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SMILE

Smart Island Energy Systems

Deliverable D4.5
Detailed plan of action for the DSM demo

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Keywords, Acronyms

A	Amps
AC	Alternate Current
AM	Ante Meridiem: Before noon
AMI	Advanced Metering Infrastructure
API	Application Programming Interface
BESS	Battery Energy Storage System
BMS	Battery Management System
BPU	Battery Protection Unit
CAN	Controller Area Network
CG	Carlo Gavazzi
cm	centimeters
DX.Y	SMILE Deliverable X.Y
DC	Direct Current
DL	Decree-Law
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
DTI	Danish Technological Institute (SMILE partner)
EEM	Electricity Company of Madeira
EMS	Energy Management System
EN	European Norm
EROI	Energy Return on Energy Investment
ESI	Electronically Stored Information
EV	Electric Vehicle
FF	Frequency Fluctuations
FTP	File Transfer Protocol
h	hour
HTTP	Hypertext Transfer Protocol (world wide web protocol)
Hz	Hertz
IP	Internet Protocol
IRR	Internal Rate of Return
JSON	JavaScript Object Notation
KPI	Key Performance Indicators
LIBAL	Lithium Balance (SMILE partner)
LPF	Low-pass filter
LV	Low Voltage
LVRT	Low Voltage Ride Through
MV	Medium Voltage
MX	Month X
OEM	Open energy monitor
PSL	Power Standards Labs
PV	Photovoltaic
QGBT	Low Voltage Distribution Board
QoS	Quality of Service
RAM	Autonomous Region of Madeira
RES	Renewable Energy Systems
ROI	Return of Investment
RQS	Quality of Service Regulation

RTU	Remote Terminal Unit
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SMA	SMA Solar Technology AG
SMILE	Smart IsLand Energy systems
SOC	State of charge
SOH	State of Health
T4.X	SMILE Task 4.X
TCP	Transport Communication Protocol
THD	Total Harmonic Distortion
THDU	Total Harmonic Distortion Unit
TSO	Transmission System Operator
U	Abbreviation for UPAC
UPAC	Unit of Production for Self-Consumption
UPP	Unit of Small Production
USB	Universal Serial Bus
V	Volts
VI	Voltage Increase
W	Watts
Wp	Watt peak
WPX	Work Package X

1 Introduction

The Autonomous Region of Madeira (RAM) is extremely compromised in achieving 50% renewable energy integration by 2020/2021. In order to reach this ambitious goal, the local DSO/TSO (EEM) and the governmental entities are working in new projects (most of them integrated in H2020), which will try to overcome the challenges encountered currently.

In this regard, the SMILE project will be a useful bridge between the maximization of photovoltaic production (UPACs – self consumption only installation –, and UPPs – full grid injection installations –) using different configuration of BESS storage systems, with the integration effects on the low-voltage grid. SMILE Project solutions developed by the partners "know-how", will promote the expansion of photovoltaic installations and increase the grid absorption maintaining or even increasing energy quality and safety on delivery.

Since Madeira is one of the sunniest Islands in Europe, the photovoltaic proliferation will undoubtedly create great energy assets, promoting self-consumption with storage attractively enough to prosumers to invest in, and reducing load on low voltage grid benefiting the RES shares on the energy mix.

In Portugal, the renewable energy sources (RES) for self-consumption and micro-production obeys the rules found in the Law-Decree DL 153/2014. Nevertheless, due to the isolated nature of the electric grid, additional rules had to be defined for Madeira Island [1]. From the additional rules, the most prominent one states that *Self-consumption prosumers are free to install systems if they ensure that the* ***production excess is curtailed, preventing the injection in the grid****.*

Consequently, one of the Madeira objectives under the SMILE framework is to work towards the optimization of self-consumption from RES through the introduction of BESS and specialized battery control algorithms. By introducing such mechanisms, it should be possible to prevent the curtailment of renewable energy, which would benefit both the prosumer and the DSO/TSO. The former would be less dependent from the grid, whereas the latter would see an increase of RES in the energy mix without having to install additional renewable production capacity.

Adding to this objective, in the present, EEM is planning the implementation of a grid-code in the near-future, which will potentially allow an increase of the UPACs and UPPs with supervised injection into the electrical public grid. The grid code primarily will need to guarantee the national Quality of Service Regulation (RQS) parameters depicted in Table 1.1, while also increasing the penetration of RES in the low voltage distribution grid (230/400 V).

Table 1.1 – Grid Quality of Service thresholds as defined by the national Quality of Service Regulation, after the European norm EN 50160:2010.

Metric	Nominal Value	Unit	Thresholds	
			Min	Max
Voltage	230	V	-10% (207)	+10% (253)
Frequency	50	Hz	-2% (49)	+2% (51)
Harmonics	-	-	THD < 8%	
Flicker	-	-	Plt < 1	

On an early stage, power shares of RES will be given to specific zones in the Island to measure how the injection in the low voltage grid impacts the power flows. The case when UPACs or UPPs are producing

at their peak power and the load level in the distribution grid is medium/low, will translate in the worst-case scenario (synonymous of overvoltage and unbalanced power flows).
In order to solve this problem, the grid code presents two different approaches: i) the manipulation of the power factor, or ii) the modulation of the active power. As the low voltage grids are characterized by being mostly resistive, the manipulation of the power factor will not represent a significant impact regarding overvoltage, meaning that the most effective solution to guarantee the RQS parameters is to modulate the active power.

Against this background, another objective of Madeira under the SMILE framework is to study the possibility of providing improved grid control through the introduction of BESS and Demand Side Management techniques at the distribution station level. Ultimately, the ability to control voltage and frequency control, and coordinating active and reactive energy balances at the distribution level would represent a major step towards increasing the injection of renewable energy sources in the Madeira electric grid.

1.1 Scope and Objectives

This document presents the detailed plan of action for the DSM demo in Madeira Island in the scope of the H2020 SMILE project. To state more concretely, we present the plan of action for the three pilot studies that will demonstrate the use of BESS and DSM techniques to maximize the integration of RES in the grid, and as tools to provide increased grid quality control.

Overall, the objective of this document is to provide a comprehensive overview of what will be demonstrated in Madeira Island in terms of BESS and DSM techniques, and how and when the different demonstrations will take place.

1.2 Structure

This document is organized as follows: chapter 2 presents the detailed plan of action for the **Maximizing the Integration of RES through the Installation of BESS** demonstrator. Chapter 3 presents the detailed plan of action for the **Voltage and Frequency Control through SMILE Solutions** demonstrator. The plan of action for both demonstrators is divided in three main sections**:** i) the infrastructure preparation, ii) a description of the studies that will be performed, and iii) the proposed timelines and evaluation methodology. Finally, chapter 4 reports on the ongoing work, the main challenges, and the next deliverables related to execution of the SMILE project WP4 (Madeira Island demonstrator).

This document is complemented with an appendix consisting of an update to deliverable D4.3 related to data collection and modelling activities [2]. D4.3 consists of an overview of the consumption and solar PV production of the pilot 1 (Getting started with BESS and DSM) and pilot 2 (Moving forward with BESS and DSM) participants, as well as some initial insights regarding who are the potential candidates to receive a BESS in the scope of the pilot 1.

This appendix updates the installation date of the SMILE energy monitoring solution, and some technical details of the participating UPACs. The appendix also provides the results of the initial data analysis of the UPACs that were not analyzed in D4.3 due to the lack of data. Finally, a summary of the potential candidates to receive a BESS in the scope of the different pilots is also provided.

1.3 Relation to Other Tasks and Deliverables

This document lays the ground for the work that will be conducted in the context of the BESS and DSM demonstrators in Madeira Island. As such, it serves as a main input for the tasks T4.5 (evaluation of storage and DSM), and consequently future deliverables D4.7 (Installation report of the DSM demo), D4.9 (Report on customer acceptance and satisfaction) and D4.10 (Report on market acceptance and replicability).

It also receives inputs from deliverables D4.1 (Case study specification and assessment), D4.2 (Infrastructure preparation and kick-off), D4.3 (data collection, modelling, simulation and decision) and D4.4 (User acceptance report of the initial smart metering deployment) [1]–[4].

Regarding the other work packages and deliverables of SMILE, this deliverable is mostly related with WP5 and WP6, in particular to what it concerns to deliverables D5.1 (Most appropriate DR services for each pilot) [5], D6.1 (Report on selected evaluation indicators) [6].

2 Maximizing the Integration of RES through the Installation of BESS

This chapter presents the plan of action for the two pilot studies aimed at maximizing the integration of RES in the Madeira electric grid through the installation of BESS.

The first pilot is targeted at four domestic UPAC owners that are not allowed to sell the excess production to the utility, and thus can benefit from the usage of a BESS to maximize self-consumption. The second pilot targets a small restaurant UPAC that consumes more than what is produced from RES, and thus can benefit from BESS by doubling the batteries' utilization by pre-charging from off-peak periods to cover early morning loads, and then re-charging from the sun to cover evening loads.

The remaining of the chapter is organized in four main sections. The first section presents an overview of the infrastructure preparation (e.g., energy monitoring and energy storage hardware). The second section describes the BESS control strategies that are proposed for the domestic UPACs, whereas the proposed commercial BESS control strategies are described in section 3. Finally, section 4 presents the proposed trials with the respective timelines, and the proposed evaluation strategy.

2.1 Infrastructure Preparation

2.1.1 Energy Monitoring Hardware-Software Platform

In terms of energy monitoring, the deployed solution is comprised of two main components, namely, the Carlo Gavazzi smart-meter, and a gateway that is based on the Raspberry Pi computing eco-system. The communication between both devices is performed using the ModBUS RTU[1] serial protocol, and the communication with the EMS is currently performed using 3G hotspots connected via USB.

The gateway software consists mainly of three independent services/daemons running on the Raspberry Pi: i) to ***read*** the power consumption from the CG system using the Modbus protocol, and ***store*** the obtained measurements on a local MySQL database. This daemon is set to run roughly every second; ii) to ***compute*** and ***upload*** the data to the EMS. This service runs roughly every minute; and iii) to create ***backup*** copies of the raw measurements. This service runs once every day at 12AM.

For additional details about the hardware and software configurations, please refer to D4.2 [3].

2.1.2 Energy Management System

The EMS, also referred as the SMILE backend, is the infrastructure that is responsible for handling all the data produced in the Madeira demonstrator. The main objectives for the EMS are:

- Provide secure storage to the data generated in each of the different pilots. This includes, but it is not limited to, energy consumption, solar PV production, EV charging, and battery status.
- Provide a secure mechanism to access the pilot data. This data can be used, for instance, to populate the different end-user applications, or to provide data to our own BESS control algorithms, or third-party systems (e.g., Route Monkeys's forecasting algorithms).

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[1] ModBUS RTU, https://www.rtaautomation.com/technologies/modbus-rtu/

The EMS backend is a flexible data storage and querying system, intended to allow the creation of products/services on top of the data generated in the different pilots. It consists of four main entities: producers, devices, sources, and schemas:

- A **producer** is a user that can be related to a house or pilot location and has a registered account in our database. Producers are associated with devices (a producer can have many devices), also registered in our database.
- Each **device** refers to a physical device installed at the producer infrastructure. The devices are responsible to send consumption and/or production data to our server, which stores the information in our database, to a source.
- A **source** is basically a collection of data that stores information about power consumption/production for a specific type of device and is built based on a schema.
- A **schema** defines which fields of data (e.g. timestamp, power consumption, power production, or others) and the type of data (float, string, etc.) the collection (source) will store in the database, so each source can have a different schema, giving us greater flexibility.

For the SMILE project, a new instance of PRSMA's backend was deployed in a cloud hosting service from Linode[2]. The nature of the EMS favors configuration over custom implementation. Therefore, most of the efforts so far are focused on correctly configuring the EMS for SMILE, and on building the user interface for users and administrators.

Some security concerns were addressed in our system, starting with the usage of HTTPS to ensure the protection of the privacy and integrity of the exchanged data while in transit between the client and the server. Authentication is necessary for producers and devices, to prevent spurious data from being posted to an account, to disallow querying of private information and also to login and have access to our web interfaces. Sensitive data in our database like user passwords and device authentication tokens are encrypted (hashed). The majority of our HTTPS routes are protected with middleware mechanisms for filtering the requests and to verify authentication and authorization, to decide if the requests can be made or not. Our server does not allow loading of scripts from third-party domains, as these have to be included locally and external domains are blocked. To protect the server from undesired requests and accesses, some rules were configured in the firewall. By default, everything is denied and security rules must be included to represent what is allowed by the server. Finally, all the connections and communications with the database must be performed through previously authorized MongoDB accounts.

All the data is made available through an API to properly authenticated, therefore, third-party integration is straightforward. There are also web services available for the most common tasks such as querying and pushing data. Special web-services will also be made available to interact with active devices that may be installed in the pilot sites (especially for the pilots that encompass EVs and smart charging), for example, to turn on/off plugs remotely.

Finally, regarding the BESS control algorithms, the EMS will have to interact with an intermediate system in order to send and receive data to/from the local site controllers (see below for additional details). In this case, proper authentication mechanisms will be implemented to ensure that the EMS does not receive spurious data. As for the actual control algorithms, these will be executed either when new data is available from the site controller (i.e., near to real-time), or when certain business rules are observed (e.g., time of the day, the day of the week, etc.). In either case, once the execution is

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[2] Linode Web Hosting, https://www.linode.com/

completed, the generated outputs will be sent back to the site controller (via the intermediary system) using JSON encoded messages.

For additional details about the EMS, please refer to D4.2 [3].

2.1.3 Energy Storage Hardware

The SMILE partner Lithium Balance (LIBAL) will provide the energy storage hardware for the Madeira pilots. In the concrete case of pilots 1 and 2, the following BESS will be provided:

- 4 single-phase 3kW/8.6kWh residential BESS, to be deployed in four domestic UPACs as part of the pilot number 1.
- 3 single-phase 3kW/8.6kWh residential BESS, to be deployed on a three-phase commercial UPACs as part of the pilot number 2.

Overall, the domestic BESS provided by LIBAL will consist of the following components:

- Interconnected battery cells making up the battery system;
- The battery protection unit (BPU) – a set of switching and current sensing devices controlled by the underlying battery management system (BMS)
- The BMS, responsible for battery safety, control of BPU, monitoring and diagnostic of the BESS;
- The inverter – a bidirectional power converter DC/AC. Single phase inverters will be used for 3kW/8.6kWh systems.
- A site controller – a local controller responsible for inverter control and its safe connection and disconnection, collecting all relevant data and transferring them to the EMS using a third-party system (the VNet, provided by the SMILE partner OVO-Energy [5]), self-diagnostics of the entire BESS (battery + inverter), and receiving control signals (e.g. active, reactive power set points, operation mode) from the EMS.

The following block diagrams represent the different components that will comprise the domestic BESS. Figure 2.1 represents the single-phase BESS that will be deployed in pilot number 1, whereas Figure 2.2 represent the 3 single-phase BESS to be deployed in pilot number 2.

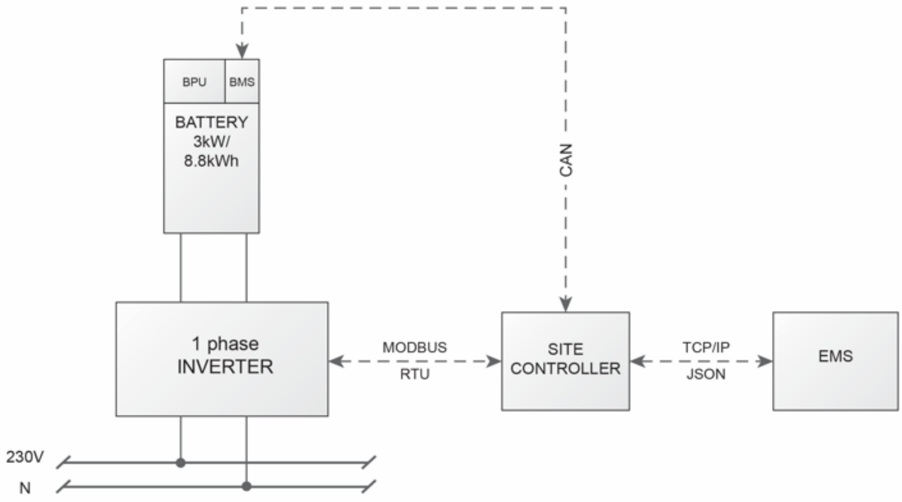

Figure 2.1 – Block diagram of the single-phase LIBAL 3kW/8.6kWh BESS and communication with the EMS. (Application: improving self-consumption of the domestic UPACs – pilot study 1).

