Cost-effective rehabilitation of public buildings into smart and resilient nano-grids using storage

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Priority: B.4.3 - Support cost-effective and innovative energy rehabilitations relevant to building types and climatic zones, with a focus on public buildings
Countries: Cyprus, Greece, Israel, Italy

Output nº: 4.2
Output Title: Case studies involving PV+ESS+DSM hybrid technology
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BERLIN

4 Contents

1 Project summary

In an effort to address high energy consumption in the building sector that is mainly fossil–fuelled, support rural areas and areas powered by weak grids, which are common in the MED region, and achieve higher grid penetration of renewable energy sources (RES) while maintaining grid stability and power quality, this project aims at the implementation of cross border pilots that will support innovative and cost–effective energy rehabilitation in public buildings based on the nanogrid concept. Thus, the BERLIN project focuses on the increase of photovoltaics (PV) penetration, which coupled with energy storage and demand–side management (DSM), will increase the energy efficiency (EE) of the buildings. Implementing these technologies cost–effectively will result in a high level of self–resilient public buildings that are green, smart, innovative, and sustainable. A total of 6 pilot buildings will be implemented by the end of the project: 1 in Cyprus, 2 in Greece, 2 in Israel, and 1 in Italy.

The project started in September 2019 and will be completed in September 2023.

2 Introduction

This report presents a joint case study, offering valuable insights into the potential for replication in all regions that fall under the MED area, including non-participating countries. The primary focus of the study is to highlight the regions where the combination of PV, BESS and DSM proves to be a cost-effective and sustainable solution. Additionally, it sheds light on regions where this combination may not be the most viable option and the underlying reasons behind it.

The report delves into various aspects, encompassing technical, policy-related, and dissemination practices across all levels. By exploring successful implementations, it outlines good practices that have proven to be effective in driving the adoption of PV+BESS+DSM technologies. These practices include the technical intricacies involved in integrating the technologies, policy frameworks that encourage and support the adoption of renewable energy solutions, and effective methods of disseminating information to the public and key stakeholders.

Equally crucial, the report also covers the lessons learned throughout the case study. It analyses challenges faced during the implementation process and provides valuable insights into overcoming potential obstacles. These lessons offer valuable guidance to future initiatives, ensuring a more streamlined and successful replication of similar projects in the future.

One of the key outcomes of this study is the creation of a unified mapping of do's and don'ts. This compilation consolidates all the essential guidelines for interested stakeholders, presented concisely and meaningfully. By adhering to these guidelines, stakeholders can effectively navigate the complexities of implementing PV+ESS+DSM projects. This mapping acts as a practical and indispensable reference, streamlining decision-making processes and ensuring successful outcomes.

The report underscores the significance of sharing knowledge and experiences across the MED regions. It promotes the adoption of renewable energy solutions and sustainable practices beyond the participating countries. By analyzing the specific conditions and challenges faced by different regions, the report provides valuable insights into tailoring the approach to suit each unique context.

3 Joint case study focusing on replication

This joint case study aims to analyze the cost-effectiveness of hybrid systems including photovoltaics (PV), battery energy storage systems (BESS) and demand side management capability, also referred as PV+BESS+DSM systems, in the Mediterranean (MED) region by considering two variations of public buildings, with different consumption patterns, such as a municipality town hall with a high match between power consumption and PV generation profiles and students dormitories that have significant demand in the afternoon hours when PV generation is low. Students' dormitories will be related in this report as Type A buildings and a municipality town hall will be defined as Type B. The study will analyze three cases of electricity tariffs in the MED region: low, medium, and high. Furthermore, the study will also consider two levels of load flexibility. The primary goal of this deliverable is to highlight the regions where the PV+ESS+DSM combination can be cost-effective and where and why this is not the case.

Tariffs Variety:

The MED region is home to a diverse group of countries with varying levels of economic development, population, and energy consumption patterns. One significant factor that differentiates these countries is their electricity tariffs. The cost of electricity as published in [1] is presented in Figure 1. A high variation of tariffs can be observed with some countries having low tariffs and others having high tariffs.

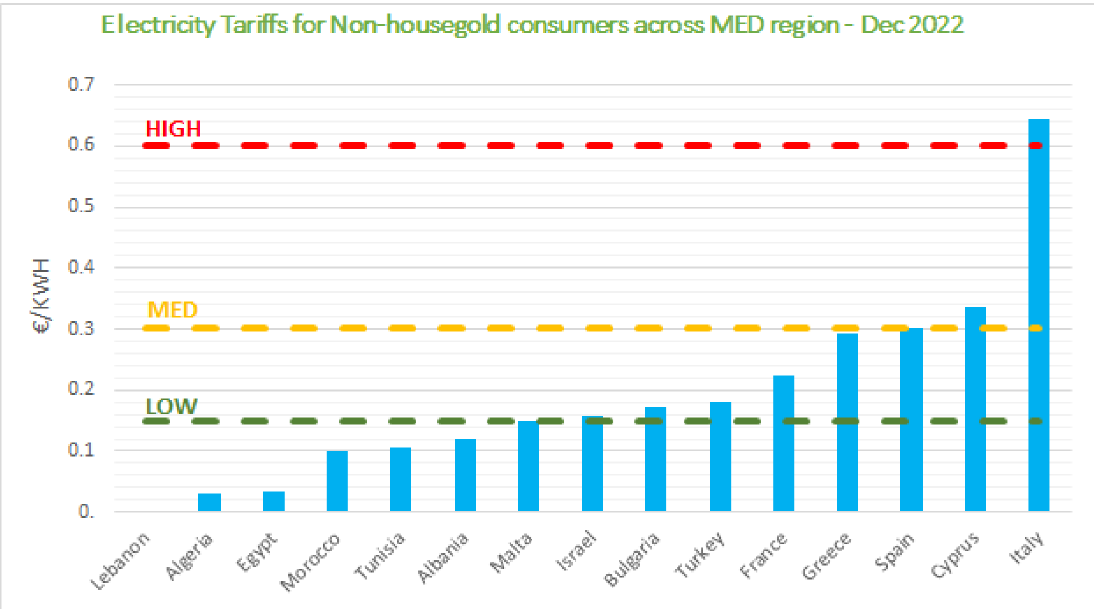

Figure 1. Electricity Tariffs for non-household consumers across MED region – Dec 2022

According to [2], European electricity prices are influenced by various factors, including energy demand and the availability of gas imports, particularly from Russia. If the demand for electricity remains at its current levels, the prices are expected to continue to stay high. This projection has implications for households and business entities, as it can result in high costs for businesses and the public sector.

Low-tariff countries like Tunisia, Malta or Israel have electricity tariffs below 0.152 €/kWh. These countries have traditionally relied on fossil fuel-based energy generation, which has kept their electricity prices low. However, the low tariffs may not reflect the actual cost of electricity production, and these countries may face challenges in investing in renewable energy systems. In low-tariff countries, the cost of electricity is low. Therefore, the installation of a PV+BESS+DSM combination may not be cost-effective. However, in regions with high solar irradiation, the PV system's energy generation can be significant, making installing the PV+BESS+DSM combination cost-effective. Furthermore, buildings with high energy consumption may also benefit from installing a PV+BESS+DSM combination.

Medium tariff countries, such as Greece, France or Turkey, have electricity tariffs ranging from 0.15€/kWh to 0.3€/kWh. These countries are moving towards renewable energy systems and implementing policies encouraging renewable energy development. The medium tariffs in these countries reflect the actual cost of electricity production and distribution. In medium-tariff countries, installing a PV+BESS+DSM combination can be cost-effective, especially for buildings with high energy consumption. Moreover, the DSM component can enhance the system's cost-effectiveness by shifting energy consumption towards peak PV generation hours. However, the level of load flexibility can significantly affect the system's cost-effectiveness. Indeed, the system's cost-effectiveness may be limited for buildings with low load flexibility.

High-tariff countries like Cyprus or Italy have electricity tariffs exceeding 0.3€/kWh. These countries have high electricity costs due to their reliance on imported fossil fuels and aging energy infrastructure. In high-tariff countries, installing a PV+BESS+DSM combination can be highly cost-effective. The high electricity tariffs make the use of PV systems economically viable. Moreover, the load flexibility component can help to optimize energy consumption during peak hours, reducing energy bills further. Additionally, the level of load flexibility can significantly affect the system's cost-effectiveness.

Load flexibility:

Load flexibility refers to the ability of electricity consumers to adjust their energy consumption patterns in response to changes in electricity tariffs or grid conditions. In the context of the MED region, load flexibility plays an essential role in determining the cost-effectiveness of PV+BESS+DSM systems under different tariff levels.

Low load flexibility is characterized by energy consumers with limited ability or willingness to change their energy consumption patterns. These consumers may have inflexible energy demands, such as industrial processes or essential services. In low load flexibility scenarios, the cost-effectiveness of PV+BESS+DSM systems is more sensitive to the electricity tariffs.

On the other hand, medium load flexibility scenarios are characterized by energy consumers who have more flexibility to adjust their energy consumption patterns. These consumers, such as residential or commercial buildings, may have more discretionary energy demands. In medium load flexibility scenarios, the cost-effectiveness of PV+BESS+DSM systems is less sensitive to the electricity tariffs.

The relationship between load flexibility and tariffs is critical in determining the cost-effectiveness of PV+BESS+DSM systems in the MED region. Countries with high tariffs may benefit from PV+BESS+DSM systems regardless of their load flexibility level. However, projects with low or medium tariffs may face challenges in achieving cost savings with PV+BESS+DSM systems if their load flexibility level is low. Therefore, policymakers and energy stakeholders in the MED region should consider the load flexibility level and the tariff structure when designing and implementing renewable energy systems.

The list below describes the joint case study technical and financial information used for the analysis of the profitability and energy self-sufficiency that PV+BESS+DSM systems can provide:

- PV capacity running from 5kWp to a maximum of 45kWp with an analysis step of 4.44kWp
- BESS capacity running from 0 to a maximum of 36kWh with an analysis step of 4kWh
- Annual consumption profile with explicit 15-minute resolution power demand data for each month's working and non-working days with an annual total of approx. 18000 and 21000 kWh for Type A and Type B public buildings, respectively, as defined above.
- Electricity tariffs variation – 0.15, 0.3, and 0.6 €/kWh
- PV system purchase cost (including a hybrid inverter) – 800 €/kWp
- BESS purchase cost
    - 600 €/kWh - 2022 average price
    - 200 €/kWh - projected price for the following years
- A typical generation profile for the MED region might require adjustments while considering replication at a specific location.
- A pure self-consumption policy is used in this study, meaning that no compensation is offered for returning excess energy to the grid.

Figure 2 bewlw demonstrates a distribution of monthly consumption in kWh for two type of buildings. The observed discrepancy between months and seasons is ex[lained by different occupancy and schedule of operation for each type of buildings.

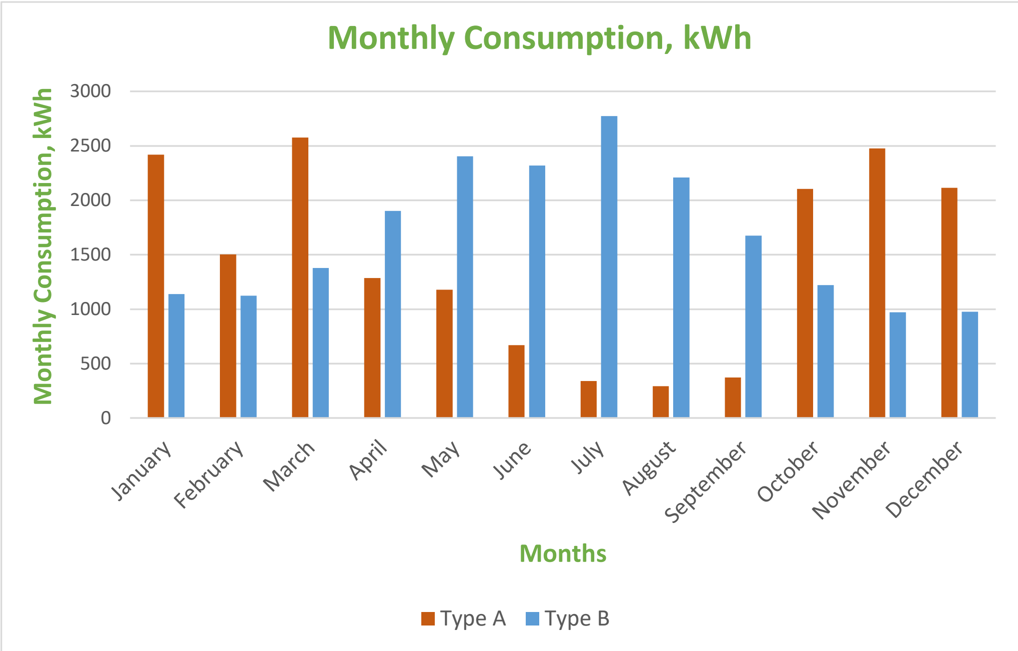

Figure 2. Monthly Consumption in kWh for two types of buildings

According to the information provided by the EU PVGIS online tool [3], the typical monthly photovoltaic generation varies across countries in the Mediterranean region due to sunlight availability, weather patterns, and geographical factors during the year.

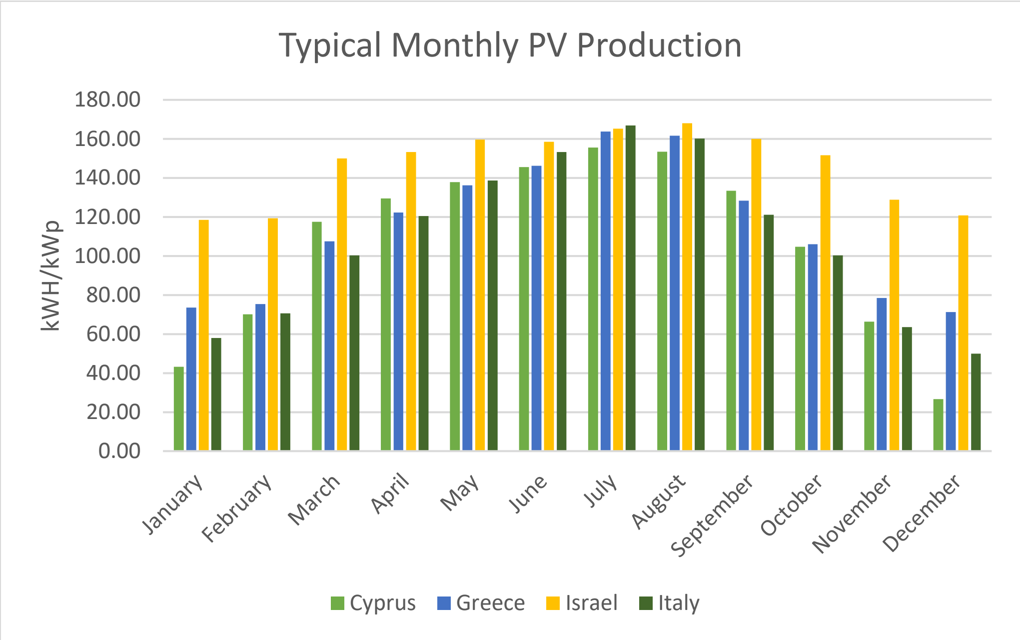

Figure 3. Typical Monthly PV generation

Figure 3 demonstrates the diversity in typical PV generation profiles across various states in the MED region.

Southern European countries like Italy and Greece generally receive abundant sunlight throughout the year, resulting in higher PV generation, experiencing higher PV generation during the summer months when the sunlight period is longer.

