Enhancing storage integration in buildings with Photovoltaics

PV-ESTIA

Final project brochure

Project co-funded by the European Union and National Funds of the participating countries
The project is co-funded by the European Union and National Funds of the participating countries

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Dear Readers,

European Union’s energy targets for 2030 include the transformation of conventional buildings to Nearly Zero Energy Buildings (NZEBs). NZEBs are characterized by reduced energy demand, where most of their energy needs are covered by Renewable Energy Sources (RES).

At the same time, the Balkan-Mediterranean (BM) region is facing the challenge of sustaining and increasing the growth of Photovoltaic (PV) systems that is challenged by several barriers and their unpredictable nature. This is especially important in the built environment, as member states are developing plans to increase the number of NZEBs, which most probably employ PVs, to reach the 2030 climate change targets.

High PV penetration levels may result in unacceptable stresses on the electrical grids during hours with high solar power generation, while important technical challenges may arise. To effectively address these challenges, the integration of Energy Storage Systems (ESSs) in NZEBs is considered as the most promising solution, as it can transform the buildings into a controllable power source. With the high solar potential of the BM region and the decreasing cost of PV and ESS, such solutions are becoming cost-effective.

As the number of NZEBs increases, PV integration in the distribution grids is expected to reach top limits, unless buildings become more grid-friendly and policies and regulations are suitably adapted. In the above context, the overall objective of the PV-ESTIA project is to enhance the penetration of PVs and ESSs in the built environment, facilitating in this way the transition towards NZEBs.

The project aims to change the way buildings with PVs are treated and conceptualize them as systems, that are efficiently interacting with the grids. In addition, it aims to alleviate the above barriers and pave the way for the NZEB development.

Linking 4 countries of the BM region, Greece, Cyprus, Bulgaria and the Republic of North Macedonia, having as common ground similar weather and economic conditions, the project contributes in the transnational knowledge exchange and promotes the adoption of the good practices among the partners.

Through the study of the existing situation in the participating countries and analyzing the data of the pilot installations, project partners identify the barriers and possibilities of such systems.

As final target, ways to tackle the barriers are proposed, aiming at the increase of PV + Storage systems in NZEBs in the BM area both per country and as a whole.
PV-ESTIA AT A GLANCE

The primary goal of PV-ESTIA project is to enhance the integration of PVs coupled with ESS in the building environment facilitating the transition towards NZEBs.

PV - ESTIA
ENHANCING STORAGE INTEGRATION IN BUILDINGS WITH PHOTOVOLTAICS

Enhancing storage integration in buildings with photovoltaics (PV-ESTIA) is a project funded by the transnational cooperation programme Interreg V-B "Balkan-Mediterranean 2014-2020" and co-funded by the national funds.

COORDINATOR: Aristotle University of Thessaloniki – Department of Electrical & Computer Engineering, GREECE
DURATION: 1st August 2017 – 31st March 2020

WEBSITE: www.pv-estia.eu

PV-ESTIA PILOT ACTIVITIES

- PV systems
- LiFePO4 & LTO Battery ESS
- Hybrid inverters
- Electrical and thermal energy metering and control equipment
- Data acquisition & display features
- Smart Meters in prosumers and consumers installations
PV-ESTIA OBJECTIVES

Main target

- To enhance the integration of PVs and ESS in the building environment.

Why?

- To transform buildings into a controllable energy source;
- To enable the transition towards NZEB concept;
- To add flexibility to the electrical network.

How?

- Through the implementation of PV and ESS pilots in the participating countries;
- Through the data analysis of the implemented PV and ESS pilots.
- Through an Innovative Management Scheme of the hybrid PV+Storage system.

PV-ESTIA project aimed to evaluate under real-field conditions the performance of an Innovative Management Scheme for hybrid PV+Storage systems, to study the current national regulations and legislations and to propose new policies and recommendations for the countries of the BM region, in order to facilitate an easier integration of PV+Storage systems in the building stock.

Pilot installations were selected with the aim to examine if and how the size of the ESS and the different geographical conditions affect the performance of the implemented pilots.

PV-ESTIA METHODOLOGY

- Analysis of existing policies and regulatory frameworks of the participating countries;
- Development of an innovative management scheme for hybrid PV+Storage systems;
- Development of optimization tools to evaluate the performance of the hybrid PV+Storage systems under different electricity pricing policies;
- Implementation of pilot installations for the assessment of the hybrid PV+Storage under real-field conditions.
- The project transforms buildings into a controllable energy source by providing a new energy management solution, taking into consideration potential interactions with the electrical grid.