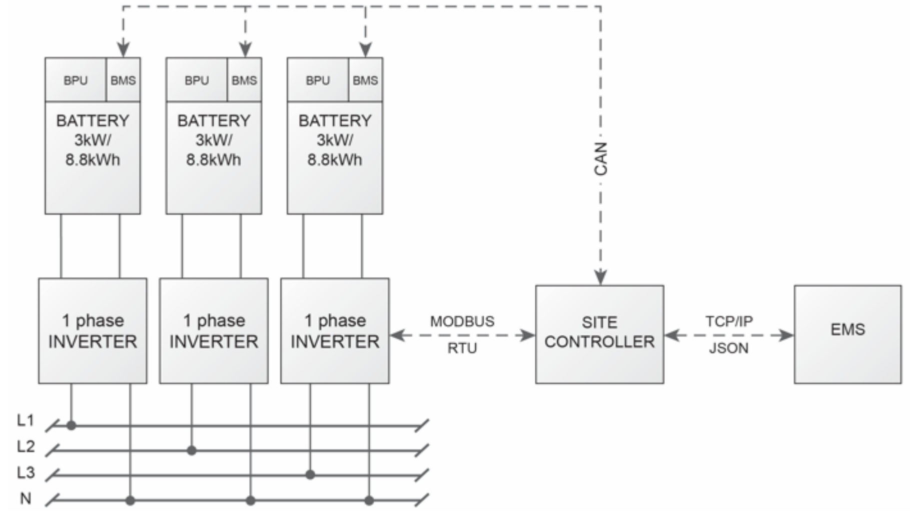

Figure 2.2 – Block diagram of the three single-phase LIBAL 3kW/8.6kWh BESS and communication with the EMS. (Application: improving self-consumption on commercial UPACs – pilot study 2).

The main parameters of the residential systems are presented in Table 2.1:

Table 2.1 – Main parameters of the residential BESS

Item	Value	Unit
Dimensions (height*width*depth))	110*44*29.5	cm
Battery type	LPF	-
Power	3.0	kW
Nominal battery DC voltage	48	V
Maximum rack voltage	54.75	V
Minimum rack voltage	42	V
Energy content	8.6	kWh

Regarding, the inverter hardware, this has not been yet selected by LIBAL, therefore additional details cannot be provided at this stage. These, and other relevant technical details will be provided in D4.7 (Installation report of the DSM demo), on month 48.

Finally, concerning the physical installation of the different hardware, this will be done with the support of DTI, another of the SMILE partners. All the installation details will be provided in D4.7.

2.1.4 BESS Remote Control

All the communications with the BESS will be done through the LIBAL site controller, via OVO's VNet cloud platform [5]. The main tasks of the site controller are:

- Connect up to several racks to a common DC BUS
- Safe connection and disconnection of the inverter
- Inverter control
- Collect and transfer all the relevant data to the EMS (via VNet)
- Implement the operation profiles provided by the EMS (via VNet)

- Implement the control schemes defined by the EMS (via VNet), by controlling the current int/out flux
- Self-diagnosis for automated service execution.

The EMS will communicate with VNet that will in turn communicate with the site controller using TCP/IP communications. The JSON format will be used for telemetry, and BESS information will be sent to VNet every 10 seconds. However, the control signals from VNet (also in JSON format), will be received and processed as they come (i.e., client – server architecture).

2.1.5 BESS Control Strategies

The different BESS control strategies (i.e., algorithms) will be running inside the EMS, and will communicate with the BESS controllers using the VNet cloud. The flowchart in Figure 2.3 provides a general overview of the control strategy.

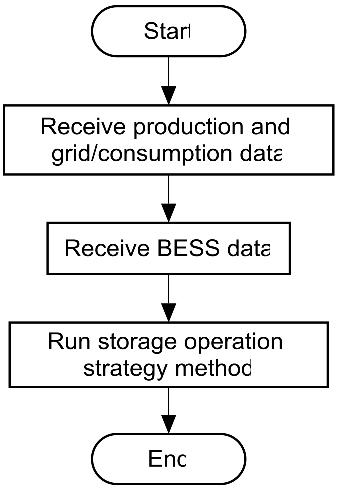

Figure 2.3 – General operation of the BESS control algorithms

The production and grid/consumption data are received from the systems described in section 2.1.1 and the BESS data is received from the BESS controllers via VNet cloud.

The main module of the algorithm is the **storage operation/control strategy** that can be adapted for different situations. Within this module, depending on the inputs (consumption, production, BESS status and operation strategy), the control algorithm will decide if the battery should be charged, discharged or kept untouched. In general terms, the BESS strategy method is responsible for deciding when and how to actuate in the battery.

2.2 Pilot Study 1: Getting Started with BESS and DSM

In this pilot, we will investigate the real-world performance and impacts of BESS systems in a sample of four domestic UPACs by deploying and evaluating several distinct BESS control strategies. The different control strategies are described in the following sections.

2.2.1 Standard BESS Control Strategies: Greedy Operation

In this particular case, we will use a greedy strategy, where the goal is to maximize self-consumption by storing as much of the excess energy from renewable sources as possible.

This is the simplest operation strategy possible, as it determines the residual load (i.e., the difference between production and consumption) and instantly actuates the BESS accordingly by storing excess production until the BESS is fully charged or supplying the excess demand from the BESS until it is fully discharged. Figure 2.4 shows the flowchart of the greedy strategy.

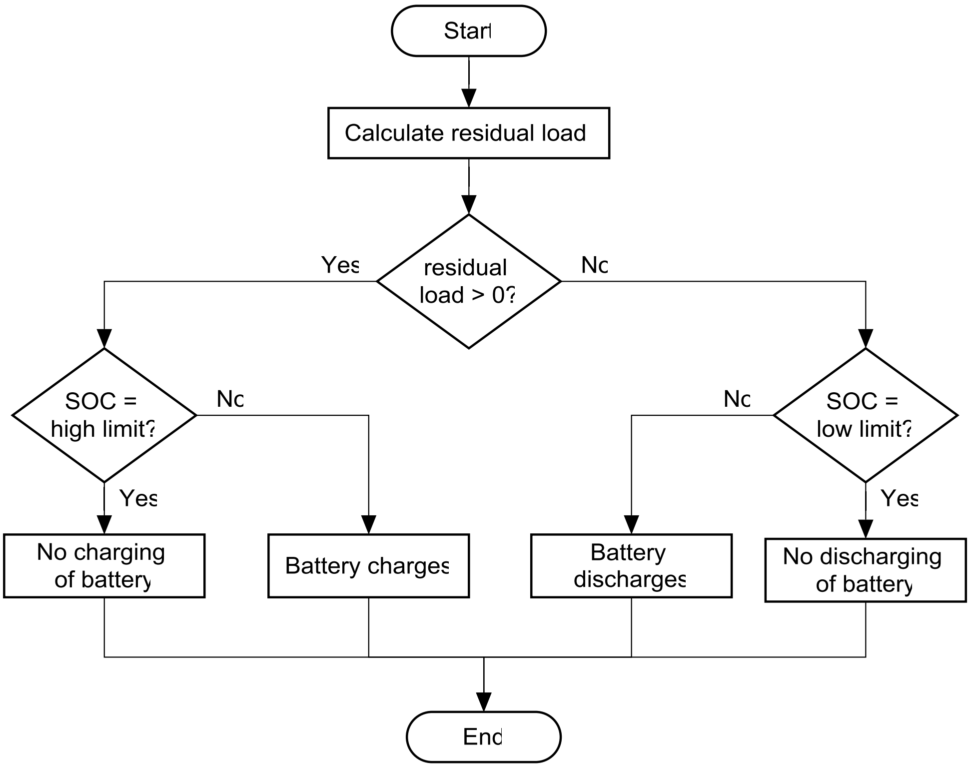

Figure 2.4 – Flowchart showing the greedy strategy for BESS operation

One of the main limitations of the greedy strategy is the fact that it does not consider the possibility of having different energy tariffs during the day. Consequently, we will implement a version of the greedy algorithm that also takes into consideration the actual tariffs as per Figure 2.5 and Table 2.2.

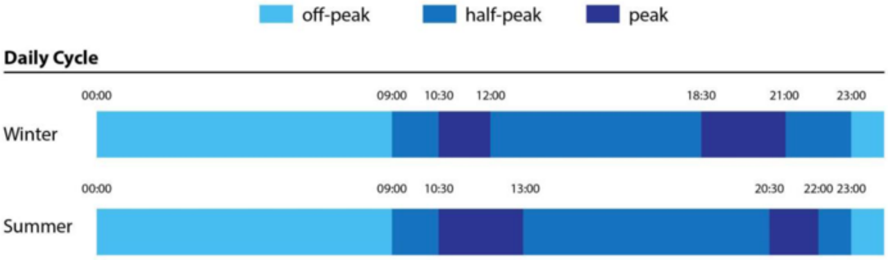

Figure 2.5 – Different billing periods in Madeira Island

Table 2.2 – Billing periods for each of the available tariffs

Tariff	Billing Periods
Single Tariff	Always
Dual Tariff	Off Peak
	Half Peak and Peak
Triple Tarif	Off Peak
	Half Peak
	Peak

In this enhanced version of the greedy strategy, during off-peak periods, the excess demand is supplied from the grid. On the other periods, the excess demand is supplied by the BESS, as long as the battery is not totally discharged. Therefore, the energy stored in the BESS is only used when the energy tariff is higher (which corresponds to the half-peak and peak periods for dual tariff installations). Figure 2.6 shows the flowchart of the billing period-aware greedy strategy.

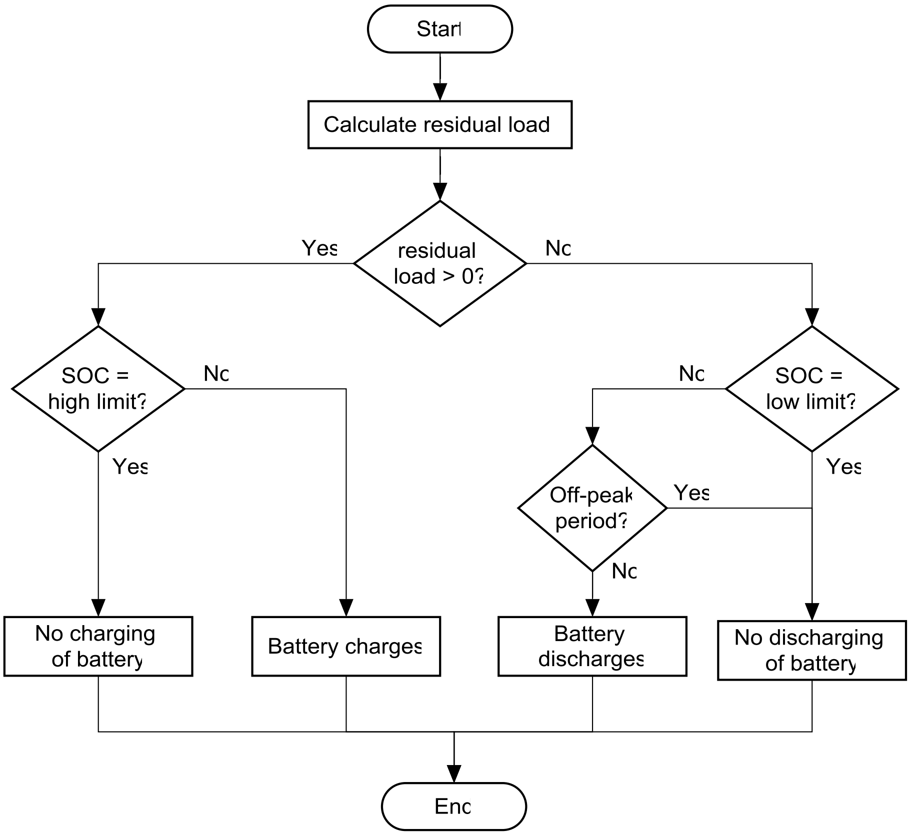

Figure 2.6 – Flowchart showing the billing period-aware greedy strategy for BESS operation

2.2.2 Better BESS Control Strategies: via Forecasting

As a more advanced study, we will also consider the effects of incorporating consumption and production forecasts in the BESS control strategy. Ultimately, the main goal is to understand if incorporating such kind of information improves the BESS operation.

To this end, we will rely on a series of machine-learning algorithms to forecast the consumption and solar PV production for each of the participating UPACs. The forecasts will then be used to decide the battery operation strategy. For example, if the forecasted production for the next hour is low, then maybe the best strategy is to store as much renewable energy as possible. On the other hand, if the algorithm predicts that the consumption will not be very high early in the evening, perhaps a better strategy is to consume as much renewable energy as possible with the support of the BESS (i.e., use a greedy strategy).

2.3 Pilot Study 2: Moving Forward with BESS and DSM

In this pilot, we are mainly interested in understanding to what extent a BESS can be beneficial for a commercial UPAC, and if arbitrage (i.e., charging the BESS with power from the grid) can increase such benefits without seriously reducing the battery lifetime.

To this end, we will deploy and evaluate two distinct BESS control strategies in a small restaurant that serves lunches on a daily basis, and very sporadically serves dinners as well. The two strategies are briefly described in the following sections.

2.3.1 Standard BESS Control Strategies: Greedy Operation and Rule Based Arbitrage

This strategy is very similar to the standard BESS control strategies that will be tested in the domestic UPACs. The only difference is that the BESS will be pre-charged from the grid, based on a pre-defined set of rules.

In this operation strategy, the rules will be defined taking into consideration only the past consumption data, and will be changed a pre-defined number of times. The number of times in which the rules will be changed will be also defined based on past consumption data, with the minimum period set for one week. I.e., in one year, the arbitrage rules can only change 52 times.

Additionally, when defining the rules, we will also take into consideration what is best for the local grid, i.e., pre-charge will only be allowed during off-peak periods.

2.3.2 Better BESS Control Strategies: via Forecasting and Dynamic Arbitrage

This strategy is similar to the domestic control strategy with forecasting, yet, in this situation forecasting will also be used to set the arbitrage periods dynamically.

To state more concretely, in this operation strategy we want to test at least two different scheduling strategies: i) day-ahead forecasting, and ii) hour-ahead forecasting. In former strategy, the arbitrage periods for the next day will be fixed based on the forecasted consumption and production for the next 24 hours. As for the latter, the arbitrage periods will be updated hourly, based on the forecasted consumption and production.

Ultimately, by deploying these different strategies we are interested in understanding which of the strategies offer the best trade-off between energy savings and battery degradation, as this is currently one of the open-ended questions regarding the application of arbitrage at large scale [7], [8].

2.4 Trials and Evaluation Methodology

2.4.1 Proposed Trials

In order to test the different strategies, two long-term trials in each UPAC will be conducted, according to the installations conditions. I.e., for an UPAC with a single-tariff power contract only single tariff strategies will be placed into practice. Nevertheless, all the proposed strategies will be tested against each UPAC through simulation, similarly to what was done in D4.3. The simulation outputs will then serve as baseline data for the overall evaluations.

Figure 2.7 shows the proposed trials and the respective timelines. We are proposing that each trial lasts for 12 consecutive months, as this timeline makes it possible to capture seasonal variations that may or may not affect the outcomes of the proposed trials.

Figure 2.7 – Proposed trials and respective timelines

2.4.2 Proposed Evaluation Methodology

The purpose of testing different control strategies in two different trials as well as using computer simulations is to be able to generate and compare a good number of different scenarios that can later be generalized to other sites.

