
| 11 | 43.97 | *1319.00* |
| 12 | 49.35 | *1530.00* |

***Table III**: Unexploited kWhs of the proposed D.E.S$^2$ of 62.5kWh nominal capacity and 50kWh useful capacity, either at Typical Day or Monthly level ("**Scenario I**")*

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Additionally, the proposed Li-ion D.E.S$^2$ of 62.5kWh (nominal capacity) is not fully utilized during January, February, March, October, November and December due to the low solar energy potential of these months. Thus, 7118 kWhs of the D.E.S$^2$ remain unexploited. **Table III** presents the unexploited kWhs of Li-ion D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources. This service could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 356€ per year for the PV-C.S owners will result. Therefore, the total annual savings from energy bills amount to 8422€.

Next, we are going to study a second scenario, named "**scenario II**", by introducing a second bigger, D.E.S$^2$ (125kWh nominal capacity and 100kWh useful capacity) to the current PV-C.S. **Table IV** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices after the addition of the new Li-ion D.E.S$^2$ of 125kWh. According to these data the annual value of PVs self-consumed energy amounts to 77.17%, whilst the corresponding value of PVs injected Energy amounts to 13.89%.

| "Scenario II": addition of 125kWh Li-ion D.E.S² with 100kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total produced PV Energy [kWh] | PVs Self Consumed Energy [kWh] | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 128.65 | 14.13 | 14.13 | 0.00 | 114.52 | 100.00 | 0.00 |
| 2 | 122.54 | 53.32 | 53.32 | 0.00 | 69.21 | 100.00 | 0.00 |
| 3 | 229.61 | 89.03 | 89.03 | 0.00 | 140.58 | 100.00 | 0.00 |
| 4 | 129.90 | 145.03 | 129.90 | 0.00 | 0.00 | 89.57 | 0.00 |
| 5 | 147.32 | 256.06 | 147.32 | 69.42 | 0.00 | 57.53 | 27.11 |
| 6 | 167.80 | 224.17 | 167.80 | 28.83 | 0.00 | 74.86 | 12.86 |
| 7 | 160.90 | 280.06 | 160.90 | 86.35 | 0.00 | 57.45 | 30.83 |
| 8 | 160.58 | 204.42 | 160.58 | 23.77 | 0.00 | 78.55 | 11.63 |
| 9 | 175.80 | 164.53 | 164.53 | 0.00 | 11.27 | 100.00 | 0.00 |
| 10 | 113.26 | 49.71 | 49.71 | 0.00 | 63.55 | 100.00 | 0.00 |
| 11 | 120.33 | 25.90 | 25.90 | 0.00 | 94.43 | 100.00 | 0.00 |
| 12 | 131.77 | 10.23 | 10.23 | 0.00 | 121.55 | 100.00 | 0.00 |

***Table IV**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**scenario II**")*

By studying the data from **Table IV**, we conclude that in "**scenario II**" the PV-C.S self-produces and consumes simultaneously 35726kWh. Considering the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 7803€.

At this point, it should be noted that the increase of 15360kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.4. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload). Additionally, the proposed Li-ion D.E.S$^2$ of 125kWh (nominal capacity) is not fully utilized due to the small size of the installed PV system. Thus, 17004 kWhs of the D.E.S$^2$ remain unexploited. **Table V** presents the unexploited kWhs of the proposed D.E.S$^2$ either at

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Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources and therefore could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 850€ per year for the PV-C.S owners will result.

| "Scenario II": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 99.35 | 3080.00 |
| 2 | 79.46 | 2225.00 |
| 3 | 79.94 | 2478.00 |
| 4 | 18.87 | 566.00 |
| 5 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 |
| 7 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 |
| 9 | 7.33 | 220.00 |
| 10 | 81.81 | 2536.00 |
| 11 | 93.97 | 2819.00 |
| 12 | 99.35 | 3080.00 |

***Table V**: Unexploited kWhs of the proposed D.E.S$^2$ of 125kWh nominal capacity and 100kWh useful capacity, either at Typical Day or Monthly level ("**Scenario II**")*

By introducing the D.E.S$^2$ of 125Wh (nominal capacity), we can store not only all the energy needed to meet the day-to-day energy needs of the PV-C.S (for the period of June) but even more. This is technically feasible due to the high solar energy potential of these months and the low energy demand of the PV-C.S. Considering that these KWhs are stored during midday hours (under high irradiation) it is concluded that they contribute to the mitigation of grid congestion. Therefore, these amounts of stored PV energy should be remunerated by the DNOs. This conclusion is clear by studying the data (at typical day level) set out in **Table IV**. In more detail the difference between the Total Produced PV Energy and the sum of the PVs Self Consumed Energy and PVs Injected Energy, corresponds to kWhs that contribute to mitigation of congestion **Table VI** presents the kWhs that contribute to mitigation of congestion either at Typical Day or Monthly level. Adopting a target price of 5 euro-cents per KWh (almost half of the competitive energy tariff), an additional benefit of about 207€ per year for the PV-C.S owners will result. Considering both ancillary services, the total annual savings from energy bills amount to 8860€.

| "Scenario II": kWhs that contribute to mitigation of congestion (Typical Days and Monthly values) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| Typical Day of Month [kWh] | 0.000 | 0.000 | 0.000 | 15.133 | 39.323 | 27.533 | 32.806 | 20.065 | 0.000 | 0.000 | 0.000 | 0.000 |
| Monthly Values [kWh] | 0 | 0 | 0 | 454 | 1219 | 826 | 1017 | 622 | 0 | 0 | 0 | 0 |

***Table VI**: kWhs that contribute to mitigation of congestion (Typical Days and Monthly values)*

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Last but not least, **Figures 3** and **4** present the S-C and uncontrolled PVI indices of the PV-C.S for the typical day of twelve calendar months for: the Current Situation and the two hypothetical Scenarios (**Scenario I** and **Scenario II**). According to the data presented in this figure, it is concluded that D.E.S$^2$ can: a) maximize the self-utilization of locally generated clean electricity and b) contribute to the flexibility by reducing RES power production peaks.