The proposed scheme targets to maximize the self-consumption of prosumers by taking into account current Distribution System Operator (DSO) technical regulations, consumption and generation profiles, electricity pricing policies, as well as thermal and electrical needs of the building.

Results from pilot installations were utilized to develop policies and technical regulation recommendations for the further integration of PVs and ESS in the BM region.

The following pilot installations were implemented accordingly:
THESSALONIKI, GREECE

The research committee building of the Aristotle University of Thessaloniki (AUTH) has been selected as the pilot site for the installation of 15 kWp PV panels + 15 kW inverters + 18 kWh batteries.

KOZANI, GREECE

22 kWp PV installation coupled with 2 hybrid inverters (2x10 kW) and LiFePO₄ (10.24 kWh/inverter), located within one of the buildings of the student dormitories of the University of Western Macedonia (UOWM).

NICOSIA, CYPRUS

1) A public pilot - an existing 12 kWp PV system is AC-coupled with a 15 kW / 27.9 kWh Lithium-ion Energy Storage System.
2) 5 residential pilots are implemented - an existing 3 kWp PV system is AC-coupled with a 2.5 kW / 9.3 kWh Lithium-ion ESS at each site in the wider area of Nicosia.

PLOVDIV, BULGARIA

A total of 13.5 kWp + 48 kWh storage capacity is implemented within 5 prosumers in Plovdiv area, each one consisted of:
- 2.70 kWp PV panels + 9.6kWh LiFePO4 ESS + 5kW hybrid inverter.

SKOPJE, REPUBLIC OF NORTH MACEDONIA

A 7.7 kWh Lithium Titanate (LTO) battery is DC-coupled with a 10 kWp PV generator through a 10 kW hybrid inverter at the Faculty of Electrical Engineering and Information Technologies.
NZEB SITUATION IN PARTNER COUNTRIES

Following the European Union’s (EU) Energy Performance of Buildings Directive (EPBD), all new buildings (private and public) must be officially categorized as NZEBs by 2021. Moreover, this already applies for all new public buildings since 2019. The general NZEB definition, which sets the overall criteria for a building to be considered as NZEB is:

a) A building that has a very high energy performance
b) The nearly zero or very low amount of energy required should be covered to a very significant extent from renewable sources, including sources produced on-site or nearby.

Each EU Member-State is responsible to interpret this clarification towards a national NZEB definition and set clear requirements according to its discretion, based on the environmental conditions in each country.

NZEB definition in Greece

The adaptation in the Greek legislation of the EPBD and its recast leads to the commitment that every new public building by 1.1.2019 and every new private building by 1.1.2021 will be NZEB. Despite the increased interest, the full adaptation of the EPBD has been postponed for the March of 2020. The National Plan and the legislation about the definition of NZEBs is still under development.

The existing regulatory framework regarding the energy efficiency of building in Greece is described by the Energy Performance of Buildings Regulation, known as KENAK. KENAK is applied at construction of new buildings and during full renovation of existing buildings. An EPC is necessary to be issued with the building permit, renting or any other change of the building use or structure.

The new NZEB buildings should achieve an EPC class of A or A+, however without specific definitions on the performance of the individual parts of the building (envelop, installations etc.) and without including any provision for use of RES.

NZEB definition in Cyprus

The NZEB requirements for residential and non-residential buildings, which include office, retail, public and industrial buildings, are defined by a dedicated regulation since 2014 (Regulation 366/2014: Requirements for NZEB in Cyprus), following the minimum requirements from a previous regulation (Regulation 432/2013).

NZEB definition in Bulgaria

Official NZEB definition was presented in 2015, with the amended Law on Energy Efficiency, which transposed Directive 2012/27/EU. In Bulgaria, NZEB buildings needs to simultaneously satisfy the following two conditions:

1) the energy consumption of the building, defined as primary energy, needs to meet
Energy efficiency Class A of the scale of energy consumption classes for the type of the building (9 type of buildings are considered);

2) not less than 55% from the energy consumption for heating, cooling, ventilation, domestic hot water (DHW) and lighting should be renewable energy.

Renewable energy should be produced on-site or near the building (the maximum distance is not specified).