Three of the possible comparisons are: i) field trials vs the current situation (i.e., BESS + PV vs. PV only), ii) field trial 1 vs field trial 2, and iii) field trials vs simulations (of BESS + PV). Ultimately, these, and other scenarios, will be assessed using a variety of methodologies and performance metrics developed to properly evaluate the human and technological aspects of real-world pilots.

2.4.2.1 Human Aspects

The human aspects that will be evaluated will be customer engagement and satisfaction. These will be assessed through Contextual Inquiries where the team will approach the domestic UPAC users and collect information before and after the installation of our equipment. Contextual inquiries are a combination of semi-structured interviews with observations of users interacting with the equipment installed for the pilots [9]. By equipment, we refer specifically to the interfaces users will have available with their energy production information. In addition, with the evolution of the pilots and the growing information needs from the users, this evaluation will include the use of the Wizard of Oz techniques, to test potential features or information availability at later stages of the project. These techniques allow to observe the users operating a system where some of the services or features are simulated by a Wizard [10]. This allows testing features without having to fully implement, ensuring these are understood by users and refined according to the testing, saving time in implementation efforts.

2.4.2.2 Technological Aspects

The technological aspects will be evaluated taking into consideration different metrics, depending on the final objective whether it is technical, environmental, economic, or social. To state more concretely, the evaluation will be based on the KPIs defined in D6.1 [6]. Table 2.3, Table 2.4, Table 2.5, and Table 2.6.

Table 2.3 – List of technical KPIs to evaluate the commercial and domestic UPACs demonstrator

KPI	Description
On-site energy ratio	Relation between the annual energy supply from local renewable sources and the annual energy demand
Reduced energy curtailment of RES/DES	The difference between the energy curtailments before and after the integration of a/all the SMILE solutions
Voltage variations	Difference between the actual voltage supplied to MV/LV users and the nominal value
Grid congestion	Grid sustainability to peaks
Battery degradation rate	The rate at which the battery performance is reducing over a year/cycle.
Storage energy losses	Losses because of energy storage solutions
Degree of self-supply	Measures the percentage of PV generation which is used for self-supply, and not sold to the grid

Table 2.4 – List of environmental KPIs to evaluate the commercial and domestic UPACs demonstrator

KPI	Description
Energy Return On Energy Investment (EROI)	Investment taking into consideration the component's whole lifetime
CO_2 Tons Saved	Tones saved per annum as compared with gas and grid electricity
Reduced Fossil Fuel Consumption	Reduction in the fossil fuels consumption for heating, transportation and power generation

Table 2.5 – List of economical KPIs to evaluate the commercial and domestic UPACs demonstrator

KPI	Description
Life-cycle cost of energy generation	Relation between the annual energy supply from local renewable sources and the annual energy demand
Internal Rate of Return (IRR)	Profitability of an investment
Return of Investment (ROI)	Difference between the actual voltage supplied to MV/LV users and the nominal value

KPI	Description
Investment Payback Period	The length of time that it takes for the cumulative gains from an investment to equal the cumulative cost
Annuity Gain	Measures the annual profits of an investment throughout its lifetime
Total Capital Cost per kW installed	Examines the initial cost of an investment depending on the size of the capacity being installed

Table 2.6 – List of social KPIs to evaluate the commercial and domestic UPACs demonstrator

KPI	Description
Improved Access to Online Services	The extent to which access to online service was improved
Degree of Landscape Impact	Refers to the possible opposition from citizens. A wind turbine or battery may look ugly or obstruct the view to the horizon. An aesthetical measure

Independently of the objective, all the metrics require technical, environmental, economic, and social parameters that will need to be collected from the field trials and computational simulations. For example, most of the economic metrics are based on economic parameters like the installation cost, interest rate, inflation rate. As such, the research team is currently conducting extensive research towards understanding what are the requirements to calculate each of the performance metrics, and assessing if such requirements can be accomplished with the data that will be generated by the different live pilots and the computer simulations.

3 Voltage and Frequency Control through SMILE Solutions

This chapter presents the plan of action for the two pilot studies aimed at controlling the voltage and frequency through the installation of BESS at the distribution station level.

The electrical Low-Voltage (LV) networks in the rural areas of Madeira Island are mainly of the aerial type, and have considerable extensions. When associated with low consumption and high production periods (normally around midday), it is very likely to observe the phenomena of Voltage Increase (VI). Additionally, since the Madeira Island's power grid is completely isolated, it is subject to frequency fluctuations (FF) that are much larger than that of the interconnected networks.

With the installation of a BESS in a transformation station, our goal with this pilot is to study the possibility of using RES not only to power the energy mix, but also to stabilize the grid, improving the Quality of Service (QoS) associated with low voltage distribution networks, with many dispersed production facilities, mainly solar PV.

The remaining of the chapter is organized in five main sections. The first provide a characterization of the distribution station and low-voltage grid where the BESS will be installed. The second section presents an overview of the infrastructure preparation (e.g., energy monitoring and energy storage hardware). The third section describes the voltage and frequency control pilot though BESS, whereas the peak shaving using BESS is described in section 4. Finally, section 5 presents the proposed trials with the respective timelines, and the proposed evaluation strategy.

3.1 Distribution Substation and Low Voltage Grid Characterization

The local TSO/DSO (EEM) suggested changing from the *Lombo do Alho* low voltage distribution substation, presented in the previous deliverable (see D4.1), sto the *Fazendinha* low voltage distribution substation due to several reasons, namely:

- Best ratio between installed UPPs capacity and the distribution substation load diagram;
- Lowest off-peak power (77 kW) compared to the previous chosen substation;
- 70% of the Ppeak installed in the *Fazendinha* low voltage grid is located in the same transformer output (25 out of 36 kWp);
- The *Fazendinha* low voltage distribution substation provides more physical space (Figure 3.1), to install the BESS system according to the minimum distances required between electrical components.

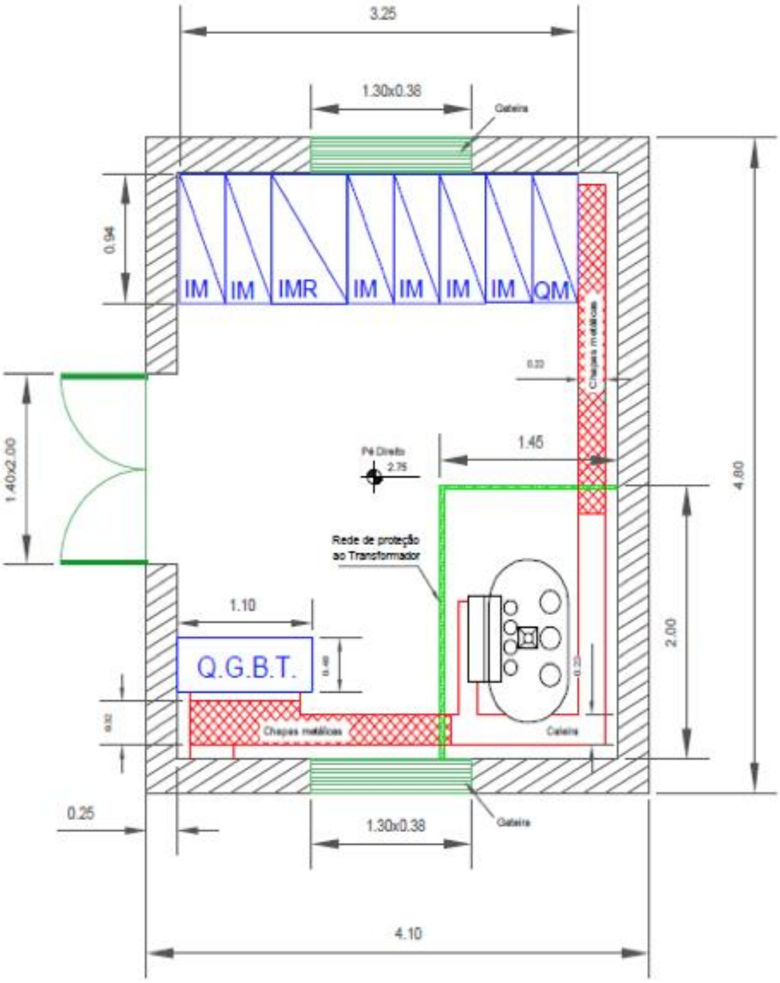

Figure 3.1 – *Fazendinha* MV/LV substation blueprint (C-EC-005)

Fazendinha's low voltage distribution substation is located in one of the most western villages of Madeira Island, Estreito da Calheta. This substation has a transformer with an apparent power of 250 kVA, connected in delta-wye, which transforms the voltage from the transmission grid (6600 V) to the distribution grid (400 V).

The daily load diagram at this substation, has some similarities to the average Madeira Island load diagram (see deliverable D4.1), having its load peak during the evening.

As shown in Table 3.1, *Fazendinha* has a daily average load of 27 kW, an Off-Peak power of 1 kW and a Peak power of 63 kW. At the moment, the capacity of the transformer is relatively high when compared with the power requested by the grid, mostly due to the expectation of growth in farming activities and local accommodation businesses in this rural area. The three power outputs represent 11%, 0.4%, 25% of the transformer capacity, respectively.

Table 3.1 – Power values at the *Fazendinha* substation during 2017

Daily Period	Power (kW)
Average load	27
Off-Peak	1
Peak	63

The transformer feeds a low voltage distribution board (QGBT) with five outputs (Figure 3.2) that distributes the electricity throughout the public grid, supplying around 100 customers consisting mostly of domestic, small businesses and agricultural facilities.

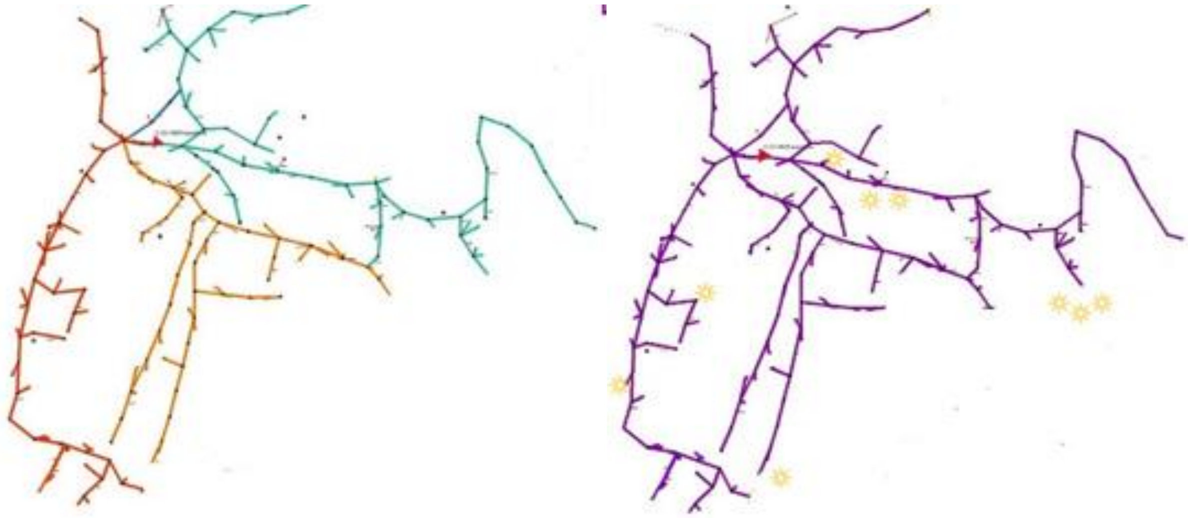

Figure 3.2 – *Fazendinha's* transformer output branches and connected UPPs

Fazendinha is one of Madeira's low voltage grids with higher micro photovoltaic generation, with a total installed capacity of 36 kWp, distributed over 9 UPPs as shown in table:

Table 3.2 – UPPs connected to the Fazendinha low voltage grid, and the respective installed PPV capacities

UPP Number	Installed PPV (kWp)
UPP 1	5.17
UPP 2	3.3
UPP 3	1.95
UPP 4	3.45
UPP 5	3.45
UPP 6	3.45
UPP 7	5.17
UPP 8	5.17
UPP 9	5.17
Total	**36.28**

3.2 Infrastructure Preparation

3.2.1 Energy Monitoring Hardware-Software Platform

Regarding the energy monitoring system in the distribution substation, it will consist of the PQube3, which is a power quality analyzer from Power Standards Labs (PSL)[3] and a gateway based on the

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[3] PQube3 power analyser, https://www.powerstandards.com/product/pqube-3/highlights/

Raspberry Pi. These devices communicate by using the ModBUS TCP/IP[4] protocol, thus, a local Wi-Fi network needs to be installed in the substation.

The software running inside this gateway will comprise the same three services as in the UPACs gateway, namely, one daemon for reading and storing data (i.e., voltage, current, frequency, power) from the PQube3 running almost every second, one daemon for uploading the average data to the EMS every minute and one daemon for storing backup copies in the Cloud once per day. Moreover, additional scripts will be added in order to read high frequency data, stored in the PQube3's FTP server, when a pre-configured event is triggered and to actuate in the BESS system during the trigger of any event by reading the PQube3's output relay signal and directly communicating with Vnet.

Lastly, it is important to remark that, for this particular pilot, the PQube3 was chosen over the Carlo Gavazzi smart meter due to the nominal current and voltage requirements of the secondary winding of the substation transformer that are considerably higher than that for domestic installations. And also, the fact that PQube3 enables the possibility of triggering real-time events when selected metrics are outside pre-defined thresholds, which is key for Voltage and Frequency control as described in section 3.3.1.

3.2.2 Energy Management System

All the Madeira pilots will rely on the SMILE EMS, as described in section 2.1.2.

3.2.3 Energy Storage Hardware

For this pilot, LIBAL will provide the following BESS:

- One 40kW/80 kWh LIBAL BESS (1 rack) with a three-phase ABB inverter to be deployed on a selected distribution station in Madeira Island.

The BESS provided by LIBAL will consist of:

- Interconnected battery cells making up the battery system;
- The battery protection unit (BPU) – a set of switching and current sensing devices controlled by the underlying battery management system (BMS)
- The BMS, responsible for battery safety, control of BPU, monitoring and diagnostic of the BESS;
- The inverter – a bidirectional power converter DC/AC. A three-phase inverter will be used for this 40kW/80kWh system.
- A site controller – a local controller responsible for inverter control and its safe connection and disconnection, collecting all relevant data and transferring them to the EMS using a third-party system (the VNet, provided by the SMILE partner OVO-Energy), self-diagnostics of the entire BESS (battery + inverter), and receiving control signals (e.g. active, reactive power set points, operation mode) from the EMS.

The block diagram in Figure 3.3 presents the BESS structure:

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[4] ModBUS TCP/IP, https://www.rtaautomation.com/technologies/modbus-tcpip/

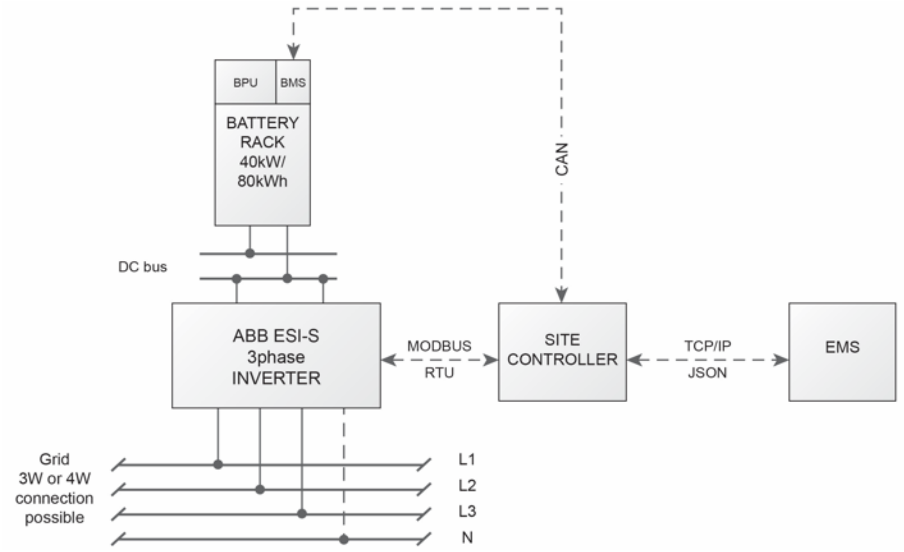

Figure 3.3 – Block diagram of the LIBAL 40kW/80kWh BESS and communication with EMS (application: grid support)

The main parameters of the grid support system are presented in Table 3.3.