Countries located even further south, such as Morocco, Israel and Tunisia also benefit from high solar irradiation and can have significant PV generation potential. These countries have a high solar irradiation level, particularly in the Israeli Negev Desert region. Monthly PV generation tends to be relatively consistent, with higher output during the summer months due to longer daylight.

Eastern Mediterranean countries like Turkey and Cyprus also have favorable conditions for PV generation, with ample sunlight and longer summer seasons. However, local variations in weather patterns can affect monthly PV generation.

Factors such as shading, cloud cover, and local microclimates can impact PV generation on a more localized scale, even within the same country or region.

Parametric study:

The joint case study examined the impact of load flexibility on self-sufficiency for various generation and storage capacities for two public buildings. Two building types are included in the analysis as follows:

- Type A: consumption pattern presents a high mismatch with the typical PV generation power profile and is represented by the Greek partner's pilot case study at student dormitories.
- Type B: consumption pattern presents a lower mismatch with the typical PV generation power profile and is represented by the Greek partner's pilot case study at the municipality town hall.

A variation of PV capacity from 5 to 45 kWp and storage variation from 0 to 36 kWh were tested.

3.1 Self Sufficiency Rate

Table 1 . SSR-PV parametric analysis for Type A building

Sensitivity Factors			**Battery Size [KWh]**									
Policy	**Load Flexibility %**	**PV [KWp]**	**0.00**	**4.00**	**8.00**	**12.00**	**16.00**	**20.00**	**24.00**	**28.00**	**32.00**	**36.00**
Pure self-consumption	0	5	30.71	35.45	39.19	40.97	42.12	42.65	43.02	43.25	43.44	43.63
Pure self-consumption	0	9.44	37.58	44.43	50.54	54.63	57.91	60.37	62.03	63.18	64.01	64.48
Pure self-consumption	0	13.89	39.51	46.36	52.48	57.34	61.91	66.03	69.81	72.65	74.82	76.40
Pure self-consumption	0	18.33	40.49	47.34	53.43	58.27	62.81	66.92	70.74	74.26	77.48	80.27
Pure self-consumption	0	22.78	41.12	47.96	54.03	58.87	63.37	67.47	71.29	74.77	77.95	80.73
Pure self-consumption	0	27.22	41.59	48.43	54.48	59.31	63.79	67.88	71.69	75.14	78.28	81.06
Pure self-consumption	0	31.67	41.96	48.80	54.84	59.66	64.13	68.21	72.01	75.44	78.56	81.33
Pure self-consumption	0	36.11	42.26	49.10	55.13	59.95	64.40	68.48	72.27	75.69	78.78	81.55
Pure self-consumption	0	40.56	42.50	49.34	55.36	60.18	64.62	68.69	72.48	75.88	78.96	81.73
Pure self-consumption	0	45	42.70	49.54	55.55	60.37	64.80	68.86	72.64	76.03	79.09	81.86
Pure self-consumption	25	5	35.61	39.31	41.46	42.46	42.95	43.28	43.53	43.72	43.91	44.10
Pure self-consumption	25	9.44	50.50	55.20	58.54	60.89	62.51	63.76	64.61	65.08	65.48	65.87
Pure self-consumption	25	13.89	55.00	61.76	66.92	70.57	73.40	75.84	77.72	78.77	79.49	80.01
Pure self-consumption	25	18.33	55.74	62.49	67.86	72.42	76.46	80.10	83.32	85.41	86.96	88.35
Pure self-consumption	25	22.78	56.19	62.94	68.28	72.82	76.85	80.47	83.66	86.42	89.08	91.53
Pure self-consumption	25	27.22	56.55	63.29	68.62	73.15	77.17	80.77	83.93	86.69	89.33	91.77
Pure self-consumption	25	31.67	56.83	63.57	68.90	73.42	77.43	81.02	84.16	86.91	89.55	91.97
Pure self-consumption	25	36.11	57.04	63.78	69.10	73.60	77.61	81.19	84.31	87.06	89.69	92.10
Pure self-consumption	25	40.56	57.21	63.95	69.26	73.76	77.76	81.33	84.43	87.18	89.80	92.21
Pure self-consumption	25	45	57.36	64.10	69.41	73.90	77.90	81.46	84.55	87.30	89.91	92.31
Pure self-consumption	50	5	38.44	41.53	42.57	43.00	43.34	43.60	43.80	43.99	44.18	44.37
Pure self-consumption	50	9.44	55.61	59.78	61.99	63.49	64.39	64.88	65.31	65.71	66.06	66.38
Pure self-consumption	50	13.89	66.97	72.21	75.63	77.65	78.86	79.58	80.11	80.60	81.10	81.59
Pure self-consumption	50	18.33	70.74	77.17	81.64	84.71	86.73	88.23	89.62	90.62	91.28	91.88
Pure self-consumption	50	22.78	71.05	77.48	82.10	86.02	89.25	91.98	94.47	96.13	96.85	97.45
Pure self-consumption	50	27.22	71.29	77.71	82.32	86.23	89.44	92.16	94.64	96.54	97.99	99.19
Pure self-consumption	50	31.67	71.51	77.93	82.53	86.42	89.62	92.34	94.80	96.68	98.11	99.27
Pure self-consumption	50	36.11	71.66	78.08	82.67	86.56	89.74	92.46	94.91	96.78	98.19	99.33
Pure self-consumption	50	40.56	71.79	78.21	82.79	86.67	89.84	92.56	94.99	96.85	98.26	99.38
Pure self-consumption	50	45	71.90	78.32	82.90	86.77	89.94	92.65	95.07	96.92	98.32	99.43

Table 1 above presents parametric analysis results for the Joint Case of Type A building. Self Sufficiency Rate was evaluated as a function of PV and battery size variation from 5 to 45 kWp and 0 to 36 kWh, respectively.

SSR growths upon battery size increase from zero to 36 kWh for any selected PV capacity. Moreover, SSR increases upon variation of PV capacity for constant battery size. It can be concluded that a mismatch between the production profile and energy demand can be compensated by higher PV or battery capacity. The increase of load flexibility rate leads to higher levels of SSR, so that for PV of 9.44kWp and BESS of 12kWh, SSR reaches levels of 54%, 60% and 63% according to the zero, 25% and 50% load flexibility rate.

Table 2. SSR-PV parametric analysis for Type B case

Sensitivity Factors			**Battery Size [KWh]**									
Policy	**Load Flexibility %**	**PV [KWp]**	**0.00**	**4.00**	**8.00**	**12.00**	**16.00**	**20.00**	**24.00**	**28.00**	**32.00**	**36.00**
Pure self-consumption	0	5	39.9	44.0	46.0	46.8	47.1	47.2	47.3	47.3	47.3	47.3
Pure self-consumption	0	9.44	60.6	66.7	72.1	75.7	77.7	78.9	79.7	80.4	81.1	81.8
Pure self-consumption	0	13.89	72.2	78.2	83.4	87.3	90.3	92.4	94.2	95.2	95.8	96.1
Pure self-consumption	0	18.33	79.0	85.0	90.0	93.7	96.3	97.9	98.8	99.1	99.4	99.8
Pure self-consumption	0	22.78	82.5	88.5	93.4	96.9	99.0	99.5	99.8	100.0	100.0	100.0
Pure self-consumption	0	27.22	84.2	90.0	94.9	98.3	99.6	99.9	100.0	100.0	100.0	100.0
Pure self-consumption	0	31.67	85.2	91.0	95.8	99.1	99.9	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	0	36.11	85.9	91.6	96.4	99.4	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	0	40.56	86.3	92.1	96.9	99.6	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	0	45	86.7	92.5	97.2	99.8	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	25	5	43.9	45.7	46.8	47.3	47.5	47.6	47.6	47.6	47.6	47.6
Pure self-consumption	25	9.44	67.3	72.9	76.5	78.1	79.2	80.0	80.8	81.5	82.2	82.9
Pure self-consumption	25	13.89	78.5	84.2	88.7	91.9	94.0	95.3	95.9	96.3	96.6	96.8
Pure self-consumption	25	18.33	85.2	90.8	95.2	97.8	98.8	99.2	99.5	99.9	100.0	100.0
Pure self-consumption	25	22.78	88.2	93.9	98.1	99.6	99.9	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	25	27.22	89.3	94.9	98.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	25	31.67	89.8	95.4	99.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	25	36.11	90.1	95.8	99.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	25	40.56	90.4	96.0	99.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	25	45	90.6	96.2	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	50	5	44.7	46.4	47.1	47.4	47.6	47.7	47.7	47.7	47.7	47.7
Pure self-consumption	50	9.44	72.7	76.6	78.2	79.2	80.0	80.8	81.6	82.4	83.0	83.6
Pure self-consumption	50	13.89	84.5	89.8	93.3	95.1	95.9	96.4	96.7	97.0	97.3	97.5
Pure self-consumption	50	18.33	90.5	95.7	98.6	99.3	99.6	99.9	100.0	100.0	100.0	100.0
Pure self-consumption	50	22.78	92.9	98.1	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	50	27.22	93.5	98.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	50	31.67	93.7	98.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	50	36.11	93.9	99.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	50	40.56	94.0	99.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pure self-consumption	50	45	94.1	99.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 2 above presents parametric analysis results for Type B building. SSR demonstrates a relationship with both PV capacity and battery size. When considering a fixed PV capacity, increasing the battery size leads to an increase in SSR. Similarly, increasing the PV capacity increases SSR when keeping the battery size constant. These findings suggest adjusting the PV or battery capacity can mitigate a mismatch between energy production and demand. In other words, a higher capacity in PV or battery can help compensate for any discrepancies between the energy production profile and the energy demand, ultimately leading to an improved SSR.

In order to visualize the dependency of SSR with battery size, SSR for constant PV size 9.44kWp regarding Type A and Type B buildings were selected and presented in

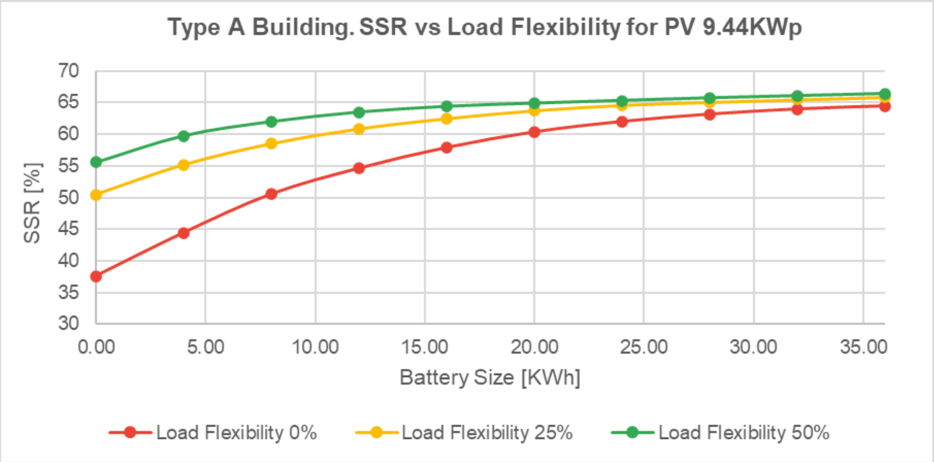

Figure 4 and Figure 5.

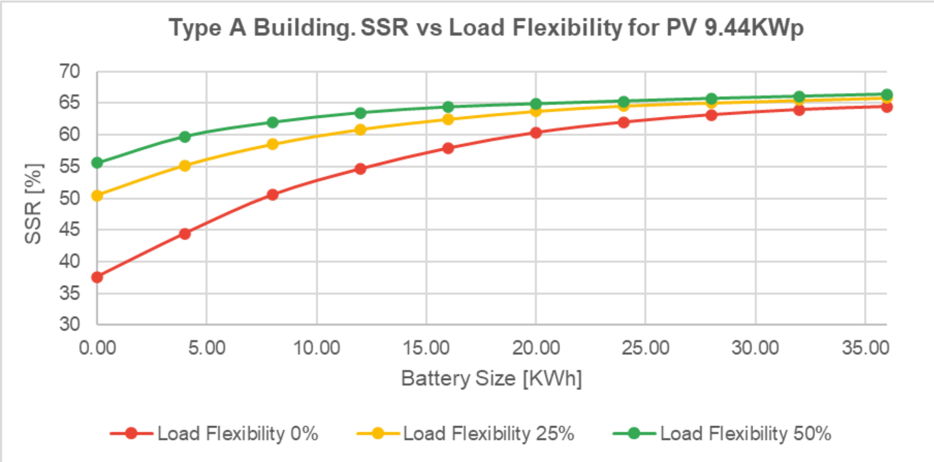

Figure 4. Joint Type A case. SSR vs Load Flexibility. PV 9.44kWp

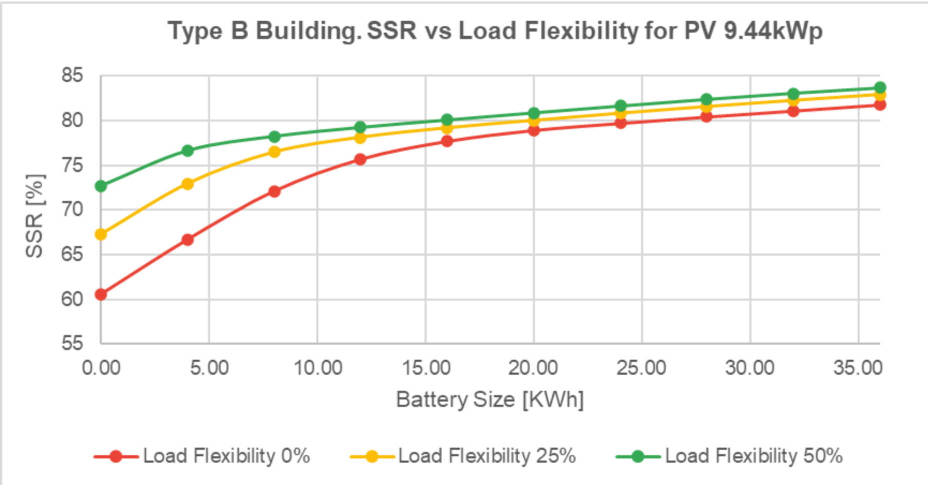

Figure 5. Joint Type B case. SSR vs Load Flexibility. PV 10kWp

In buildings with a low mismatch between production and demand, similar to Type B, the impact of load flexibility is generally lower, resulting in higher self-sufficiency rates even without storage. For type B building, SSR regarding zero battery case increases from 61% to 67% and 72% for load flexibility of 25% and 50%, respectively. For Type A buildings, the same scenario leads to lower SSR rates but a higher impact of load flexibility, resulting SSR of 37% to be increased to 50% and 55%.

Furthermore, when the storage capacity is increased, the corresponding impact of load flexibility on improving the SSR is reduced. When battery storage exceeds 16kWh, the impact of load flexibility vanishes for both types of buildings, indicating that SSR may be increased by expanding battery storage only.

The SSR parametric study highlights the significance of adopting a hybrid approach that combines load flexibility and storage capacity to achieve significantly higher self-sufficiency rates. This approach is particularly crucial in cases where there is a low alignment between sunlight availability and the building's demand profile. Considering these factors, policymakers and stakeholders can develop more effective strategies for maximizing public buildings' self-sufficiency and renewable energy utilization.

3.2 Net Present Value

3.2.1 NPV analysis of Type A building

Apart from SSR parametric analysis, this joint case study focused on the economic feasibility assessment of PV+BESS+DSM systems.