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Bulgaria</th>
<th>Cyprus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Energy efficiency class</td>
<td>A or A+</td>
<td>A</td>
</tr>
<tr>
<td>2 Maximum primary energy consumption for residential buildings</td>
<td>95 kWh per m² per year</td>
<td>100 kWh per m² per year</td>
</tr>
<tr>
<td>3 Maximum primary energy consumption for non-residential buildings.</td>
<td>50±275 per m² per year</td>
<td>125 kWh per m² per year</td>
</tr>
<tr>
<td>4 Maximum energy demand for heating</td>
<td>n/a</td>
<td>15 kWh per m² per year</td>
</tr>
<tr>
<td>5 RES share in the final energy consumption</td>
<td>At least 55%</td>
<td>At least 25%</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Requirement</th>
<th>Bulgaria</th>
<th>Cyprus</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Maximum [U, w/m²K] value of external walls</td>
<td>0.28 W/m²/K</td>
<td>0.4 W/m²/K</td>
</tr>
<tr>
<td>7 Maximum [U, w/m²K] value of floor of a heated space bordering facing outside air</td>
<td>0.4 W/m²/K</td>
<td>0.4 W/m²/K</td>
</tr>
<tr>
<td>8 Maximum [U, w/m²K] value of flat roof without air layer</td>
<td>0.25 W/m²/K</td>
<td>0.4 W/m²/K</td>
</tr>
<tr>
<td>9 Maximum [U, w/m²K] value of windows</td>
<td>1.4 W/m²/K</td>
<td>2.25 W/m²/K</td>
</tr>
<tr>
<td>10 Maximum installed lighting power</td>
<td>n/a</td>
<td>10 W/m²</td>
</tr>
</tbody>
</table>

Fig. 1 NZEB requirements comparison in Bulgaria and Cyprus.

NZEB definition in N. Macedonia

In 2020, the NZEB definition and the RES requirement are still not introduced in the Energy Law and the national legislation of the Republic of North Macedonia. Therefore, the NZEB targets are not compulsory, because there is no NZEB definition transposition in the national legislation and hence no NZEB targets are set. In N. Macedonia currently there are only standards, part of the Rulebook for Energy Performance of Buildings, regulating new building, which have to comply with energy class C (<100 kWh/m²y) and with energy class D (<150 kWh/m²y) during refurbishment.
A core task of the project was the definition and implementation of the monitoring and data collection method in each of the participating countries.

Project partners have defined a common monitoring scheme and set the objectives for data assessment according to the needs for data analysis. The data collected by each partner is either directly measured at the pilot location or obtained through post-processing of the measured data. Data collection has been initiated in all pilot installations, where measurements are locally collected with a 15-min time-step. Afterwards, each partner performs the necessary post-processing to obtain the data required for the commonly defined dataset template. The template contains the time-series with regards to:

1. **MANDATORY DATA**

   **Electrical parameters:**
   - PV generation
   - Storage charge & discharge power
   - Grid import & export power
   - Direct PV consumption
   - Load consumption
   - Battery State-of-Charge (SoC).

   **Grid reactive power.**

   **Thermal parameters:**
   - Thermal energy consumption
   - Indoor & ambient temperature
   - Indoor & ambient humidity.

   **Other parameters:**
   - Solar irradiation
   - Wind speed, etc.

The mandatory electrical parameters are collected in all pilots, while the thermal parameters are collected in three of the pilot locations. Moreover, optional data are monitored, so as to provide better clarity and a wider scope of the analysis.

Once the data is collected, it must be filtered with the aim of determining possible errors and inconsistencies. As a result, the collected data undergoes a crosscheck on a set of validation criteria which ensure that the data is valid and congruent. This crosscheck is performed twice – once locally and a second time after the data has been stored in a central database. A dedicated central database has been set-up in UOWM for this purpose.

![Figure 2: Power flow as derived by the monitoring system of a pilot.](image-url)
PV-ESTIA PILOT DESCRIPTION

Through the PV-ESTIA project the technical requirements for PV and storage integration in the built environment were defined and the experimental pilot locations were selected, following a transparent procedure. The work included the definition of the exact technical characteristics of the pilot activities. The output outlines how each pilot will be implemented, taking into account local regulations and special technical requirements, to investigate potentials for a common context. Different particularities of each region were identified in the process of analysing the pilot selection criteria and defining the features and characteristics of the experimental pilot activities. The experimental pilot sites of the project are categorized in two groups.