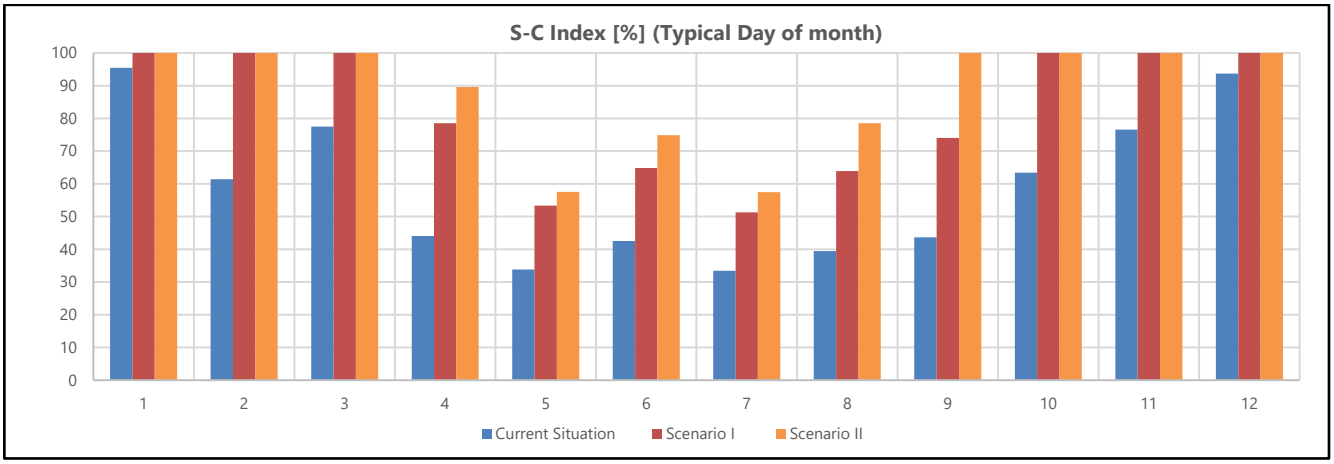


***Figure 3**: S-C Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 62.5kWh nominal capacity and b) 125kWh nominal*

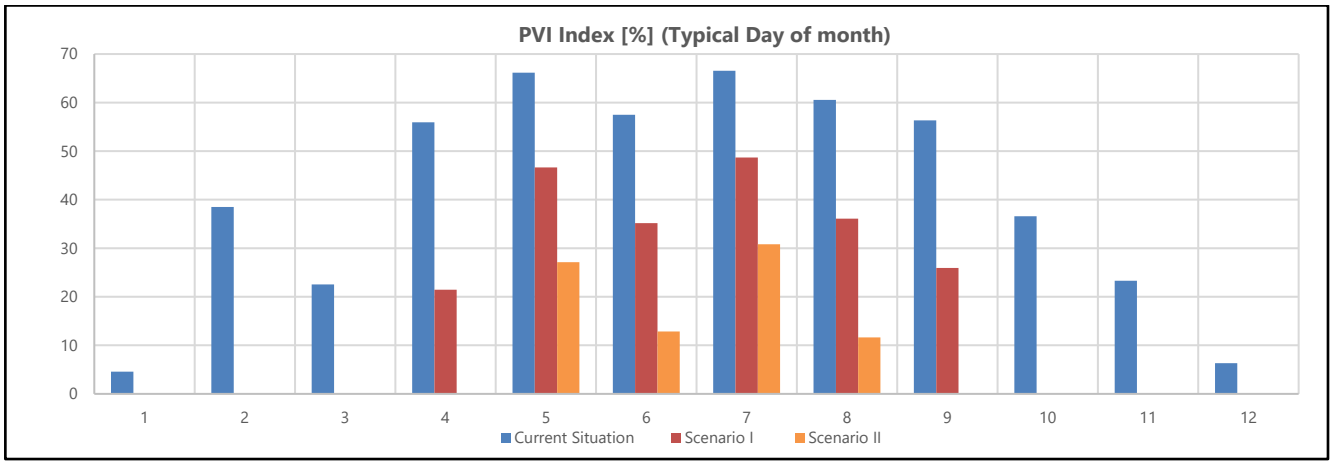


***Figure 4**: Uncontrolled PVI Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 62.5kWh nominal capacity and b) 125kWh nominal capacity*

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## 4.5. Aardehuizen-Olst Grid Connected PV-C.S (The Netherlands)

**Table I** presents the energy transactions between the PV-C.S and the LDN for the Typical Day of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices. According to these data the annual value of PVs Self-Consumed Energy amounts to 39.86%, whilst the corresponding value of PVs Injected Energy amounts to 60.14%. It is recalled here that, although the second component of Total Produced PV Energy injected into the grid, can be used at a later time to compensate PV-C.S's consumption during times when PV generation is absent or not sufficient (accounting treatment).

| Current situation (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 357.74 | 33.87 | 26.19 | 7.65 | 331.55 | 77.33 | 22.57 |
| 2 | 321.79 | 139.64 | 83.07 | 56.54 | 238.71 | 59.49 | 40.49 |
| 3 | 300.00 | 181.61 | 67.77 | 113.94 | 232.23 | 37.32 | 62.74 |
| 4 | 262.67 | 242.33 | 91.90 | 150.33 | 170.77 | 37.92 | 62.04 |
| 5 | 197.74 | 352.26 | 95.48 | 256.74 | 102.26 | 27.11 | 72.88 |
| 6 | 230.33 | 290.00 | 104.50 | 185.53 | 125.83 | 36.03 | 63.98 |
| 7 | 207.29 | 363.58 | 131.77 | 231.81 | 75.52 | 36.24 | 63.76 |
| 8 | 178.23 | 264.06 | 109.45 | 154.61 | 68.74 | 41.45 | 58.55 |
| 9 | 230.40 | 290.03 | 104.50 | 185.53 | 125.90 | 36.03 | 63.97 |
| 10 | 315.55 | 111.48 | 56.68 | 54.84 | 258.87 | 50.84 | 49.19 |
| 11 | 342.67 | 48.33 | 47.10 | 1.30 | 295.57 | 97.45 | 2.69 |
| 12 | 343.55 | 17.74 | 15.03 | 2.68 | 328.52 | 84.73 | 15.09 |

***Table I**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar (Current Situation)*

Considering the data from the table above, we conclude that PV-C.S' total Electrical Energy Consumption amounts to 99895kWh, whilst the PV-C.S self-produces and consumes simultaneously 28340kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 11084€. Following the capital expenditure value of 1000€/kWp (as discussed in section 4), the total cost of this PV investment amounts to 69180€ and therefore, a period of 75 months is required to recoup the investment.

Next, we are going to study a new scenario, called "**scenario I**", by introducing a small Li-ion D.E.S$^2$ to the current PV-C.S. In order to select the appropriate capacity of the D.E.S$^2$ we draw valuable information from **Figure 1**. In more detail, **Figure 1** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Day of twelve calendar months. After a careful assessment of these curves, we conclude that self-consumed PV Energy can be increased in a significant way by storing 80kWh of generated PV energy (at midday hours with high irradiation) and use them at a later time to compensate consumption during hours where PV generation is not sufficient or absent. Thus, the self-consumed PV Energy becomes comparable to the Total Electrical Energy Consumption of the PV-C.S.

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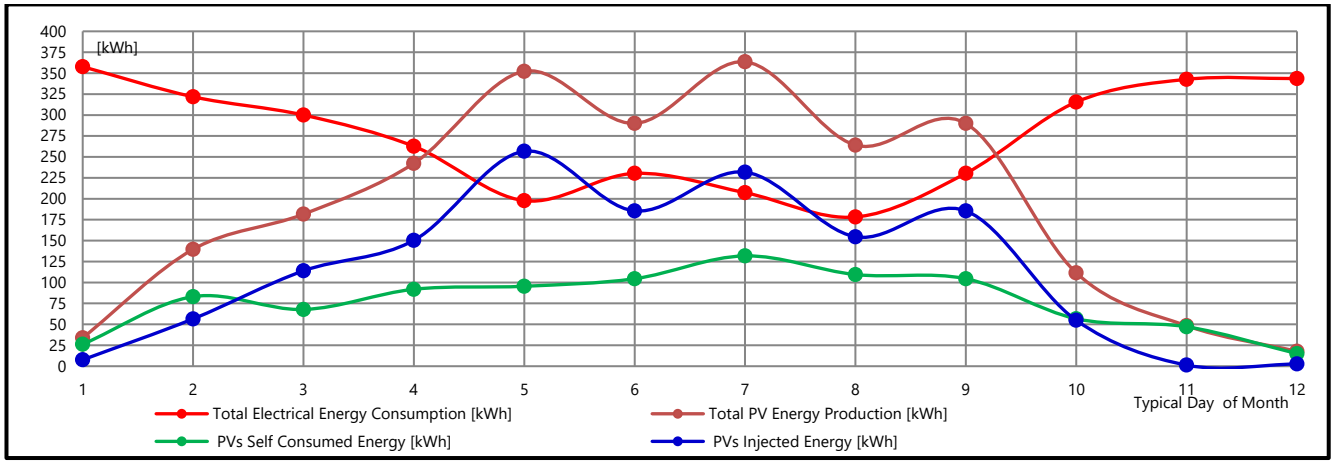


***Figure 1**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Day of twelve calendar months **(current situation)***

Considering that DOD value of an electrochemical storage system reflects its performance and protects batteries from over-discharge (improving so their life expectancy) we select the nominal capacity of the D.E.S$^2$ to be equal to 100kWh and its useful capacity equal to 80 kWh (DOD≤80%).