In the feasibility analysis, the NPV indicator is evaluated, and the following variables are considered:

- PV Capacity: Different PV capacity levels are evaluated, ranging from 5 to 45 kWp.
- Electricity Tariffs: Based on EU statistics, three electricity tariff scenarios were considered: low 0.15 €/kWh, medium 0.3 €/kWh, and high 0.6 €/kWh.
- Storage Costs: The analysis factored in two different storage cost scenarios. The first scenario considered the current average cost of 600 €/kWh. The second scenario accounted for a projected reduced cost of 200 €/kWh.
- Load Flexibility: Three load flexibility rates, namely 0%, 25%, and 50%, were also considered to assess their impact on NPV.
- The analysis is conducted under the assumption of a pure self-consumption policy. No compensation is provided for any excess energy generated or stored on-site and returned to the grid.

Considering these variables and conducting the NPV analysis, one can assess the financial viability of investing in a PV system with different capacities, electricity tariffs, and storage costs. NPV calculation incorporates the costs of installation, maintenance, electricity savings, and the time value of money to determine whether the investment is economically beneficial.

Table 3. NPV. Joint Type A case. Battery cost 600€/kWh. Load Flexibility 0%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
600	0	0.15	5	5409	4039	2272	-283	-3086	-6115	-9227	-12386	-15553	-18721
600	0	0.15	9.44	2216	1712	871	-767	-2729	-5028	-7639	-10418	-13336	-16398
600	0	0.15	13.89	-2997	-3503	-4299	-5597	-7011	-8606	-10391	-12532	-14942	-17574
600	0	0.15	18.33	-8604	-9111	-9919	-11224	-12653	-14253	-15966	-17800	-19756	-21883
600	0	0.15	22.78	-14358	-14865	-15683	-16991	-18431	-20034	-21753	-23599	-25572	-27703
600	0	0.15	27.22	-20176	-20684	-21508	-22819	-24267	-25874	-27597	-29456	-31444	-33576
600	0	0.15	31.67	-26032	-26541	-27369	-28683	-30138	-31749	-33473	-35342	-37339	-39473
600	0	0.15	36.11	-31915	-32424	-33257	-34573	-36034	-37647	-39373	-41250	-43255	-45389
600	0	0.15	40.56	-37825	-38333	-39169	-40485	-41951	-43566	-45293	-47177	-49189	-51324
600	0	0.15	45	-43752	-44260	-45098	-46416	-47886	-49503	-51235	-53121	-55139	-57275
600	0	0.3	5	17575	18078	17788	15920	13559	10745	7763	4690	1598	-1493
600	0	0.3	9.44	17195	19431	20993	20959	20279	18924	16945	14632	12038	9158
600	0	0.3	13.89	12776	15008	16660	17306	17722	17776	17449	16411	14833	12813
600	0	0.3	18.33	7568	9797	11425	12059	12444	12488	12306	11881	11211	10201
600	0	0.3	22.78	2067	4295	5904	6531	6895	6931	6738	6288	5587	4567
600	0	0.3	27.22	-3563	-1336	260	881	1228	1258	1056	581	-151	-1173
600	0	0.3	31.67	-9270	-7043	-5457	-4840	-4508	-4485	-4690	-5185	-5936	-6959
600	0	0.3	36.11	-15029	-12803	-11226	-10613	-10293	-10275	-10483	-10994	-11761	-12786
600	0	0.3	40.56	-20841	-18615	-17043	-16432	-16121	-16108	-16318	-16842	-17623	-18649
600	0	0.3	45	-26689	-24463	-22895	-22287	-21983	-21975	-22195	-22724	-23517	-24545
600	0	0.6	5	41907	46157	48820	48328	46849	44464	41744	38841	35901	32962
600	0	0.6	9.44	47153	54870	61236	64412	66295	66829	66115	64732	62787	60270
600	0	0.6	13.89	44323	52029	58576	63112	67188	70539	73128	74295	74384	73587
600	0	0.6	18.33	39912	47615	54114	58624	62638	65968	68848	71242	73145	74369
600	0	0.6	22.78	34916	42616	49078	53574	57546	60862	63719	66063	67904	69108
600	0	0.6	27.22	29662	37360	43797	48282	52218	55521	58360	60655	62435	63635
600	0	0.6	31.67	24256	31953	38369	42845	46753	50042	52875	55130	56871	58067
600	0	0.6	36.11	18743	26440	32837	37306	41190	44468	47296	49518	51227	52420
600	0	0.6	40.56	13126	20821	27209	31673	35540	38809	41633	43828	45510	46700
600	0	0.6	45	7436	15131	21512	25971	29821	33081	35886	38070	39728	40915

Table 3 displays the NPV outcomes for a battery cost of 600€ per kWh, zero percent load flexibility, and varying battery sizes ranging from 0 to 36 kWh. Additionally, it includes PV sizes ranging from 5 to 45 kWp and three different electricity tariff values of 0.15€, 0.3€, and 0.6€ per kWh. Given the current levels of battery cost, significant profitability can be achieved if the electricity tariff is at the highest level. For this combination, the highest NPV of 74K€ is obtained when PV is 18kWp and the battery size of 32kWh. If the electricity tariff is at a medium level of 0.3€/kWh, then NPV is much lower and reaches its local maximum of 19K€ for PV of 9.5kWp and BESS of 8kWh.

Table 4. NPV. Joint Type A case. Battery cost 600€/kWh. Load Flexibility 25%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
600	25	0.15	5	7324	5532	3140	291	-2765	-5884	-9034	-12202	-15369	-18537
600	25	0.15	9.44	7227	5862	3955	1622	-974	-3715	-6617	-9684	-12768	-15870
600	25	0.15	13.89	3205	2662	1406	-421	-2534	-4802	-7348	-10237	-13212	-16256
600	25	0.15	18.33	-2500	-3044	-4142	-5560	-7186	-8972	-10989	-13471	-16129	-18817
600	25	0.15	22.78	-8325	-8871	-9976	-11402	-13034	-14829	-16797	-18936	-21117	-23378
600	25	0.15	27.22	-14190	-14737	-15847	-17279	-18915	-20717	-22695	-24835	-27021	-29288
600	25	0.15	31.67	-20080	-20627	-21741	-23177	-24816	-26623	-28610	-30750	-32940	-35213
600	25	0.15	36.11	-26002	-26550	-27665	-29106	-30747	-32559	-34554	-36695	-38888	-41164
600	25	0.15	40.56	-31939	-32487	-33605	-35050	-36694	-38509	-40511	-42653	-44848	-47128
600	25	0.15	45	-37884	-38432	-39552	-40999	-42645	-44463	-46471	-48613	-50810	-53093
600	25	0.3	5	21406	21065	19524	17069	14200	11206	8149	5058	1966	-1125
600	25	0.3	9.44	27218	27731	27161	25737	23790	21551	18990	16099	13175	10215
600	25	0.3	13.89	25179	27337	28069	27658	26676	25384	23535	21000	18294	15448
600	25	0.3	18.33	19776	21931	22979	23386	23377	23049	22258	20539	18466	16334
600	25	0.3	22.78	14132	16284	17318	17710	17689	17341	16649	15615	14496	13217
600	25	0.3	27.22	8409	10559	11581	11961	11933	11572	10859	9822	8695	7403
600	25	0.3	31.67	2636	4784	5801	6172	6138	5767	5036	3998	2862	1560
600	25	0.3	36.11	-3201	-1054	-42	320	281	-99	-845	-1885	-3027	-4336
600	25	0.3	40.56	-9070	-6924	-5916	-5561	-5606	-5993	-6754	-7794	-8941	-10258
600	25	0.3	45	-14953	-12807	-11802	-11454	-11502	-11894	-12667	-13707	-14859	-16181
600	25	0.6	5	49569	52130	52293	50625	48131	45385	42516	39577	36637	33698
600	25	0.6	9.44	67199	71469	73573	73968	73318	72083	70203	67666	65061	62384
600	25	0.6	13.89	69129	76688	81394	83817	85095	85755	85300	83475	81305	78857
600	25	0.6	18.33	64329	71882	77221	81279	84504	87092	88753	88557	87657	86634
600	25	0.6	22.78	59047	66594	71906	75932	79135	81682	83541	84716	85722	86407
600	25	0.6	27.22	53607	61149	66439	70441	73628	76151	77967	79138	80126	80786
600	25	0.6	31.67	48067	55606	60884	64869	68044	70547	72329	73496	74467	75107
600	25	0.6	36.11	42399	49936	55204	59173	62336	64821	66572	67736	68695	69320
600	25	0.6	40.56	36668	44204	49463	53416	56570	59039	60761	61924	62873	63484
600	25	0.6	45	30909	38444	43697	47637	50784	53243	54942	56103	57044	57642

Table 4 presents the results of the NPV analysis based on a battery cost of €600 per kWh, 25% load flexibility, and varying battery sizes ranging from 0 to 36 kWh. It also includes PV sizes ranging from 5 to 45 kWp and three different electricity tariff values of 0.15€, 0.3€, and 0.6€ per kWh. The combination that yields the highest profitability is when the electricity tariff is at its highest level. Compared to the zero-flexibility case, the NPV peaked at almost 89k€, achieved with the same PV size of 18kWp, but a lower battery size of 24kWh. Lower electricity tariffs set at the low and medium levels introduce low positive or even negative NPV levels.

Table 5. NPV. Joint Type A case. Battery cost 600€/kWh. Load Flexibility 50%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
600	50	0.15	5	8419	6402	3570	487	-2628	-5769	-8936	-12104	-15271	-18439
600	50	0.15	9.44	9240	7659	5303	2659	-223	-3275	-6354	-9442	-12553	-15677
600	50	0.15	13.89	7858	6709	4764	2273	-487	-3459	-6503	-9549	-12594	-15641
600	50	0.15	18.33	3501	2825	1299	-809	-3244	-5887	-8576	-11418	-14398	-17428
600	50	0.15	22.78	-2378	-3051	-4445	-6120	-8073	-10223	-12484	-15178	-18160	-21160
600	50	0.15	27.22	-8288	-8963	-10362	-12044	-14004	-16155	-18409	-20892	-23553	-26315
600	50	0.15	31.67	-14208	-14884	-16287	-17972	-19938	-22091	-24351	-26841	-29511	-32288
600	50	0.15	36.11	-20150	-20827	-22233	-23922	-25892	-28046	-30311	-32807	-35483	-38270
600	50	0.15	40.56	-26105	-26783	-28191	-29884	-31858	-34014	-36283	-38784	-41463	-44257
600	50	0.15	45	-32066	-32744	-34154	-35849	-37827	-39985	-42260	-44763	-47444	-50245
600	50	0.3	5	23596	22805	20384	17462	14475	11435	8345	5253	2162	-929
600	50	0.3	9.44	31244	31325	29857	27812	25292	22430	19515	16584	13604	10600
600	50	0.3	13.89	34485	35431	34785	33046	30770	28069	25225	22377	19529	16679
600	50	0.3	18.33	31778	33669	33861	32889	31261	29220	27085	24644	21928	19111
600	50	0.3	22.78	26027	27924	28379	28273	27611	26554	25274	23131	20410	17653
600	50	0.3	27.22	20213	22106	22551	22432	21755	20695	19432	17709	15630	13350
600	50	0.3	31.67	14379	16271	16708	16581	15893	14831	13554	11816	9721	7411
600	50	0.3	36.11	8501	10391	10823	10688	9991	8926	7640	5891	3784	1452
600	50	0.3	40.56	2597	4486	4913	4770	4065	2997	1702	-56	-2170	-4515
600	50	0.3	45	-3317	-1430	-1006	-1154	-1866	-2938	-4245	-6008	-8127	-10485
600	50	0.6	5	53948	55611	54012	51412	48681	45845	42907	39968	37029	34089
600	50	0.6	9.44	75252	78658	78964	78118	76321	73842	71255	68635	65920	63154
600	50	0.6	13.89	87741	92876	94827	94593	93284	91125	88680	86227	83774	81319
600	50	0.6	18.33	88333	95358	98985	100284	100273	99433	98406	96768	94581	92188
600	50	0.6	22.78	82837	89875	94028	97058	98979	100107	100792	99748	97550	95280
600	50	0.6	27.22	77214	84245	88378	91383	93273	94397	95114	94911	93995	92680
600	50	0.6	31.67	71553	78580	82699	85687	87554	88674	89364	89132	88184	86807
600	50	0.6	36.11	65804	72827	76935	79908	81757	82871	83542	83288	82316	80896
600	50	0.6	40.56	60003	67022	71120	74079	75912	77019	77672	77400	76416	74969
600	50	0.6	45	54180	61198	65288	68237	70056	71156	71785	71502	70507	69035

Table 5 showcases the results of NPV analysis considering a battery cost of 600€ per kWh, 50% load flexibility, and varying battery sizes ranging from 0 to 36 kWh, PV sizes ranging from 5 to 45 kWp and three levels of electricity tariff. Given the high load flexibility rate, a much higher NPV of 100K€ can be achieved with a PV size 18kWp and a battery size 12-16kWh. It is worth noting that the same level of profitability is obtained when the PV size is 23kWp and the storage capacity is 20-24kWh.

Therefore, having higher load flexibility is crucial for achieving greater profitability and optimizing the design of on-site energy facilities more effectively.

Table 6. NPV. Joint Type A case. Battery cost 200€/kWh. Load Flexibility 0%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
200	0	0.15	5	5409	6201	6597	6203	5563	4697	3747	2750	1745	740
200	0	0.15	9.44	2216	3875	5196	5719	5920	5783	5334	4718	3962	3062
200	0	0.15	13.89	-2997	-1340	26	890	1638	2206	2583	2604	2356	1887
200	0	0.15	18.33	-8604	-6949	-5594	-4737	-4004	-3441	-2992	-2664	-2458	-2423
200	0	0.15	22.78	-14358	-12703	-11358	-10504	-9782	-9223	-8779	-8463	-8273	-8243
200	0	0.15	27.22	-20176	-18522	-17183	-16332	-15618	-15063	-14623	-14320	-14145	-14116
200	0	0.15	31.67	-26032	-24378	-23045	-22196	-21489	-20937	-20499	-20206	-20041	-20012
200	0	0.15	36.11	-31915	-30262	-28933	-28086	-27385	-26836	-26399	-26114	-25957	-25929
200	0	0.15	40.56	-37825	-36171	-34844	-33998	-33302	-32755	-32320	-32041	-31891	-31864
200	0	0.15	45	-43752	-42098	-40773	-39929	-39237	-38692	-38261	-37985	-37841	-37815
200	0	0.3	5	17575	20241	22112	22407	22208	21556	20737	19826	18897	17968
200	0	0.3	9.44	17195	21594	25317	27446	28928	29736	29919	29768	29337	28618
200	0	0.3	13.89	12776	17170	20984	23793	26371	28587	30422	31547	32132	32274
200	0	0.3	18.33	7568	11960	15750	18546	21093	23299	25279	27017	28509	29661
200	0	0.3	22.78	2067	6457	10229	13018	15544	17743	19712	21424	22885	24028
200	0	0.3	27.22	-3563	826	4585	7368	9877	12069	14029	15717	17147	18288
200	0	0.3	31.67	-9270	-4880	-1132	1647	4141	6326	8283	9951	11362	12501
200	0	0.3	36.11	-15029	-10640	-6901	-4126	-1643	536	2490	4142	5537	6675
200	0	0.3	40.56	-20841	-16453	-12718	-9946	-7471	-5296	-3344	-1706	-324	811
200	0	0.3	45	-26689	-22301	-18570	-15800	-13334	-11164	-9221	-7588	-6218	-5085
200	0	0.6	5	41907	48320	53144	54815	55499	55275	54718	53977	53200	52423
200	0	0.6	9.44	47153	57032	65561	70898	74944	77641	79089	79868	80086	79730
200	0	0.6	13.89	44323	54191	62900	69599	75837	81350	86102	89431	91682	93048
200	0	0.6	18.33	39912	49777	58438	65111	71287	76780	81822	86378	90443	93829
200	0	0.6	22.78	34916	44778	53403	60061	66195	71673	76693	81199	85202	88568
200	0	0.6	27.22	29662	39523	48121	54768	60867	66333	71334	75791	79733	83095
200	0	0.6	31.67	24256	34116	42693	49332	55402	60854	65849	70266	74169	77528
200	0	0.6	36.11	18743	28602	37161	43792	49839	55280	60269	64654	68526	71881
200	0	0.6	40.56	13126	22984	31534	38160	44190	49621	54606	58964	62809	66161
200	0	0.6	45	7436	17294	25837	32458	38471	43892	48860	53206	57027	60375

Table 6 displays the NPV outcomes for a much lower battery cost of 200€ per kWh, as expected by the experts for the upcoming years. Zero percent load flexibility, varying battery sizes ranging from 0 to 36 kWh, PV sizes ranging from 5 to 45 kWp and three different electricity tariff values of 0.15€, 0.3€, and 0.6€ per kWh were assumed for this analysis. Given low levels of battery cost, higher profitability of 93K€ is observed compared to the NPV of 74K€ obtained for the same load flexibility and 600€/kWh battery cost, thus introducing 25% additional profitability.

