StoRES

Promotion of higher penetration of Distributed PV through storage for all

Priority Axis 2: Fostering low-carbon strategies and energy efficiency in specific MED territories: cities, islands and remote areas
2.2: To increase the share of renewable local energy sources in energy mix strategies and plans in specific MED territories

Deliverable n°: **3.7.1**
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6. Project Summary

The project addresses the development of an optimal policy for the effective integration of Renewable Energy Sources (RESs) and Energy Storage Systems (ESSs). The primary challenge is to achieve increased penetration of RES and predominantly Photovoltaics (PV), in the energy mix of islands and rural areas in the Mediterranean (MED) region without compromising grid stability. The main objective of StoRES is to boost self-consumption in the MED region with the integration of optimal storage solutions. Testing coupled PV-ESS solutions in different pilot sites and considering local particularities for optimization, current barriers concerning grid reliability with higher RES deployment will be addressed. In addition to this, the development and integration of the proposed solution at both residential and community levels and the application of different policy scenarios will give evidence for identifying policies that can lift the barriers related to the grid integration of ESS and will extend the practical knowledge about this technology. It is expected that shortcomings regarding the intermittent nature of PV energy for increased penetration into the energy mix will be addressed contributing to the smooth operation of the grid.

The project started on the 1st of November 2016 and is expected to be completed within 36 months.

7. Introduction to Deliverable 3.7.1

7.1 Introduction

The integration of RESs and ESSs is a promising route for the decarbonisation of the current power sector and for providing the required resilience to the power network. Although Energy Storage is generally considered as an effective means for reducing the energy mismatch between rooftop PV generation and domestic load demand, it remains unclear when and under what conditions an installation of an ESS can be profitably operated at the residential level.

Given the economic potential of residential ESSs and the substantial investments required, there is a need for a methodological approach to estimate the costs and benefits of residential ESSs when they are combined with residential RESs, based as much as possible, on actual data from residential ESSs pilot projects. In this context, the present study proposes a comprehensive assessment framework of residential ESS projects centred on a Cost-Benefit Analysis (CBA). The StoRES project is used as a case study to fine-tune the developed CBA and to illustrate the proposed assessment framework.

7.2 Aim of the deliverable

A meticulous techno-economic CBA of ESSs requires consistent, up-to-date cost data and a holistic cost analysis framework. The main pillars of a generic CBA are: 1) Project Characterisation, 2) Cost Estimation, 3) Benefit Estimation and, 4) Costs and Benefits Comparisons. To implement the pillars of the CBA, the following steps were followed: 1. Review and description of technologies, elements and goals of the project, 2. Quantify costs, 3. Map assets onto functionalities, 4. Map functionalities onto benefits, 5. Establish the baselines, 6. Monetise benefits and identify beneficiaries, and 7. Compare costs and benefits. After the implementation of the four stages which combine the seven suggested steps, the outcome of the CBA of this study is refined through a sensitivity analysis, which its primary aim is to identify the range of the critical variables of the project, for which, the analysis' outcomes are positive.

7.3 Goal of the report

The goal of this report is to provide guidance and advice for residential ESSs connected to rooftop PV systems. A step-by-step assessment framework is presented, and the guidelines and the best practices are provided. The assessment framework is structured into a set of guidelines to tailor assumptions to local conditions (the main focus of this study is the

MED region) in order to identify and then monetise costs and benefits associated with a residential ESS installation. Then, a sensitivity analysis of the most critical values is performed. This study also identifies externalities and social impacts which are the result of the ESS installation but they cannot be easily monetised and factored into the cost-benefit computation.

A comprehensive and detailed analysis of residential ESS projects requires adaption to local conditions, policies and circumstances, and it is ultimately relying on the professional skills and judgement of the project developers, end-users and relevant decision-makers. Hence, the goal of this report is not to provide an exhaustive and detailed set of indications to fit all possible scenarios, systems, projects and local specificities. The content of this study should be seen as a structured set of suggestions and/or as a checklist of critical elements, which need to be considered for residential ESS installations.

8. Background

Energy Storage is widely recognised as an increasingly important element for power systems, as it modulates energy demand by acting as a flexible generation when it is needed. Energy Storage can support the European Union's (EU's) plans for the Energy Union (security of supply, energy efficiency, decarbonisation of the economy, research innovation and competitiveness) by improving the energy security and a well-functioning internal market, and supporting the integration of more carbon-cutting renewable sources domestically [1], [2]. Energy Storage can contribute at every level of the power system (Behind-the-Meter - BtM, Distribution, Transmission and Generation level) and complement other flexible elements and grid development [3].

Currently, 97% of the global electricity storage capacity consists of pumped hydro Energy Storage [4], [5]. Despite their rapid growth and the significant purchased cost reduction, residential ESS are not yet extensively used in the global power systems. In addition to the high purchased cost of ESSs, other barriers to their diffusion may include technical hurdles, social resistance, environmental impacts or a lack of viable business models [6]. Given the economic potential of the ES, there is a need for a methodological approach to estimate the costs and benefits of ESSs, based as much as possible on data from ESS pilot projects.

In this context, the StoRES project was implemented with the primary aim of addressing the current barriers concerning the deployment of ESSs BtM in the MED regions. To complement this work with a quantitative analysis, this study proposes a comprehensive assessment framework of ESS projects centred on a CBA. The proposed approach was tested and fine-tuned using data from the StoRES pilots.

8.1 Policy background

In the past few years, Energy Storage was not considered as a priority for the energy system development, mainly because in a fossil fuel based electricity system, the benefits of storage are limited [1], [7]. When the Electricity Directive (Directive 2009/72/EC concerning common rules for the internal market in electricity) was approved in 2009, Energy Storage was not included in the framework planning [8]. Not considering storage of electricity in the Electricity Directive has several unintended barriers and bottlenecks in the legislation, such as: i) unclear role of Energy Storage (part of supply or production or both), ii) not clear how grid tariffs are applied to the use of storage (different rules apply in different countries), iii) no common EU regulatory approach towards cost reductions or increase of subsidies, iv) issues like Net-Metering are entirely regulated at Member

State level, etc. [2], [9]. Furthermore, [10] stated through the 'Ten Year Network Development Plan' that it is still an open question who will own and manage ESSs (regulated operators or private market operators). Currently, across the EU there is no common regulatory approach for ES, so potentially creating significant differences between the Member States. The decisions taken by national government could actually prevent any possible deployment of ESSs; example of this statement is the Spanish decree on self-consumption [11].

The transition to a low carbon electricity system has resulted in fast-growing shares of intermittent RESs, with coincidence, the increased concern over the future electricity grid stability [2]. In 2017, the Electricity Directive was recast, and recognised the Energy Storage as a possible source for providing the required stability and flexibility to the power grid [12]. It also addressed unclear frameworks for the value streams of ancillary services, curtailment and balancing obligations and electricity pricing. However, as Energy Storage was not recognised as a 'new asset' in the electricity grid, issues of double taxation are not yet resolved. Additionally, the revised Electricity Directive does not allow the Transmission System Operators (TSOs) and Distribution System Operators (DSOs) to own, develop, manage or operate Energy Storage facilities [13]. An exception could be allowed for a 5-year derogation if no interest from other parties is received, if the facilities are necessary for the efficient, reliable and secure operation of the system and if the regulatory authority has assessed the necessity of such derogation. Currently there are discussions for adding a new definition – 'fully integrated network components', which can include in-front-of-the meter ESSs, as it refers to the system components that are integrated in the transmission or the distribution system and are used for the only purpose of ensuring a secure and reliable operation of the transmission or distribution system [7], [13]. In early 2018, the European Parliament Committee on Industry, Research and Energy (ITRE) prepared a report and recommended to the European Parliament and the European Council, common rules and modifications for the Energy Storage in the electricity system [14]. The main recommendations include the right to grid connection, allowance of providing several services simultaneously, Energy Storage to be distinguished from generators, and the electricity stored to be relieved from additional taxes, surcharges and fees.

Today, EU supports storage projects through R&D with several initiatives, such as the Strategic Energy Technology (SET) Plan, Clear Energy Package, GEAR 2030, Horizon 2020, Batstorm and, Fuel Cells and Hydrogen JU [1], [7], [15]. In order though for the pilot projects to be transformed into real installations and hence to fully unleash the potentials of ESSs, further development of the storage related regulatory framework and market mechanisms are required to enable full contribution of storage to a cost-efficient energy system [1].