**Table II** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of Self-Consumption, and PVs Injection Indices after the addition of the proposed Li-ion D.E.S$^2$ of 100kWh (nominal capacity) . According to these data the annual value of PVs self-consumed energy amounts to 68.38%, whilst the corresponding value of PVs injected Energy amounts to 30.93%.

| **"Scenario I": addition of 12.5kWh Li-ion D.E.S$^2$ with 10kWh useful capacity (Typical Day of month)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 357.74 | 33.87 | 33.87 | 0.00 | 323.87 | 100.00 | 0.00 |
| 2 | 321.79 | 139.64 | 139.64 | 0.00 | 182.14 | 100.00 | 0.00 |
| 3 | 300.00 | 181.61 | 147.77 | 33.94 | 152.23 | 81.37 | 18.69 |
| 4 | 262.67 | 242.33 | 171.90 | 70.33 | 90.77 | 70.94 | 29.02 |
| 5 | 197.74 | 352.26 | 175.48 | 176.74 | 22.26 | 49.82 | 50.17 |
| 6 | 230.33 | 290.00 | 184.50 | 105.53 | 45.83 | 63.62 | 36.39 |
| 7 | 207.29 | 363.58 | 207.29 | 151.81 | 0.00 | 57.01 | 41.75 |
| 8 | 178.23 | 264.06 | 178.23 | 74.61 | 0.00 | 67.49 | 28.26 |
| 9 | 230.40 | 290.03 | 184.50 | 105.53 | 45.90 | 63.61 | 36.39 |
| 10 | 315.55 | 111.48 | 111.48 | 0.00 | 204.06 | 100.00 | 0.00 |
| 11 | 342.67 | 48.33 | 48.33 | 0.00 | 294.33 | 100.00 | 0.00 |
| 12 | 343.55 | 17.74 | 17.74 | 0.00 | 325.81 | 100.00 | 0.00 |

***Table II**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**Scenario I**")*

By studying the data from **Table II**, we conclude that in "**scenario I**" the PV-C.S self-produces and consumes simultaneously 48615kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to

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12339€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement and installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 79180€.

**Figure 2** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy), after the addition of the proposed 100kWh Li-ion D.E.S$^2$ and for the Typical Day of twelve calendar months.

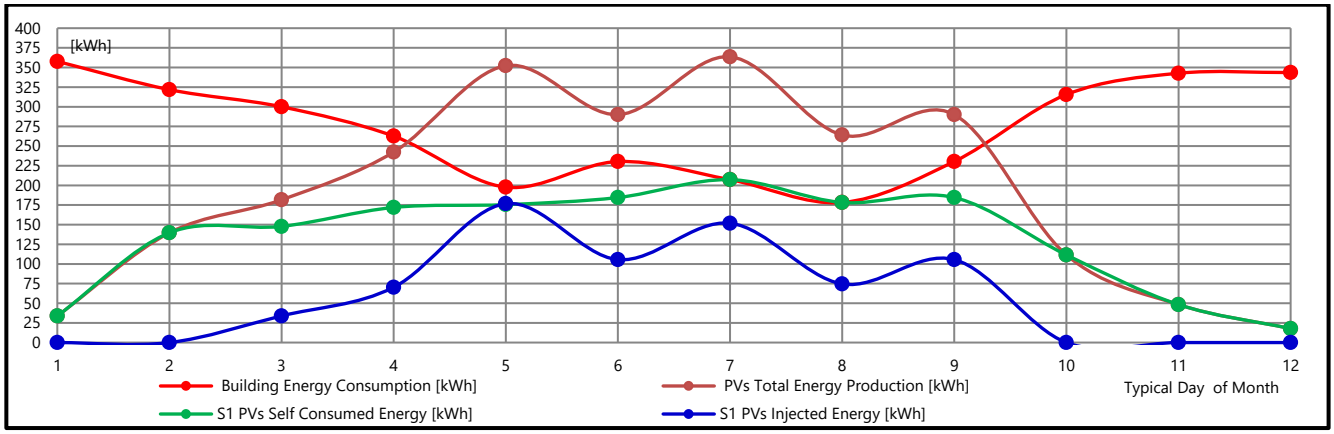


***Figure 2**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components after the addition of 100kWh Li-ion D.E.S$^2$ and for the Typical Day of twelve calendar months (**"scenario I"**)*

At this point, it should be noted that the increase of 20275kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.5. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload).

| "Scenario I": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 72.35 | *2243.00* |
| 2 | 23.46 | *657.00* |
| 3 | 0.00 | *0.00* |
| 4 | 0.00 | *0.00* |
| 5 | 0.00 | *0.00* |
| 6 | 0.00 | *0.00* |
| 7 | 0.00 | *0.00* |
| 8 | 0.00 | *0.00* |
| 9 | 0.00 | *0.00* |
| 10 | 25.16 | *780.00* |
| 11 | 78.70 | *2361.00* |
| 12 | 77.32 | *2397.00* |

***Table III**: Unexploited kWhs of the proposed D.E.S$^2$ of 100kWh nominal capacity and 80kWh useful capacity, either at Typical Day or Monthly level (**"Scenario I"**)*

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Additionally, the proposed Li-ion D.E.S$^2$ of 100kWh (nominal capacity) is not fully utilized during January, February, October, November and December due to the low solar energy potential of these months. Thus, 8438 kWhs of the D.E.S$^2$ remain unexploited. **Table III** presents the unexploited kWhs of Li-ion D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources. This service could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (less than half of the competitive energy tariff), an additional benefit of about 422€ per year for the PV-C.S owners will result.

There is another very interesting point in this scenario. By introducing the D.E.S$^2$ of 100kWh (nominal capacity), we can store not only all the energy needed to meet the day-to-day energy needs of the PV-C.S (for the period from July to August) but even more. This is technically feasible due to the high solar energy potential of these months and the low energy demand of the PV-C.S. Considering that these KWhs are stored during midday hours (under high irradiation) it is concluded that they contribute to the mitigation of grid congestion. Therefore, these amounts of stored PV energy should be remunerated by the DNOs. This conclusion is clear by studying the data (at typical day level) set out in **Table IV**. In more detail the difference between the Total Produced PV Energy and the sum of the PVs Self Consumed Energy and PVs Injected Energy, corresponds to kWhs that contribute to mitigation of congestion Table VI presents the kWhs that contribute to mitigation of congestion either at Typical Day or Monthly level. Adopting a target price of 5 euro-cents per KWh (less than half of the competitive energy tariff), an additional very small benefit of about 24€ per year for the PV-C.S owners will result. Taking into account both ancillary services a period of 74 months is required to recoup the PV system and the D.E.S2 together.

| "Scenario I": kWhs that contribute to mitigation of congestion (Typical Days and Monthly values) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| Typical Day of Month [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.48 | 11.23 | 0.00 | 0.00 | 0.00 | 0 |
| Monthly Values [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 139.00 | 348.00 | 0.00 | 0.00 | 0.00 | 0 |

***Table IV**: kWhs that contribute to mitigation of congestion (Typical Days and Monthly values)*

Next, we are going to study a second scenario, named "**scenario II**", by introducing a second bigger, D.E.S$^2$ (150kWh nominal capacity and 120kWh useful capacity) to the current PV-C.S. **Table V** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices after the addition of the new Li-ion D.E.S$^2$ of 200kWh. According to these data the annual value of PVs self-consumed energy amounts to 75.89%, whilst the corresponding value of PVs injected Energy amounts to 19.16%.