The 1st group of pilots considers the implementation of hybrid PV+Storage installations in existing or new PV installations in all four participating countries (Greece, Cyprus, Bulgaria and North Macedonia). Two public buildings were selected in Greece (in Thessaloniki and Kozani), one in Cyprus, and one in North Macedonia to host a hybrid PV+Storage system. Furthermore, PV+Storage systems were installed in residential premises in Cyprus and Bulgaria in order to allow valid comparison.

The 2nd group of pilots refers to existing prosumers in Greece (both Thessaloniki and Kozani) and consumers in North Macedonia. Hence, the performance of the proposed hybrid PV+Storage solution was evaluated under real-field conditions. Pilot installations were selected to examine whether the size of the ESS and the different geographical conditions affect the performance of the proposed innovative management scheme.

There are three important decisions during the design of a PV+Storage system. The system configuration, the selected battery technology and finally, the features that the system is desired to support.

To integrate batteries with PV systems two main configurations are available. The first is the AC-coupled system and is favorable since it can be easily fitted to existing PV systems.

![Figure 3: AC-coupled configurations for PV+Storage systems](image-url)
It consists of a PV inverter and a battery unit with an additional battery inverter for charging & discharging the battery. The system can be upgraded to higher PV power or battery capacity by replacing the corresponding inverter. However, the need for two different inverters makes the installation difficult since many premises have limited available space. This system is characterized as AC-coupled since both PV and battery inverters share a common AC bus.

The second configuration is the Hybrid or DC-coupled system. The term hybrid is used since a single inverter integrates both PV and the battery unit which are connected to a common DC bus. A DC-coupled system requires fewer components since the hybrid inverter is used instead of the PV and battery inverters, resulting in lower unit costs. The round-trip efficiency is higher compared to the AC-coupled system but DC-coupled systems have limited expandability.
PILOTS IN GREECE

In Greece, 2 pilot systems have been installed in public buildings, and a set of 30 measurement systems in prosumers.

PILOT SYSTEM

The AUTH pilot installation in the AUTH Research Committee building consists of:

- 15 kWp PV panels + 15 kW inverters + 18 kWh batteries;
- Metering and control equipment for monitoring both electrical and thermal energy;
- Communication, data acquisition & display features.

During the pilot operation, the overall building energy performance, both thermal and electrical, is monitored under different operational scenarios for storage utilization. Following building features are monitored: Thermal loads (heating & cooling), ventilation, outdoor and indoor temperatures, PV generation, electrical loads, and energy storage.

The UOWM has installed a 22 kWp PV system coupled with 2 hybrid inverters (2x10kW) and a LiFePO4 energy storage system (10.24 kWh/inverter), located within one of the buildings of the student dormitories of the University. The system also includes power metering system to collect data for the electrical consumption, the PV production and the BESS utilization of the pilot, along with the thermal energy of the dormitories.

Figure 5: Pilot installation in Thessaloniki-Greece.

Figure 6: Pilot installation in Kozani.

METERING SYSTEMS IN PROSUERS

AUTH and UOWM installed dedicated power loggers for the monitoring of the energy exchange in 30 prosumers and/or consumers in the Thessaloniki and W. Macedonia regions, in order to collect datasets of energy profiles for generation and consumption. These datasets will be used to create typical generation and consumption profiles. The installed power loggers monitor the consumption and generation of the prosumers and wirelessly transmit the measured data to a cloud hosted by AUTH. Own data can be accessed in real time by the prosumers, while the collected data is properly stored in a data server in UOWM.
The residential pilots in Cyprus consist of a 2.5 kW / 9.8 kWh BESS, AC-coupled to an existing PV system on-site (a 3 kWp roof-top PV system) at each of the five selected residential premises in the wider area of Nicosia. The BESS constitutes of a bidirectional SMA battery inverter, a Lithium-ion LG battery unit and an additional meter which is responsible for the management of the system, able to operate in two modes, namely “Increase Self-consumption” and “Time-scheduled Charging”. Regarding the first mode, the system maximizes the use of self-generated PV power and the second one is more suitable for Time-of-Use Tariffs. Typical Cypriot residences (both 1-phase and 3-phase) with typical load demand were selected for the installation of the Residential Pilots and were also equipped with special sensors to monitor both the indoor and outdoor environmental conditions (temperature and humidity).