8.2 Literature review

There are few studies in the literature which are intended to identify the costs and/or the benefits associated with ESSs by developing financial analysis and CBAs. Studies that extensively investigated the costs associated with the battery installation are [16] and [17], which presented a comparative life cycle cost analysis for grid-scale electrical ESSs and a methodology for calculating the Levelised Cost of Electricity (LCOE) for utility-scale ESSs respectively. The economics of battery storage system used in small communities by using a life-cycle CBA were evaluated by [18]. It was found that the inclusion of externalities (such as decrease of manufacturing CO_2 emissions and decrease of appliances' damages because of power outages) can improve the economic value of battery systems significantly in the examined countries. [19] obtained a life-cycle CBA for PV-ESSs for remote islands in Greece, in an attempt to improve the life quality of isolated communities. [20] explored the social costs and benefits of grid-scale electrical Energy Storage projects in the UK by proposing a social CBA through Monte Carlo simulation. [21] implemented a CBA of a battery storage system for industry consumers based on different operation modes (including peak load shifting, Demand Response - DR and user's capacity cost reduction modes). [22] proposed a strategy for optimal allocation of multiple community Energy Storage units in a distribution system with PV generation, by considering all possible benefits accrued from and costs incurred by Energy Storage deployment to a utility. [23] investigated the profitability of residential PV-battery systems in Germany, with the aim the reduction of the purchased electricity from the power grid. It concluded that the major factor for the profitability of such systems is the interest rate, followed by the PV price, the retail electricity price and the Feed-in-Tariff (FiT). Lastly, [24] investigated when and under what conditions battery storage will be economically viable in residential PV systems without policy support in Germany, building upon a review of previous economic studies.

Focusing on the residential level and more specifically on single-house grid-connected ESSs combined with PV systems, several recent studies which investigated the profitability of such systems with focus on the ESSs investment, have concluded that the profitability of the battery installation highly depends on: the supporting schemes, the electricity pricing, the battery cost, the pricing scheme and the self-consumption rates [25]–[31]. In more detail, [25] which performed investigation of grid-connected residential PV-battery systems focusing on the self-consumption and peak shaving ESS benefits for Japan, concluded that the profitability of residential battery installations highly depends on supporting schemes such as FiT and on the increased electricity pricing. [26], which aimed to improve the profitability of residential batteries by exploring both PV self-consumption and demand-load shifting battery applications under different dynamic tariff structures, concluded that in order for residential ESSs to become an attractive investment in Switzerland, the cost of the batteries needs to be halved. [27] examined the drivers for profitability for grid-connected residential battery storage systems in the short-term horizon in Germany and identified that as the current conditions are favourable for standalone PV systems, the battery installations will be profitable if they are synchronised with the decrease of the battery prices. [26] and [27] analysed comparative studies for Germany, Switzerland, Spain, France and Italy, agreed that the higher electricity prices will contribute to the profitability of a residential PV and Battery system in the examined countries. [30] presented an energetic and economic analysis of an ESS in Italy by considering the current Net-Metering scheme[1] and found that the power losses generated by the non-ideal ESS appeared to be a significant disadvantage for the battery investment over the Net-Metering scheme. Lastly, [31] examined the economic feasibility of residential ESSs combined with PV panels and found that these systems can reach profitability through subsidies and/or by high self-consumption rates.

Despite the fact that many studies have touched upon the subject of residential ESS benefits, it is difficult to find studies which have attempted to develop a systematic approach for the definition and evaluation of all the costs and benefits associated with a residential ESS installation and which have tested their approach on real case studies. The main reason for this lack of the formal analysis framework is that evaluating residential ESS projects on their investment needs and resulting benefits can prove difficult. The challenge is linked to four main reasons, as they were identified through the literature review:

- At present, Energy Storage often falls into the generation system category and therefore, under the network codes for generation systems [11]. As Energy Storage is only valued under one domain, it is difficult to assign its value without being significantly undervalued (can contribute also to transmission and distribution levels and provide ancillary services) [32].

- ESS projects are typically characterised by high initial costs and benefit streams that are uncertain and often long term in nature. In fact, all the ESS benefits are systemic in nature, as they only come into play once the entire ESS is in place and new market players have successfully assumed their roles and operation [33], [34].

- The current Net-Metering scheme existing in many countries, in combination with the power losses of the ESS, creates a difficulty to

[1] Net-Metering scheme is an effective economic support for residential PV systems in different countries.

foresee financial benefits for a future Energy Storage installation combined with an existing residential PV system [2], [9], [30]. ESS could potentially make sense with a Net-Metering scheme, if it was applied under certain time-steps (i.e. 30-minute time-steps).

- The passive radial distribution power grid infrastructures are not suitable for the full exploitation of residential ESSs [34]. Smart grid infrastructures which support the bidirectional communication between the electricity utility and the end-users are needed in order to fully exploit the potential benefits of a residential ESS. Also, storage operators should be allowed to provide multiple services to the electricity system operators [35]. Especially at this early stage of the residential ESSs development, prosumers' participation and response are still uncertain, and relevant behavioural information such as detailed power profiles, is often not accessible to electricity utilities through the current power grids [36].

9. CBA Methodology

A meticulous techno-economic CBA of ESSs requires consistent, updated cost data and a holistic cost analysis framework. The main pillars of a generic CBA are: 1) Project Characterisation, 2) Cost Estimation, 3) Benefit Estimation and, 4) Costs and Benefits Comparisons. [33] suggested that a complete CBA for Smart Grid projects should follow seven steps: 1. Review and description of technologies, elements and goals of the project, 2. Map assets onto functionalities, 3. Map functionalities onto benefits, 4. Establish the baselines, 5. Monetise benefits and identify beneficiaries, 6. Quantify costs, and 7. Compare costs and benefits. By combining the two methodologies for the conduction of a CBA, the methodology followed for this study was structured, as presented in Figure 1. After the implementation of the four stages which combine the seven suggested steps, the outcome of the CBA of this study are refined through a sensitivity analysis, which its primary aim is to identify the range of the critical variables of the project, for which, the analysis' outcomes are positive.