By studying the data from **Table V**, we conclude that in "**scenario II**" the PV-C.S self-produces and consumes simultaneously 53954kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 12292€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement

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and installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 84180€.

| "Scenario II": addition of 150kWh Li-ion D.E.S$^2$ with 120kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total produced PV Energy [kWh] | PVs Self Consumed Energy [kWh] | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 357.74 | 33.87 | 33.87 | 0.00 | 323.87 | 100.00 | 0.00 |
| 2 | 321.79 | 139.64 | 139.64 | 0.00 | 182.14 | 100.00 | 0.00 |
| 3 | 300.00 | 181.61 | 181.61 | 0.00 | 118.39 | 100.00 | 0.00 |
| 4 | 262.67 | 242.33 | 211.90 | 30.33 | 50.77 | 87.44 | 12.52 |
| 5 | 197.74 | 352.26 | 197.74 | 136.74 | 0.00 | 56.14 | 38.82 |
| 6 | 230.33 | 290.00 | 224.50 | 65.53 | 5.83 | 77.41 | 22.60 |
| 7 | 207.29 | 363.58 | 207.29 | 111.81 | 0.00 | 57.01 | 30.75 |
| 8 | 178.23 | 264.06 | 178.23 | 34.61 | 0.00 | 67.49 | 13.11 |
| 9 | 230.40 | 290.03 | 224.50 | 65.53 | 5.90 | 77.40 | 22.60 |
| 10 | 315.55 | 111.48 | 111.48 | 0.00 | 204.06 | 100.00 | 0.00 |
| 11 | 342.67 | 48.33 | 48.33 | 0.00 | 294.33 | 100.00 | 0.00 |
| 12 | 343.55 | 17.74 | 17.74 | 0.00 | 325.81 | 100.00 | 0.00 |

***Table V**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**scenario II**")*

At this point, it should be noted that the increase of 25614kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. This conclusion is endorsed by studying **Figures 6** and **7** of Section 3.5. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload).

| "Scenario II": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 112.35 | *3483.00* |
| 2 | 63.46 | *1777.00* |
| 3 | 6.06 | *188.00* |
| 4 | 0.00 | *0.00* |
| 5 | 0.00 | *0.00* |
| 6 | 0.00 | *0.00* |
| 7 | 0.00 | *0.00* |
| 8 | 0.00 | *0.00* |
| 9 | 0.00 | *0.00* |
| 10 | 65.16 | *2020.00* |
| 11 | 118.70 | *3561.00* |
| 12 | 117.32 | *3637.00* |

***Table VI**: Unexploited kWhs of the proposed D.E.S$^2$ of 150kWh nominal capacity and 120kWh useful capacity, either at Typical Day or Monthly level ("**Scenario II**")*

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Additionally, the proposed Li-ion D.E.S$^2$ of 150kWh (nominal capacity) is not fully utilized due to the small size of the installed PV system. Thus, 14667 kWhs of the D.E.S$^2$ remain unexploited. **Table VI** presents the unexploited kWhs of the proposed D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources and therefore could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (less than half of the competitive energy tariff), an additional benefit of about 733€ per year for the PV-C.S owners will result.

By introducing the D.E.S$^2$ of 150kWh (nominal capacity), we can store not only all the energy needed to meet the day-to-day energy needs of the PV-C.S (for the period from May to August) but even more. This is technically feasible due to the high solar energy potential of these months and the low energy demand of the PV-C.S. Considering that these KWhs are stored during midday hours (under high irradiation) it is concluded that they contribute to the mitigation of grid congestion. Therefore, these amounts of stored PV energy should be remunerated by the DNOs. This conclusion is clear by studying the data (at typical day level) set out in **Table V**. In more detail the difference between the Total Produced PV Energy and the sum of the PVs Self Consumed Energy and PVs Injected Energy, corresponds to kWhs that contribute to mitigation of congestion **Table VII** presents the kWhs that contribute to mitigation of congestion either at Typical Day or Monthly level. Adopting a target price of 5 euro-cents per KWh (less than half of the competitive energy tariff), an additional benefit of about 176€ per year for the PV-C.S owners will result. Taking into account both ancillary services a period of 77 months is required to recoup the PV system and the D.E.S$^2$ together.

| "Scenario II": kWhs that contribute to mitigation of congestion (Typical Days and Monthly values) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| Typical Day of Month [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 17.74 | 0.00 | 44.48 | 51.23 | 0.00 | 0.00 | 0.00 | 0.00 |
| Monthly Values [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 550.00 | 0.00 | 1379.00 | 1588.00 | 0.00 | 0.00 | 0.00 | 0.00 |

***Table VII**: kWhs that contribute to mitigation of congestion (Typical Days and Monthly values)*

Last but not least, **Figures 3** and **4** present the S-C and uncontrolled PVI indices of the PV-C.S for the typical day of twelve calendar months for: the Current Situation and the two hypothetical Scenarios (**Scenario I** and **Scenario II**). According to the data presented in this figure, it is concluded that D.E.S$^2$ can: a) maximize the self-utilization of locally generated clean electricity and b) contribute to the flexibility by reducing RES power production peaks.

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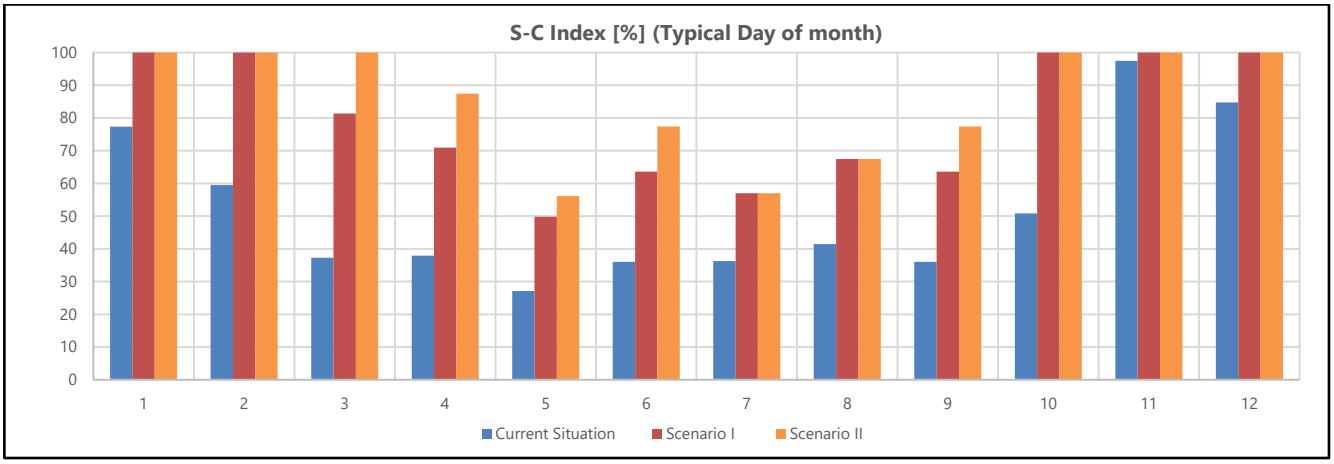


***Figure 3**: S-C Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 100kWh nominal capacity and b) 150kWh nominal*

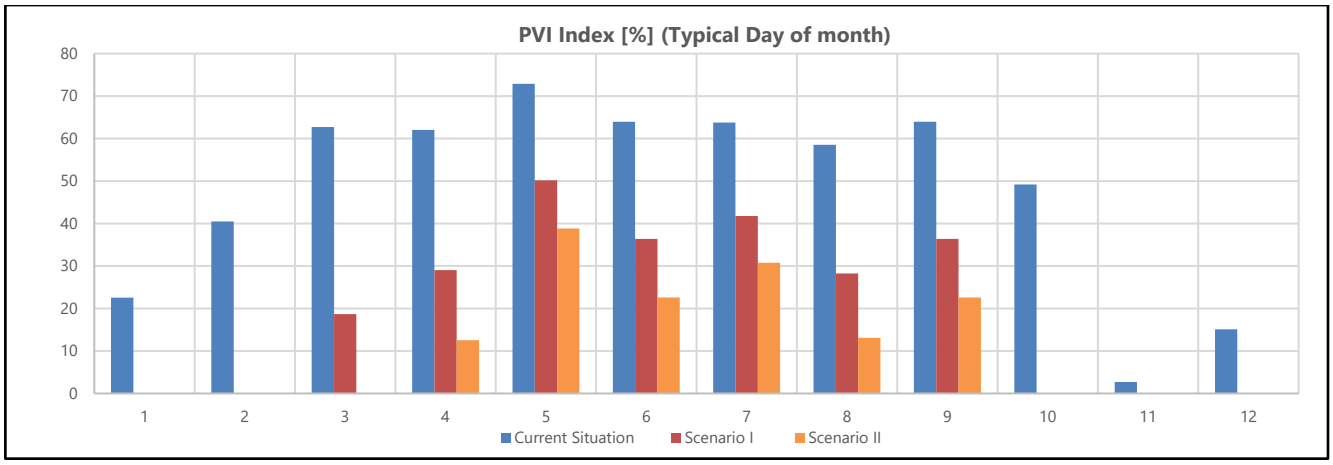


***Figure 4**: Uncontrolled PVI Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 100kWh nominal capacity and b) 150kWh nominal capacity*