Table 7. NPV. Joint Type A case. Battery cost 200€/kWh. Load Flexibility 25%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
200	25	0.15	5	7324	7694	7465	6778	5884	4927	3939	2934	1929	924
200	25	0.15	9.44	7227	8024	8280	8109	7676	7097	6356	5452	4530	3591
200	25	0.15	13.89	3205	4824	5731	6066	6115	6010	5626	4899	4087	3204
200	25	0.15	18.33	-2500	-882	183	927	1463	1839	1984	1665	1170	644
200	25	0.15	22.78	-8325	-6709	-5651	-4915	-4384	-4018	-3823	-3800	-3819	-3918
200	25	0.15	27.22	-14190	-12575	-11523	-10792	-10266	-9905	-9722	-9699	-9722	-9828
200	25	0.15	31.67	-20080	-18465	-17416	-16690	-16167	-15811	-15636	-15614	-15642	-15752
200	25	0.15	36.11	-26002	-24387	-23341	-22619	-22098	-21747	-21580	-21559	-21590	-21704
200	25	0.15	40.56	-31939	-30325	-29281	-28563	-28045	-27698	-27538	-27517	-27550	-27668
200	25	0.15	45	-37884	-36270	-35227	-34512	-33996	-33651	-33497	-33477	-33512	-33633
200	25	0.3	5	21406	23227	23849	23556	22849	22017	21123	20194	19265	18335
200	25	0.3	9.44	27218	29893	31486	32224	32439	32363	31963	31235	30473	29675
200	25	0.3	13.89	25179	29500	32393	34145	35325	36195	36509	36136	35592	34909
200	25	0.3	18.33	19776	24093	27304	29873	32026	33861	35232	35675	35765	35794
200	25	0.3	22.78	14132	18446	21643	24197	26338	28153	29623	30751	31794	32677
200	25	0.3	27.22	8409	12721	15906	18448	20582	22384	23832	24958	25993	26864
200	25	0.3	31.67	2636	6946	10126	12659	14787	16579	18010	19134	20161	21021
200	25	0.3	36.11	-3201	1108	4282	6807	8930	10712	12128	13251	14271	15124
200	25	0.3	40.56	-9070	-4761	-1591	926	3043	4819	6220	7342	8357	9203
200	25	0.3	45	-14953	-10645	-7478	-4967	-2853	-1083	307	1429	2440	3279
200	25	0.6	5	49569	54292	56617	57112	56780	56197	55490	54713	53935	53158
200	25	0.6	9.44	67199	73631	77897	80455	81967	82895	83177	82802	82359	81845
200	25	0.6	13.89	69129	78850	85719	90304	93745	96566	98274	98611	98603	98317
200	25	0.6	18.33	64329	74044	81546	87766	93153	97903	101727	103693	104955	106095
200	25	0.6	22.78	59047	68757	76230	82419	87784	92494	96515	99852	103021	105868
200	25	0.6	27.22	53607	63312	70763	76928	82277	86962	90940	94274	97424	100247
200	25	0.6	31.67	48067	57769	65209	71356	76693	81359	85302	88632	91765	94567
200	25	0.6	36.11	42399	52099	59529	65660	70985	75632	79545	82872	85993	88780
200	25	0.6	40.56	36668	46366	53788	59903	65219	69851	73734	77060	80171	82944
200	25	0.6	45	30909	40606	48021	54124	59433	64055	67915	71239	74343	77103

Table 7 presents the results under the same conditions, except for adjusting the load flexibility from 0% to 25%. The presented NPV distribution reaches its maximum of 106K€, which is higher by 25% than the similar case with a nominal battery cost of 600€/kWh, thus keeping the same excessed profitability as zero flexibility conditions.

Table 8. NPV. Joint Type A case. Battery cost 200€/kWh. Load Flexibility 50%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
200	50	0.15	5	8419	8565	7895	6974	6021	5042	4037	3032	2027	1022
200	50	0.15	9.44	9240	9822	9628	9146	8427	7536	6619	5694	4745	3783
200	50	0.15	13.89	7858	8871	9089	8760	8162	7352	6471	5587	4704	3820
200	50	0.15	18.33	3501	4987	5623	5678	5405	4925	4398	3718	2901	2032
200	50	0.15	22.78	-2378	-889	-120	367	577	589	489	-42	-862	-1699
200	50	0.15	27.22	-8288	-6801	-6038	-5557	-5355	-5344	-5435	-5756	-6255	-6854
200	50	0.15	31.67	-14208	-12722	-11962	-11486	-11289	-11279	-11377	-11705	-12213	-12827
200	50	0.15	36.11	-20150	-18665	-17908	-17435	-17243	-17235	-17337	-17671	-18184	-18810
200	50	0.15	40.56	-26105	-24621	-23867	-23397	-23209	-23203	-23310	-23648	-24164	-24796
200	50	0.15	45	-32066	-30581	-29829	-29362	-29178	-29173	-29286	-29627	-30146	-30784
200	50	0.3	5	23596	24967	24709	23949	23124	22247	21319	20389	19460	18531
200	50	0.3	9.44	31244	33488	34181	34299	33941	33242	32489	31720	30903	30061
200	50	0.3	13.89	34485	37594	39110	39533	39419	38880	38199	37513	36827	36140
200	50	0.3	18.33	31778	35831	38185	39376	39911	40031	40058	39780	39227	38571
200	50	0.3	22.78	26027	30087	32704	34760	36260	37365	38248	38267	37709	37114
200	50	0.3	27.22	20213	24269	26876	28919	30404	31507	32406	32845	32928	32811
200	50	0.3	31.67	14379	18433	21033	23068	24542	25642	26528	26952	27019	26871
200	50	0.3	36.11	8501	12553	15148	17175	18640	19738	20614	21027	21082	20912
200	50	0.3	40.56	2597	6648	9237	11257	12714	13808	14676	15080	15128	14946
200	50	0.3	45	-3317	732	3318	5333	6783	7874	8729	9128	9171	8976
200	50	0.6	5	53948	57773	58336	57899	57330	56656	55881	55104	54327	53550
200	50	0.6	9.44	75252	80820	83289	84605	84971	84653	84228	83771	83218	82615
200	50	0.6	13.89	87741	95038	99151	101080	101933	101936	101654	101363	101073	100779
200	50	0.6	18.33	88333	97520	103309	106771	108922	110245	111380	111904	111879	111649
200	50	0.6	22.78	82837	92037	98353	103545	107628	110919	113766	114884	114849	114741
200	50	0.6	27.22	77214	86407	92703	97870	101922	105208	108088	110047	111294	112141
200	50	0.6	31.67	71553	80743	87024	92174	96204	99485	102337	104268	105482	106268
200	50	0.6	36.11	65804	74990	81260	86394	90406	93683	96516	98424	99615	100356
200	50	0.6	40.56	60003	69185	75445	80566	84561	87830	90646	92536	93714	94430
200	50	0.6	45	54180	63360	69613	74724	78705	81967	84759	86638	87805	88496

Table 8 presents the NPV results with low battery cost and 50% load flexibility. The highest NPV of 114K€ corresponds to a PV of 22kWp and a battery size of 36kWh. These results are higher by 14% than those with the same load flexibility and higher battery cost, reflecting a lower NPV margin induced by reduced battery cost compared to other load flexibility rates.

To emphasize the sensitivity of the Type A joint case study to variations in the design characteristics, a single PV size and a single battery cost were selected and presented below.

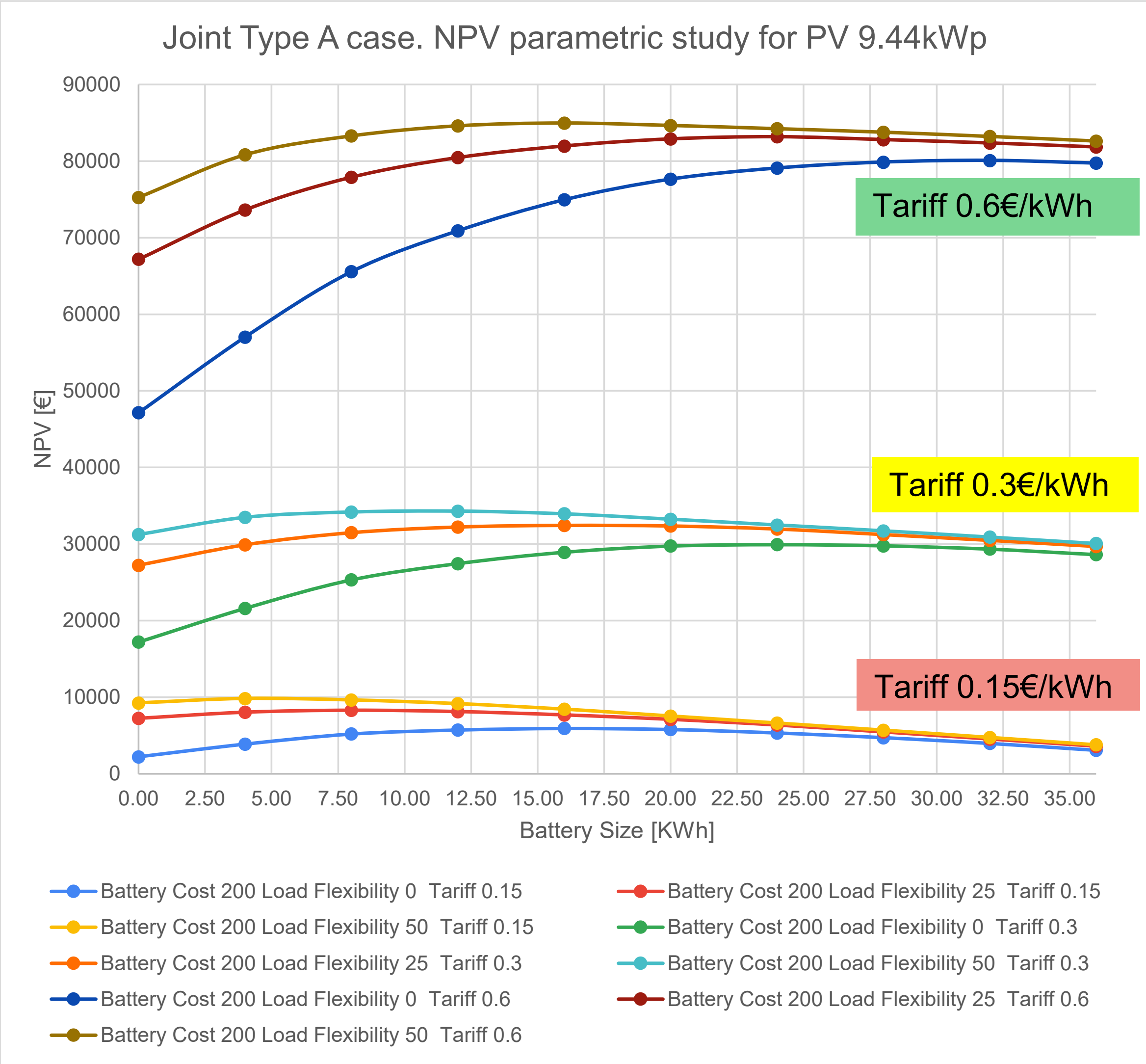

Figure 6. Type A case. NPV parametric study. Battery Cost 200€/kWh. PV 9.44kWp

Figure 5 above presents an NPV parametric study for a Type A building. A clear dependence on electricity tariffs can be observed in higher NPV for higher tariffs. A less significant impact is also observed between NPV and load flexibility, which can improve the tariff's profitability.

An optimal battery size varies across the combinations for a given PV capacity. For low tariff and 25% load flexibility, the best NPV is obtained for a low battery capacity of 8 kWh, and for a high tariff, the best NPV is evaluated for 24 kWh storage.

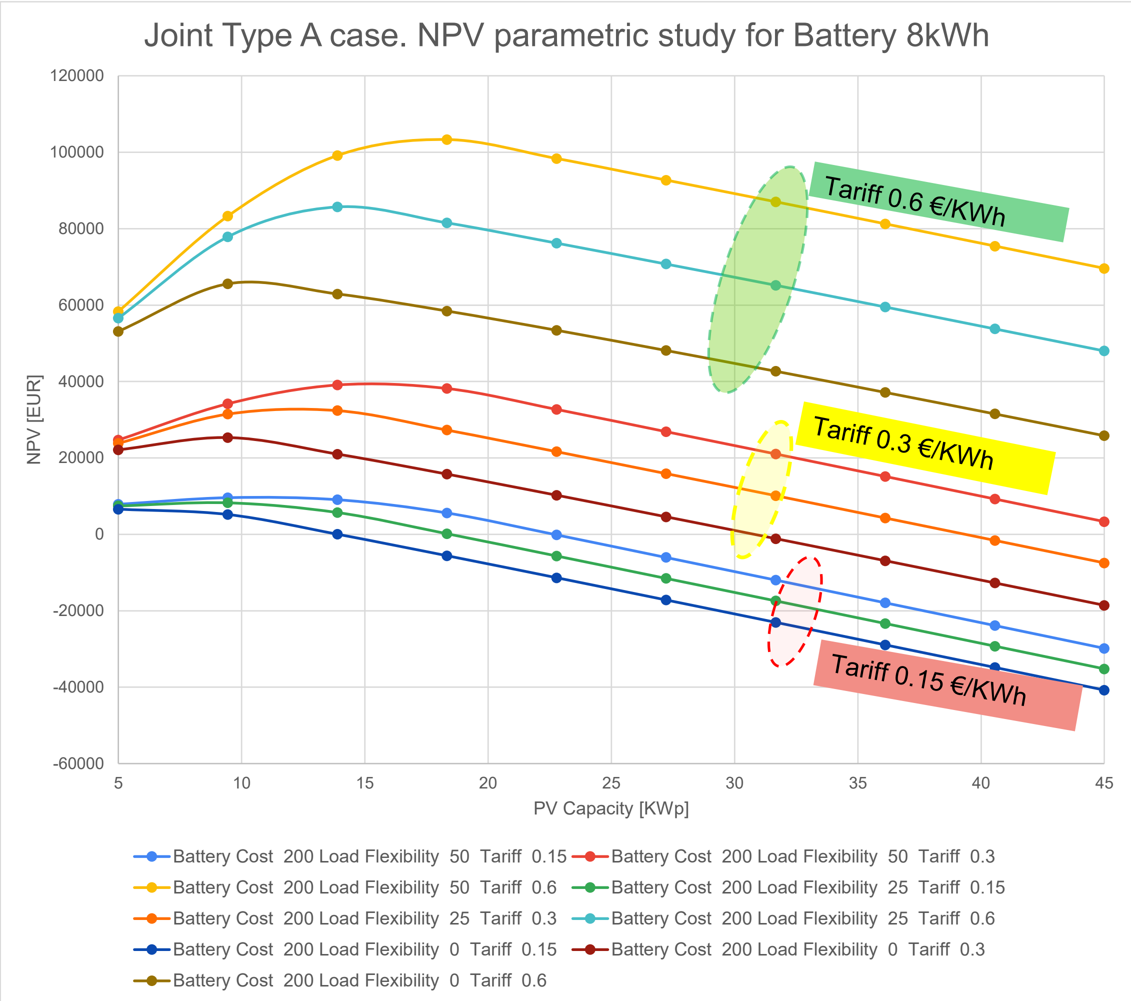

Figure 7. Type A case. NPV parametric study. Battery cost 200€/kWh. Battery 8kWh

Figure 6 above presents another NPV parametric study for Type A buildings with a low battery cost of 200€ per kWh. This time, a battery size of 8kWh is constant, and the PV size varies. A noticeable correlation between the electricity tariff and the NPV can be observed, indicating that higher tariffs result in greater NPV values. Furthermore, there is a substantial connection between the NPV and load flexibility, suggesting that adjusting the load flexibility can improve profitability, even under a fixed tariff. An optimal PV capacity has limited variation across the combinations for a given battery size. For all the cases, the best NPV is obtained for PV in the range of 12-16kWp.