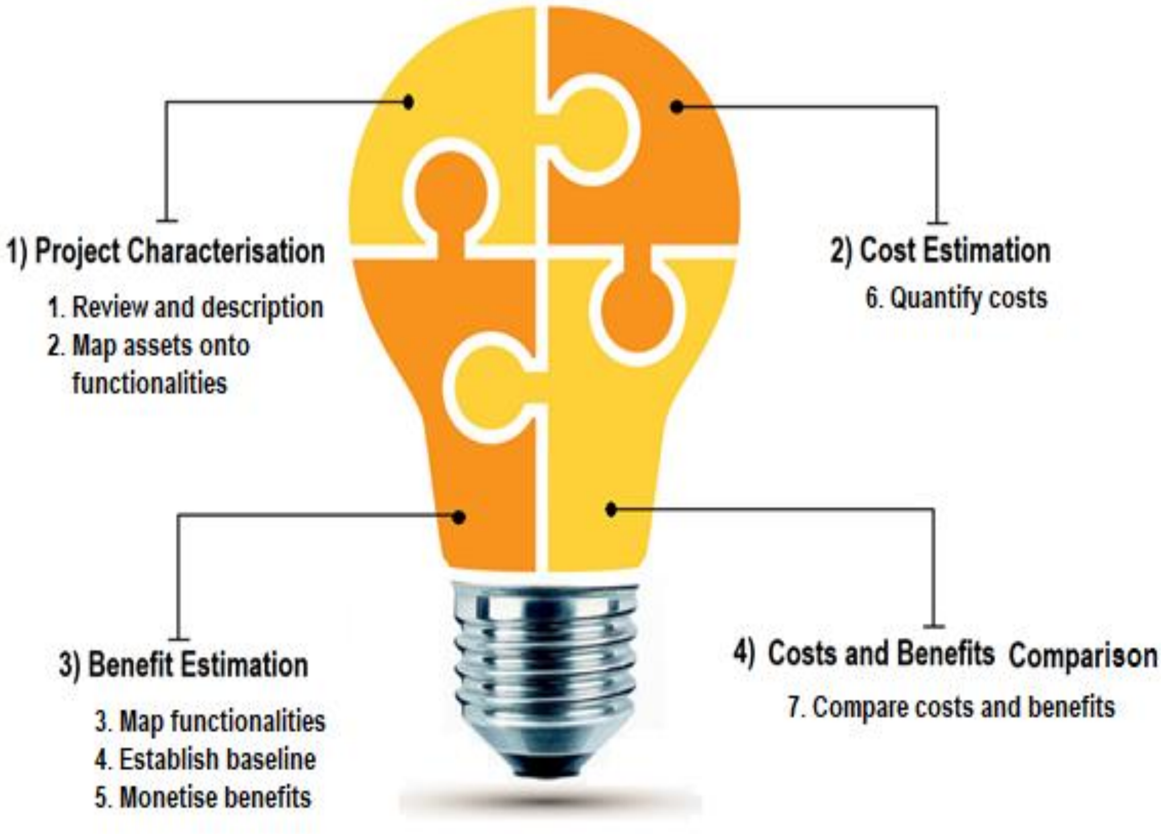

Figure 1: CBA methodology followed in this study

9.1 Project characterization

The project characterisation stage is divided into two steps: 1. Review and describe the technologies, elements and goals of the project, and 2. Map assets onto functionalities. For the first step, the main summary and, elements and goals description are provided: scale and dimension of the project, engineering features, local characteristics of the grid, relevant stakeholders, project objectives and regulatory context. During the second step, the functionalities which are activated by the assets proposed by the project are determined.

9.1.1 Review and description of technologies, elements and goals of the project

ESSs are considered a suitable technology to be coupled with residential PV systems and achieve higher integration of RES into the power generation mixture and at the same time, to provide the desired flexibility to the power grid. The StoRES project with the installation of residential ESSs to certain houses with existing rooftop PV systems, aims to boost self-consumption in the MED region with the integration of optimal storage solutions. The main components of an ESS are the battery unit, the battery inverter and the communication system.

9.1.2 Map assets onto functionalities

Table 1 provides the mapping of ESS assets to functionalities for residential grid-connected ESS projects. The dots in the cells represent the functionalities provided by the project and show which asset activates them.

Table 1: Map of each asset on the functionalities it provides

Assets	**Functionality**				
	Accurate power measurements	Enables communication between components	System control and quality of supply	Store energy	Provide energy
Battery unit				•	•
Battery inverter	•		•		
Communication and management system	•	•	•		
PV system			•		•
Power grid			•	•	•

9.2 Cost estimation

For an Energy Storage installation, there are two types of costs: costs incurred in implementing the project (Capital expenditure - CAPEX) and costs occurring during the project duration (Operational expenditure - OPEX).

9.2.1 Capital expenditure

The CAPEXs or investment costs for a residential ESS include the purchase of the Energy Storage equipment (battery and battery power converter), the metering system including the license of the monitoring portal (once off) and the cost for the ESS installation and assembly. In the present CBA, it was considered that the ESS is added to an existing PV system, as it occurred in the pilot sites, then, the PV purchased cost was not included in the system cost calculations[2].

It has been reported that the battery purchased cost will continue to decrease through the next years. In more detail, it has been predicted that the battery cost will continue to decrease but at a slower pace (32% drop in 2015, 27% in 2016, 16% in 2017, and 14% in 2018), and it has been estimated that the ESS purchased prices are expected to decline at a rate of 8% annually through 2022 [37]–[40]. Additionally, study [41] which examined the future cost of electrical Energy Storage based on experience rates, concluded that even though the prices of storage technologies differ by scope, application and size, the prices will be decreasing with increasing cumulative installed capacities. The electric Energy Storage learning curves as identified by [41] is illustrated in Figure 2. From the figure, it can be seen that the trend of the residential ESS is to fall with the increase of the installed nominal capacity (12±4% for lithium-ion technologies).

[2] With exception Scenario D of Cyprus (Section 6.3.3), which examined the case of adding more PV capacity. In this case, the extra PV cost was included in the system CAPEX.

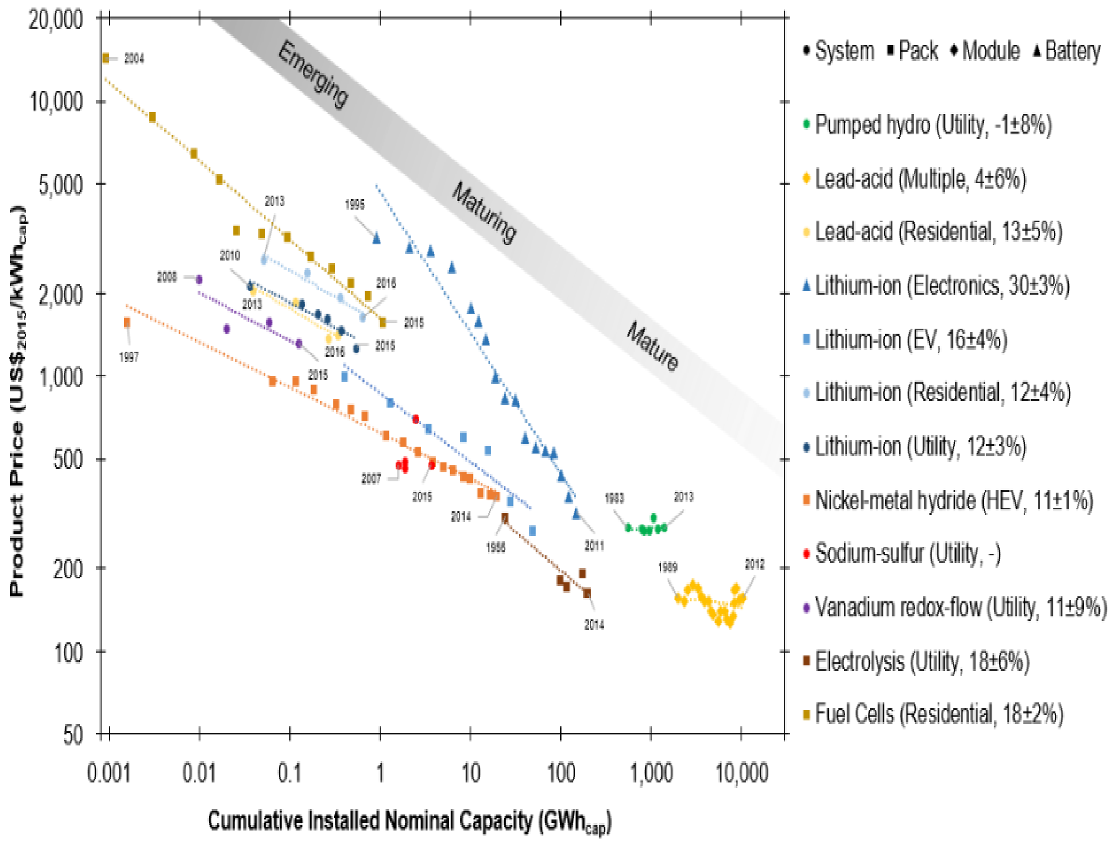

Figure 2: Learning curves of electric ESSs [41]

9.2.2 Operational expenditure

OPEX strongly varies with the power profile, the battery aging, the ESS operational conditions, the level of the battery capacity utilisation, etc. The OPEXs account for i) the maintenance costs which might be caused out of the warranty period (usually 10 years), and ii) the operational battery and inverter costs which are usually caused in the form of power losses. The operational power losses occurred due to the battery internal resistance (which increases through the lifetime of the battery - a side effect of the battery degradation) and to the power converter operational losses (the operational efficiency of the battery power converter depends on the level of the operational power), to the self-discharge losses and to the balancing and communication services. In order for these power losses to be covered, extra energy is needed to be imported from the power grid or/and less energy to be exported to the power grid.

[20] suggested that due to the improved efficiency of the new battery systems, a good estimation of the total maintenance cost for a typical residential ESS will be around €150 per year. According to [42], the OPEXs were estimated to be 2% of the overall investment cost (i.e. for a 2.5kW / 9.8kWh battery system, the OPEX was assumed to be €150 per year, which

is the 2% of the investment cost). This cost will fluctuate year-over-year as the performance and dispatch of the battery change over its lifespan due to the degradation effect (more discussion can be found in Section 5.5).

9.3 Benefit estimation

Currently, energy regulators and utilities assign value to the ESS based on its categorisation; either a generation, transmission, distribution, or end-use resource. This categorisation works well for traditional energy systems, but not for ES, as it falls into all four categories. Hence, if Energy Storage is valued as one resource type, it is artificially undervalued. This study aims to also address potential benefits to all four-system levels and assign a suitable value for the offered services on each level (Scenario E for Cyprus).