Table 3.3 – Main parameters of the grid support BESS

Item	Value	Unit
Dimensions (height*width*depth)	Not Available	cm
Battery type	NMC	-
Number of racks	1	-
Power	50	kW
Nominal battery DC voltage	700.8	V
Maximum rack voltage	806.4	V
Minimum rack voltage	499.2	V
Energy content	80	kWh

The grid support BMS will be provided by an ABB ESI-S[5] inverter, with the unique function of reducing power losses for improving system economy (very low standby power consumption). LIBAL will provide the inverter together with AC side grid filter and AC contactors.

The main parameters of the inverter are presented in Table 3.4 below:

Table 3.4 – The main parameters of the ABB ESI-S inverter

Item	Value	Unit
Dimensions (height*width*depth)	58.5*32.6*75.5	cm
Type	ESI-S – IP30	-
Mounting type	Wall mounted	-

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[5] ABB ESI-S inverter, https://new.abb.com/high-voltage/capacitors/lv/energy-storage-inverters-esi

Item	Value	Unit
Nominal power	40	kW
Rating	60	Arms
Nominal network voltage	400	V
DC voltage control range	585 – 830	V
Main features * available only for 4-W device	Dynamic power control (P) and reactive power control (Q)	
	Individual power control per phase *	
	Harmonic mitigation up to the 50th *	
	Stepless reactive power compensation	
	Load balancing (3-Phases/ 3-Phases + Neutral) *	
	Islanding mode	
	Black start (as an option)	
	LVRT (Low Voltage Ride Through)	
	Modularity (several units can be put in parallel) for high-current applications	
	Full redundancy and flexibility (master/master configuration and independent DC busses) *	

Finally, as with the domestic BESS, the installation will be accomplished with the support of DTI and LIBAL. Details about the installation will be added to D4.7.

3.2.4 BESS Remote Control

The interface and site controller used in the domestic BESS will also be used to control this BESS. Furthermore, despite the fact that the PQube can communicate directly with the site controller using TCP/IP since the VNet platform will already be integrated with the EMS, we have decided to use it as well in this pilot.

With regard to the frequency and voltage control, special middleware will be placed between PQube and the VNet. This middleware will be responsible for reading the DC signals from the PQube (indicating frequency and/or voltage issues), and communicate with the VNet system, that will, in turn, send the necessary commands to the BESS (i.e., charge/discharge).

As for the duck curve mitigation, the implemented system will be similar to the domestic BESS control strategies. I.e., the algorithms will be executed on the EMS, and the outputs will be sent to the BESS controller using the VNet cloud.

3.2.5 BESS Control Strategies

The BESS control process will be very similar to the one for the domestic BESS. The main difference is that in the case of Voltage and Frequency control, the control algorithms will be running locally and will interact with VNet to actuate the battery controller. In the present we are also studying the possibility of interacting directly with the local controller (i.e., without passing through VNet), which will make the entire process happen closer to real-time, which may be important in this particular scenario.

As for the peak shaving with BESS scenario, the different algorithms will be running in the EMS, and the BESS operation will be handled through the VNet cloud.

3.3 Pilot: Voltage and Frequency Control with BESS

Comparing to the European grid connected electrical systems, isolated electrical systems, such as Madeira Island, have higher limits concerning the RQS. Consequently, electrical quantities (voltage variations - dips and swells, frequency, harmonics, flicker etc.) are frequently monitored in random distribution substations (for a certain period of analysis) to ensure that the quality and safety of the electricity are according to the thresholds stipulated in Table 1.1.

One of the main objectives of this pilot is to study a realm of new technologies with the expectation of replication throughout the low voltage distribution substations in the Island. With the installation of the BESS system at the *Fazendinha* low voltage distribution substation, we expect to have a highly responsive storage backup to regulate events that may transcend some of the parameters described in Table 1.1.

On an initial stage, the events that will be easier to control/regulate are mainly the voltage events, active and reactive power. Although frequency events can also be controlled by the BESS, its influence will be not perceptible, due to the fact that the grid frequency in the island is imposed by the highest generation group. Nevertheless, if the system is replicated on a higher scale (i.e., more low voltage distribution substations) the contribution for frequency control will certainly be more substantial.

3.3.1 Pilot Setup

One of the main features of the PQube3 is the possibility of configuring the detection of events (such as sudden rise or drop of the mains voltage or frequency, depending on a certain and also configurable threshold). When an event occurs, the PQube3 stores data, in a high rate (kHz) and sends it to an FTP server once the event is finished. Afterwards, the data can be download from the FTP server for further analysis.

The PQube3 holds a DC relay output which is normally closed when the PQube3 is ON and normally open when the PQube3 is OFF. However, when a pre-configured event is triggered, this DC relay output is opened. The PQube3 gateway can use this feature for detecting the event by periodically reading the state of the DC relay output. For that, some additional hardware components will be needed as the Raspberry Pi pins cannot read analog signals. After the detection of the event, the gateway can directly communicate with the VNet system, which in turns actuates the BESS accordingly. Figure 3.4 shows the most relevant connections of the PQube3 in this pilot setup.

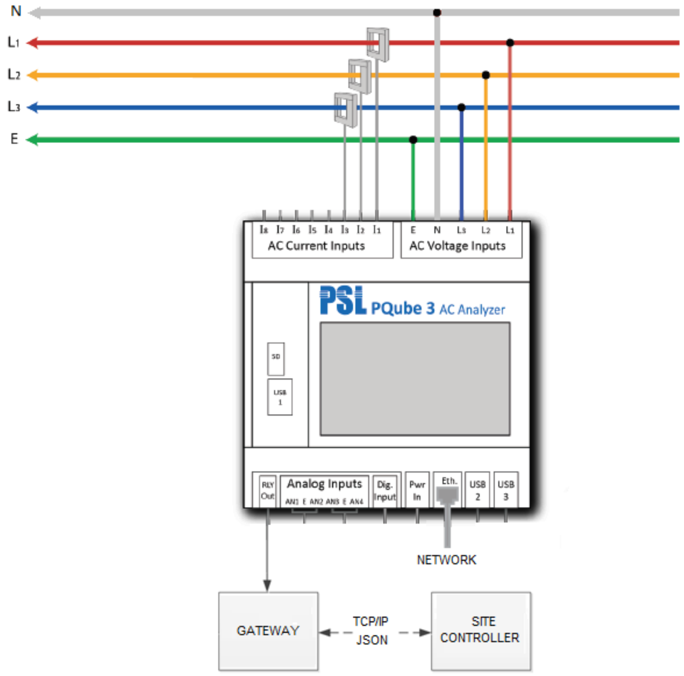

Figure 3.4 – Illustration of the PQube3 setup at the substation level

3.4 Extra Pilot: Peak Shaving using BESS

With the high generation of energy from photovoltaic in micro-grids new problems start to arise to the DSO management system. One of the major challenges with photovoltaic generation is the lack of load in the grid when the production reaches high values.

This outcome was first verified in California, where the installation of photovoltaic power plants with high power peak capacity installed caused a sudden decrease/increase in the load when the sun starts rises/sets respectively [11]. Consequently, in order to account for such an effect, the TSO/DSO must have higher reserves (normally on the form of conventional thermal power plants) ready to respond when such load events may occur.

As mentioned in a previous section, the load diagram in *Fazendinha* has some similarities with the Madeira Island diagram (D4.1, figure 2.5 –Typical load demand curve in Madeira Island) [1]. Nevertheless, when analyzed in higher detail, it is possible to observe that the photovoltaic production inducts a duck silhouette in the load diagram on that low voltage distribution substation. This effect can be easily recognized in Figure 3.5 that represents the two days with the highest and the lowest peak load diagrams verified during the last year.

In line with what is being done around the world, through the SMILE project, a storage system will be installed at this distribution station to minimize, and ultimately overcome the duck curve challenge. EEM expectations is to be able to smooth the load diagram. Therefore, the BESS must be parameterized to store the energy during the photovoltaic production period (between 10h and 13h depending on the season), and supply that energy during the load peak. Furthermore, considering that EEM plans to replicate this technology in other low voltage distribution substations, the BESS control strategies must take into consideration the battery lifetime, by properly controlling parameters such as the SOC, SOH, and battery no-standing-zones.

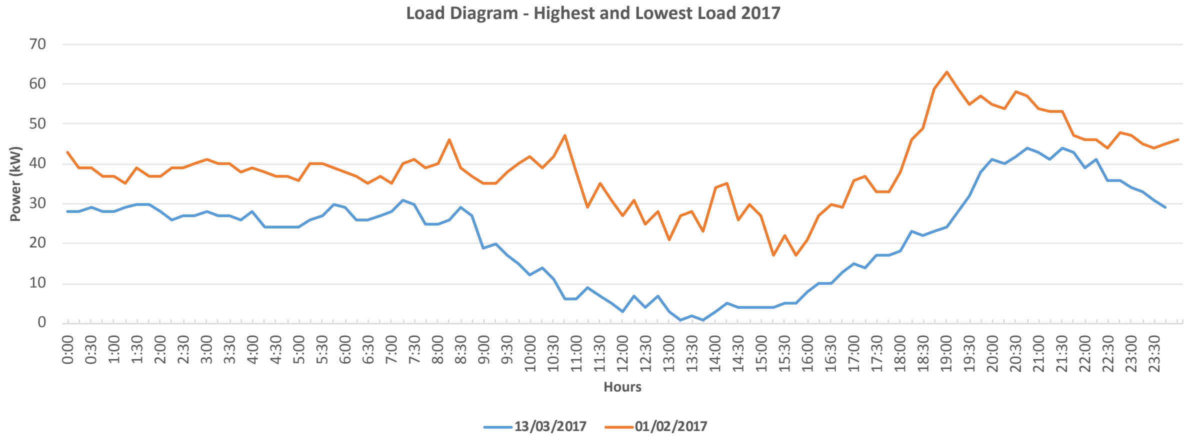

Figure 3.5 – *Fazendinha* load diagram showing the highest and lowest peaks observed in 2017

3.4.1 Pilot Setup

Considering the real-world nature of the problem, and the importance of this distribution station to the local grid, the research team decided to run the pilot using sets of fixed rules to charge and discharge the battery. These rules will be devised based on previous data and on the expertise of the EEM engineering team.

This research will be complemented by computational simulation of other relevant algorithms, that will be using the data collected on-site. Finally, depending on the success of the physical pilot, it may be possible to implement some of these algorithms in practice for some shorter periods of time.

3.5 Trials and Evaluation Methodology

3.5.1 Proposed Trials

For these two pilots we propose two long-term deployments, as shown in Figure 3.6. In the initial phase, while the BESS is not yet installed, we will collect baseline data for both pilots. Then, in the first three months after the BESS installation we will conduct physical tests to the infrastructure, as well as simulations using the baseline data.

The two pilots will then be conducted in parallel, and will last for 12 consecutive months. By running the two pilots in parallel it will also be possible to identify trade-offs that may occur. For example, at some point, it may happen that the voltage regulation algorithm needs to discharge the battery, while the peak-shaving algorithm has set the BESS in storage mode.

Finally, we leave another six months for the eventuality that we want to repeat some tests, or implement any of the more advanced algorithms in practice.

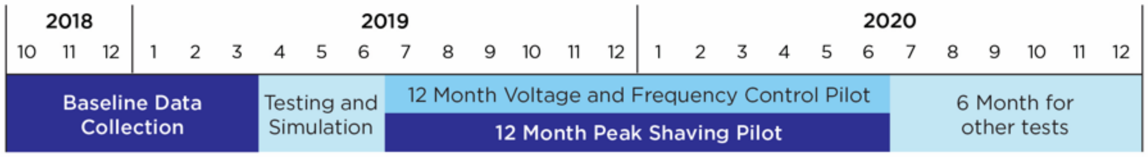

Figure 3.6 – Proposed trials and respective timelines

3.5.2 Proposed Evaluation Methodology

The evaluation methodology for these two pilots will be similar to the methodology used to evaluate the UPAC pilots. Nevertheless, due to the almost fully automatic nature of the pilots, only the technical aspects will be evaluated.

Two of the possible comparisons are: i) field trials vs the current situation (i.e., no control whatsoever), and ii) peak shaving field trial vs simulations. Ultimately, these, and other scenarios, will be assessed using a variety of methodologies and performance metrics developed to properly evaluate the human and technological aspects of real-world pilots.

To state more concretely, we will use the metrics and KPIs defined on D6.1 [6], which are summarized in Table 3.5, Table 3.6, and Table 3.7.

Table 3.5 – List of technical KPIs to evaluate the Voltage and Frequency control demonstrator

KPI	Description
Energy Losses	Yearly amount of energy lost on grid's conductors, transformers, etc.)
Voltage Variation	Difference between the actual voltage supplied to MV/LV users and the nominal value
Grid Congestion	Grid sustainability to peaks
System Average Interruption Frequency Index (SAIFI	Measures the average frequency of power-supply interruptions in the system
System Average Interruption Duration Index (SAIDI)	Measures the average cumulative duration of power-supply interruptions in the system
Unbalance of the Three-phase Voltage System	Difference in the voltage of the three phases
Harmonic Distortion	THDU ≤ 5%, each harmonic/U1 ≤ 3%; THDU=Total Harmonic Distortion Unit
Storage Energy Losses	Losses associated with the energy storage solutions
Frequency Control	This KPI calculates the number of times that the average value of the fundamental frequency measured over periods of 10 seconds goes out of the stated ranges

Table 3.6 – List of environmental KPIs to evaluate the Voltage and Frequency control demonstrator

KPI	Description
Energy Losses	Yearly amount of energy lost on grid's conductors, transformers, etc.)

Table 3.7 – List of economic KPIs to evaluate the Voltage and Frequency control demonstrator

KPI	Description
Life-cycle cost of energy generation	The sum of all the costs throughout the lifetime of the energy investment, normalized to the energy generated
Internal Rate of Return	Profitability of an investment

KPI	Description
Return of Investment (ROI)	Difference between the actual voltage supplied to MV/LV users and the nominal value
Investment Payback Period	The length of time that it takes for the cumulative gains from an investment to equal the cumulative cost
Annuity Gain	Measures the annual profits of an investment throughout its lifetime
Total Capital Cost per kW Installed	Examines the initial cost of an investment depending on the size of the capacity being installed

4 Conclusion

Throughout this document the plan of action to conduct and evaluate the different pilot studies of BESS and DSM technology in Madeira island was presented. In the one hand, Pilot 1 (Getting started with BESS and DSM), and Pilot 2 (Moving forward with BESS and DSM) are targeted at maximizing the self-consumption of RES in domestic and commercial solar PV installations. On the other hand, Pilot 3 (Voltage and Frequency Control with BESS), and the extra pilot (Peak-shaving using BESS) are aimed at demonstrating how the deployment of BESS at the distribution station level can leveraged to provide grid stability services, including voltage and frequency regulation, and peak-shaving.

The following sections present the progress towards the completion of the different tasks that will lead to the completion of each demonstrator, as well as an overview of the corresponding milestones and deliverables.