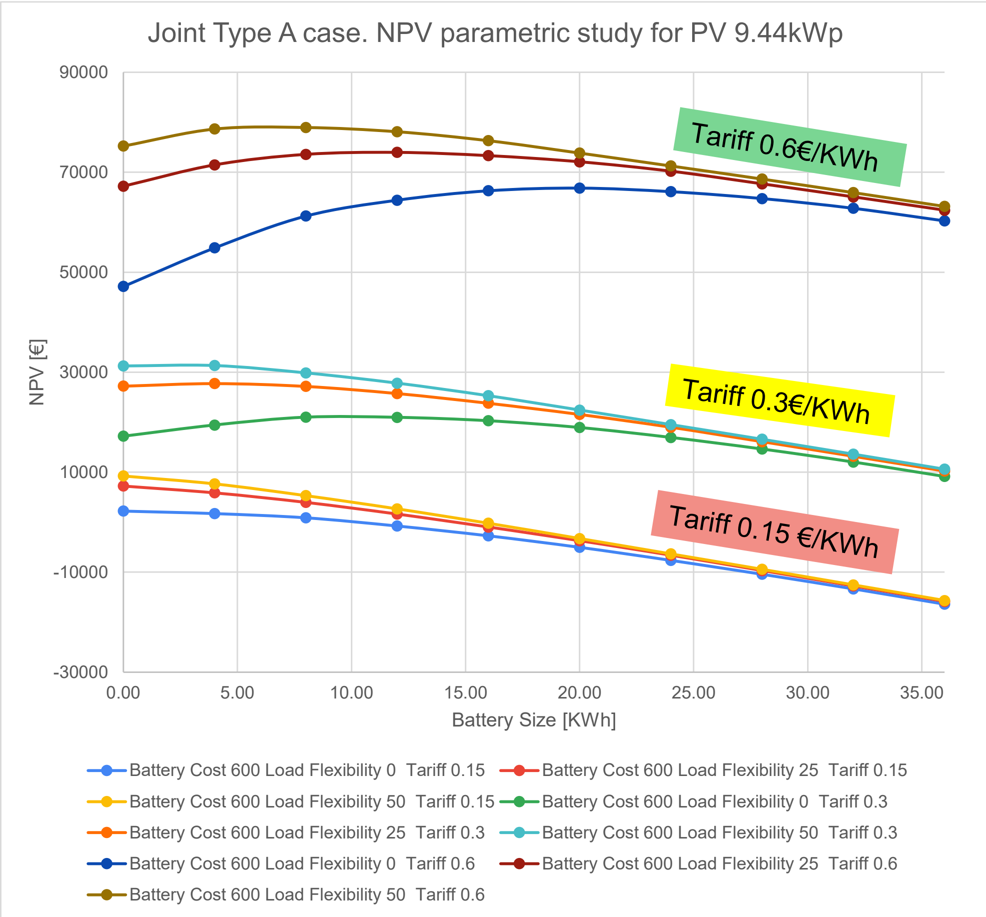

Figure 8. NPV. Joint Type A case. Battery cost 600€/kWh. PV 9.44kWp

Figure 8 above and Figure 9 below depict NPV parametric studies for Type A buildings and a higher battery cost of 600€ per kWh. Battery cost has a direct impact on profitability. Thus, rising battery cost from 200 to 600€ per kWh reduces the NPV by 15-25% depending on the applied load flexibility rate.

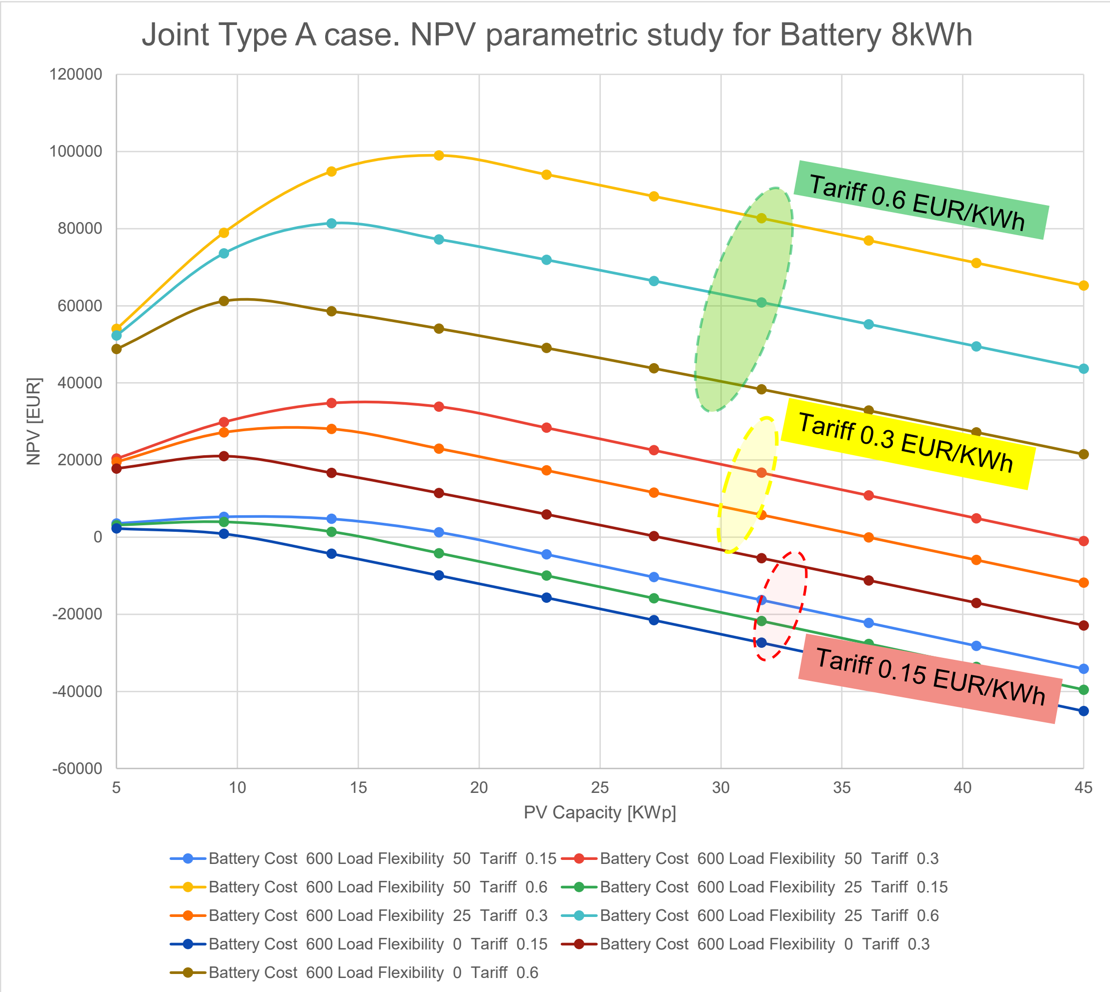

Figure 9. NPV. Joint Type A case. Battery cost 600€/kWh. Battery 8kWh

Type A building study showed that significant NPV could be reached, especially in countries with higher electricity tariffs. Nevertheless, all the combinations showed higher profitability if the PV generation is complemented by storage, where a higher load flexibility rate supplies additional potential for higher NPV.

3.2.2 NPV analysis of Type B building

NPV analysis of Type B building is presented below. It includes various crucial technical parameters, such as battery and PV size, load flexibility and financial characteristics, i.e., battery cost and electricity tariffs.

Table 9. NPV. Joint Type B case. Battery cost 600€/kWh. Load Flexibility 0%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
600	0	0.15	5	11887	10571	8247	5339	2234	-958	-4185	-7428	-10672	-13915
600	0	0.15	9.44	15686	15367	14681	13017	10687	7971	5117	2236	-674	-3595
600	0	0.15	13.89	15211	14814	14023	12673	10827	8615	6217	3437	422	-2685
600	0	0.15	18.33	12539	12123	11258	9794	7780	5334	2527	-534	-3618	-6702
600	0	0.15	22.78	8257	7819	6898	5357	3135	146	-2938	-6068	-9310	-12554
600	0	0.15	27.22	3075	2602	1650	59	-2532	-5626	-8830	-12073	-15317	-18560
600	0	0.15	31.67	-2452	-2944	-3916	-5578	-8398	-11593	-14836	-18080	-21323	-24567
600	0	0.15	36.11	-8128	-8622	-9611	-11391	-14356	-17599	-20843	-24086	-27329	-30573
600	0	0.15	40.56	-13898	-14392	-15394	-17294	-20362	-23606	-26849	-30092	-33336	-36579
600	0	0.15	45	-19730	-20225	-21236	-23238	-26368	-29612	-32855	-36099	-39342	-42586
600	0	0.3	5	30532	31143	29737	27166	24200	21057	17848	14605	11362	8118
600	0	0.3	9.44	44136	46740	48612	48527	47111	44923	42458	39940	37362	34764
600	0	0.3	13.89	49192	51641	53303	53846	53397	52216	50665	48347	45561	42591
600	0	0.3	18.33	49854	52266	53779	54095	53310	51661	49290	46412	43488	40564
600	0	0.3	22.78	47296	49664	51066	51226	50027	47292	44367	41351	38109	34866
600	0	0.3	27.22	42939	45236	46576	46637	44700	41753	38590	35346	32103	28859
600	0	0.3	31.67	37891	40151	41449	41370	38974	35827	32583	29340	26097	22853
600	0	0.3	36.11	32545	34801	36066	35751	33064	29820	26577	23334	20090	16847
600	0	0.3	40.56	27012	29267	30507	29951	27058	23814	20571	17327	14084	10840
600	0	0.3	45	21354	23608	24829	24069	21051	17808	14564	11321	8077	4834
600	0	0.6	5	67821	72287	72719	70820	68130	65089	61915	58671	55428	52184
600	0	0.6	9.44	101035	109487	116475	119547	119960	118826	117141	115348	113435	111482
600	0	0.6	13.89	117154	125295	131864	136191	138539	139420	139561	138168	135839	133143
600	0	0.6	18.33	124484	132551	138822	142697	144370	144315	142817	140305	137700	135094
600	0	0.6	22.78	125375	133354	139401	142965	143810	141583	138978	136189	132948	129705
600	0	0.6	27.22	122667	130505	136428	139792	139162	136512	133429	130185	126942	123699
600	0	0.6	31.67	118578	126341	132180	135266	133716	130666	127423	124179	120936	117692
600	0	0.6	36.11	113893	121646	127421	130033	127903	124660	121416	118173	114929	111686
600	0	0.6	40.56	108832	116585	122309	124439	121897	118653	115410	112166	108923	105680
600	0	0.6	45	103521	111275	116959	118682	115890	112647	109403	106160	102917	99673

Type A building study showed that significant NPV could be reached, especially in countries with higher electricity tariffs. Nevertheless, all the combinations showed higher profitability if the PV generation is complemented by storage, where a higher load flexibility rate supplies additional potential for higher NPV.

3.2.3 NPV analysis of Type B building

NPV analysis of Type B building is presented below. It includes various crucial technical parameters, such as battery and PV size, load flexibility and financial characteristics, i.e., battery cost and electricity tariffs.

Table 9 depicts the NPV distribution of Type B building upon variation of all the sensitivity factors apart from load flexibility which is fixed at 0%. Compared with a similar analysis for Type A buildings, a much higher NPV of 144K€ is obtained for high electricity tariff, a difference of 95%. Moreover, higher NPV is also obtained for low and medium tariffs. For each tested tariff, the highest NPV corresponds to a

PV of 14-18kWp and storage of 12-20kWh, addressing the greater profitability of the hybrid solution involving photovoltaics and storage.

Table 10. NPV. Joint Type B case. Battery cost 600€/kWh. Load Flexibility 25%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
600	25	0.15	5	13690	11319	8581	5527	2395	-814	-4050	-7293	-10537	-13780
600	25	0.15	9.44	18808	18228	16526	14030	11251	8403	5551	2683	-205	-3115
600	25	0.15	13.89	18196	17675	16566	14853	12612	9940	6991	3891	784	-2323
600	25	0.15	18.33	15443	14903	13711	11743	9047	6008	2924	-163	-3357	-6578
600	25	0.15	22.78	10960	10412	9153	6688	3602	421	-2822	-6066	-9309	-12553
600	25	0.15	27.22	5500	4939	3612	893	-2342	-5585	-8829	-12072	-15316	-18559
600	25	0.15	31.67	-237	-804	-2187	-5105	-8348	-11592	-14835	-18078	-21322	-24565
600	25	0.15	36.11	-6080	-6648	-8109	-11111	-14355	-17598	-20841	-24085	-27328	-30572
600	25	0.15	40.56	-11964	-12532	-14056	-17117	-20361	-23604	-26848	-30091	-33335	-36578
600	25	0.15	45	-17874	-18442	-20026	-23124	-26367	-29611	-32854	-36098	-39341	-42584
600	25	0.3	5	34137	32638	30407	27542	24520	21347	18118	14875	11631	8388
600	25	0.3	9.44	50379	52462	52303	50554	48240	45787	43325	40834	38300	35724
600	25	0.3	13.89	55163	57363	58389	58206	56968	54866	52213	49255	46285	43315
600	25	0.3	18.33	55662	57825	58686	57993	55843	53009	50085	47153	44010	40810
600	25	0.3	22.78	52702	54849	55575	53888	50960	47842	44598	41355	38112	34868
600	25	0.3	27.22	47790	49911	50500	48304	45079	41836	38592	35349	32105	28862
600	25	0.3	31.67	42321	44430	44909	42316	39073	35829	32586	29342	26099	22855
600	25	0.3	36.11	36642	38749	39070	36310	33066	29823	26579	23336	20093	16849
600	25	0.3	40.56	30879	32987	33183	30303	27060	23816	20573	17330	14086	10843
600	25	0.3	45	25067	27174	27249	24297	21054	17810	14567	11323	8080	4836
600	25	0.6	5	75030	75278	74058	71572	68771	65668	62454	59211	55967	52724
600	25	0.6	9.44	113522	120932	123856	123602	122217	120555	118875	117136	115312	113403
600	25	0.6	13.89	129095	136740	142034	144912	145680	144719	142656	139984	137288	134592
600	25	0.6	18.33	136100	143669	148635	150493	149437	147011	144406	141787	138743	135588
600	25	0.6	22.78	136186	143725	148420	148289	145676	142683	139440	136197	132953	129710
600	25	0.6	27.22	132368	139854	144277	143128	139920	136677	133434	130190	126947	123703
600	25	0.6	31.67	127438	134899	139099	137158	133914	130671	127427	124184	120940	117697
600	25	0.6	36.11	122085	129542	133429	131151	127908	124664	121421	118178	114934	111691
600	25	0.6	40.56	116566	124025	127661	125145	121901	118658	115415	112171	108928	105684
600	25	0.6	45	110948	118406	121799	119139	115895	112652	109408	106165	102921	99678

Table 10 depicts the NPV of a Type B building with 25% load flexibility. The impact of load flexibility is less valuable for Type B building since Type B is achieved due to better matching between demand and production profiles. The difference between 0% and 25% load flexibility concerning the highest NPV is 4% only, in contrast with 13% in the case of Type A buildings.