As mentioned earlier in this section, the Benefit Estimation is divided into three steps (Map functionalities onto benefits, Establish the baselines, and Monetise benefits and identify beneficiaries), which are analysed below.

9.3.1 Map functionalities onto benefits

The purpose of this second mapping is to link the functionalities identified in Section 4.1.1.2 (Map assets onto functionalities) to the potential benefits they might provide. The potential benefits arising from the installation of a residential ESS found to be: 1. Ancillary services, 2. Distribution network support, 3. Transmission support, 4. Increase of self-consumption, 5. Decrease of peak dependence, and 6. Reduction of the CO_2 emissions. The backup/off-grid function of the ESS was excluded from this study, as it is out of the scope of the project.

1. Ancillary services

Battery ESSs (BESSs) demonstrate great potential in delivering ancillary services to the power grid due to their fast response time (typically within 20 ms [43]). Three are the main applications of the ancillary services: frequency regulation, electric supply reserve capacity and voltage support. Residential BESSs can be used mainly for providing frequency response and mitigate short-term frequency fluctuations, as frequency regulation is mostly a capacity service, with high power and low energy requirements [44]. Despite the fact that the prices for providing such services should be dynamic as the actual energy mix, the level of interconnections, the penetration of RESs, the real-time generation and consumption etc., should be constantly considered, there are few countries that have already launched some static prices for providing ancillary services. Currently, Austria, Belgium, Switzerland, Germany, France, Netherlands and UK have provided support to the power grid by allowing tenders to provide frequency regulation when it is needed [45], [46]. The average benefit per stand-by MW per hour is 14.56€ [44].

On the other hand, [47] suggested that the system cost saving from frequency regulation provision over a week need to be variable; from almost zero in the high net demand conditions to more than £200/MW/h in the low net demand conditions. The same study assumes that the average yearly payment for the capacity market is £80[3]/kW per year for providing frequency regulation and £180/kW per year for providing both arbitrage and balancing services. A SANDIA report of 2010 [48] assumed the following benefits for ancillary services: load following: $7-12/kW/year and voltage support: $40/kW/year. For this study, a 1.456 c€ per kW per hour was assumed to be rewarded to the end-users for providing ancillary services.

2. Distribution network support

The transmission and distribution network can be supported by congestion relief and transmission and distribution deferral. Congestion in transmission systems occurs when the demand for transmission capacity exceeds the transmission network capability. Consequently, transmission systems are becoming congested during periods of peak demand, driving the need and cost for more transmission capacity and increased transmission access charges. A diminishing spare capacity of the power grid and inadequate transmission capability can result in network congestions causing line outage, generator outage, failures of equipment, etc. Typical solutions for avoiding network congestions (which incur additional costs as generation/distribution companies need to change their pre-committed schedules) are: flexible alternating current transmission system devices, sensitivity based generation rescheduling and load shedding [49]. Residential ESSs could offer network congestion relief if they are included into the congestion management and be charged/discharged when it is needed. [50] showed through simulations that despite the high costs of grid-scale batteries, they can offer congestion relief to the power grid by paying back their CAPEX and OPEX, and by reducing the overall congestion relief cost by 3% during their lifetime.

On the other hand, Energy Storage can be used to delay costly transmission and distribution upgrades by deferring the need to upgrade electrical transmission and distribution equipment and/or by extending the life of existing equipment [48]. A key premise for this value proposition is that a small amount of Energy Storage can allow the utility to delay the need for

[3] The currency exchange rate considered in this study can be found in Appendix A.

expensive, demand-growth-related transmission and distribution equipment upgrades or/and reduce demand served by existing equipment such that the equipment's life is extended [51].

[52], which analysed the optimal power flow of Energy Storage for congestion relief, assumed that the financial benefit for each MW provided to the power grid for network relief should be €17-35/MW/h. The financial benefit of storage for equipment upgrade deferral strongly depends on the demand growing, on the load carrying by the existing transmission and distribution equipment, the peak demand served by the equipment, the age of the existing equipment, the degradation equipment rate, the purchased cost of new equipment, etc. [51], by assuming realistic numbers for the aforementioned parameters, estimated that for one-year deferral services, the benefit to storage would be around $460/kW (without regard to time-value of money). For this study, a 2.6 c€ per kW per hour was assumed to be rewarded to the end-users for congestion relieve.

3. Transmission support

ES can be used for transmission support by improving the performance of transmission and distribution system by compensating for electrical anomalies and disturbances such as voltage sag, unstable voltage, and sub-synchronous resonance [53]. Energy Storage can contribute to transmission stability damping, sub-synchronous resonance damping, voltage control and stability, and under-frequency load shedding reduction [48]. A SANDIA report [48] assumed that the benefit provided to an Energy Storage for providing transmission support should be $3/MW/h. For this study, a 0.34 c€ per kW per hour was assumed to be rewarded to the end-users for transmission support.

4. Increase of self-consumption

Through storing the energy produced domestically and then using it when there is not sufficient production, the amount of self-consumed energy domestically increases. According to [54], a house with a residential PV and ESS can increase the percentage of the self-consumed electricity from about 30% without storage to around 60-70%, whereas [55] supports that the increase of the self-consumption with the ESS installation could reach 65-80%. Considering the StoRES project, for the Cypriot pilots, it was calculated that the average PV self-consumption percentage throughout the available dataset duration from the four examined houses is 78% (self-consumption and stored energy). A detailed analysis of the self-consumption increase for all the 35 StoRES pilots can be found in Deliverable 3.6.1 of the project.

5. Decrease of peak dependence

In addition to the flat electricity pricing, most of the EU electricity authorities have launched variable electricity tariffs for the residential sector [56]. According to [57], a day could be divided into peak (from 10 am to 8 pm), mid-peak (from between 7 am to 10 am and 8 pm to 11 pm) and off-peak hours (from 11 pm to 5 pm). [58] found that, for a two-rate pricing scheme with 16% difference between the peak and off-peak tariff and a flat tariff 4% lower than the average of the peak and off-peak tariffs, from the 650 kWh electricity consumption monthly, the 84% of the consumption needs to occur during the off-peak hours in order to pay the same amount under the flat and the Time-of-Use (ToU) pricing schemes. Hence, under the conditions quantified in [58], in order to get advantage from the two-rate pricing, at least 85% of the electricity needs to be consumed during the off-peak period, which is almost impossible for a conventional house. However, a residential ESS has the capability to shift electricity demand from peak to off-peak hours and hence, to decrease the peak dependence.

6. Reduction of CO_2 emissions

By integrating renewable generation into the power generation mixture, BEESs can contribute to the reduction of the CO_2 emissions and the carbon footage produced by conventional electricity plans. An analysis carried out on behalf of the European Commission suggested that the emissions trading scheme price would follow only a slowly increasing trend until 2025 and a stronger increases thereafter. The predicted prices are the following: €10/tCO2 in 2020, €35/tCO_2 in 2030 and €100/tCO2 in 2050 [59]. In average, each kWhe of electricity generated by conventional power plants produces 0.7kg of CO_2 [60], [61]. On the other hand, the Organisation for Economic Co-operation and Development (OECD), it calculated that for the year 2013, the CO_2 from electricity generation in OECD countries was 0.432kg per kWhe [62]. In this study, a 1.7 c€ reward per kWhe was assumed for integrating RESs into the electricity mix.

Table 2 presents the set of benefits (as identified below) of each functionality illustrated in Table 1. The green rows illustrate the benefits offered to the end-users involved in the StoRES project: Increase of self-consumption and Decrease of peak dependence (Benefits 4 & 5).

Table 2: Map of each functionality onto a set of benefits

Benefits	Functionalities						
	Accurate power measurements	Enables communication between components	System control and quality of supply	Store generated PV energy	Store energy from the grid	Provide energy to the house	Provide energy to the grid
1. Ancillary services (1,456c/kW/h)	•	•	•	•	•		•
2. Distribution network support (2,6c/kW/h)				•		•	
3. Transmission support (0,34c/kW/h)				•		•	
4. Increase of self-consumption				•	•		
5. Decrease of peak dependence				•	•		
6. Reduction of CO2 emissions (1,7c/kWhe)				•		•	•

9.3.2 Establish the baseline

The objective of establishing the baseline is to define the control state that reflects the system conditions - this is the baseline situation against all other scenarios associated with the implementation of the project. The CBA of any action/installation/investment is based on the difference between the Business-as-Usual (BaU) scenario and those associated with the ESS installation. For all the examined countries, Scenario A (the BaU scenario) was common: Scenario A represents the baseline conditions that reflect to what the system condition would have been without the ESS.