4.1 Progress Report

A summary of the progress towards the completion of the two demonstrators is provided below, based on the current status of the tasks that are directly or indirectly related with the different pilots:

- **T 4.2: Infrastructure preparation (M1 – M6) –** Concluded (see deliverable D4.2 [3]).
- **T 4.3: Data collection, modelling, analysis, decision (M6 – M12)** – Concluded (see deliverable D4.3 [2], and appendix A of this document).
- **T 4.4: Kick-off of the Madeira pilot including storage and DSM (M13 – M48)** – Ongoing. This task refers to the installation of all the necessary equipment (hardware and software), and the maintenance of the different pilots.
    - At this point the Advanced Metering Infrastructure (AMI) is fully deployed at the different domestic and commercial UPAC sites (see Table A.1 and Table A.2 in Appendix A). Regarding the distribution station, the research team is currently conducting the necessary integration tests to the PQube3 + Raspberry Pi monitoring solution.
    - Regarding the selection of the domestic UPACs that will receive the BESS systems, 4 candidates have already been selected based on the outputs of D4.3. The next step will be to assess if the candidate sites comply with all the necessary requirements to receive a BESS (e.g., space and cooling requirements).
    - Concerning the commercial UPAC that will receive a BESS, the site was already selected and the installation requirements assessed by the research team.
    - Finally, regarding the installation of the BESS, this is planned to happen between November and December 2018. In the meanwhile, Prsma, LIBAL, VCharge, DTI and RINA-C are currently working towards the seamless integration of all the hardware (BESS site controller) and software components (Ovo's VNet and Prsma's EMS).
- **T 4.5: Evaluation of storage and DSM (M16 – M48)** – This task is planned to start in month 16. The main goal of this task is to assess the all the different results of the DSM pilot in Madeira.
    - At this point the research team is planning the first round of interviews with the participants, which will precede the deployment of the EMS on the participant households.
    - Regarding the technical evaluations, the research team is currently building the software eco-systems that will be used to perform the several simulations and data analysis tasks.

- The research team is also compiling information about data requirements of the different metrics that will be used to evaluate and benchmark the different pilots.

4.2 Demonstrators Timeline

This section presents the timeline of the different tasks that will be conducted in the scope of the DSM demonstrators in Madeira island.

- **M16 – M18**
  - Sub-task 4.4.1: PQube3 installation and integration tests
  - Sub-task 4.4.2: Baseline data collection for pilots 1 and 2
  - Sub-task 4.5.1: Initial interviews with pilot participants
  - Sub-task 4.5.1.1: UI testing and feedback for both pilots
- **M19 – M24**
  - Sub-task 4.5.2: BESS installation and integration tests
  - Sub-task 4.5.3: Start of pilot study 1
  - Sub-task 4.5.4: Testing and simulations for pilot studies 3 and extra
  - Sub-task 4.5.10: Follow up interviews with pilot participants
- **M25 – M30**
  - Sub-task 4.5.4: Testing and simulations for pilot studies 3 and extra
  - Sub-task 4.5.5: Preliminary technical evaluation of pilot study 1
  - Sub-task 4.5.6: Start of pilot studies 3 and extra
- **M31 – M36**
  - Sub-task 4.5.7: Technical evaluation of pilot study 1
  - Sub-task 4.5.8: Start of pilot study 2
  - Sub-task 4.5.9: Preliminary technical evaluation of pilot studies 3 and extra
  - Sub-task 4.5.14: Report on market acceptance and replicability (draft)
  - Sub-task 4.5.15: Technical report on BESS and DSM pilots (draft)
  - Sub-task 4.5.16: Report on customer acceptance and satisfaction (draft)
- **M37 – M42**
  - 4.5.10: Follow up interviews with pilot participants
  - 4.5.11: Preliminary technical evaluation of pilot study 2
  - 4.5.12: Technical evaluation of pilot studies 3 and extra
- **M43 – M48**
  - 4.5.13: Technical evaluation of pilot 2
  - 4.5.14: Report on market acceptance and replicability
  - 4.5.15: Technical report on BESS and DSM pilots
  - 4.5.16: Report on customer acceptance and satisfaction
  - 4.5.16.1: Satisfaction analysis and acceptance information collection

Figure 4.1 presents the envisioned timeline for the execution of the different pilots in Madeira Island. The electric vehicles pilots are shown on the top using blue bars), whereas the BESS + DSM pilots are shown in the bottom with red bars.

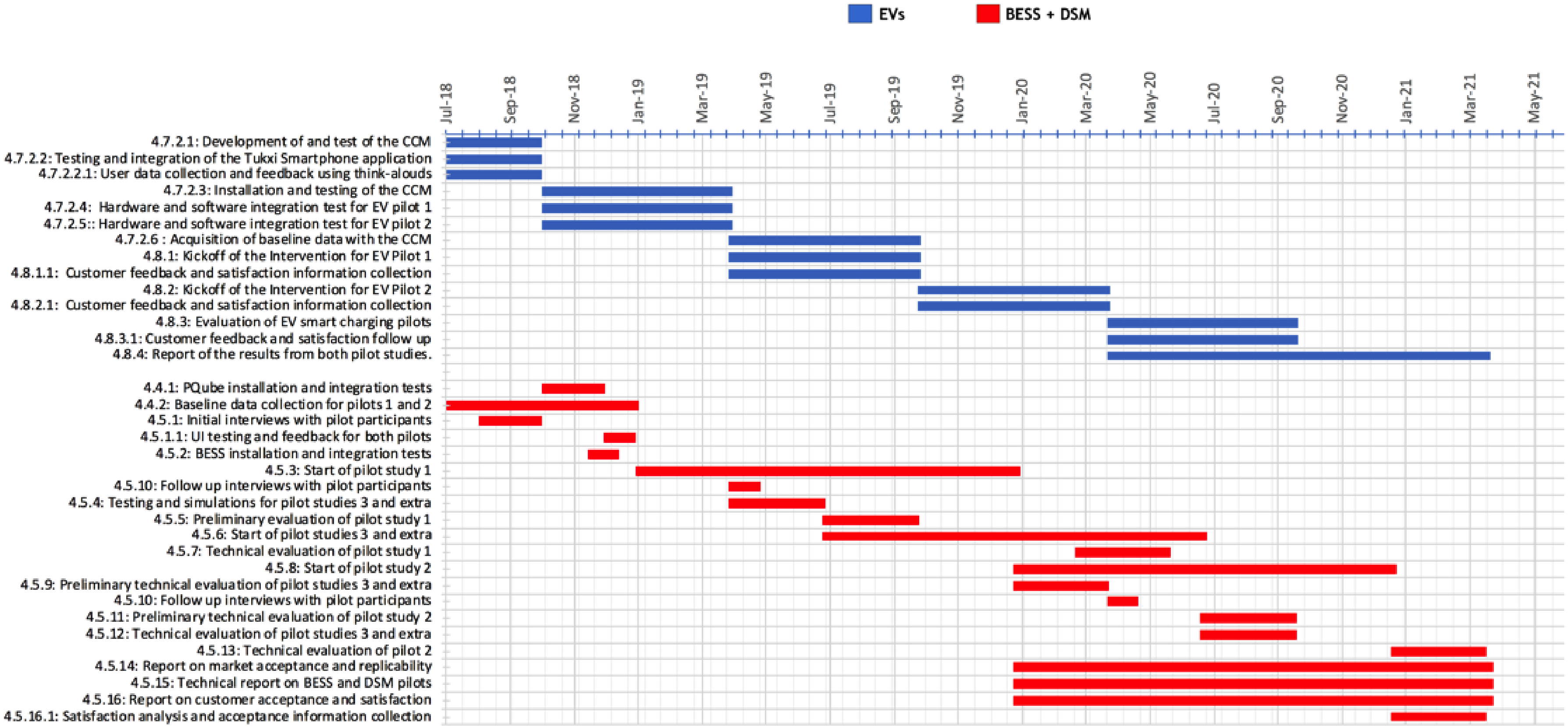

Figure 4.1 – Envisioned timeline for the execution of the Madeira Island pilots: Electric Vehicles (top with blue bars), BESS + DSM (bottom with red bars)

4.3 Next Milestones and Deliverables

The next milestone related to the Madeira demonstrator is due in month 36:

- **M 4.2: Pilots in Madeira completed** – a full working demonstration of the BESS/DSM and EV smart-charging demos.

The next deliverables related to the DSM pilots in Madeira island are due in month 48:

- **D 4.7: Report on the installation of the DSM demo** – Report documenting the installation and evaluations of the DSM demos in Madeira. The report will provide photographic evidence of the installation and the outcome of the testing activity. A draft version of the report will be delivered at month 36, while the final version will be delivered at month 48.
- **D 4.9: Report on customer acceptance and satisfaction** – Report describing the outcomes of the assessment of the overall user satisfaction and acceptance of the Madeira pilot including the DSM and EV demos. A draft version of the report will be delivered at month 36, the final version will be delivered at month 48.
- **D 4.10: Report on market acceptance and replicability** – Report describing the outcomes of the assessment of replication possibilities within the national and international markets. A draft version of the report will be delivered at month 36, while the final version will be delivered at month 48.

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[11] P. Denholm, M. O’Connell, G. Brinkman, and J. Jorgenson, “Overgeneration from Solar Energy in California. A Field Guide to the Duck Chart,” National Renewable Energy Lab. (NREL), Golden, CO (United States), NREL/TP-6A20-65023, Nov. 2015.

APPENDIX A: Updates to Deliverable 4.3

Updates to the Participants Technical Data

Table A.1 and Table A.2 below show the updated installation dates of the domestic and commercial UPACs in Madeira Island. The original tables from which this update corresponds are present in D4.3 [3].

Table A.1 – Technical details of the domestic UPACS in the Madeira island demonstration site

ID	Contracted Power (kVA)	Installed PV Power (kWp)	Tariff	Existing Energy Monitor	Installation Date
U1	6.9	0.39	Dual-rate	--	18 June 2018
U2	6.9	1.5	Single-rate	SMA[6]	22 June 2018 [a]
U3	5.75	1	Dual-rate	OEM[7]	[b]
U4	6.9	0.5	Single-rate	--	5 June 2018
U5	6.9	1.25	Single-rate	SMA	28 May 2018 [a]
U6	10.35	2.7	Single-rate	--	30 April 2018
U7	10.35	3.0	Single-rate	--	Off
U9	6.9	4.5	Single-rate	--	01 June 2018
U10	6.9	1.5	Dual-rate	--	19 June 2018
U11	6.9	1.5	Dual-rate	OEM	Not Applicable [b]
U12	6.9	3	Dual-rate	SolarImpact[8]	[b,d]
U13	10.35	1.5	Single-rate	--	28 June 2018
U14	3.45	0.75	Single-rate	--	8 June 2018
U15	6.9	1.05	Dual-rate	--	Not Applicable [c]
U16	3.45	1.5	Single-rate	--	Off

[a] Data available since May 2017

[b] Data available since April 2017, not hardware needs to be installed

[c] Production and consumption are installed different places. The possibility of developing a customized monitoring solution is currently being explored.

[d] A custom DC smart-meter will be installed.

Table A.2 – Technical details of the commercial UPACS in the Madeira island demonstration site

ID	Contracted Power (kVA)	Installed PV Power (kWp)	Tariff	Existing Energy Monitor	Installation Date
U8	20.7	3.92	Single-rate	--	24 May 2018
U18	10.35	1.5	Single-rate	--	28 March 2018

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[6] SMA Sunny Portal, https://www.sunnyportal.com

[7] Open Energy Monitor, https://openenergymonitor.org/

[8] SolarImpact, http://www.solarimpact.pt/

Updates to the Initial Data Collection

In D4.3 an initial data analysis was performed for UPACs 2, 3, 5, 11 and 12. This section presents the initial data analysis for the remaining UPACs that will participate in the Madeira Island pilots (i.e., 1, 4, 6, 8, 9, 10, 13, 14, and 18).

Domestic UPACs

UPAC 1

UPAC 1 contracted power is 6.9 kVA with a dual-rate power tariff. The installed solar PV is 0.39 kWp, with a chance of increasing for 0.89 kWp during the project. As it can be seen by Figure A.1 and Figure A.2, there is very little waste of renewable energy. Consequently, this UPAC is not a candidate to receive a BESS system, even if the installed solar PV grows to 0.89 kWp.

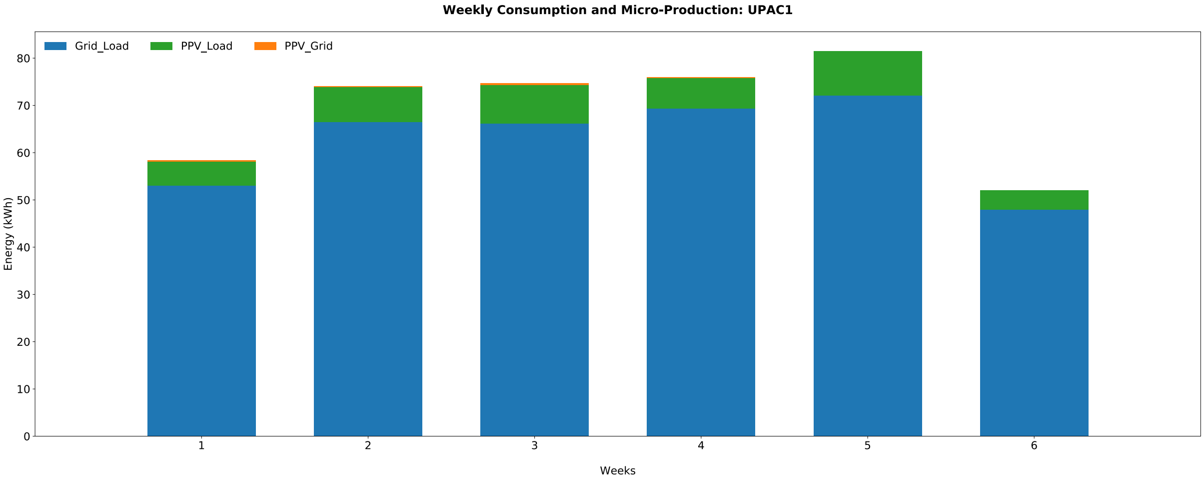

Figure A.1 – Weekly Consumption and Micro-Production for UPAC 1 between June 18 and July 26, 2018

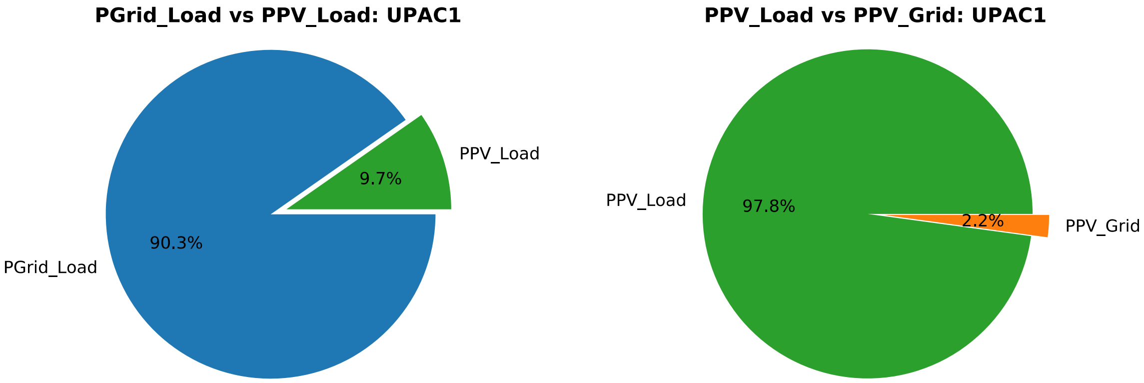

Figure A.2 – Proportion between grid and self-consumption (left), and between self-consumption and grid-injection (right) for UPAC 1.

UPAC 4

UPAC 4 contracted power is 6.9 kVA with a single-rate tariff. The installed solar PV is 0.5 kWp. As it can be seen from Figure A.3 and Figure A.4, despite the small installation size, almost 30% of the production is not being self-consumed. Still, due to the very small size of the installation, a BESS would not be very beneficial in this situation. Instead, this UPAC can benefit from an in-depth analysis of the consumption patterns as a way to highlight opportunities to move consumption to the periods with higher production, thus reducing the amount of renewable energy being injected into the grid.