Table 11. NPV. Joint Type B case. Battery cost 600€/kWh. Load Flexibility 50%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
600	50	0.15	5	14060	11641	8693	5599	2439	-779	-4022	-7265	-10508	-13752
600	50	0.15	9.44	21281	19808	17269	14479	11631	8779	5918	3043	153	-2782
600	50	0.15	13.89	21050	20343	18766	16345	13504	10440	7334	4227	1121	-1987
600	50	0.15	18.33	17961	17228	15411	12533	9449	6356	3147	-79	-3310	-6547
600	50	0.15	22.78	13165	12416	10061	6909	3666	422	-2821	-6065	-9308	-12551
600	50	0.15	27.22	7498	6728	4146	903	-2341	-5584	-8828	-12071	-15314	-18558
600	50	0.15	31.67	1629	846	-1860	-5104	-8347	-11590	-14834	-18077	-21321	-24564
600	50	0.15	36.11	-4297	-5086	-7866	-11110	-14353	-17597	-20840	-24084	-27327	-30570
600	50	0.15	40.56	-10247	-11042	-13873	-17116	-20360	-23603	-26847	-30090	-33333	-36577
600	50	0.15	45	-16213	-17014	-19879	-23123	-26366	-29609	-32853	-36096	-39340	-42583
600	50	0.3	5	34877	33282	30630	27686	24610	21417	18175	14931	11688	8444
600	50	0.3	9.44	55325	55624	53788	51451	48999	46539	44061	41553	39017	36391
600	50	0.3	13.89	60870	62699	62789	61189	58752	55868	52898	49928	46958	43987
600	50	0.3	18.33	60698	62477	62084	59573	56649	53704	50531	47323	44104	40874
600	50	0.3	22.78	57112	58859	57391	54331	51088	47844	44601	41357	38114	34871
600	50	0.3	27.22	51784	53489	51568	48325	45081	41838	38594	35351	32108	28864
600	50	0.3	31.67	46054	47730	45562	42318	39075	35832	32588	29345	26101	22858
600	50	0.3	36.11	40208	41872	39555	36312	33069	29825	26582	23338	20095	16851
600	50	0.3	40.56	34314	35966	33549	30306	27062	23819	20575	17332	14089	10845
600	50	0.3	45	28389	30030	27543	24299	21056	17812	14569	11326	8082	4839
600	50	0.6	5	76511	76564	74504	71860	68950	65809	62567	59324	56080	52837
600	50	0.6	9.44	123414	127254	126827	125397	123734	122058	120346	118574	116745	114736
600	50	0.6	13.89	140509	147412	150834	150879	149247	146723	144026	141330	138634	135934
600	50	0.6	18.33	146173	152973	155431	153653	151048	148402	145299	142126	138931	135714
600	50	0.6	22.78	145006	151744	152051	149175	145932	142688	139445	136201	132958	129714
600	50	0.6	27.22	140357	147010	146412	143169	139925	136682	133438	130195	126952	123708
600	50	0.6	31.67	134903	141499	140406	137162	133919	130675	127432	124189	120945	117702
600	50	0.6	36.11	129217	135789	134399	131156	127913	124669	121426	118182	114939	111695
600	50	0.6	40.56	123436	129984	128393	125150	121906	118663	115419	112176	108932	105689
600	50	0.6	45	117592	124118	122387	119143	115900	112656	109413	106170	102926	99683

Table 11 depicts the NPV of a Type B building with 50% load flexibility. The impact of load flexibility here is less valuable for Type B building since higher SSR is achieved due to better matching between demand and production profiles. The difference between 25% and 50% load flexibility with respect to the highest NPV is 2.6% only, in contrast with 10% in the case of Type A buildings. Nevertheless, the profitability 155K€ can be observed for the on-site solar generation and storage capacity combination of 18kWp and 8kWh.

Table 12. NPV. Joint Type B case. Battery cost 200€/kWh. Load Flexibility 0%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
200	0	0.15	5	11887	12734	12571	11826	10884	9853	8789	7708	6627	5546
200	0	0.15	9.44	15686	17529	19006	19503	19336	18782	18091	17372	16624	15865
200	0	0.15	13.89	15211	16976	18348	19160	19476	19426	19191	18573	17720	16776
200	0	0.15	18.33	12539	14285	15583	16281	16429	16145	15500	14602	13681	12759
200	0	0.15	22.78	8257	9981	11223	11844	11784	10957	10036	9068	7988	6907
200	0	0.15	27.22	3075	4764	5975	6546	6118	5185	4144	3063	1982	900
200	0	0.15	31.67	-2452	-781	408	909	251	-781	-1863	-2944	-4025	-5106
200	0	0.15	36.11	-8128	-6460	-5287	-4904	-5707	-6788	-7869	-8950	-10031	-11112
200	0	0.15	40.56	-13898	-12230	-11069	-10807	-11713	-12794	-13875	-14956	-16037	-17119
200	0	0.15	45	-19730	-18062	-16912	-16751	-17719	-18800	-19882	-20963	-22044	-23125
200	0	0.3	5	30532	33305	34062	33653	32849	31869	30822	29741	28660	27579
200	0	0.3	9.44	44136	48902	52937	55014	55761	55734	55432	55076	54660	54224
200	0	0.3	13.89	49192	53803	57628	60332	62047	63028	63639	63483	62859	62052
200	0	0.3	18.33	49854	54428	58104	60582	61959	62472	62264	61548	60786	60024
200	0	0.3	22.78	47296	51826	55390	57713	58676	58103	57341	56487	55407	54326
200	0	0.3	27.22	42939	47398	50901	53123	53349	52565	51563	50482	49401	48320
200	0	0.3	31.67	37891	42314	45774	47857	47623	46638	45557	44476	43395	42314
200	0	0.3	36.11	32545	36963	40391	42237	41713	40632	39551	38470	37388	36307
200	0	0.3	40.56	27012	31429	34831	36437	35707	34626	33544	32463	31382	30301
200	0	0.3	45	21354	25771	29153	30556	29700	28619	27538	26457	25376	24295
200	0	0.6	5	67821	74449	77043	77307	76779	75901	74888	73807	72726	71645
200	0	0.6	9.44	101035	111649	120799	126034	128609	129637	130114	130484	130734	130942
200	0	0.6	13.89	117154	127457	136188	142678	147188	150231	152534	153304	153137	152604
200	0	0.6	18.33	124484	134714	143146	149184	153019	155126	155791	155441	154998	154555
200	0	0.6	22.78	125375	135516	143725	149452	152459	152395	151952	151325	150247	149166
200	0	0.6	27.22	122667	132667	140753	146279	147811	147324	146403	145321	144240	143159
200	0	0.6	31.67	118578	128504	136505	141753	142365	141477	140396	139315	138234	137153
200	0	0.6	36.11	113893	123809	131745	136520	136552	135471	134390	133309	132228	131146
200	0	0.6	40.56	108832	118747	126633	130926	130546	129465	128384	127302	126221	125140
200	0	0.6	45	103521	113437	121283	125169	124539	123458	122377	121296	120215	119134

Table 11 depicts the NPV of a Type B building with 50% load flexibility. The impact of load flexibility here is less valuable for Type B building since higher SSR is achieved due to better matching between demand and production profiles. The difference between 25% and 50% load flexibility with respect to the highest NPV is 2.6% only, in contrast with 10% in the case of Type A buildings. Nevertheless, the profitability 155K€ can be observed for the on-site solar generation and storage capacity combination of 18kWp and 8kWh.

Table 12 depicts the NPV of a Type B building with 0% load flexibility, but this time the battery cost is reduced to 200€ per kWh. Compared to the case of the higher cost of 600€ per kWh, the highest NPV, in this case, is 155K€, obtained for the same PV capacity of 18kWp and higher battery capacity of 24kWh, also introducing a higher SSR. In the Type B building scenario, lower battery cost with zero load flexibility improves NPV by 7%, compared with the Type A building, where the impact of lower battery cost was an NPV improvement of 25%., concluding that battery cost affects a higher level the buildings that present low matching between consumption and production.

Table 13. NPV. Joint Type B case. Battery cost 200€/kWh. Load Flexibility 25%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
200	25	0.15	5	13690	13481	12906	12014	11044	9998	8924	7843	6762	5680
200	25	0.15	9.44	18808	20390	20851	20517	19901	19215	18524	17819	17093	16346
200	25	0.15	13.89	18196	19837	20891	21340	21262	20751	19965	19027	18082	17138
200	25	0.15	18.33	15443	17065	18036	18230	17696	16819	15898	14973	13941	12882
200	25	0.15	22.78	10960	12574	13478	13174	12251	11233	10151	9070	7989	6908
200	25	0.15	27.22	5500	7101	7937	7379	6307	5226	4145	3064	1983	902
200	25	0.15	31.67	-237	1358	2138	1382	301	-780	-1861	-2942	-4024	-5105
200	25	0.15	36.11	-6080	-4486	-3784	-4624	-5705	-6787	-7868	-8949	-10030	-11111
200	25	0.15	40.56	-11964	-10370	-9731	-10631	-11712	-12793	-13874	-14955	-16036	-17117
200	25	0.15	45	-17874	-16280	-15701	-16637	-17718	-18799	-19880	-20962	-22043	-23124
200	25	0.3	5	34137	34801	34732	34029	33169	32159	31092	30011	28930	27848
200	25	0.3	9.44	50379	54625	56627	57041	56889	56599	56299	55970	55599	55185
200	25	0.3	13.89	55163	59526	62713	64693	65618	65677	65187	64391	63584	62776
200	25	0.3	18.33	55662	59987	63010	64480	64493	63820	63058	62289	61308	60271
200	25	0.3	22.78	52702	57012	59900	60375	59609	58653	57572	56491	55410	54329
200	25	0.3	27.22	47790	52073	54825	54791	53728	52647	51566	50485	49404	48322
200	25	0.3	31.67	42321	46593	49233	48803	47722	46641	45559	44478	43397	42316
200	25	0.3	36.11	36642	40911	43395	42797	41715	40634	39553	38472	37391	36310
200	25	0.3	40.56	30879	35149	37508	36790	35709	34628	33547	32466	31384	30303
200	25	0.3	45	25067	29336	31574	30784	29703	28622	27540	26459	25378	24297
200	25	0.6	5	75030	77440	78382	78058	77420	76480	75428	74347	73265	72184
200	25	0.6	9.44	113522	123094	128181	130089	130867	131367	131848	132272	132610	132864
200	25	0.6	13.89	129095	138903	146359	151399	154330	155530	155630	155120	154586	154052
200	25	0.6	18.33	136100	145831	152959	156980	158086	157822	157380	156923	156041	155048
200	25	0.6	22.78	136186	145887	152745	154776	154325	153495	152414	151333	150251	149170
200	25	0.6	27.22	132368	142016	148601	149614	148570	147488	146407	145326	144245	143164
200	25	0.6	31.67	127438	137062	143424	143644	142563	141482	140401	139320	138239	137158
200	25	0.6	36.11	122085	131704	137754	137638	136557	135476	134395	133314	132232	131151
200	25	0.6	40.56	116566	126188	131986	131632	130551	129469	128388	127307	126226	125145
200	25	0.6	45	110948	120568	126124	125625	124544	123463	122382	121301	120220	119139

Table 13 demonstrates the NPV distribution of Type B buildings with 25% load flexibility. Further NPV increase is obtained compared to the zero-flexibility scenario, achieving NPV of 158K€ for a battery size of 16kWh.

Table 14. NPV. Joint Type B case. Battery cost 200€/kWh. Load Flexibility 50%

Sensitivity Factors				Battery Size [KWh]									
Battery Cost [EUR/KWh]	Load Flexibility %	Electricity Tariff [EUR/KWh]	PV size [KWp]	0.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00
200	50	0.15	5	14060	13803	13018	12086	11089	10033	8952	7871	6790	5709
200	50	0.15	9.44	21281	21971	21594	20966	20280	19591	18892	18179	17451	16679
200	50	0.15	13.89	21050	22505	23091	22831	22153	21252	20308	19363	18419	17474
200	50	0.15	18.33	17961	19391	19735	19020	18099	17167	16121	15057	13988	12914
200	50	0.15	22.78	13165	14579	14385	13396	12315	11234	10153	9071	7990	6909
200	50	0.15	27.22	7498	8890	8471	7390	6308	5227	4146	3065	1984	903
200	50	0.15	31.67	1629	3008	2464	1383	302	-779	-1860	-2941	-4022	-5104
200	50	0.15	36.11	-4297	-2924	-3542	-4623	-5704	-6785	-7866	-8948	-10029	-11110
200	50	0.15	40.56	-10247	-8880	-9548	-10629	-11711	-12792	-13873	-14954	-16035	-17116
200	50	0.15	45	-16213	-14851	-15555	-16636	-17717	-18798	-19879	-20960	-22041	-23123
200	50	0.3	5	34877	35444	34955	34173	33259	32229	31148	30067	28986	27905
200	50	0.3	9.44	55325	57786	58113	57938	57648	57350	57035	56689	56315	55851
200	50	0.3	13.89	60870	64862	67113	67676	67401	66679	65872	65064	64257	63447
200	50	0.3	18.33	60698	64639	66409	66060	65298	64516	63505	62459	61402	60334
200	50	0.3	22.78	57112	61021	61716	60818	59737	58656	57575	56493	55412	54331
200	50	0.3	27.22	51784	55651	55893	54812	53730	52649	51568	50487	49406	48325
200	50	0.3	31.67	46054	49892	49886	48805	47724	46643	45562	44481	43400	42318
200	50	0.3	36.11	40208	44034	43880	42799	41718	40637	39555	38474	37393	36312
200	50	0.3	40.56	34314	38129	37874	36793	35711	34630	33549	32468	31387	30306
200	50	0.3	45	28389	32193	31867	30786	29705	28624	27543	26462	25380	24299
200	50	0.6	5	76511	78726	78829	78347	77599	76620	75541	74460	73378	72297
200	50	0.6	9.44	123414	129417	131152	131884	132384	132870	133320	133710	134043	134197
200	50	0.6	13.89	140509	149574	155159	157365	157896	157534	157000	156466	155932	155394
200	50	0.6	18.33	146173	155135	159756	160139	159697	159214	158272	157262	156229	155175
200	50	0.6	22.78	145006	153906	156376	155662	154581	153500	152418	151337	150256	149175
200	50	0.6	27.22	140357	149172	150737	149656	148574	147493	146412	145331	144250	143169
200	50	0.6	31.67	134903	143661	144730	143649	142568	141487	140406	139325	138243	137162
200	50	0.6	36.11	129217	137952	138724	137643	136562	135481	134399	133318	132237	131156
200	50	0.6	40.56	123436	132147	132718	131636	130555	129474	128393	127312	126231	125150
200	50	0.6	45	117592	126281	126711	125630	124549	123468	122387	121306	120224	119143

Table 14 presents the best scenario of NPV distribution regarding Type B building with 50% load flexibility and a lower battery cost of 200€/kWh. The maximum NPV of 160K€ is obtained for a battery size 12kWh.