For this study, depending on the existing policies and current conditions, different scenarios were investigated for each examined country.

9.3.3 Monetise the benefits and identify the beneficiaries

To quantify the monetised benefits of a certain scenario, all scenarios are compared with the baseline scenario (Scenario A - BaU). The monetary value of a benefit for a certain scenario can be calculated through Equation

1, as the BaU scenario, for most of the examined cases, provides the highest electricity cost to the end-users. The beneficiaries from a service are defined as the ones that benefit from the service and thus, the ones that should pay – the providers should receive the generated revenues.

$$Value(€) = [Condition]_{BaU} - [Condition]_{Scenario\ \#} \tag{1}$$

1. Ancillary services

The value of the ancillary services could be calculated through Equation 2. Beneficiaries of the ancillary services are the system operators and/or the ones that cause the problem, i.e. the intermittent generators, etc.

$$Value_{Ancillary\ Services}(€) = \sum_{n=0}^{N} (Benefit_n\ (\frac{\frac{€}{kW}}{h}) * Standby\ kW_n(kW) * Standby\ duration_n(h)) \tag{2}$$

Where,

n: the number of the ancillary service,

N: the total number of ancillary services provided to the power grid.

2. Distribution network support

The value of the network congestion relief and transmission and distribution deferral could be calculated through Equation 3. The beneficiaries of this application are the transmission and distribution system operators (DSO and TSO) for getting the transmission and distribution technical support.

$$Value\ (€)_{network\ csupport} = Benefit\ \left(\frac{\frac{€}{kW}}{h}\right) * Standby\ kW(kW) * Standby\ duration(h) \tag{3}$$

3. Transmission support

The value of the transmission support and the beneficiaries could be calculated through Equation 3, similar to the distribution network support.

4. Increase of self-consumption

The value of the increase of the self-consumption because of the ESS installation can be monetarised through Equation (4). The bill cost of Equation (4) was calculated by considering the import tariff (including the transport fees, cost of energy, fuel cost, levies, taxation for electricity, the monitoring costs, etc.), the export tariff and the self-consumption tariff of the consumption supplied, the excess energy exported and the self-consumed energy for the corresponding pricing tariff (according to the pricing scheme followed). The beneficiaries of this application are the power grid (less exported and purchased energy) and the end-users (less interaction with the power grid).

$$Value_{self-consumption}(€) = Bill\ cost_{Scenario\ A} - Bill\ cost_{Scenario\ B} \quad (4)$$

5. Decrease of peak dependence

By assuming that a residential ESS can offer the Decrease of peak dependence service, the value can be monetarised through Equation (5). The beneficiaries of this application are the power grid (reduction of peak demand) and potentially the end-users (reduced electricity cost through decrease of peak dependence).

$$Value_{decrease\ of\ peak\ dependence}(€) = Bill\ cost_{without\ shift} - Bill\ cost_{with\ shift} \quad (5)$$

6. Reduction of CO_2 emissions

The value for reducing the CO_2 emissions could be addressed through the penalty/social cost which would have been paid per CO_2 ton, as shown in Equation (6). The beneficiaries of this application are the power grid (avoiding EU penalties for high CO_2 emissions) and society at large (environmental viability).

$$Value_{Reduction\ of\ CO2\ emissions}(€) = Reward/Penalty/Social\_cost\ _{per\ CO2\ ton}(€/ton) * Reduced\ CO2\ tons\ (ton) \quad (6)$$

9.4 Cost and benefit comparisons

After estimating the relevant costs and benefits of a residential ESS installation, the costs and benefits need to be compared. Two different approaches were followed in this study in order to evaluate the cost-effectiveness of the examined project: i) Net Present Value (NPV), and ii) Cumulative comparison.

9.4.1 Net Present Value

This method estimates the potential change in an investor's wealth caused by the investigated project while the time value of money is being included. NPV equals the present value of net cash inflows generated by a project minus the initial investment on the project. In order to apply the NPV, the estimated costs and benefits for each year need to be subtracted, the annual net benefit amount to be discounted and to sum up the discounted values - the positive NPV indicates a profitable investment. For this study, as the cash inflows are uneven each year (costs and benefits are variable through the years), the NPV was calculated through Equation 7. The time horizon of the CBA can be found in Section 5.2.

$$NPV = \frac{R1}{(1+i)^1} + \frac{R2}{(1+i)^2} + \frac{R3}{(1+i)^3} + \cdots - Initial\ Investment \tag{7}$$

Where,

i: discount rate (taken to be 4% for the baseline analysis – see Section 5.1),

R1: net cash inflow during the first period,

R2: net cash inflow during the second period,

R3: net cash inflow during the third period, and so on.

9.4.2 Cumulative comparison

This method presents costs and benefits cumulatively over the study period. This approach is useful in identifying the point when benefits exceed costs, i.e. identifying the breakeven point/year for the investment.

10. Define Boundaries Conditions and Set Parameters

The overall assignment should be tailored to local conditions, as different values of parameters determine different impacts on the costs and benefits quantifications. Definition of assumptions and setting of critical parameters provide the boundary conditions of the undertaken analysis and the system under investigation.

10.1 Discount rate

The discount rate considers the value of money and the risk/uncertainty of anticipated future cash flows. The discount rate is very significant for assessing ESS projects as costs are incurred predominately at the beginning of the project while the financial revenues of the installation are received only in the long-term [33]. According to Article 19 (Discounting of cash flows) for the programming period 2014-2020 of the EU Commission Delegated Regulation (No 480/2014), the European Commission recommended that a 4% discount rate reflects a real reference parameter in the long term [63]. Considering this number, for the benchmark scenario of this study, the discount rate was taken to be 4%. However, as the discount rate varies for different countries, different kind of investments, etc., the impact of the discount rate was under investigation through the sensitivity analysis section (considering discount rate values from 0% to 8% with a 2% step).

10.2 Time horizon of the CBA

It is necessary to estimate for how long the costs and benefits are to be analysed and to properly justify the chosen time period. Despite that the energy infrastructure projects are generally appraised to 25-30 years [64], power electronic devices and batteries come with a 10-year life guarantee. Depending on the number of charging/discharging cycles, the Depth-of Discharge (DoD), the operational conditions, the battery chemistry, etc., on average, a residential battery can last between 10 to 20 years[4].

Specifically for the Cyprus case, the datasheet of the purchased batteries states that they can offer 10,000 cycles for 80% DoD [65]. After statistical analysis of the data of the Cypriot pilots, it was found that the batteries mostly obtain a cycle per day for Cyprus, with average DoD through the year the 65%. For this study, the time horizon of the CBA was taken to be identical to the lifetime of the battery, and thus, it was calculated through

[4] After 15-20years, the battery capacity degrades to 70-75% of the original installed capacity, at which point the battery bank must be replaced. This implies about 365 cycles per year, for 20 years, or 10,000 cycles.

the average operational hours of the battery and the cycles obtained by the StoRES pilots through a calendar year. As the calculated lifetime of the battery through the average operational cycles was found to be higher than the maximum expected calendar lifetime, the time horizon of the CBA was taken to be the 20 years.

10.3 Impact of the regulatory framework

The regulatory framework of each country significantly affects the benefits of the ESSs, as it can restrict or proactive potential Energy Storage services (such as ancillary services), de-incentivise or encourage the Energy Storage investment as a whole or/and provide barriers or supporting schemes for the full exploitation of the Energy Storage installation. In this study, the current regulatory framework of each examined country was taken into consideration, in order to provide recommendations to the actors of the electricity market for the residential ESSs according to the current conditions. Through the undertaken analysis, the impact of the regulatory framework on the distribution of costs and benefits is highlighted.

10.4 Maturity of technologies

Every technology goes through the various life cycle phases; introduction, growth, maturity and decline. The CBA outcomes can be affected by the level of the system parameters maturity, as their purchased cost is strongly related to their life cycle phase. Critical technologies for an ESS include the battery chemistry, the power inverter, the battery controller, the monitor equipment, etc. As the dominant cost for installing an ESS is the battery purchased cost, the cost reduction associated to the battery technology maturity will be considered in this study. More discussion on the battery CAPEX reduction can be found in Section 4.2.1.