The Public Pilot was installed at the New Nicosia Town Hall, which has been recently constructed. It is located in the municipality of Nicosia and is the first building in Cyprus in which all the required bioclimatic design principles have been implemented in order the building to be considered as a passive building. A passive building implies that it offers excellent comfort conditions and a healthy internal environment while consuming less than 30 kW of electricity for each m², instead of 150-400 kW in the case of conventional buildings. The 15 kW / 29.4 kWh BESS is AC-coupled to a 3-phase 12 kWp PV system already installed on the roof of the New Nicosia Town Hall.

Similarly, with the Residential Pilots, the Public Pilot consists of three bidirectional SMA battery inverters connected with three Lithium-ion LG battery assets. The Public Pilot constitutes the first grid-connected energy storage system in a building of public use in Cyprus.

In summary:

- **5 Residential Pilots:**
  An existing 3 kWp PV system is AC-coupled with a 2.5 kW / 9.3 kWh Lithium-ion BESS at each residential premises in the wider area of Nicosia.

- **1 Public Pilot:**
  An existing 12 kWp PV system is AC-coupled with a 15 kW / 27.9 kWh Lithium-ion BESS in the New Nicosia Town Hall.
PILOTS IN BULGARIA

The Energy Agency of Plovdiv (EAP) established 5 pilots in the south-central region of Bulgaria, consisting of the following main features: Hybrid inverter, a Lithium iron phosphate battery energy storage system (BESS) (LiFePO₄) and AC & DC power analyzers forming a Data Acquisition System. A common selection procedure for all installations was followed in order to guarantee a fair and transparent process. Hence a selection process of those who fulfilled the initial requirements and current national regulations was implemented. The aim of the pilot installations is to assist the development of the optimum model in order to achieve maximum self-consumption via the analysis of real data generated by the pilots.

Data from each residential installation is collected and recorded in SQL Database in a server on EAP’s premises. To this end, a structured database and a Server Application (Service) is created - a specialized tool for reading and storing data from the monitoring system, which reports values from the individual devices on average of 15 minutes.

**5 RESIDENTIAL PILOTS:**

A total of 13.5 kWp + 48 kWh storage capacity is implemented within 5 prosumers in Plovdiv area.

- 2.70 kWp PV panels + 9.6 kWh LiFePO4 low-voltage BESS + 5kW 1-ph hybrid inverter – 4 prosumers.
- 2.70 kWp PV panels + 9.6 kWh LiFePO4 high-voltage BESS + 6kW 3-ph hybrid inverter – 1 prosumer.

**Table:** Technical data of 5 prosumers from Bulgaria

<table>
<thead>
<tr>
<th>Location</th>
<th>PVs (kWp)</th>
<th>Battery power (kW)</th>
<th>ESS nominal capacity (kWh)</th>
<th>ESS usable capacity (kWh)</th>
<th>ESS inverter power (kW)</th>
<th>Phase</th>
<th>ESS technology</th>
<th>Coupling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plovdiv</td>
<td>2,75</td>
<td>5</td>
<td>9,6</td>
<td>8,8</td>
<td>5</td>
<td>1-ph</td>
<td>LiFePO4</td>
<td>DC</td>
</tr>
<tr>
<td>Markovo (Plovdiv)</td>
<td>2,75</td>
<td>5</td>
<td>9,6</td>
<td>8,8</td>
<td>5</td>
<td>1-ph</td>
<td>LiFePO4</td>
<td>DC</td>
</tr>
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<td>Hisarya</td>
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<td>LiFePO4</td>
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<tr>
<td>Stamboliyski</td>
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<td>Topolovo</td>
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<td>6</td>
<td>3-ph</td>
<td>LiFePO4</td>
<td>DC</td>
</tr>
</tbody>
</table>
PILOTS IN NORTH MACEDONIA:

PUBLIC PILOT SYSTEM

The public pilot project consists of a 10 kWp PV panels, a 7.7 kWh Lithium Titanate (LTO) battery and a three-phase hybrid inverter. The hybrid inverter and the battery pack were purchased using the PV-ESTIA funding, while the PV generator was purchased by the Faculty of Electrical Engineering and Information Technologies for the purposes of the PV-ESTIA project. The hybrid system is used to supply the electricity consumption of the Center for Technology Transfer and Innovations – INNOFEIT, which is at the premises of the Faculty of Electrical Engineering and Information Technologies, University Ss. Cyril and Methodius in Skopje, North Macedonia.