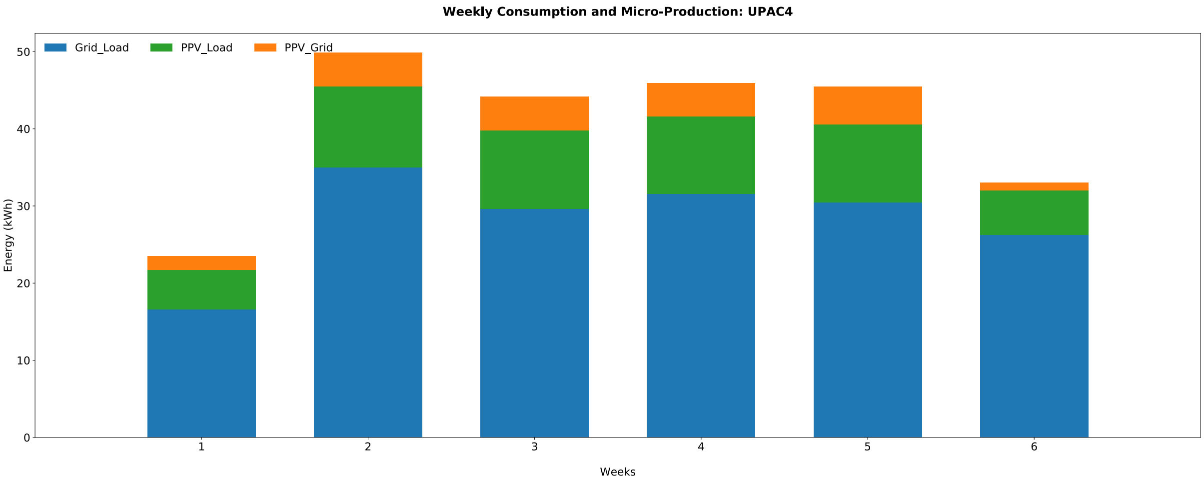

Figure A.3 – Weekly Consumption and Micro-Production for UPAC 4 between June 22 and July 26, 2018

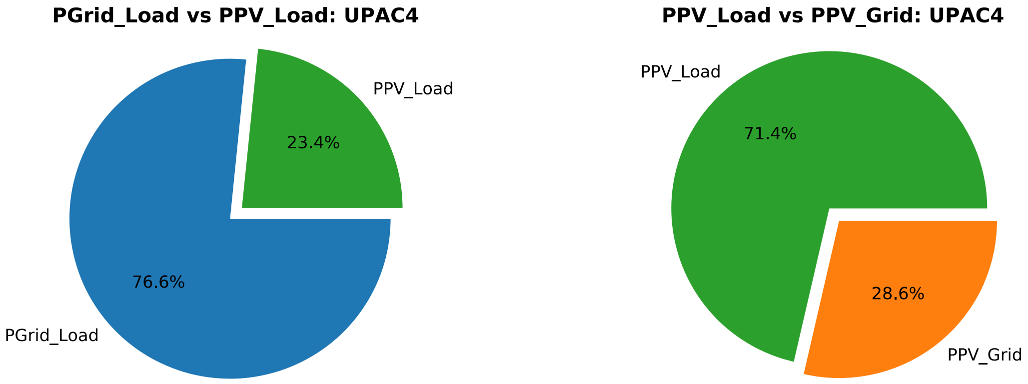

Figure A.4 – Proportion between grid and self-consumption (left), and between self-consumption and grid-injection (right) for UPAC 4.

UPAC 6

UPAC 6 contracted power is 10.35 kVA with a single-rate tariff. The installed solar PV capacity is 2.7 kWp. As it can be seen from Figure A.5 and Figure A.6, the solar PV installation of UPAC 6 is seriously under-optimized, which is reflected by more than 60% of the solar PV production being injected in the grid.

This is a clear situation where a properly dimensioned BESS system can bring great benefits to the installation. To further understand the BESS requirements, Figure A.7 shows the minutely distribution of the solar PV power being injected in the grid on a weekly basis. This figure shows that the peak power being injected in the grid can reach 2.5 kW, suggesting that the minimum feasible inverter size would be of 3 kW.

Furthermore, per Figure A.8, it is possible to see that the daily average of wasted renewable energy is around 8 kWh, which suggests that the minimum capacity of the BESS should be around that number.

To conclude, UPAC 6 is definitely a candidate to receive a BESS in the scope of the SMILE project.

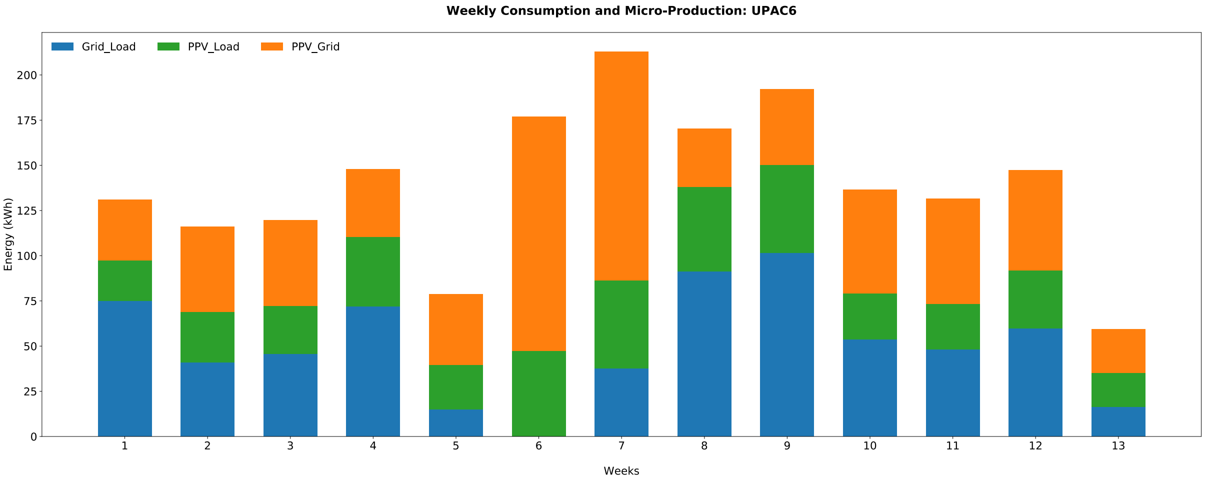

Figure A.5 – Weekly Consumption and Micro-Production for UPAC 6 between April 30 and July 26, 2018.

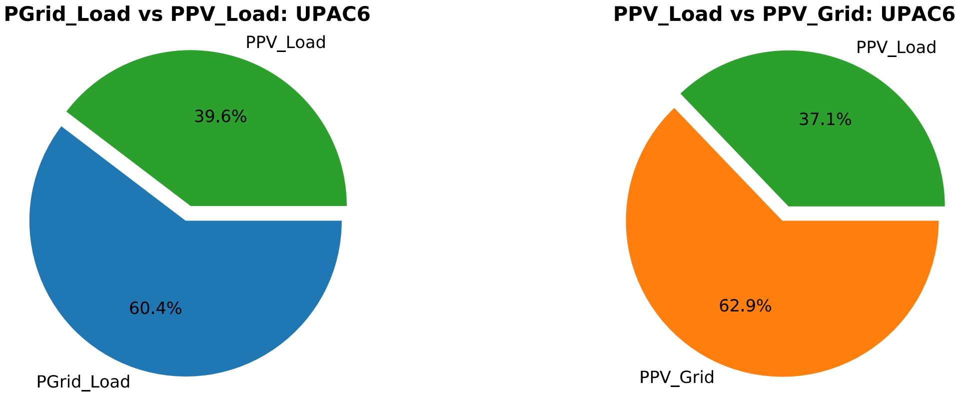

Figure A.6 – Proportion between grid and self-consumption (left), and between self-consumption and grid-injection (right) for UPAC 6.

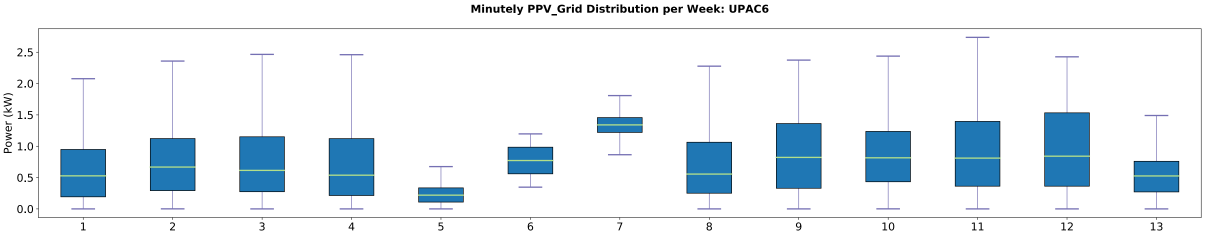

Figure A.7 – Minutely distribution of the solar PV power being injected in the grid on a weekly basis.

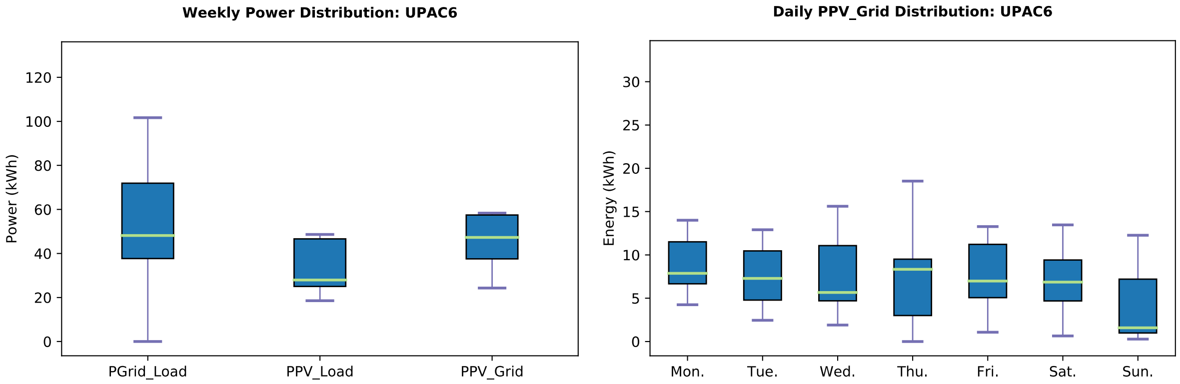

Figure A.8 – Weekly power distribution (left), and daily P_{PV_Grid} distribution (right) for UPAC 6.

UPAC 9

UPAC 9 contracted power is 6.9 kVA with a single-rate tariff. The installed solar PV capacity is 4.5 kWp. As with UPAC 6, it can be seen from Figure A.9 and Figure A.10, the solar PV installation of UPAC 9 is seriously under-optimized, which is reflected by almost 70% of the solar PV production being injected in the grid.

This is a clear situation where a properly dimensioned BESS system can bring great benefits to the installation. To further understand the BESS requirements, Figure A.7 shows the minutely distribution of the solar PV power being injected into the grid on a weekly basis. This figure shows that the peak power being injected in the grid can reach 3.5 kW, suggesting that the minimum feasible inverter size would be of 4 kW.

Furthermore, per Figure A.12, it is possible to see that the daily average of wasted renewable energy is around 13 kWh, which suggests that the installation can benefit from a BESS with a capacity around that number.

To conclude, UPAC 9 is definitely a candidate to receive a BESS in the scope of the SMILE project.

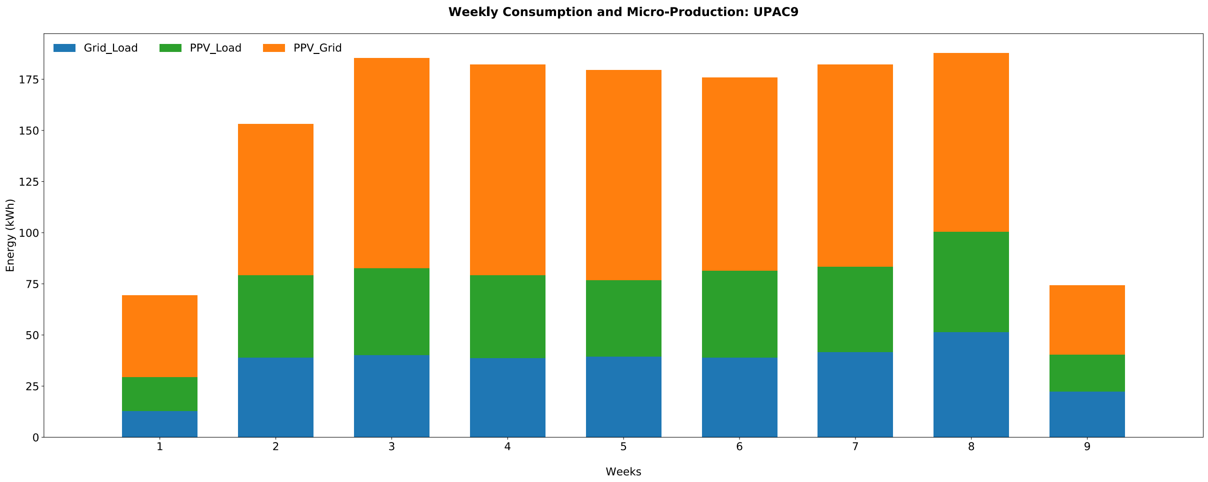

Figure A.9 – Weekly Consumption and Micro-Production for UPAC 9 between June 1 and July 26, 2018.

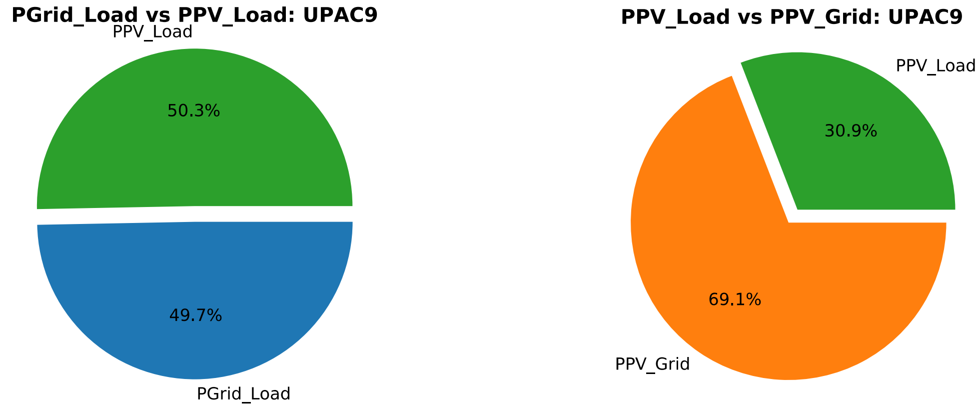

Figure A.10 – Proportion between grid and self-consumption (left), and between self-consumption and grid-injection (right) for UPAC 9.

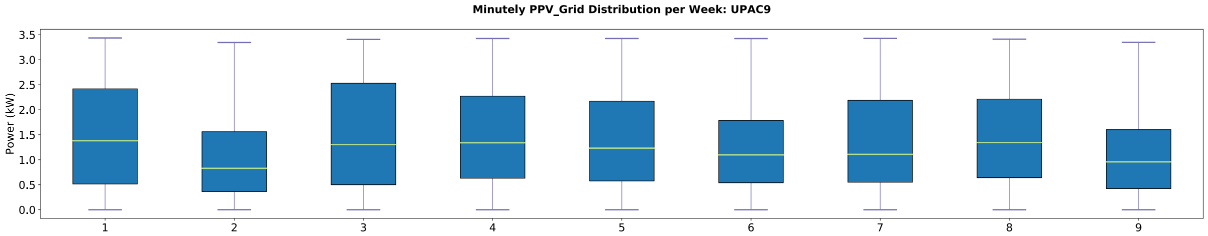

Figure A.11 – Minutely distribution of the solar PV power being injected in the grid on a weekly basis.