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## 4.6. Iveron Monastery Autonomous Hybrid PV-C.S (Greece)

**Table I** presents the energy transactions between the PV-C.S and the LDN (diesel generator) for the Typical Days of twelve calendar months, as well as the corresponding values of S-S, and PVE Indices. Additionally, it presents the calculated Maximum Theoretical PVs Production and the corresponding Maximum S-S Index. It is recalled here that Iveron Monastery is not connected to a central electric grid, as well as that there are not installed E.S$^2$. Therefore, PVs production falls under curtailed operation. Indeed, in case there is an excess of produced PV energy, an external controller adjusts extremely quickly the MPPT operation of each inverter (reducing the produced PV energy). Considering the data from the following table, we conclude that PV-C.S' total Electrical Energy Consumption amounts to 360620kWh, whilst the PVs production amounts to 82690kWh.

| Current situation (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Produced PV Energy [kWh] | Electricity fed by the LDN [kWh] | S-S Index [%] | PVE Index [%] | Maximum Theoretical PVs Production [kWh] | Maximum Theoretical S-S index [%] |
| 1 | 972.06 | 127.45 | 844.61 | 13.11 | 89.82 | 141.90 | 14.60 |
| 2 | 1036.75 | 75.79 | 960.96 | 7.31 | 92.87 | 81.60 | 7.87 |
| 3 | 1017.13 | 210.55 | 806.58 | 20.70 | 86.13 | 244.45 | 24.03 |
| 4 | 763.17 | 254.67 | 508.50 | 33.37 | 84.68 | 300.74 | 39.41 |
| 5 | 824.94 | 312.26 | 512.68 | 37.85 | 84.03 | 371.60 | 45.05 |
| 6 | 1045.07 | 320.13 | 724.93 | 30.63 | 93.18 | 343.56 | 32.87 |
| 7 | 1103.03 | 332.10 | 770.94 | 30.11 | 92.62 | 358.56 | 32.51 |
| 8 | 1061.29 | 334.06 | 727.23 | 31.48 | 89.63 | 372.72 | 35.12 |
| 9 | 952.73 | 246.10 | 706.63 | 25.83 | 87.54 | 281.13 | 29.51 |
| 10 | 1025.77 | 241.58 | 784.19 | 23.55 | 90.40 | 267.24 | 26.05 |
| 11 | 1072.27 | 116.47 | 955.80 | 10.86 | 96.77 | 120.35 | 11.22 |
| 12 | 982.77 | 133.87 | 848.90 | 13.62 | 91.29 | 146.64 | 14.92 |

***Table I**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar (Current Situation)*

According to the specification of the diesel generator, one (1) litre of oil is needed to produce four (4) electric kWh. Additionally, the cost of one litre of oil is about 0,65 € (Tax-free). Taking into account the above-mentioned costs the annual saving from the reduction of oil consumption, amount to 13437€. Following the capital expenditure value of 1000€/kWp (as discussed in section 4), the total cost of this PV investment amounts to 60840€ and therefore, a period of 54 months is required to recoup the investment.

When comparing the current PV Energy Production and the Maximum Theoretical PVs Production, it emerges that curtailed operation of PVs results in a loss of 9964 kWh on an annual basis. Next, we are going to study a new scenario, called "scenario I", by introducing a small Li-ion E.S$^2$ to the current PV-C.S. Considering the data from **Table II**, we conclude that on a daily basis the unexploited potential of PVs varies between 3.89 and 59.35 kWh. Therefore, to fully exploit the advantages of PVs production the capacity of ES$^2$ should be at least equal to 60kWh. Considering that the DOD value of an electrochemical storage system reflects its performance and protects batteries from over-discharge (improving so their

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life expectancy) we select the nominal capacity of the Li-ion D.E.S$^2$ to be equal to 75kWh and its useful capacity equal to 60 kWh (DOD≤80%).

| "Scenario II": unexploited potential of PVs (Typical Days and Monthly values) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| Typical Day of Month [kWh] | 14.45 | 5.82 | 33.91 | 46.07 | 59.35 | 23.43 | 26.46 | 38.65 | 35.03 | 25.65 | 3.89 | 12.77 |
| Monthly Values [kWh] | 447.80 | 162.91 | 1051.08 | 1382.20 | 1839.70 | 702.93 | 820.31 | 1198.17 | 1050.86 | 795.29 | 116.62 | 395.95 |

***Table II**: unexploited potential of PVs (Typical Days and Monthly values)*

Following the capital expenditure value of 100€/kWh for the procurement and installation of the E.S$^2$ system, the total cost of this PV investment amounts to 66840€, whilst the new saving from the reduction of oil consumption, will amount to 15056€. Therefore, a period of 53 months is required to recoup the total investment (PVs and Li-ion E.S$^2$).

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## 4.7. Primary school of Warthausen Grid Connected PV-C.S (Germany)

**Table I** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices. According to these data the annual value of PVs Self-Consumed Energy amounts to 28.52%, whilst the corresponding value of PVs Injected Energy amounts to 71.48%. It is recalled here that, although the second component of Total Produced PV Energy injected into the grid, can be used at a later time to compensate PV-C.S's consumption during times when PV generation is absent or not sufficient (accounting treatment).

| Current situation (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 196.77 | 20.65 | 20.65 | 0.00 | 176.13 | 100.00 | 0.00 |
| 2 | 178.57 | 120.00 | 75.00 | 45.00 | 103.57 | 62.50 | 37.50 |
| 3 | 196.77 | 253.23 | 67.74 | 185.48 | 129.03 | 26.75 | 73.25 |
| 4 | 163.33 | 260.33 | 70.00 | 190.33 | 93.33 | 26.89 | 73.11 |
| 5 | 158.06 | 337.74 | 67.74 | 270.00 | 90.32 | 20.06 | 79.94 |
| 6 | 133.33 | 365.00 | 70.00 | 295.00 | 63.33 | 19.18 | 80.82 |
| 7 | 112.90 | 318.71 | 67.74 | 250.97 | 45.16 | 21.26 | 78.74 |
| 8 | 112.90 | 310.32 | 48.39 | 261.94 | 64.52 | 15.59 | 84.41 |
| 9 | 150.00 | 238.33 | 70.00 | 168.33 | 80.00 | 29.37 | 70.63 |
| 10 | 158.06 | 198.06 | 67.74 | 130.32 | 90.32 | 34.20 | 65.80 |
| 11 | 206.67 | 70.00 | 70.00 | 0.00 | 136.67 | 100.00 | 0.00 |
| 12 | 203.23 | 42.26 | 32.26 | 10.00 | 170.97 | 76.34 | 23.66 |

***Table I**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar (Current Situation)*

Considering the data from the table above, we conclude that PV-C.S' total Electrical Energy Consumption amounts to 59900kWh, whilst the PV-C.S self-produces and consumes simultaneously 22040kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 9220€. Following the capital expenditure value of 1000€/kWp (as discussed in section 4), the total cost of this PV investment amounts to 76000€ and therefore, a period of 99 months is required to recoup the investment.

Next, we are going to study a new scenario, called "**scenario I**", by introducing a small Li-ion D.E.S$^2$ to the current PV-C.S. In order to select the appropriate capacity of the D.E.S$^2$ we draw valuable information from **Figure 1**. In more detail, **Figure 1** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Day of twelve calendar months. After a careful assessment of these curves, we conclude that self-consumed PV Energy can be increased in a significant way by storing 50kWh of generated PV energy (at midday hours with high irradiation) and use them at a later time to compensate consumption during hours where PV generation is not sufficient or absent. Thus, the self-consumed PV Energy becomes comparable to the Total Electrical Energy Consumption of the PV-C.S.