The 10 kWp PV generator consists of 36 PV panels, 280 Wp each, manufactured by Canadian Solar.

Another 12 kWp PV generator is also located at the rooftop of the faculty building, but it is outside of the project’s scope. The surplus 10 kWp PV generation is stored in the battery pack comprised of Yinlong Lithium Titanate battery cells (LTO) with a total capacity of 7.736 kWh. The battery pack is operated under a C-rate of 0.5. This pilot project provides opportunities for research with LTO batteries, which is of high value considering the limited experience with this battery technology. The PV panels and the battery pack are DC-coupled through a Voltronic Power three-phase inverter with a rated capacity of 10 kW.

A dedicated system monitors the electrical parameters such as the electrical load, the PV generation, grid export/import, battery SoC, battery charge and discharge power, direct PV consumption, grid voltage, grid reactive power etc. These parameters are obtained using two subsystems:

a. Monitoring subsystem A (consumption, PV generation, grid export/import, grid voltage)

b. Monitoring subsystem B (PV generation, storage charge/discharge power, direct PV consumption)
PILOTS RESULTS AND DATA ANALYSIS

Data analysis is conducted based on the measurements collected by the pilot installations of all partner countries. The analysis aims to extract the self-consumption (SCR) and self-sufficiency (SSR) rates. SCR indicates the percentage of PV produced energy that is consumed by the installation on-site, either directly or using the battery storage system. SSR is the degree of energy demand of the installation that is covered locally by the PV.

When measurements are available, SCR and SSR indicate the exact behavior of the prosumer. However, measurements are not always available. Therefore, typical characteristic profiles for consumption and generation are usually utilized. PV typical profiles are usually derived by publicly available datasets, while load profiles can be constructed based on the characteristics of the household (number of occupants, building characteristics, electrical appliances, etc.), or can be derived by datasets.

Through the data analysis, we try to identify at what rate the typical data can replicate the real performance of a PV and storage system. For this reason, we compare the SCR and SSR indicators as derived by the annual measurements of our pilots (Method A) and by using typical profiles (Method B).

To calculate SCR and SSR using Method B, we use typical profiles for PV and consumption. Typical profiles for PV generation are derived by the PVGIS platform [https://ec.europa.eu/jrc/en/pvgis]. Load profiles are built upon the measured consumption of the pilots; an average profile is derived for the consumed power per month. The performance of the battery asset is not known; thus, it needs to be simulated. We calculate the battery charged and discharged energy amounts, assuming a control strategy that aims at the maximization of self-consumption, which is the most used control strategy for residential storage systems.

Indicative results of a certain pilot installation located in Cyprus are presented below. The annual SCR and SSR indicators present a lower value when calculated based on Method A. Nevertheless, the difference is limited to 13 % for SCR and 17.5 % for SSR.

<table>
<thead>
<tr>
<th></th>
<th>Method A</th>
<th>Method B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual SCR</td>
<td>74.05 %</td>
<td>83.52 %</td>
</tr>
<tr>
<td>Annual SSR</td>
<td>70.20 %</td>
<td>82.53 %</td>
</tr>
</tbody>
</table>

Figure 9: SCR comparison per month.

Figure 10: SSR comparison per month.
DESCRIPTION OF TOOLS

PV-ESTIA has developed two tools that aim to facilitate the design of PV and storage systems in buildings.

The online tool can model both the thermal and the electrical energy demand of the building. The modeling of thermal energy demand is made using an hourly method based on ISO 52016-01:2017. The electrical demand is modeled using a bottom-up approach and a questionnaire that the user has to answer. These mean that the user should provide inputs related to the main building elements (i.e. number of windows, useful areas, etc.) and to how the electrical appliances are used.

The inputs to the tool are split into 6 screens in different categories. Once all inputs are provided, an optimization procedure is employed aiming to minimize the total cost of the prosumer, taking into account the electricity costs and the installation costs for a PV and battery system. The results portray the optimal combination of PV and battery sizes for the chosen configuration that yields the highest profits for the prosumer.

The second tool targets mainly policy makers and is based on MS Excel. It uses certain files as inputs, containing the average monthly consumption for working and non-working days, and the average monthly PV generation. Additionally, the tool can model different support schemes, hybrid ones, or a no-support scheme scenario.