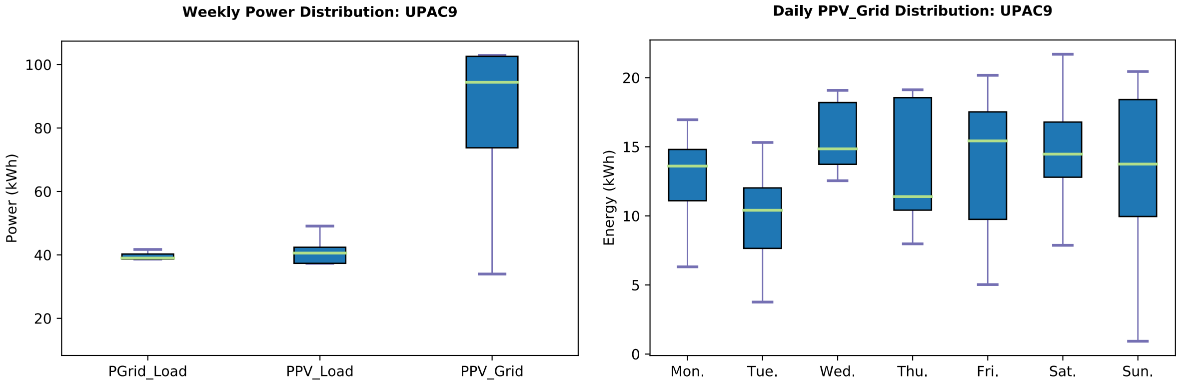

Figure A.12 – Weekly power distribution (left), and daily P_{PV_Grid} distribution (right) for UPAC 9.

UPAC 10

UPAC 10 contracted power is 6.9 kVA with a dual-rate tariff. The installed solar PV is 1.5 kWp. As it can be seen from Figure A.13 and Figure A.14, about 40% of the solar PV production is not being self-consumed.

To further understand if a BESS would benefit this installation, Figure A.15 shows the minutely distribution of the solar PV power being injected into the grid on a weekly basis, whereas Figure A.16 shows the weekly (left chart) and daily (right chart) distribution of renewable energy being injected in the grid.

As it can be observed, the peak power injected in the grid is around 1.4 kW which would suggest that a 2 kW inverter would suffice. Still, Figure A.15 also shows a considerable decrease in grid-injection in the last two weeks. Our guess is that this can be happening due to the holiday period, meaning that there are more people at home during the day. Still, more data is needed in order to see if this situation remains or not.

Finally, regarding the BESS capacity, per Figure A.16 it is possible to infer that a BESS with a capacity of 4 kWh could suffice for this installation.

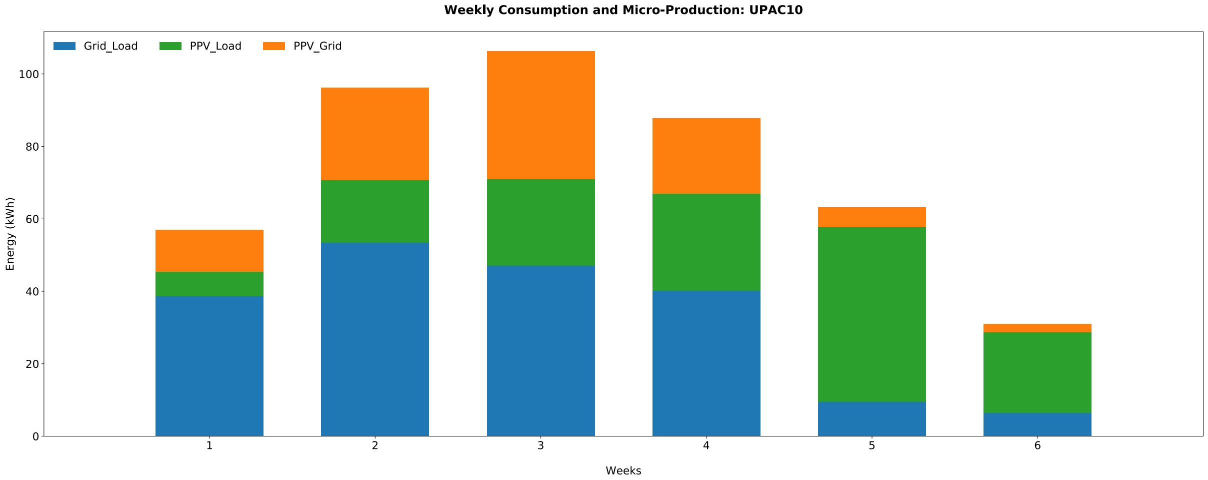

Figure A.13 – Weekly Consumption and Micro-Production for UPAC 10 between June 19 and July 26, 2018.

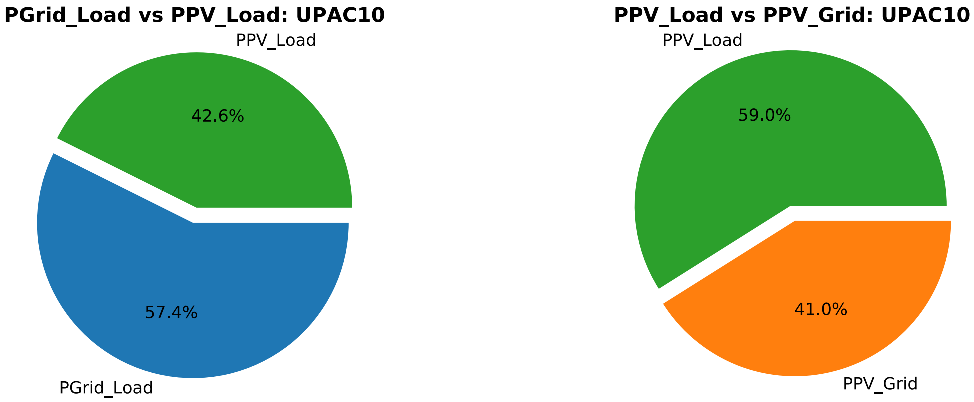

Figure A.14 – Proportion between grid and self-consumption (left), and between self-consumption and grid-injection (right) for UPAC 10.

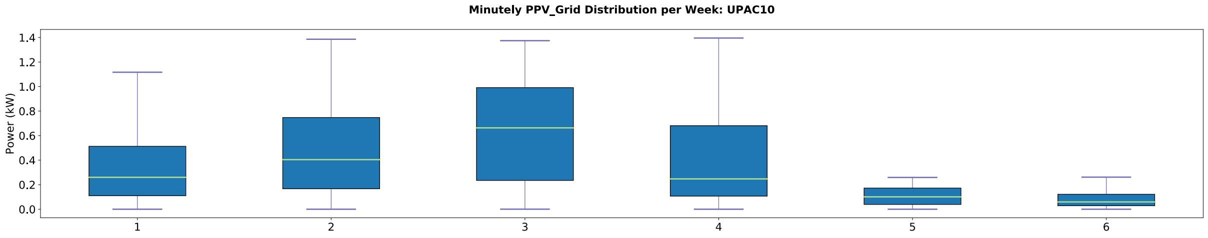

Figure A.15 – Minutely distribution of the solar PV power being injected in the grid on a weekly basis.

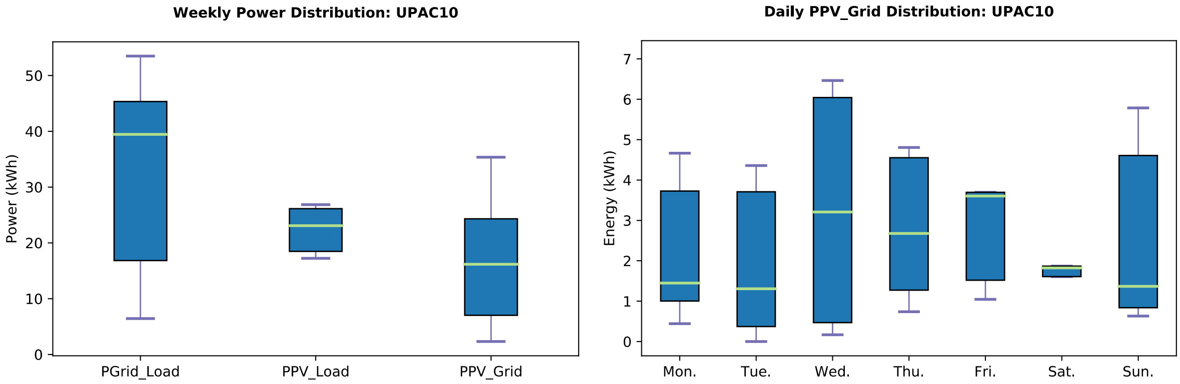

Figure A.16 – Weekly power distribution (left), and daily P_{PV_Grid} distribution (right) for UPAC 10.

UPAC 13

UPAC 13 contracted power is 10.35 kVA with a single-rate tariff. The installed solar PV is 1.5 kWp. As it can be seen by Figure A.17 and Figure A.18, there is very little waste of renewable energy. Consequently, this UPAC is not a suitable candidate to receive a BESS system.

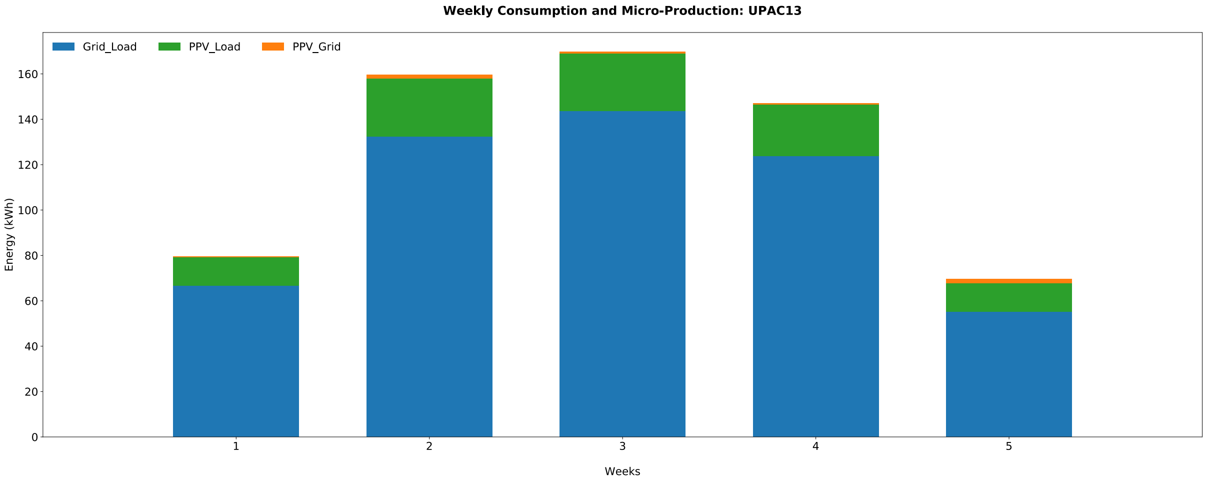

Figure A.17 – Weekly Consumption and Micro-Production for UPAC 13 between June 28 and July 26, 2018.

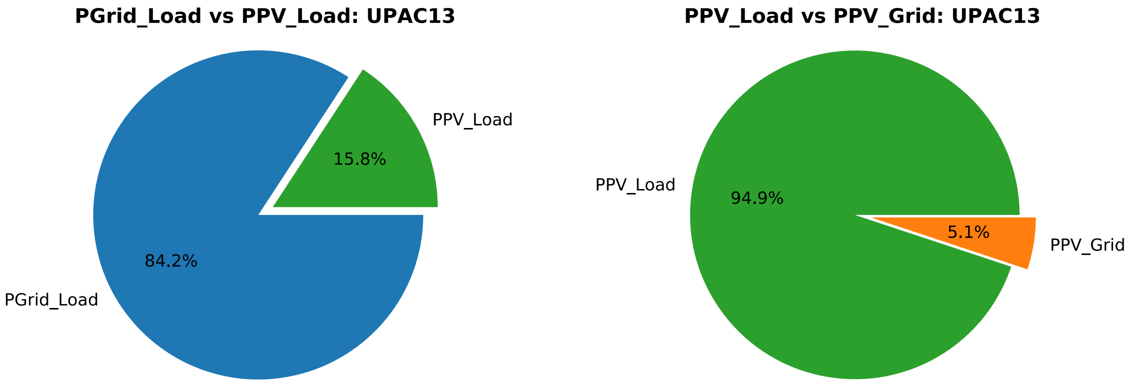

Figure A.18 – Proportion between grid and self-consumption (left), and between self-consumption and grid-injection (right) for UPAC 13.

UPAC 14

UPAC 14 contracted power is 3.45 kVA with a single-rate tariff. The installed solar PV is 0.75 kWp. As it can be seen from Figure A.19 and Figure A.20, despite the small installation size, around 30% of the solar PV production is not being self-consumed. Still, due to the very small size of the installation, a BESS would not be very beneficial in this situation. Instead, this is another UPAC that can benefit from an in-depth analysis of the consumption patterns as a way to highlight opportunities to shift consumption to the periods with higher production, thus reducing the amount of renewable energy being injected into the grid.

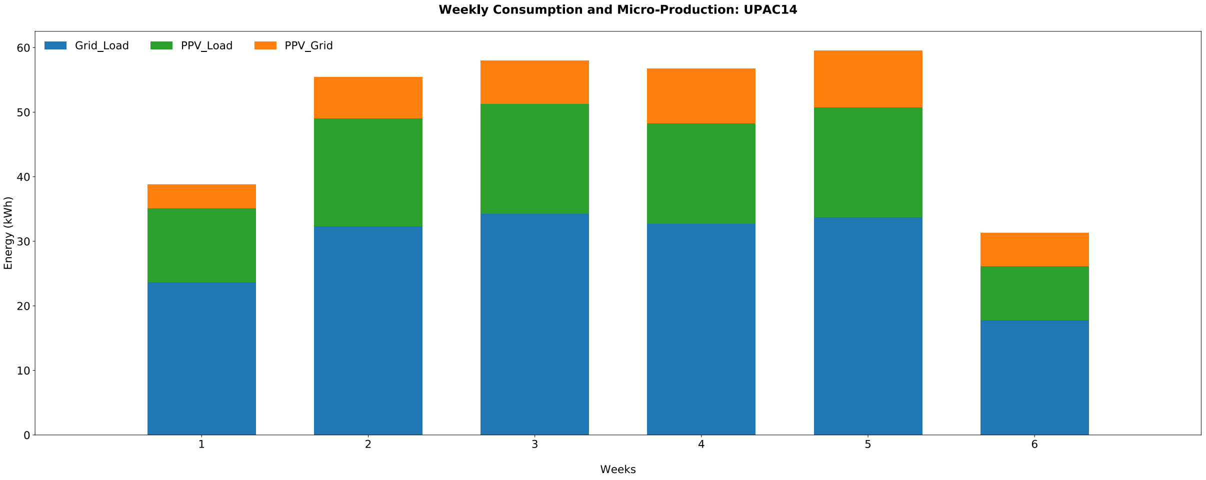

Figure A.19 – Weekly Consumption and Micro-Production for UPAC 14 between June 20 and July 26, 2018.

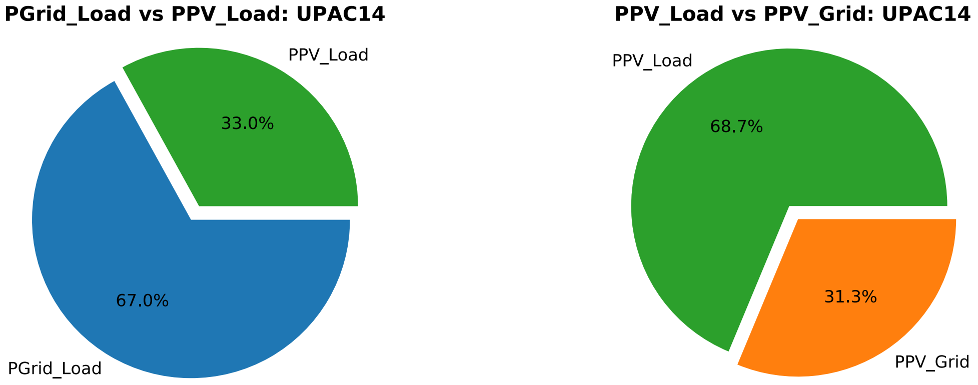

Figure A.20 – Proportion between grid and self-consumption (left), and between self-consumption and grid-injection (right) for UPAC 14.