In order to emphasize the correlation between NPV, PV size, and battery capacity, the data from the aforementioned tables were consolidated and analyzed. This analysis focused on fixed values for PV and battery while considering two different scenarios involving variations in battery cost.

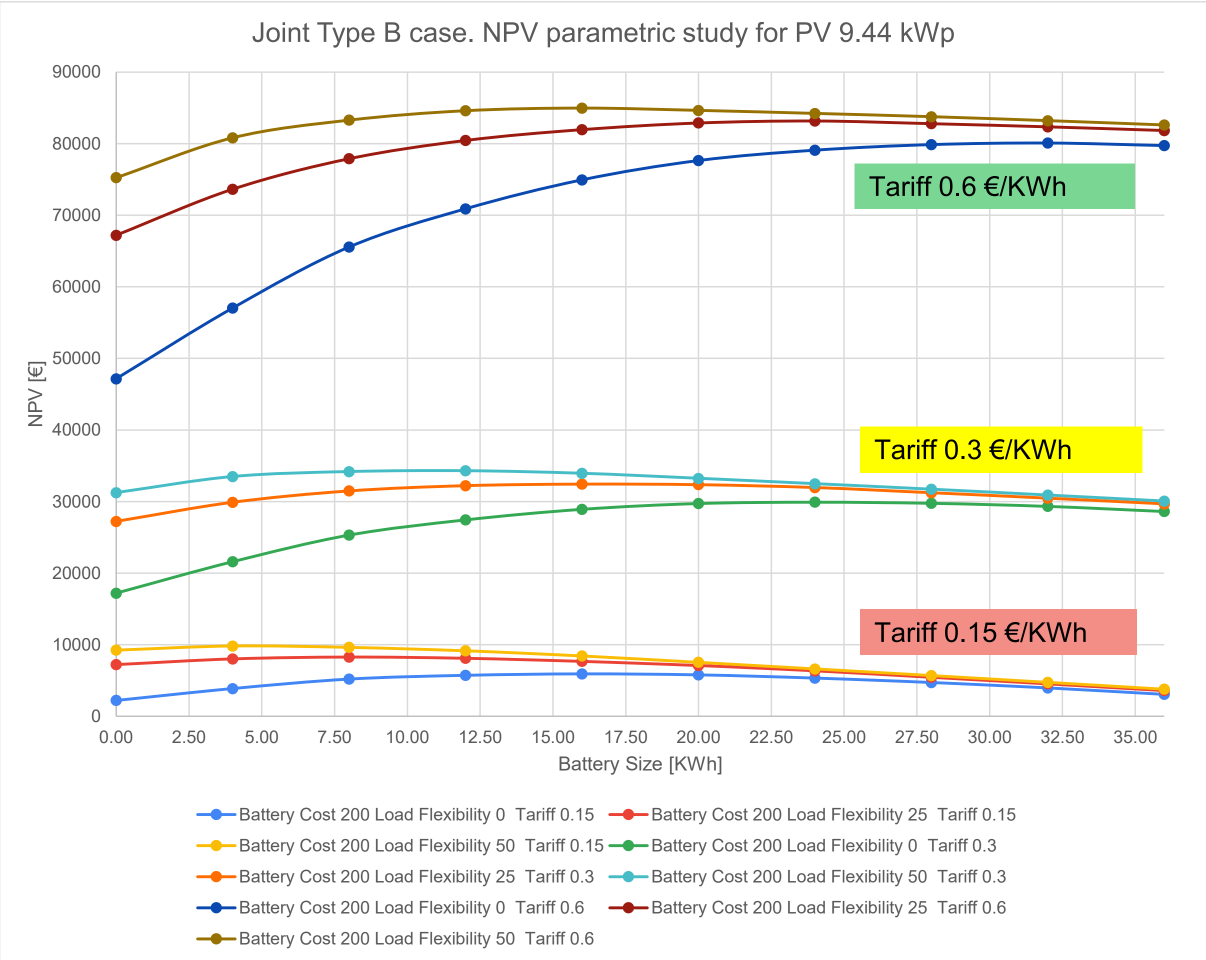

Figure 10. NPV. Joint Type B case. Battery cost 200€/kWh. PV 9.44 kWp

In the scenario presented in Figure 10, the PV size is fixed at 9.44kWp and the battery cost is 200€/kWh. For low tariffs, low NPV values are calculated when the optimal battery size varies between 4 to 16kWh. Higher NPV obtained with the best battery size of 8 to 24kWh for medium tariff. The highest tariff NPV is obtained with the optimal battery size of 16 to 32kWh. The variation of optimal battery capacity for each tariff depends on the load flexibility rate.

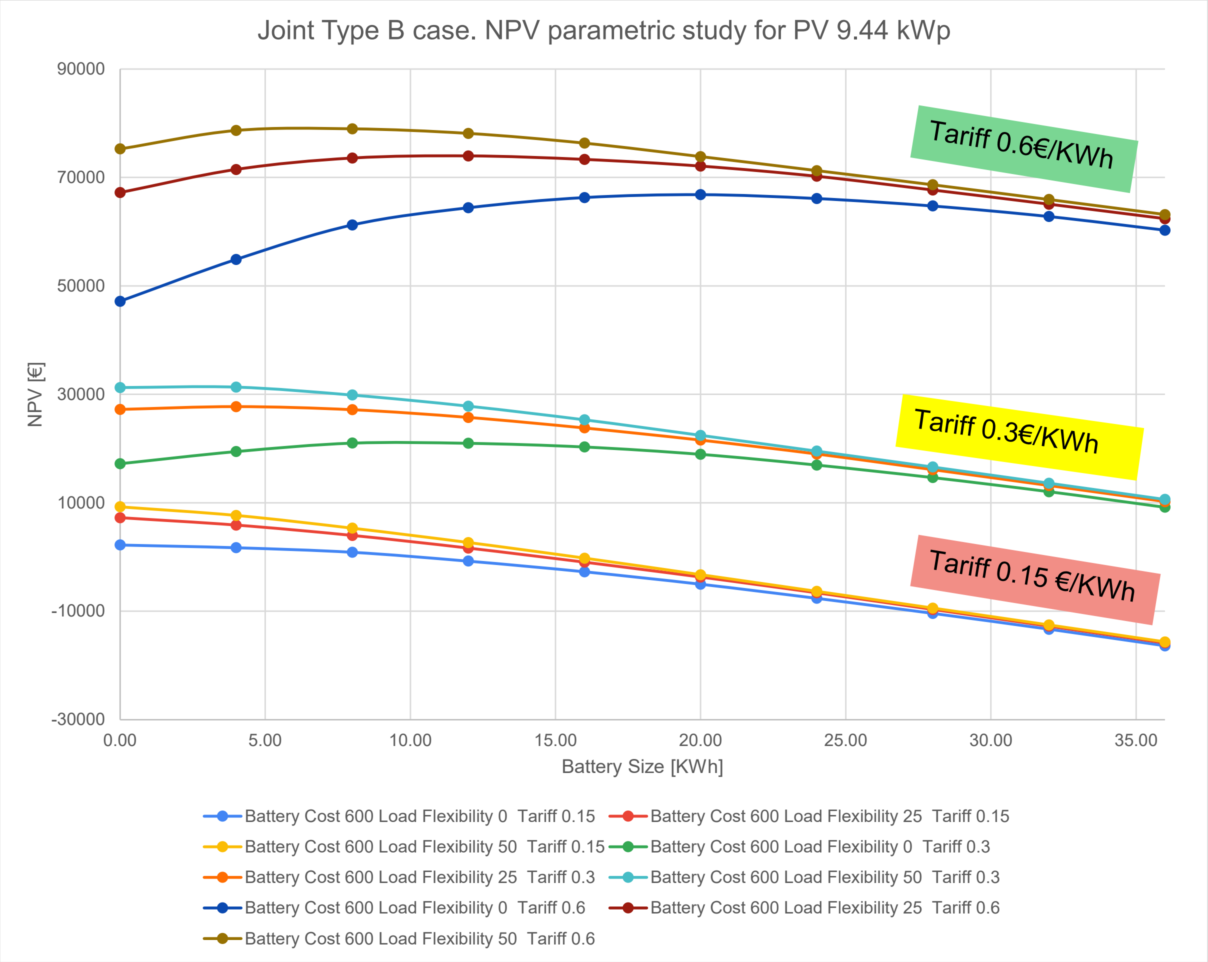

Figure 11. NPV. Joint Type B case. Battery cost 600€/kWh. PV 9.44 kWp

In the scenario presented in Figure 11, the PV size is fixed at 9.44kWp and the battery cost is 600€/kWh. This case introduces lower profitability than the previous one, caused by higher battery cost. Moreover, the most profitable case for countries with low tariffs is without storage. The situation is different if the tariff is medium or high, so hybrid PV and storage facilities are more profitable.

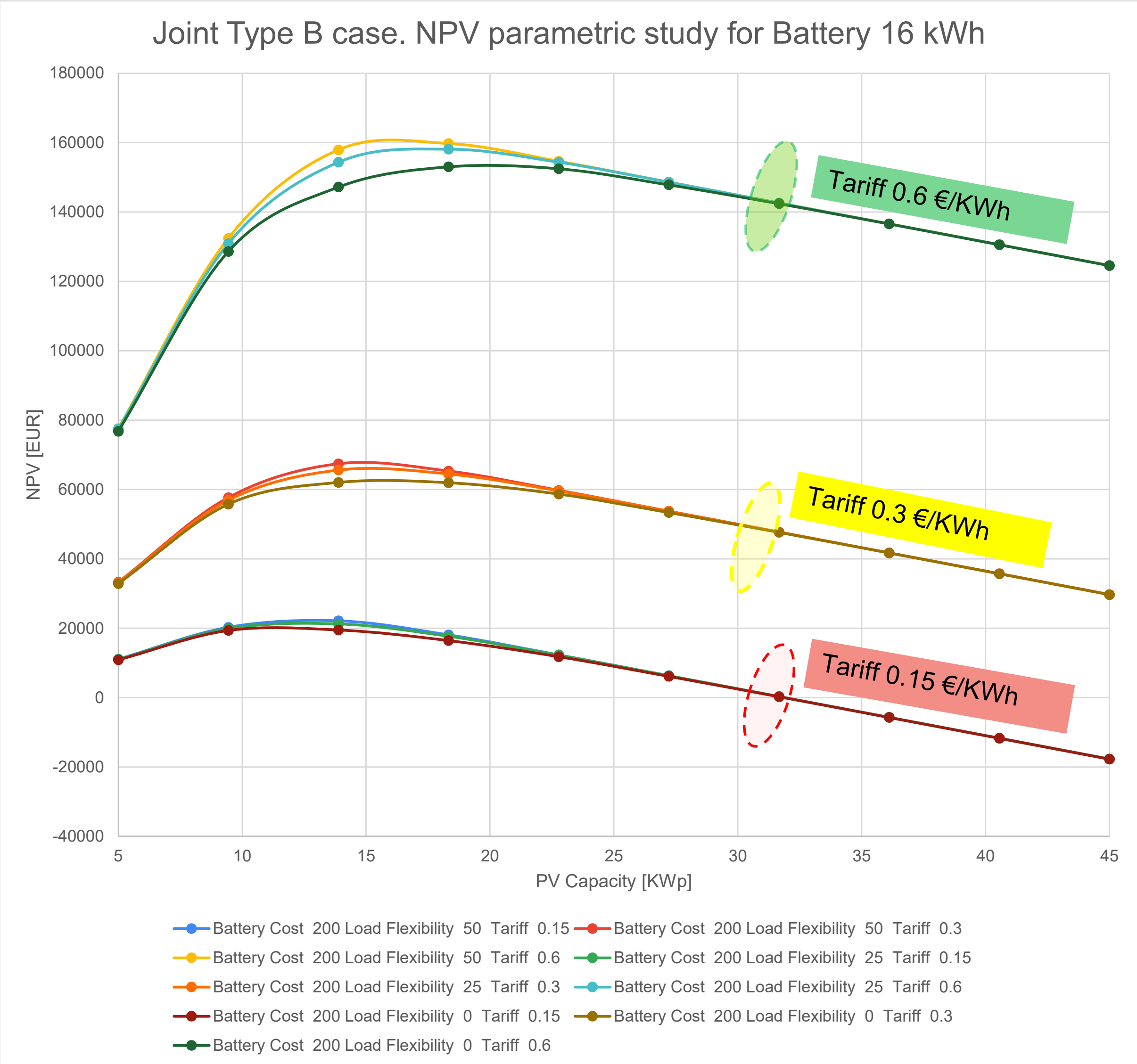

Figure 12. NPV. Joint Type B case. Battery cost 200€/kWh. Battery 16kWh

Figure 12 and Figure 13 demonstrate the cutout of NPV distribution with a fixed battery size of 16kWh, which is close to the optimal battery capacity in most scenarios. Interestingly, load flexibility has almost no impact on Type B buildings, excluding the PV range of 8 to 22kWp.