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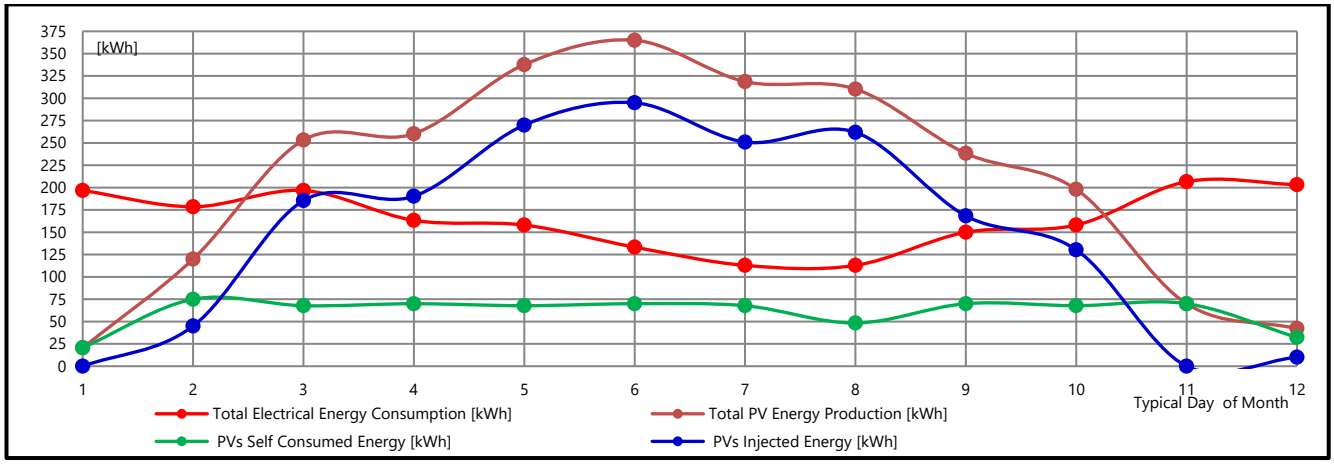


***Figure 1**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components (self-consumed & injected PV Energy) for the Typical Day of twelve calendar months **(current situation)***

Considering that the DOD value of an electrochemical storage system reflects its performance and protects batteries from over-discharge (improving so their life expectancy) we select the nominal capacity of the Li-ion D.E.S$^2$ to be equal to 62.5kWh and its useful capacity equal to 50 kWh (DOD≤80%).

**Table II** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of Self-Consumption, and PVs Injection Indices after the addition of the proposed Li-ion D.E.S$^2$ of 62.5kWh (nominal capacity) . According to these data the annual value of PVs self-consumed energy amounts to 46.21%, whilst the corresponding value of PVs injected Energy amounts to 53.6%.

| "Scenario I": addition of 62.5kWh Li-ion D.E.S$^2$ with 50kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total Produced PV Energy [kWh] | PVs Self Consumed Energy [kWh | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 196.77 | 20.65 | 20.65 | 0.00 | 176.13 | 100.00 | 0.00 |
| 2 | 178.57 | 120.00 | 120.00 | 0.00 | 58.57 | 100.00 | 0.00 |
| 3 | 196.77 | 253.23 | 117.74 | 135.48 | 79.03 | 46.50 | 53.50 |
| 4 | 163.33 | 260.33 | 120.00 | 140.33 | 43.33 | 46.09 | 53.91 |
| 5 | 158.06 | 337.74 | 117.74 | 220.00 | 40.32 | 34.86 | 65.14 |
| 6 | 133.33 | 365.00 | 120.00 | 245.00 | 13.33 | 32.88 | 67.12 |
| 7 | 112.90 | 318.71 | 112.90 | 200.97 | 0.00 | 35.43 | 63.06 |
| 8 | 112.90 | 310.32 | 98.39 | 211.94 | 14.52 | 31.70 | 68.30 |
| 9 | 150.00 | 238.33 | 120.00 | 118.33 | 30.00 | 50.35 | 49.65 |
| 10 | 158.06 | 198.06 | 117.74 | 80.32 | 40.32 | 59.45 | 40.55 |
| 11 | 206.67 | 70.00 | 70.00 | 0.00 | 136.67 | 100.00 | 0.00 |
| 12 | 203.23 | 42.26 | 42.26 | 0.00 | 160.97 | 100.00 | 0.00 |

***Table II**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**Scenario I**")*

By studying the data from **Table II**, we conclude that in "**scenario I**" the PV-C.S self-produces and consumes simultaneously 35710kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to

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12348€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement and installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 82250€.

**Figure 2** depicts the Total Electrical Energy Consumption of the PV-C.S, the Total Produced PV Energy and its components (self-consumed & injected PV Energy), after the addition of the proposed 62.5kWh Li-ion D.E.S$^2$ and for the Typical Day of twelve calendar months.

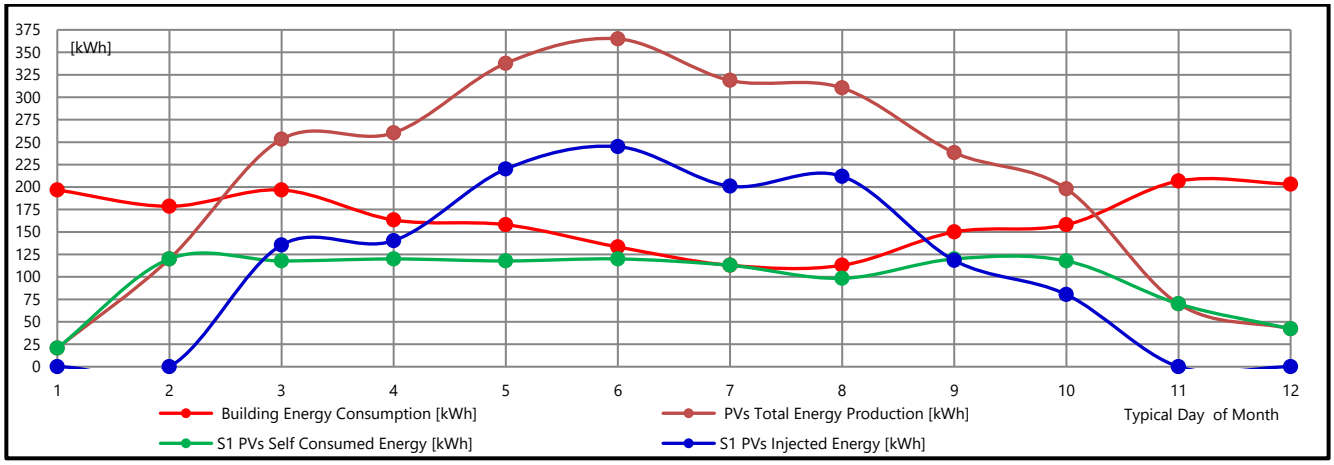


***Figure 2**: Total Electrical Energy Consumption of the PV-C.S, Total Produced PV Energy and its components after the addition of 62.5kWh Li-ion D.E.S$^2$ and for the Typical Day of twelve calendar months ("**scenario I**")*

At this point, it should be noted that the increase of 13670kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload).

| "Scenario I": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 50.00 | 1550.00 |
| 2 | 5.00 | 140.00 |
| 3 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 |
| 7 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 |
| 9 | 0.00 | 0.00 |
| 10 | 0.00 | 0.00 |
| 11 | 50.00 | 1500.00 |
| 12 | 40.00 | 1240.00 |

***Table III**: Unexploited kWhs of the proposed D.E.S$^2$ of 62.5kWh nominal capacity and 50kWh useful capacity, either at Typical Day or Monthly level ("**Scenario I**")*

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Additionally, the proposed Li-ion D.E.S$^2$ of 62.5kWh (nominal capacity) is not fully utilized during January, February, November and December due to the low solar energy potential of these months. Thus, 4430 kWhs of the D.E.S$^2$ remain unexploited. **Table III** presents the unexploited kWhs of Li-ion D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources. This service could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (less than half of the competitive energy tariff), an additional benefit of about 222€ per year for the PV-C.S owners will result.