10.5 Degradation of equipment

For this report, the real behaviour of the ESSs was considered: the operational ESS losses, the extra imported energy from the power grid because of the power inverter rating, and the reduced exported energy due to the round-trip efficiency of the battery system were included in the financial analysis. For the first 10 years[5] of the ESS operation, it was assumed that the battery does not create any extra operational costs associated to the battery ageing. After the 10th operational year, the aging of the battery, and more specifically, the degradation effect (increase of the battery internal resistance and the restriction of the usable battery capacity)

[5] 10 years were considered as the battery equipment comes with a 10year warranty

was included in the system analysis through an increased OPEX. This OPEX corresponds to the extra energy that needs to be purchased due to the higher battery internal resistance and the less available usable battery capacity. More specifically, for this study, the extra OPEX corresponds to the degradation of the equipment was considered to be zero for the first 10 years of the system operation and then, it was assumed to be increased by 5% each year.

10.6 Power profile

The load consumption of the house and the generated energy of the residential renewable sources (for this study, the installed rooftop PV system) compose the power profile of a house. After the instant self-consumed power, the battery charges or discharges according to the power profile. Thus, the battery charging pattern, and hence the amount of the self-consumed, imported and exported energies is strongly correlated to the power profile of the house.

For this study, the typical power profile for each country was extracted from the residential StoRES pilots. In order to illustrate the impact of the power profile on the financial benefits provided by the ESS installation, the Cypriot typical power profile as extracted from the SmartPV project[6] is examined in Section 7.3.

[6] Details of the project can be found on: http://www.smartpvproject.eu/

11. Case Studies

In this section, the CBA methodology described in Section 4 is applied for the boundary conditions and set parameters defined in Section 5, for the three countries under examination: Italy, Greece and Cyprus. For the needs of this study, algorithms were developed, suitable to analysis the systems under examination.

11.1 Italy

11.1.1 Project characterisation

In Italy, there are 13 residential StoRES pilots with three different installed battery capacity sizes (4/6/8 kWh) and three different PV installed sizes (3/4.5/6kWp). In order to be consistent, for the CBA, four pilots with identical system component sizes were examined. More specifically, the system components of the four pilots are (illustrated in Figure 3):

- **Battery**: SONNEN LiF_ePO_4 4kWh usable / 2.5kW maximum power battery,
- **Power Inverter**: 1-ph 2.5kW rated power at 220V / 50Hz - AC coupling,
- **Communication system**: Energy Manager, SONNEN Portal and Smart Meter device - remote control via mobile app,
- **PV system**: 3 kWp PV rooftop system, installed at 30^o,
- **Residential load**: electricity consumption of the house,
- **Power grid**: all the system components are connected to the power grid via a common bus

The overall reference architecture of the StoRES residential installations in Italy, highlighting the connections between the system components can be seen in Figure 4. The ESS operates under the self-consumption mode (the battery utilises solar energy to feed first the consumption loads and then to charge the battery with the excess generated energy). AC-coupled systems were used to avoid changes in the PV power production measure and consequent losses in the incentives tariffs received for all the PV energy production (incentive scheme “Conto Energia”, since 2007 to 2012).

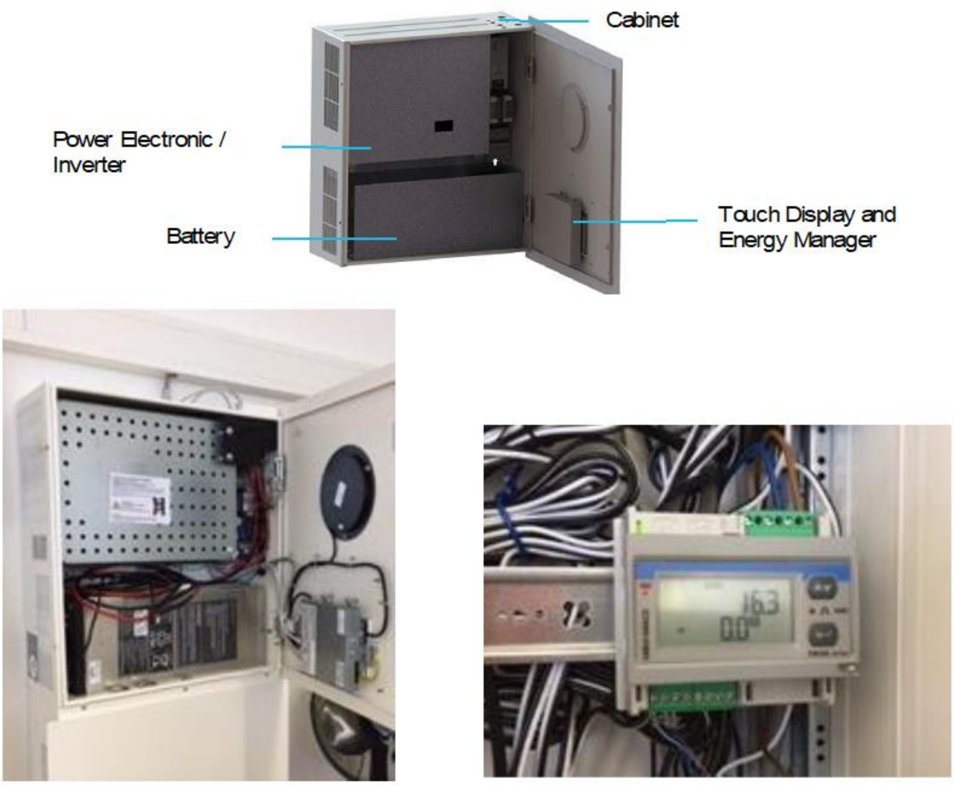

Figure 3: ESS components of the StoRES pilots in Italy: battery inverter, battery unit, energy manager device and power meter device

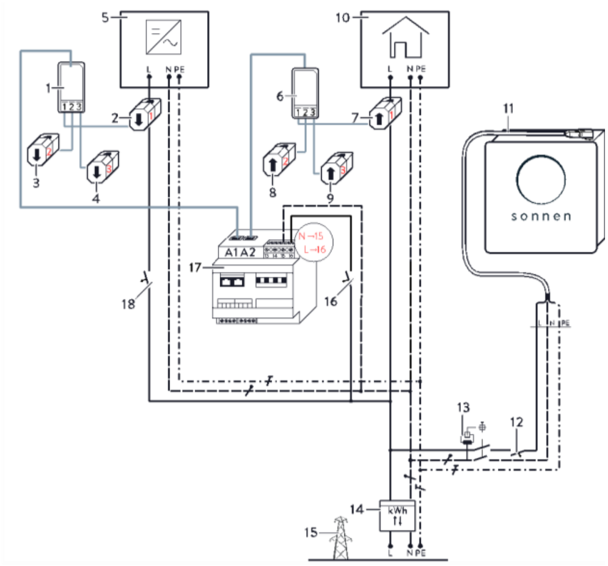

Figure 4: Interconnections of the system components (Italy)

11.1.2 Cost estimation

The overall purchased and installation cost of each residential ESS in Italy as identified during the StoRES project was €1,260/kWh in 2018 (10% VAT and power inverter purchased cost and installation costs are included).

11.1.3 Benefit estimation

To estimate the financial benefits from the ESS installation, the electricity cost before and after the installation were identified. More specifically, for the Italy case, two scenarios are investigated:

Scenario A: Presents the baseline conditions that reflect to what the system condition would have been without the ESS (house contains only the installed rooftop PV system (3kWp) - BaU)

Scenario B: Illustrates the realised and measured conditions with the ESS (current StoRES house with PV and ESS)

Currently in Italy, only the Net-Metering scheme, which is based on energy credits through a year, is applicable for residential PV systems. The current residential electricity charge (electricity tariff) and export benefit for each imported and exported kWh is 0.21957 €/kWh. Depending on the month that the energy credits are zeroed, the annual electricity cost varies. For this study, three different cases are examined:

- **Case i)** Electricity authority allows negative monthly electricity bills,
- **Case ii)** Top-up month is October, and
- **Case iii)** Top-up month is January.

The electricity cost of each month and the annual electricity cost for the three examined cases for Scenarios A and B can be found in Appendix B.