Commercial UPACs

UPAC 8

UPAC 8 is a small snack-bar and restaurant. The contracted power is a three-phase 20.7 kVA, with a single-tariff. The installed solar PV capacity is 3.92 kWp distributed across three-phases.

As per Figure A.21 and Figure A.22, it is possible to observe that despite the large difference between contracted and installed power, there is still a loss of about 10% of the solar PV production. Furthermore, Figure A.23 shows that the peak injected power can reach 3.5 kW suggesting that the need for at least a 4 kW inverter.

Finally, Figure A.24 suggests that a BESS with a capacity around 4 kWh would suffice to considerably reduce the 10% average grid injection. However, since the objective of the pilot involving this UPAC is to study the potential benefits of arbitrage, 4 kWh is probably not enough. Instead, a three-phase 3 kW/ 8.6 kWh BESS will be installed in this UPAC as mentioned in sub-section 2.1.3.

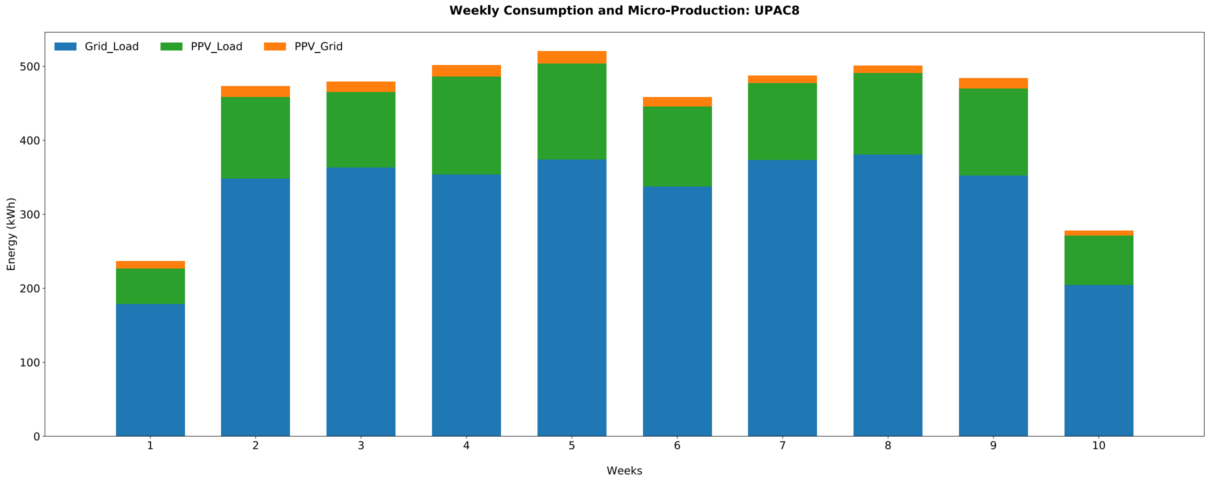

Figure A.21 – Weekly Consumption and Micro-Production for UPAC 8 between May 24 and July 26, 2018.

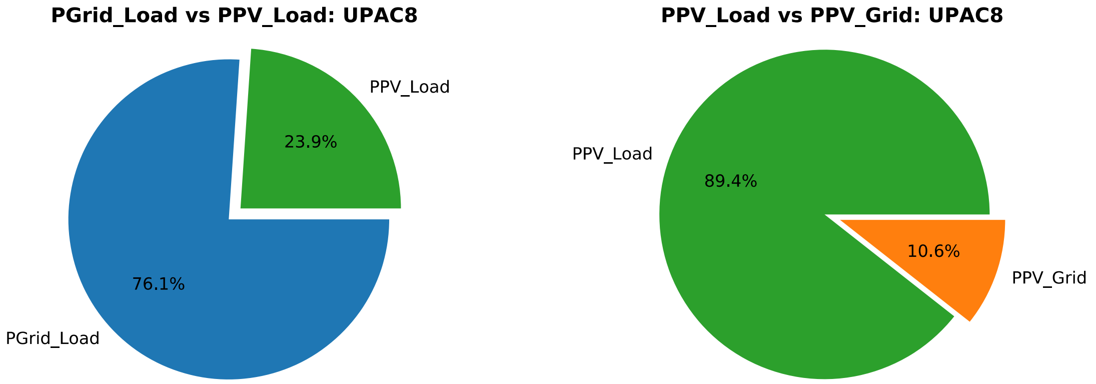

Figure A.22 – Proportion between grid and self-consumption (left), and between self-consumption and grid-injection (right) for UPAC 8.

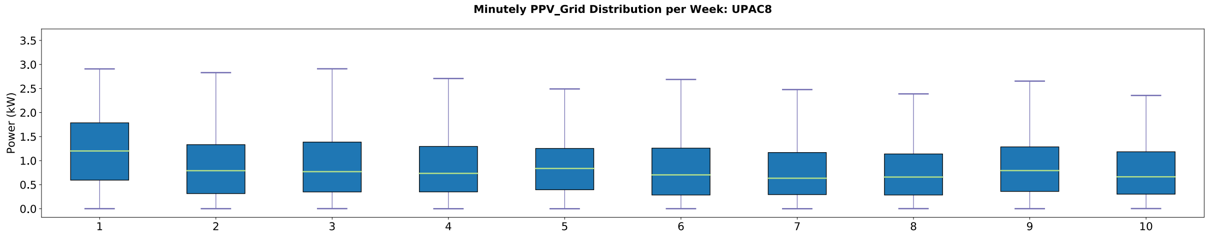

Figure A.23 – Minutely distribution of the solar PV power being injected in the grid on a weekly basis.

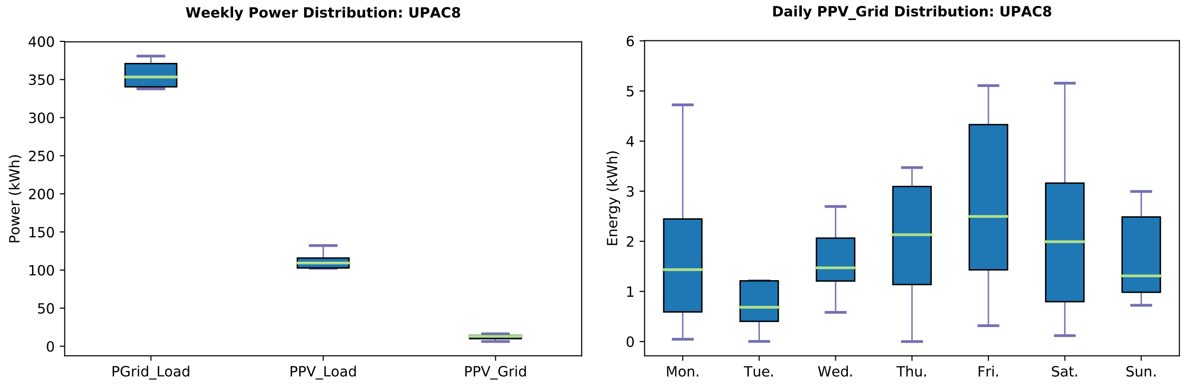

Figure A.24 – Weekly power distribution (left), and daily P_{PV_Grid} distribution (right) for UPAC 8.

UPAC 18

UPAC 18 is the office space of an electrical and electronic engineering company. The contracted power is a three-phase 10.35 kVA, with a single-tariff. The installed solar PV capacity is 1.5 kWp installed on a single-phase.

Figure A.25 and Figure A.26 show that about 30% of the solar PV production is injected into the grid. However, from Figure A.28 (right) it is possible to see that most of the grid injections happens on weekends when the office happens to be closed.

Finally, despite Figure A.27 and Figure A.28 suggest that a 2 kW inverter and a 4 kWh BESS would suffice, this is probably not the case. In fact, since most of the injection happens on weekends, the only way to optimize this installation would be with a BESS with enough capacity to host most of the production in that period. The stored energy would then be used during the weekends to fill “gaps” where there is not enough solar PV production. This is a situation that will be explored via simulation under the scope of the SMILE project, since the installation of a BESS is not foreseen for this UPAC.

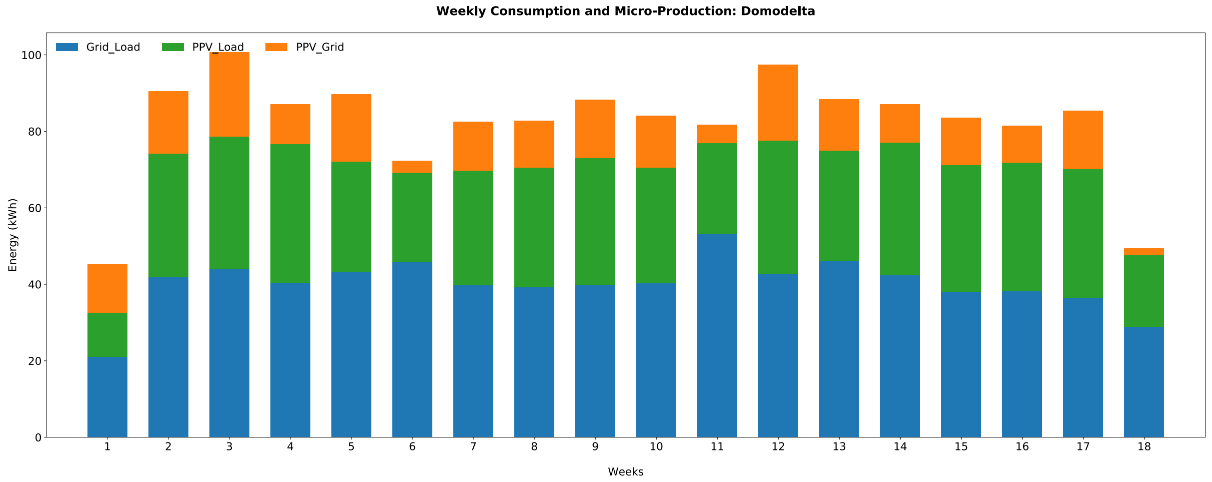

Figure A.25 – Weekly Consumption and Micro-Production for UPAC 8 between March 28 and July 26, 2018.

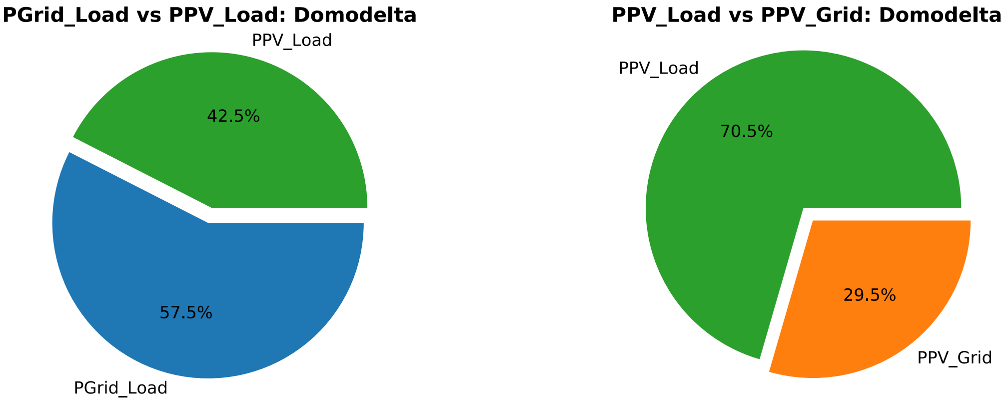

Figure A.26 – Proportion between grid and self-consumption (left), and between self-consumption and grid-injection (right) for UPAC 18.

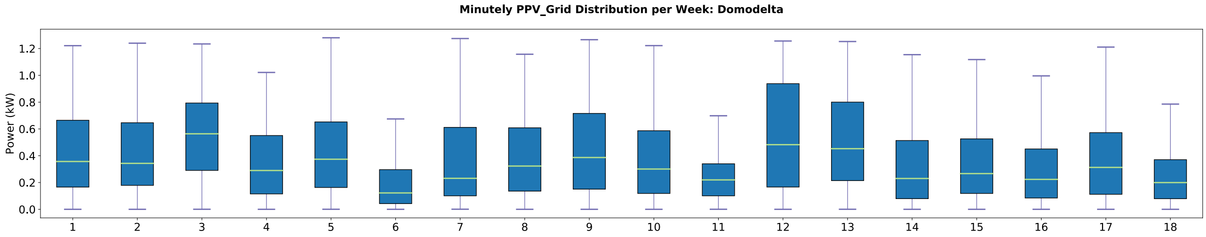

Figure A.27 – Minutely distribution of the solar PV power being injected in the grid on a weekly basis.

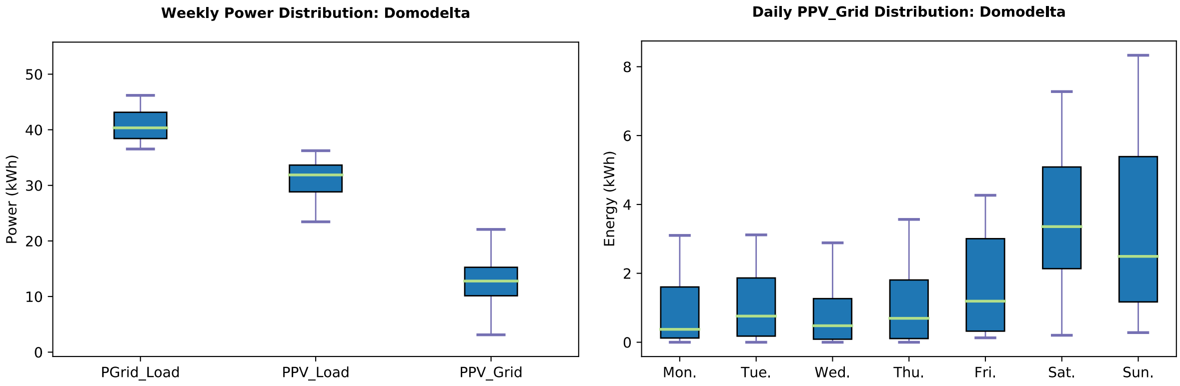

Figure A.28 – Weekly power distribution (left), and daily P_{PV_Grid} distribution (right) for UPAC 18.

Selected UPACs

Regarding the selection of the domestic UPACs that should receive a BESS, according to D4.3 only UPAC 12 had enough solar PV production to justify the deployment of storage devices. Furthermore, D4.3 also suggested that UPACs 6, and 9 were also good candidates, which after this initial analysis happens to be the case.

As for the domestic UPACs that are very unlikely to receive a BESS, the initial data analysis suggests that UPACs 1, 3, 4, 11, 13, 14 do not have enough surplus of solar PV energy to benefit from the installation of a BESS.

In contrast, UPACs 2 (1.5 kWp), 5 (1.25 kWp), and 10 (1.5 kWp) still need to be further studied in order to understand where the fourth BESS will be installed. These are all small UPACs, and present a perfect opportunity to understand how smaller UPACs can benefit from the installation of storage.

Finally, regarding the commercial UPAC, a BESS system will be installed in UPAC 8, whereas UPAC 18 will only be studied through simulation.

To conclude, Table A.3 shows a summary of the BESS that will be deployed in Madeira Island, and the respective installation sites.

Table A.3 – Summary of the BESS to deploy in Madeira Island, and the respective installation sites

UPAC	Type	Contracted Power (kVA)	Installed PV Power (kWp)	Tariff	BESS Size
U06	Domestic	10.35	2.7	Single-rate	3 kW / 8.6 kWh Single-phase
U09		6.9	4.5	Single-rate	
U12		6.9	3	Dual-rate	
U2, U5, U10		10.35	1.5	Single-rate	
U8	Commercial	20.7	3.92	Single-rate	3 kW / 8.6 kWh Three-phase
Fazendinha	Distribution Station	--	--	--	--