There is another very interesting point in this scenario. By introducing the D.E.S$^2$ of 62.5kWh (nominal capacity), we can store not only all the energy needed to meet the day-to-day energy needs of the PV-C.S (for the period of July) but even more. This is technically feasible due to the high solar energy potential of these months and the low energy demand of the PV-C.S. Considering that these KWhs are stored during midday hours (under high irradiation) it is concluded that they contribute to the mitigation of grid congestion. Therefore, these amounts of stored PV energy should be remunerated by the DNOs. This conclusion is clear by studying the data (at typical day level) set out in **Table IV**. In more detail the difference between the Total Produced PV Energy and the sum of the PVs Self Consumed Energy and PVs Injected Energy, corresponds to kWhs that contribute to mitigation of congestion Table VI presents the kWhs that contribute to mitigation of congestion either at Typical Day or Monthly level. Adopting a target price of 5 euro-cents per KWh (less than half of the competitive energy tariff), an additional very small benefit of about 7€ per year for the PV-C.S owners will result. Taking into account both ancillary services a period of 78 months is required to recoup the PV system and the D.E.S$^2$ together.

| "Scenario I": kWhs that contribute to mitigation of congestion (Typical Days and Monthly values) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| Typical Day of Month [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.84 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Monthly Values [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

***Table IV**: kWhs that contribute to mitigation of congestion (Typical Days and Monthly values)*

Next, we are going to study a second scenario, named "**scenario II**", by introducing a second bigger, D.E.S$^2$ (100kWh nominal capacity and 80kWh useful capacity) to the current PV-C.S. **Table V** presents the energy transactions between the PV-C.S and the LDN for the Typical Days of twelve calendar months, as well as the corresponding values of S-C, and PVI Indices after the addition of the new Li-ion D.E.S$^2$ of 100kWh. According to these data the annual value of PVs self-consumed energy amounts to 53.25%, whilst the corresponding value of PVs injected Energy amounts to 44.09%.

By studying the data from **Table V**, we conclude that in "**scenario II**" the PV-C.S self-produces and consumes simultaneously 41150kWh. Taking into account the tariffs of Competitive Charges and Regulated Charges (as listed in the Table I of section 4) the annual savings from energy bills amount to 12453€. Last but not least, following the capital expenditure value of i) 1000€/kWp for the procurement and installation of the PV system and ii) 100€/kWh for the procurement and installation of the D.E.S$^2$ system, the total cost of this PV investment amounts to 86000€.

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| "Scenario II": addition of 100kWh Li-ion D.E.S$^2$ with 80kWh useful capacity (Typical Day of month) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | Total Electrical Energy Consumption [kWh] | Total produced PV Energy [kWh] | PVs Self Consumed Energy [kWh] | PVs Injected Energy [kWh] | Electricity fed by the LDN [kWh] | S-C index [%] | PVI Index [%] |
| 1 | 196.77 | 20.65 | 20.65 | 0.00 | 176.13 | 100.00 | 0.00 |
| 2 | 178.57 | 120.00 | 120.00 | 0.00 | 58.57 | 100.00 | 0.00 |
| 3 | 196.77 | 253.23 | 147.74 | 105.48 | 49.03 | 58.34 | 41.66 |
| 4 | 163.33 | 260.33 | 150.00 | 110.33 | 13.33 | 57.62 | 42.38 |
| 5 | 158.06 | 337.74 | 147.74 | 190.00 | 10.32 | 43.74 | 56.26 |
| 6 | 133.33 | 365.00 | 133.33 | 215.00 | 0.00 | 36.53 | 58.90 |
| 7 | 112.90 | 318.71 | 112.90 | 170.97 | 0.00 | 35.43 | 53.64 |
| 8 | 112.90 | 310.32 | 112.90 | 181.94 | 0.00 | 36.38 | 58.63 |
| 9 | 150.00 | 238.33 | 150.00 | 88.33 | 0.00 | 62.94 | 37.06 |
| 10 | 158.06 | 198.06 | 147.74 | 50.32 | 10.32 | 74.59 | 25.41 |
| 11 | 206.67 | 70.00 | 70.00 | 0.00 | 136.67 | 100.00 | 0.00 |
| 12 | 203.23 | 42.26 | 42.26 | 0.00 | 160.97 | 100.00 | 0.00 |

***Table V**: Energy transactions between the PV-C.S and LDN for the typical Days of twelve calendar ("**scenario II**")*

At this point, it should be noted that the increase of 19110kWh of PVs Self-Consumed Energy (compared to the initial salutation where no D.E.S$^2$ exists) was achieved by storing PV energy at midday hours with high irradiation. Thus, the increase of PVs Self-Consumed Energy contributes to the mitigation of grid congestion (appeasement of transformers and lines thermal overload).

| "Scenario II": Unexploited KWh of the D.E.S$^2$ (Typical Days and Monthly values) | | |
|---|---|---|
| Month | Typical Day of Month [kWh] | Monthly Values [kWh] |
| 1 | 80.00 | *2480.00* |
| 2 | 35.00 | *980.00* |
| 3 | 0.00 | *0.00* |
| 4 | 0.00 | *0.00* |
| 5 | 0.00 | *0.00* |
| 6 | 0.00 | *0.00* |
| 7 | 0.00 | *0.00* |
| 8 | 0.00 | *0.00* |
| 9 | 0.00 | *0.00* |
| 10 | 0.00 | *0.00* |
| 11 | 80.00 | *2400.00* |
| 12 | 70.00 | *2170.00* |

***Table VI**: Unexploited kWhs of the proposed D.E.S$^2$ of 100kWh nominal capacity and 80kWh useful capacity, either at Typical Day or Monthly level ("**Scenario II**")*

Additionally, the proposed Li-ion D.E.S$^2$ of 100kWh (nominal capacity) is not fully utilized due to the small size of the installed PV system. Thus, 8030 kWhs of the D.E.S$^2$ remain unexploited. **Table VI** presents the unexploited kWhs of the proposed D.E.S$^2$ either at Typical Day or Monthly level. These kWhs can be used

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by DNOs to store energy from other PV investments (without storage facilities) or to store energy from other cheap energy sources and therefore could be remunerated by the DNOs. Adopting a target price of 5 euro-cents per KWh (less than half of the competitive energy tariff), an additional benefit of about 402€ per year for the PV-C.S owners will result. By introducing the D.E.S$^2$ of 100kWh (nominal capacity), we can store not only all the energy needed to meet the day-to-day energy needs of the PV-C.S (for the period from June to August) but even more. This is technically feasible due to the high solar energy potential of these months and the low energy demand of the PV-C.S. Considering that these KWhs are stored during midday hours (under high irradiation) it is concluded that they contribute to the mitigation of grid congestion. Therefore, these amounts of stored PV energy should be remunerated by the DNOs. This conclusion is clear by studying the data (at typical day level) set out in **Table V**. In more detail the difference between the Total Produced PV Energy and the sum of the PVs Self Consumed Energy and PVs Injected Energy, corresponds to kWhs that contribute to mitigation of congestion **Table VII** presents the kWhs that contribute to mitigation of congestion either at Typical Day or Monthly level. Adopting a target price of 5 euro-cents per KWh (less than half of the competitive energy tariff), an additional benefit of about 103€ per year for the PV-C.S owners will result. Taking into account both ancillary services a period of 80 months is required to recoup the PV system and the D.E.S$^2$ together.

| "Scenario II": kWhs that contribute to mitigation of congestion (Typical Days and Monthly values) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time stamp | January | February | March | April | May | June | July | August | September | October | November | December |
| Typical Day of Month [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 16.67 | 34.84 | 15.48 | 0.00 | 0.00 | 0.00 | 0.00 |
| Monthly Values [kWh] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 500.00 | 1080.00 | 480.00 | 0.00 | 0.00 | 0.00 | 0.00 |

***Table VII**: kWhs that contribute to mitigation of congestion (Typical Days and Monthly values)*

Last but not least, **Figures 3** and **4** present the S-C and uncontrolled PVI indices of the PV-C.S for the typical day of twelve calendar months for: the Current Situation and the two hypothetical Scenarios (**Scenario I** and **Scenario II**). According to the data presented in this figure, it is concluded that D.E.S$^2$ can: a) maximize the self-utilization of locally generated clean electricity and b) contribute to the flexibility by reducing RES power production peaks.