11.1.4 Costs and benefits comparisons

As the ESSs in Italy examined under the current Net-Metering scheme, installing a residential ESS to the existing PV system does not provide any financial benefit to the end-users. PV systems under the Net-Metering scheme can be seen as systems connected to a virtual infinity ideal battery. In order to cover the power losses of a real ESS (battery and the inverter power losses), extra energy needs to be purchased from the power grid and lower charging and exported energy will be occurred. Hence, under the Net-Metering scheme, the electricity cost is higher when an ESS is installed. For Italy, the annual difference on the prosumers' electricity bill between Scenario A and B for the three examined metering cases quantified as below:

- **Case i)**: Scenario B- Scenario A = **132.75€** (percentage loss: 78%)
- **Case ii)**: Scenario B- Scenario A = **29.64€** (percentage loss: 26%)
- **Case iii)**: Scenario B- Scenario A = **9.45€** (percentage loss: 9%)

The 78% difference appears for Case i) is due to the negative electricity bill allowance. By allowing negative electricity cost, the total contribution of the power losses on the annual electricity cost of a real ESS over the 'infinite virtual ESS' offered by the Net-Metering scheme are quantified. On the other hand, for Cases ii) and iii), because the electricity bill does not allow negative values and any excess energy is topped-up on the next monthly electricity cost, for most of the months, the electricity bill is equal to the fixed costs, and hence, the impact of the power losses is not significant on the annual electricity cost.

Overall, Scenario B provided higher monthly electricity bills compared to Scenario A. Hence, installing an ESS under a Net-Metering scheme does not provide any financial benefits to the end-users, as because of the ESS power losses, the monthly electricity cost increases. By investigating three sub-categories of the Net-Metering scheme, it was found that the greater financial loss is occurring when the electricity authority allows negative electricity bills (78% income loss) and the lowest one, when the top-up period starts in January (9% income loss). The results would be more encouraging, with more benefits for the owners, if the consumption were higher.

Italy recently has launched two schemes in order to promote residential ESSs: a) a 50% subsidy on the ESS purchase cost, and b) an income tax deduction. In order for the 50% subsidy on the ESS purchased cost to become a proper driver for installing an ESS in Italy, a different scheme that promotes the ESS needs to be applied for the residential PV and ESSs. On the other hand, adding an income tax deduction can create a business case for residential ESSs if the amount of the income tax deduction is at least equal to the electricity bill increase created by the ESS power losses plus the operational and capital expenses associated with the ESS installation.

11.2 Greece

11.2.1 Project characterisation

In Greece, there are five StoRES pilots of which, only one is a residential system. The system components of the examined residential system are the following:

- **Battery**: Fronius LiF_ePO_4 7.5 kWh nominal / 6kWh usable / 4kW maximum power battery,
- **Power Inverter**: 3-ph 5kW rated power, AC coupling,
- **Communication system**: Energy Manager, Ianitza Portal and Smart Meters - remote control via mobile app,
- **PV system**: 5 kWp PV rooftop system,
- **Residential load**: electricity consumption of the house,

- **Power grid**: all the system components are connected to the power grid via a common bus.

The ESS examined under the increase of self-consumption mode - the prior action for the battery is to utilise the generated energy.

11.2.2 Cost estimation

The overall purchased and installation cost of the residential ESS in Greece as identified during the StoRES project was €900/kWh plus VAT.

11.2.3 Benefit estimation

To estimate the financial benefits received through the ESS installation, the electricity cost before and after the installation were identified for two different schemes. More specifically, for the Greece case, three scenarios are investigated:

Scenario A: Presents the baseline conditions that reflect to what the system condition would have been without the ESS (house contains only the installed rooftop PV system (5kWp) - BaU)

Scenario B: Illustrates the realised and measured conditions with the ESS (current StoRES house with PV and ESS under the partial Net-Metering scheme)

Scenario C: Proposes a revised electricity pricing scheme based on the charging time-slots suggested from SmartPV project

Currently, the ESSs in Greece are under a partial Net-Metering scheme. Additionally, the imported and exported tariffs increase for imported or exported energy above 2,000 kWh per quarter. The tariffs applied in this study, which were valid until summer 2019, are: for imports, from 15.582c€//kWh to 16.4512c€//kWh, and for exports, from 10.027c€/kWh to 10.867c€/kWh. In order to quantify the difference on the electricity cost caused by this price increase, for Scenarios A and B, two cases were examined: i) without considering the increase of the prices, and ii) by considering the increase of the prices for energies above 2,000 kWh per quarter. The electricity cost of each month and the annual electricity cost for Scenarios A - C can be found in Appendix B.

11.2.4 Costs and benefits comparisons

Despite that both the imported and exported prices increase for energy above the 2,000 kWh per quarter, the electricity cost found to be higher for case ii) for both Scenarios A and B. More specifically, the prices increase above 2,000 kWh, added to the annual electricity cost €43.94 for Scenario A and €40.55 for Scenario B. The annual electricity cost for Scenario C lies between the two calculated electricity costs of Scenario B. More specifically, Scenario C gives a lower annual electricity cost compared to Scenario B which includes the increase of the prices for energies above 2,000 kWh per quarter, and a higher electricity cost compared to Scenario B when the prices do not change with the consumed and exported amount of energy.

The difference between Scenarios A and B was quantified to be €76.25 and between Scenario A and C €92.75. These differences are not sufficient to payback the ESS by considering a 20-year system operation, as for both scenarios, the NPVs found to be negative. The outcome of the cumulative comparison of costs and benefits for Scenarios B and C can be seen in Figure 5 and 6 respectively.

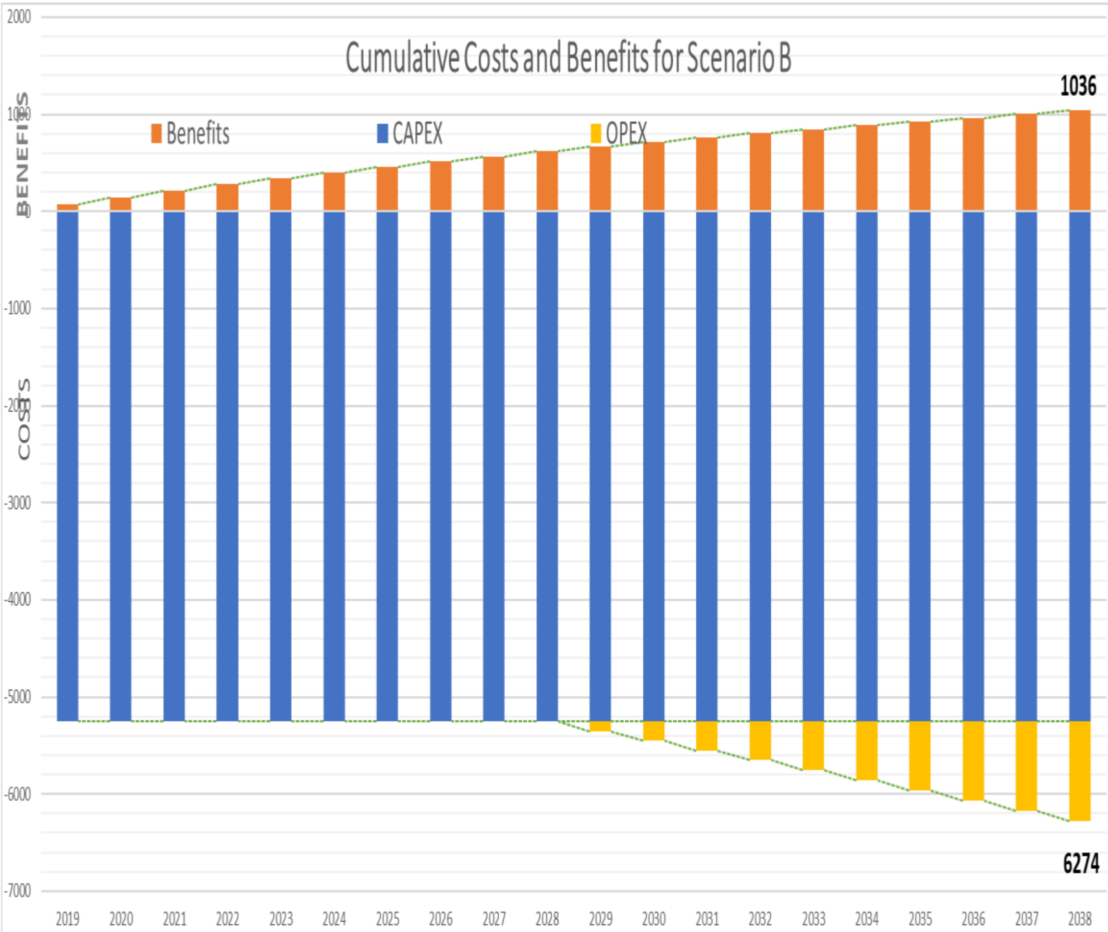

Figure 5: Cumulative costs and benefits for Scenario B (Greece)