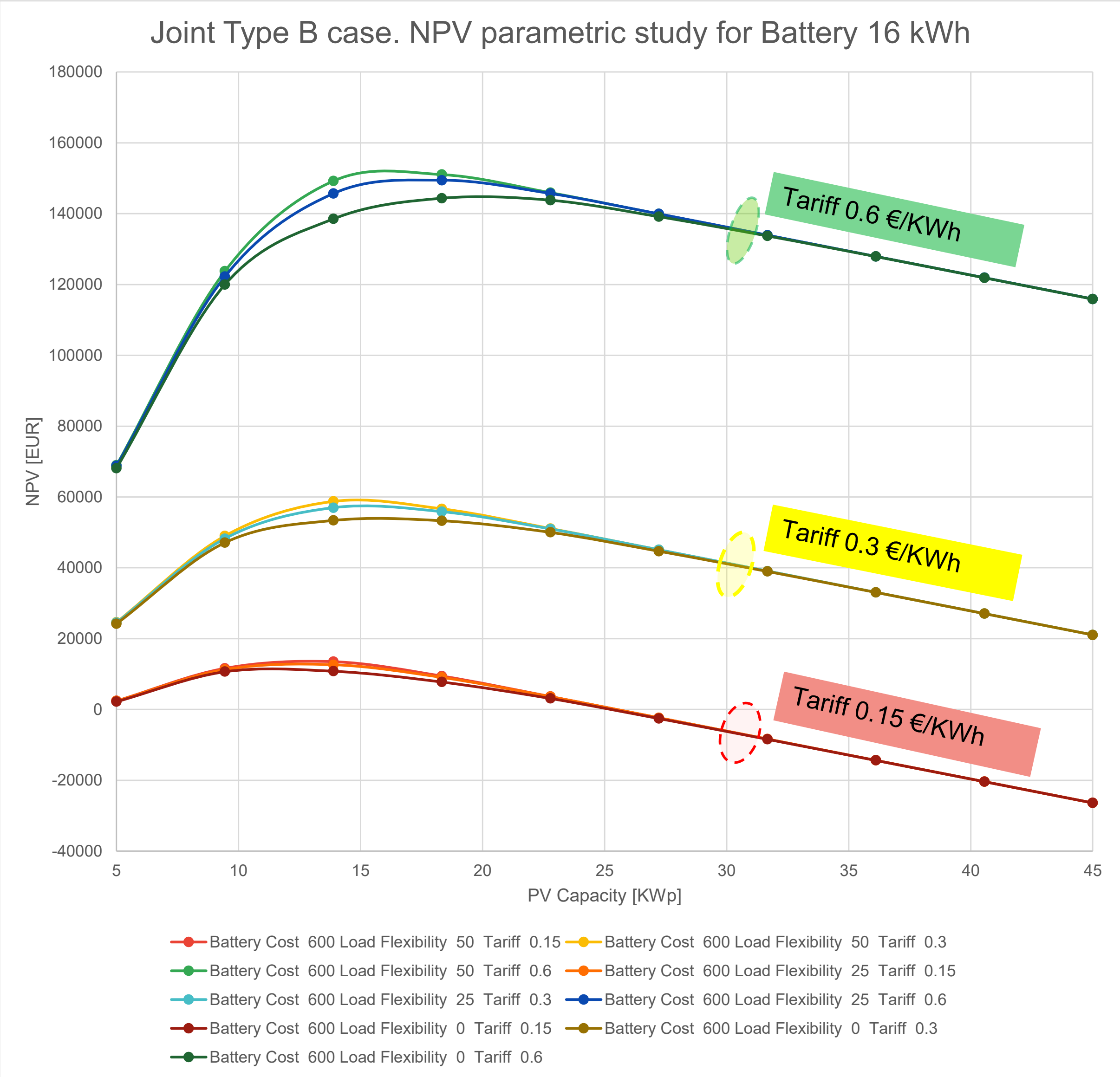

Figure 13. NPV. Joint Type B case. Battery cost 600€/kWh. Battery 16kWh

4 Non-participating countries. Examples of Bulgaria and Slovenia

The replication potential in the non-participating countries is estimated by analyzing open information available on the web regarding the energy policy, similar activities, etc.

4.1 Energy Policy Survey

In the past five years, Bulgaria has made significant progress in its energy policy. Efforts have focused on promoting renewable energy, improving energy efficiency, diversifying energy sources, and enhancing market liberalization. Examples include the construction of the Zlatna Panega solar park, energy efficiency retrofit programs, natural gas diversification projects, nuclear power commitments, and steps toward market transparency and competition. These initiatives aim to reduce reliance on imported fossil fuels, increase renewable energy capacity, and align with European Union directives.

In Slovenia, renewable energy promotion includes a two-round tender process to determine support levels and recipients. New production facilities participate in an annual public call while existing facilities sell electricity to Borzen at a feed-in or premium tariff. Subsidy applications and loans support renewable energy projects, while heating purposes receive support through loans and subsidies. Tax exemptions and loan options incentivize renewable energy use in transport. Priority access to the grid and priority use of the grid are granted to renewable energy sources. Multiple policies encourage the development, installation, and utilization of renewable energy installations.

4.2 Initiatives on Renewable Energy

Over the past five years, Bulgaria and Slovenia have been part of the broader European Union (EU) initiatives that promote renewable energy.

In Bulgaria, the country has worked towards aligning its renewable energy policies with EU directives. This has involved increasing the capacity of renewable energy sources, such as solar and wind power, through investments and the implementation of public tenders. The country has also aimed to enhance energy efficiency and reduce greenhouse gas emissions through retrofit programs and the promotion of energy-saving measures.

Similarly, Slovenia has actively participated in EU efforts to promote renewable energy sources. The country has implemented a two-round tender process to support electricity production from renewable sources. Public calls for subsidy applications and the provision of loans have incentivized the development and installation of renewable energy projects. Slovenia has also promoted renewable energy use in the heating and transport sectors through financial incentives, including loans and tax exemptions.

Both countries have prioritized grid access for renewable energy installations and integrating renewable energy into their energy systems, in line with EU objectives. These initiatives reflect the shared commitment of Bulgaria and Slovenia to transitioning towards a more sustainable and renewable energy future, guided by EU renewable energy policies.

4.3 Potential for replication

Research and innovation plans and actual projects have demonstrated the potential for replicating the hybrid PV+BESS+DSM strategy in both Bulgaria and Slovenia. These countries have recognized the importance of integrating renewable energy sources and energy storage technologies with demand-side management techniques to enhance energy efficiency and grid reliability.

In Bulgaria, research and innovation efforts have focused on advancing the deployment of hybrid PV+BESS+DSM systems. The Bulgarian Academy of Sciences and various research institutions have conducted studies to assess such systems' technical and economic viability in different country regions. These studies have highlighted the potential for reducing peak demand, improving grid stability, and increasing the self-consumption of renewable energy.

Additionally, Bulgaria has witnessed real projects implementing this strategy. For example, the "PV+ESS for DSM" pilot project in Sofia utilized a combination of PV panels, battery storage, and smart energy management systems to optimize energy consumption and reduce reliance on the grid during peak hours. The project demonstrated the feasibility and benefits of integrating PV+BESS+DSM technologies, including load shifting, peak shaving, and increased self-consumption of solar energy.

Regarding policy support, Bulgaria has implemented regulations and incentives to encourage the adoption of hybrid PV+BESS+DSM systems. Net metering schemes allow excess PV generation to be fed into the grid, while financial incentives, such as feed-in tariffs and grants, facilitate the installation of renewable energy and storage systems. The Bulgarian government has also prioritized research and development funding for renewable energy and storage technologies, encouraging further innovation in the sector.

Similarly, in Slovenia, there is a strong focus on research and innovation in renewable energy integration and energy management. Research institutions and universities have been active in studying the technical and economic feasibility of hybrid PV+BESS+DSM systems and developing advanced energy management algorithms to optimize their performance.

Real projects have also showcased the potential of this strategy in Slovenia. For instance, the "Smart PV+ESS System for Industrial Consumers" project implemented in Ljubljana involved the installation of PV panels, battery storage, and advanced energy management systems in industrial facilities. The project aimed to reduce energy costs, enhance grid stability, and increase the share of renewable energy in the industrial sector.

Slovenia has implemented supportive policies and initiatives to promote hybrid PV+BESS+DSM systems. The country's renewable energy legislation allows for net metering, enabling consumers to offset their electricity consumption with PV generation. Financial incentives, such as feed-in tariffs and investment grants, encourage deploying renewable energy systems. The Slovenian government has also established energy efficiency funds and programs to support energy-saving measures and adopt innovative energy technologies.

Both countries have also benefited from participation in European Union funding programs and initiatives focused on renewable energy research, innovation, and demonstration projects. These programs provide additional resources and opportunities for knowledge exchange and collaboration with other EU member states.

In conclusion, both Bulgaria and Slovenia have recognized the potential of hybrid PV+BESS+DSM systems to enhance renewable energy integration, energy efficiency, and grid stability. Through research and innovation plans, as well as real projects, these countries have demonstrated the feasibility and benefits of this strategy. Supportive policies, financial incentives, and participation in EU funding programs further enhance the replication potential of such systems. The continuous advancements in renewable energy and energy storage technologies, coupled with the commitment to research and innovation, pave the way for the wider adoption of hybrid PV+BESS+DSM systems in Bulgaria, Slovenia, and beyond.

5 Unified mapping of the do's and don'ts

The joint case study focuses on replication notes, includes the application of a hybrid PV+BESS+DSM strategy, two types of public buildings with low and high matching between demand and generation hours, and analyses three different cases of electricity tariffs (low, medium, and high) in the MED region, as well as two levels of load flexibility. Based on the sensitivity study of the joint case, the following is a list of unified do's and don'ts for policymakers and energy stakeholders in the region.

Do's:

- Conduct a study on building designs that incorporate high production-consumption mismatch to explore the potential for achieving significant NPV, particularly in countries with higher electricity tariffs. Additionally, investigate the profitability of different combinations of PV generation and storage, focusing on scenarios where a higher load flexibility rate can lead to increased NPV.

- Investigate the impact of load flexibility on buildings with well-matching generation and consumption profiles, aiming to determine the extent to which higher self-sufficiency can be attained through the implementation of DSM strategies.
- Analyze the economic viability of various PV and storage configurations for countries with low, medium, and high electricity tariffs. Assess the profitability of each case, and consider recommending hybrid PV and storage facilities in situations where the tariff is medium or high.
- Examine the potential effects of decreasing battery costs from 600 to 200€/kWh on NPV in buildings with different levels of consumption-production matching. Assess the financial benefits, taking into account various load flexibility rates.
- Investigate the correlation between battery costs and buildings with low matching between consumption and production. Identify the extent to which battery cost influences NPV in these scenarios and propose strategies to mitigate the impact on profitability.

Don't's:

- Rely solely on low electricity tariffs to attract investment in the energy sector. This may discourage investment in renewable energy systems and perpetuate reliance on fossil fuels.
- Neglect the importance of load flexibility when designing and implementing renewable energy systems. Without adequate load flexibility, the cost savings of PV+BESS+DSM systems may be limited.

* Overlook the challenges of energy storage and management in implementing renewable energy systems. Effective energy management strategies are critical to optimizing the performance and efficiency of these systems.
* Underestimate the importance of public awareness and education in promoting the adoption of renewable energy systems. Education campaigns can help to build public support and understanding of the benefits of these systems.
* Design the PV+BESS+DSM system based only on rough estimations of the energy consumption of the building. A detailed assessment of the building energy needs throughout the year is important to select the ideal PV and storage system size.

In conclusion, the unified do's and don'ts are based on the joint case analysis focusing on replication potential, following a parametric study of variable PV+BESS+DSM scenario, two types of buildings, battery cost variety and three different cases of electricity tariffs in the MED region, as well as three levels of load flexibility. The study revealed a useful guide for policymakers and energy stakeholders in the region. Implementing these guidelines can promote the adoption of renewable energy systems, optimize energy use, and reduce reliance on fossil fuels, contributing to a more sustainable energy future for the MED region.

6 Good practices for replication and lessons learned

Lessons can be learned from the input from partnersthe pilots installation, commissioning and operation procedures that can be applied to various projects and collaborations. Additionally, good practices for successfully replicating the Hybrid strategy implemented in the Berlin project are introduced below.

When designing and sizing a hybrid PV+BESS+DSM project, it is important to consider several key factors—understanding the consumption profiles of the facility or system where the hybrid project will be implemented. This involves monitoring energy consumption over an extended period, typically at least one year. By studying consumption patterns, valuable insights can be gained into the magnitude and timing of energy demand, which is essential for accurately sizing the PV and BESS components of the system.

Another essential aspect is mapping the potential for DSM) regarding electricity consumption. Analyzing electricity consumption patterns allows for identifying opportunities for DSM, which involves optimizing energy usage through load shifting, peak shaving, and demand response. This analysis helps in planning the BESS operation to maximize DSM's benefits.

Understanding electricity pricing and tariffs is also critical during the design and sizing processes. Evaluating the cost structure of electricity, including pricing, time-of-use rates, and demand charges, enables the determination of the system size required to achieve a positive net present value (NPV). This information is valuable for assessing the economic viability of the hybrid project and optimizing the sizing of the PV and BESS components accordingly.

By considering these factors and incorporating them into the design and sizing process, the hybrid PV+BESS+DSM project can be appropriately dimensioned to meet energy demand, maximize the utilization of renewable energy sources, and achieve positive financial outcomes.

It is crucial to ensure a reliable storage supply and other devices during procurement. This involves careful consideration of vendor selection and effective contract management. Vendor selection plays a significant role in securing quality equipment for the project. Thorough research and evaluation of potential vendors based on their reputation, experience, technical expertise, and track record in delivering reliable and efficient energy storage systems are essential. Choosing reputable vendors increases the likelihood of obtaining high-quality equipment that meets the project's requirements and performance expectations.

Effective contract management is another critical aspect of the procurement process. This involves negotiating and establishing contractual agreements with the selected vendors that clearly outline specifications, performance standards, delivery schedules, warranty terms, and other relevant provisions. By ensuring effective contract management, project risks can be mitigated by establishing clear expectations, compliance assurance, and mechanisms for dispute resolution if necessary.

Proper due diligence should be exercised during procurement to assess potential vendors' financial stability and ability to fulfill contractual obligations. This may involve reviewing financial statements, assessing production capabilities, and seeking references or testimonials from past clients.

Regarding building operations, challenges may arise in acquiring adequate-quality measurements, dealing with missing data, and generating signals when data is incomplete or unreliable. However, these challenges can be addressed through robust data management practices and the utilization of advanced algorithms.

Acquiring adequate-quality measurements requires using reliable devices and ensuring proper installation and calibration. Quality assurance measures should be in place to validate and verify the accuracy and reliability of the acquired data.

Dealing with missing data is a common issue that can be addressed through robust data management practices. Techniques such as data imputation, data validation procedures, and advanced algorithms can help handle missing data effectively and generate signals or estimate missing information.

Optimizing the operation of storage and controllable loads is another critical aspect of building operation in a hybrid PV+BESS+DSM project. This involves developing and implementing sophisticated control strategies considering energy demand, electricity pricing, renewable energy generation, and user preferences. Advanced optimization algorithms can be employed to determine the optimal scheduling and dispatch of energy resources, considering both short-term and long-term objectives.

7 Conclusions

The joint case study explores the viability of combining photovoltaic (PV) systems with battery energy storage systems (BESS) and demand-side management (DSM) in the Mediterranean (MED) region. The study focuses on the cost-effectiveness of this combination, considering various electricity tariffs, load flexibility levels, battery size variations, and cost per kWh.

The study analyses three cases of electricity tariffs, namely low, medium, and high, and considers two levels of load flexibility. The aim is to investigate how the system's cost-effectiveness changes under different scenarios. The results show that the cost-effectiveness of the PV+BESS+DSM combination can vary significantly depending on the electricity tariffs and load flexibility.

In low-tariff countries, installing a PV+BESS+DSM combination may not be cost-effective. This is because the cost of electricity is low, and there may be little incentive to install the system. However, in medium and high-tariff countries, the system's installation can be highly cost-effective, particularly for buildings with high energy consumption and load flexibility.

The study highlights the importance of load flexibility in determining the system's cost-effectiveness. Load flexibility refers to the ability of a building to adjust its energy consumption based on the availability of energy from the PV system and the BESS. Buildings with high load flexibility can shift their energy consumption to times when the PV system generates energy or when the electricity tariffs are low. This can significantly reduce the building's reliance on the grid and increase the overall cost-effectiveness of the system.

The study concludes that the PV+BESS+DSM combination can be cost-effective in the MED region, provided the system design and installation are tailored to the building's specific electricity tariffs and load flexibility. The study suggests that policymakers should consider implementing measures to increase building load flexibility, such as promoting energy-efficient appliances or introducing time-of-use tariffs.

In conclusion, the joint case study provides valuable insights into the cost-effectiveness of combining PV systems with BESS and DSM in the MED region. The study highlights the importance of considering electricity tariffs and load flexibility when designing and installing these systems. The findings can assist policymakers and building owners in making informed decisions about adopting renewable energy solutions and improving energy efficiency in buildings.

8 Bibliography

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