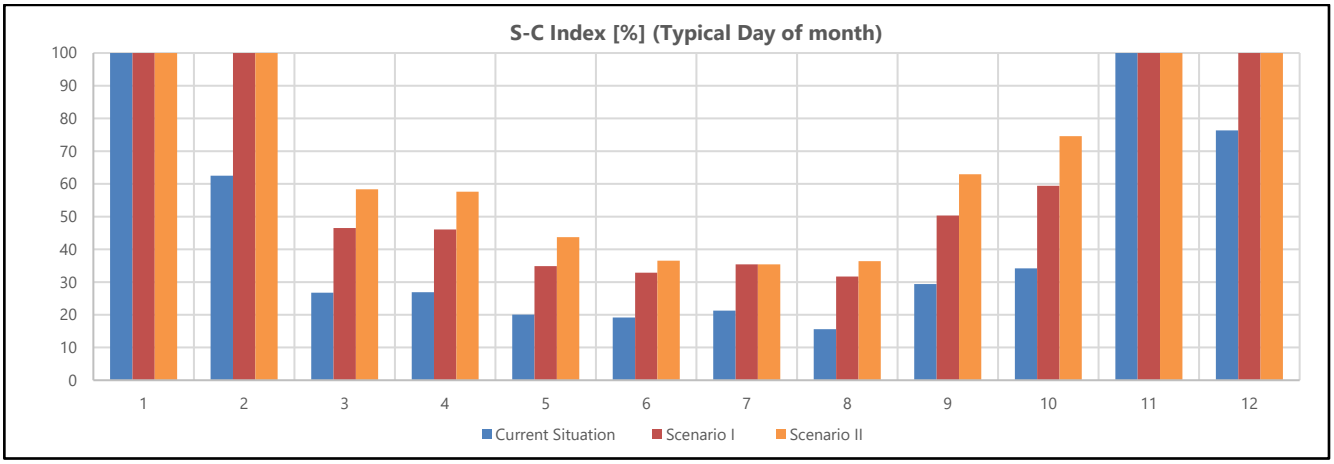


***Figure 3**: S-C Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 62.5kWh nominal capacity and b) 100kWh nominal*

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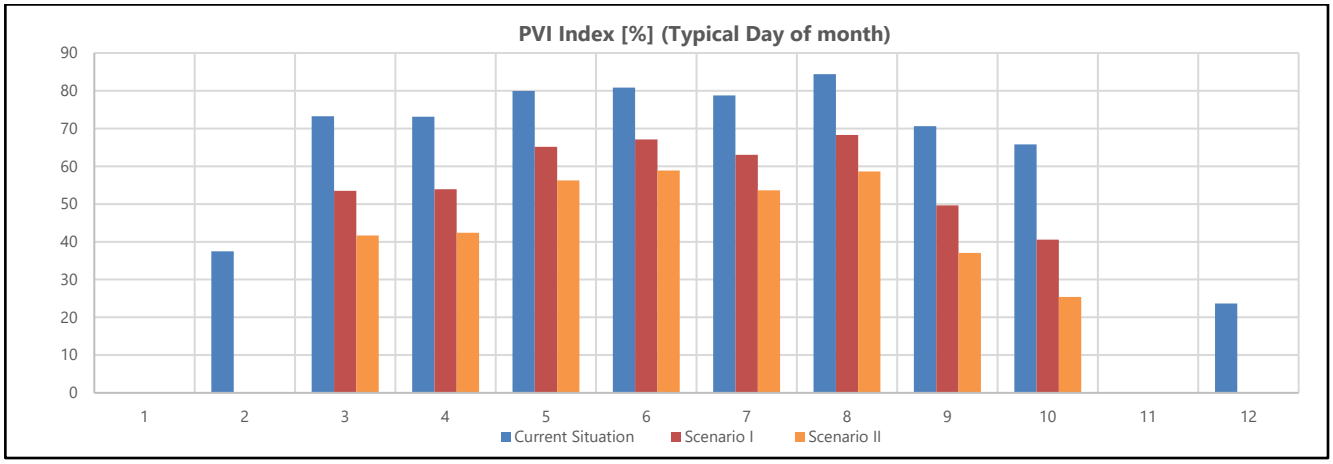


***Figure 4**: Uncontrolled PVI Index of the PV-C.S for the typical days of twelve calendar months for: the Current Situation and after the addition of a Li-ion D.E.S2 of a) 62.5kWh nominal capacity and b) 100kWh nominal capacity*

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## 4.8. Conclusions

Based on the above findings and considerations, it is concluded that the addition of D.E.S$^2$ into interconnected PV systems would contribute to mitigating concerns arising from the intermittent nature of photovoltaic systems. In more detail, D.E.S$^2$ enable PV systems to conduct themselves as controlled and dispatchable sources (similar to the conventional thermal and hydropower plants). Thus, PV systems with D.E.S$^2$ become capable of contributing to the efficient and safe operation of the grid.

D.E.S$^2$ can improve the operation of distribution networks by providing ancillary services such as reducing RES power production peaks and providing congestion management flexibility (either due to power system's physical or operational limitations). Additionally, D.E.S$^2$ can be used as a measure for time shifting, storing electrical energy when it is less expensive and selling the stored energy during peak demand periods (Load Levelling). It is recalled here that Load levelling is a method of balancing the large fluctuations associated with electricity demand.

The proposed price charging of the abovementioned ancillary services (almost at half of the competitive energy tariff) offsets the cost of adding D.E.S$^2$ and prevents any increase in time required to recoup the investment (compared to PV systems without energy storage). In certain conditions large D.E.S$^2$ may lead to shorter required depreciation periods depending on the target prices for the procurement of the abovementioned ancillary services.

Furthermore, D.E.S$^2$ can provide capability to a system for its startup from a shutdown condition without taking power from the grid (Black start). Additionally, D.E.S$^2$ can operate as Uninterruptible Power Supply systems maintaining electrical load power in the event of the power surge. These services although are not remunerated by the DNOs, are very crucial for specific groups of consumers.

Finally, in case of autonomous-hybrid PV systems, E.S$^2$ can be used for peak power reduction, RES production saving, demand response and capacity support.

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# 5. Annex

## 5.1. Annex 1: List of relevant acronyms

| ACRONYM | TERM |
|---|---|
| AC | Alternative Current |
| AHC | Aggregated Households Community |
| AVG | Average |
| CU Index | Capacity Utilisation Index |
| DC | Direct Current |
| D.E.S$^2$ | Distributed Energy Storage Systems |
| DNO | Distribution Network Operator |
| DOD | Depth of Discharge |
| D-R | Demand Response |
| E.S$^2$ | Energy Storage Systems |
| FY Index | Final Yield Index |
| LDN | Local Distribution Network |
| MPPT | Maximum Power Point Tracking |
| pu | Per-unit system<br>$\text{per unit value} = \frac{\text{actual value in any unit}}{\text{base or reference value in the same unit}}$ |
| PV | photovoltaic |
| PV-C.S | Photovoltaic Case Study |
| PV ECOs | PV Energy Communities |
| RES | Renewable Energy Sources |
| PVE Index | PVs Exploitation Index |
| PVI Index | PVs Injection Index |
| S-C Index | Self-Consumption Index |
| S-S Index | Self-Sufficiency Index |
| TD profile | Typical daily profile |