The thermal demand is taken into account in a simple way and is assumed to be covered by electrical means, and this means that a total of additional electrical demand is added on top of the provided one.

The tool can perform a parametric analysis for PV and battery sizes and outputs the optimum combination in terms of maximizing profits. The outputs include several relevant parameters, such as SCR, SSR, LCOE, etc.

Figure 11: The online optimization tool

Figure 12: The optimization tool for policy makers
DEFINITION OF INNOVATIVE MANAGEMENT SCHEME FOR PV AND STORAGE SYSTEMS

In the context of the PV-ESTIA project, the design and testing of an innovative management scheme for BESS was performed. The innovative management scheme should be suitable for residential buildings equipped with PV and BESS. The performance of the developed management scheme was examined at laboratory scale, hence a laboratory BESS pilot, installed at its facilities, was used to emulate a realistic scenario. The simulations were focused on the battery management when covering electrical and thermal loads. The latter was emulated as electricity following appropriate conversion. Typical residential load profiles for Cyprus, representing both working and non-working days for each month of the year based were used, in order to develop and validate appropriate algorithms for simulating BESS operational modes.

In order to achieve the best charging pattern in terms of optimal battery capacity utilisation, an intelligent management of the BESS is considered. The BESS is utilised more when it charges from both the off-peak energy offered by the power grid (e.g. overnight) and the excess PV generation of a household (the cheapest source of energy). Thus, the overnight charging level of the BESS must be chosen appropriately. As a result, the final step of the work was to investigate the BESS management for the Overnight Charging Level Optimisation, focusing on three examined parameters, i.e. time period, battery energy capacity and power converter rating, to achieve both the higher utilisation of the PV system and reduced electricity bills for the end-users.

From the three examined parameters, it was concluded that the overnight charging level needs to be adjusted to the corresponding time period, as the overnight charging needs for each season are different, e.g. much higher during winter rather than summer.

For the demonstrated case, the optimal overnight charging levels are: winter: 80%, autumn: 60%, summer: 20% and spring: 20%) as the PV generation varies through the year, and thus, the overnight charging level needs to be adjusted accordingly (Figure 12). Furthermore, an intelligent overnight control algorithm makes sense only if the battery is within the medium size range of energy capacity for the particular installation/system, rather than for small or large battery capacities (Figure 13).

Lastly, the power converter rating becomes more critical for the choice of the overnight charging level if it is relatively small compared to the power profile peaks for both generation and consumption. A lower power converter rating restricts the amount of the charged energy from the excess PV generation.
Thus, the overnight charging becomes more significant for the BESS. On the other hand, a low power converter rating also restricts the amount of energy which can charge the battery overnight (Figure 14).

**Figure 12:** BESS charging patterns for different overnight charging levels through different seasons.

**Figure 13:** BESS charging patterns for different battery sizes (4.65 kWh - low, 9.3 kWh - medium and 18.6 kWh – high) through different seasons.
COST-BENEFIT ANALYSIS

The PV-ESTIA Cost-Benefit Analysis (CBA) consists of an assessment of the Energy Storage integration in the residential level of the participating countries from the financial perspective. Specifically, it weighs financial costs against benefits for the implemented residential BESS coupled with PVs in the regions involved under various policy scenarios, such as Net-Metering, Net-Billing and Pure Self-Consumption, depending also on the operational mode of the BESS. The following Table illustrates the functionalities a residential BESS can have on the power network, depending on its operational mode. The modes marked in blue are the ones that the PV-ESTIA pilots can function, given the permission of the local authorities.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Residential Energy Storage functionalities on the power network</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Store energy from PV</td>
</tr>
<tr>
<td>Ancillary services</td>
<td>√</td>
</tr>
<tr>
<td>Distribution system support</td>
<td>√</td>
</tr>
<tr>
<td>Transmission system support</td>
<td>√</td>
</tr>
<tr>
<td>Increase self-consumption</td>
<td>√</td>
</tr>
<tr>
<td>Decrease peak dependence</td>
<td>√</td>
</tr>
<tr>
<td>CO₂ emissions reduction</td>
<td>√</td>
</tr>
</tbody>
</table>
Project partners have investigated the **current legislation** about ESS and NZEB in project countries and have identified the responsible authorities in each country and the **barriers** related to Energy Storage Exploitation. The main findings are:

- The main legislation for PV production are Net-Metering schemes in all countries.
- Net-Metering scheme uses the power grid as a virtual and unlimited storage asset.
- No incentives exist to compensate the high investment cost of ESS.
- The main barriers are the absence of ESS in the regulations and the absence of Time-of-Use (ToU) Tariffs, especially in residential building sector.
- NZEB definitions are defined in Cyprus and Bulgaria while their definition is in progress in the rest project countries.
- EPBD do not consider ESS in energy certificates calculations.

The current active policies and market conditions restrict any financial benefit for the end-users and hence, a PV-ESS installation is not a profitable investment under the existing conditions. It is evident that special measures and policies are needed for the promotion of ESS in building sector.

The **main recommendations** are:

- Energy Storage must be included in the regulations.
- Introduction of Net-Billing scheme, Time-of-Use Tariffs and other time-varying pricing schemes, especially in residential building sector.
- Development of local flexibility and ancillary services markets.
- Improvement of Energy Community and Aggregator regulations.
- Nondiscriminatory grid access for ESS.
- Development of standards for monitor and control communications between RES, ESS and power system equipment.

The exploitation of ESS can be **promoted with different actions and practices**, as presented below:

- Power grid support by coupling ESS with PV generation, offered by energy shifting and self-consumption maximization.
- Provide subsidies to compensate the high investment cost of ESS.
- Removal of all charges for self-consumed energy and avoidance of double taxation etc.
- Promote the share of community level ESS in existing and new Energy Communities
- Increase awareness of end-users about self-consumption and demand side management based on Time-of-Use shifting.
- Introduce time-varying tariffs in all consumer sectors.
- Promote smart-meters, real time information for end-user, and advanced software for historical data analysis.
- Develop open market access through aggregators for energy trading and ancillary services offers.
COMMUNICATION & DISSEMINATION

Communication activities within the PV-ESTIA project played an important role for the notification and disclosure of granting and use of the BM funds and for marking of the objects financed by them, as well as for the awareness raising and sharing of all project’ practical outcomes as widely as possible within a “qualified community”. During communication and dissemination activities key stakeholders were engaged in the development and delivering of project outputs, leading to more robust and useful outcomes. Hence maximum communication and dissemination of the PV-ESTIA project was achieved, leading to a successful exploitation of the project results. PV-ESTIA communication and dissemination activities included:

INTERNATIONAL EVENTS

A. First International Conference "International meeting of the consortium of PV-ESTIA with Mediterranean TP for Smart Grids under the auspices of the Cyprus TP for Smart Grids", Nicosia 22.11.2017

B. Second International Conference "Towards an efficient implementation of storage in buildings - Experiences and good practice", Thessaloniki, 5.12.,2019
LOCAL WORKSHOPS AND OTHER EVENTS

KOZANI, GREECE

SOFIA, BULGARIA

SKOPJE, N. MACEDONIA

SKOPJE, N. MACEDONIA

NICOSIA, CYPRUS

SKOPJE, N. MACEDONIA
SCIENTIFIC PUBLICATIONS


LESSONS LEARNT

• The use of BESS with PV systems can improve significantly the self-consumption and self-sufficiency of the hybrid system, thus enhancing the interaction with the distribution grids. This can be also a source of profit, depending on the policy scheme used (Net-Metering, Net-Billing, etc.).

• The installation of storage systems should be included in the legislative frameworks and regulations of all Balkan-Med countries. In most Balkan-MED countries the use of BESS is not encouraged or even permitted.

• To facilitate the use of BESS alongside PVs new policy schemes should be adapted promoting the increase of self-consumption at prosumers owning PVs. This may include multi-zone electricity tariffs.

• A comparison between thermal and battery storage in the NZEB environment has been conducted under a scheme that provides no reimbursement for excess PV energy. Results show that:
  
  o For low storage capacities, thermal storage has a greater ability to increase NZEB’s self-consumption.
  
  o This is inversed for higher electrical storage capacities. This is a result of the battery’s ability to cover all types of electric loads.
  
  o Investments on battery storage are not currently economically attractive. However, for battery costs at the range of 200 EUR/kWh, BESS have a quicker payback than thermal storage.

• An innovative management scheme for BESS has been designed and tested within the project. It has been shown that overnight charging as a load smoothing feature, can lead to more efficient utilization of the BESS, while offering also enhanced performance to the grid. However, the size of the battery, the inverter rating and the overnight charging level play an important role to the utilization rate of the battery.
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