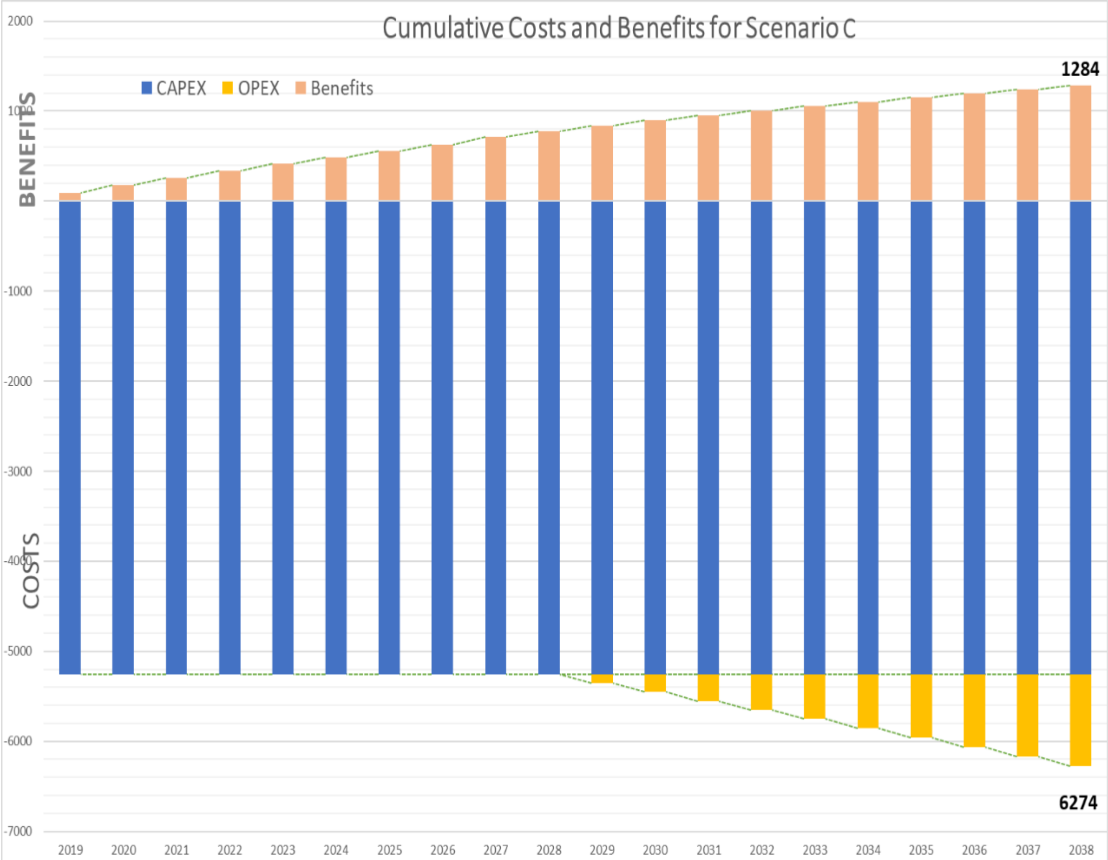

Figure 6: Cumulative costs and benefits for Scenario C (Greece)

11.3 Cyprus

11.3.1 Project characterisation

The four residential StoRES pilots of Cyprus are examined in this section. The system assets include (illustrated in Figure 7):

- **Battery unit**: LG Chem RESU 10H, 5kW maximum power, 9.8kWh installed capacity - 9.3kWh usable energy capacity (component 2 of Figure 7),
- **Battery inverter**: SMA Sunny Boy Storage 2.5, 1-ph, 2.5kW rated power at 230 V, 50 Hz – AC coupling (component 1 of Figure 7),
- **Communication and management system**: Sunny Home Manager 2.0 (component 3 of Figure 7), Sunny Portal and Energy Meter device (component 4 of Figure 7),
- **PV system**: 3kWp PV rooftop system, with south surface orientation at 30^o inclination,
- **Residential load**: electricity consumption of the house,
- **Power grid**: all the system components are connected to the power grid via a common bus.

Figure 7: ESS installed in Cyprus during SToRES project: (1) 2.5kW battery inverter, (2) 9.8 kWh battery unit, (3) Home Manager device and (4) Energy Meter device

The overall reference architecture of the StoRES residential installations, highlighting the connections between the system components can be seen in Figure 8.

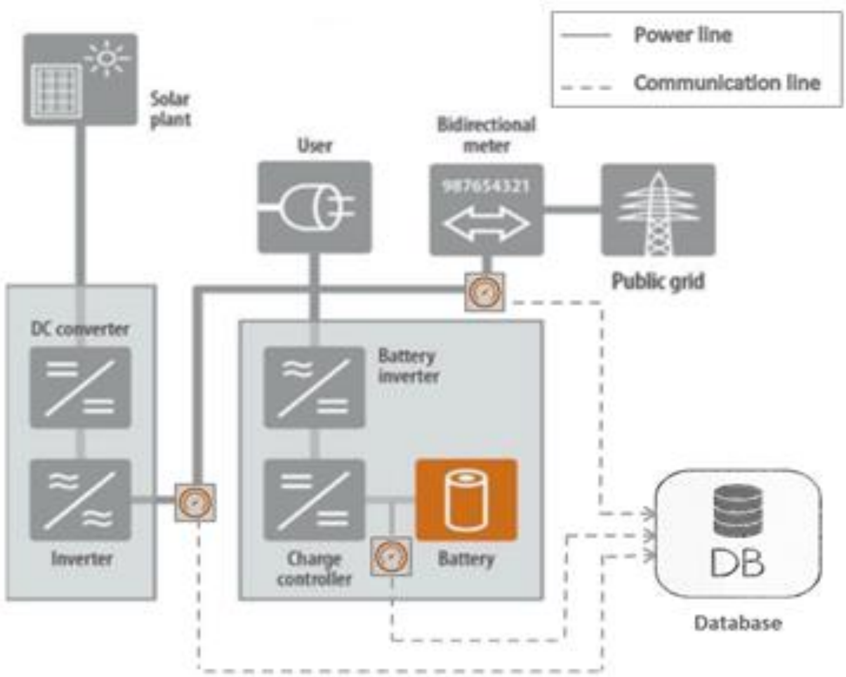

Figure 8: Interconnections of the system components

11.3.2 Cost estimation

The overall purchased and installation cost of the residential ESS in Cyprus as identified during the StoRES project was €800/kWh under a tender process obtained in 2017. This cost includes the battery purchased cost, the battery inverter purchased cost, the installation cost, the monitoring and management system cost and installation, the portal licence (unlimited), a year of full warranty for any technical support, and 10-year warranty for the complete installed system. The purchased and installation cost for extra PV capacity was taken to be €1,250/kW in 2019 (including VAT).

11.3.3 Benefit estimation

To estimate the financial benefits received through the ESS installation, the electricity costs before and after the installation were identified for different cases. More specifically, for the Cyprus case, five scenarios are investigated:

Scenario A: Presents the baseline conditions that reflect what the system condition would have been without the ESS (house contains only the installed rooftop PV system (3kWp) - BaU)

Scenario B: Illustrates the realised and measured conditions with the ESS (current StoRES house with PV and ESS under either the Net-Billing scheme or the Self-consumption scheme)

Scenario C: Proposes a revised electricity pricing scheme based on the charging time-slots suggested by the SmartPV project

Scenario D: Investigates the current revised PV capacity installed allowance in Cyprus[7] when adding a residential ESS to an existing PV system

Scenario E: Suggests a full exploitation of the installed battery capacity by stacking the battery benefits in order to use the unutilised battery capacity to provide services to the power grid[8]

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[7] Since 2013, the residential PV installed capacity in Cyprus has changed from 3kWp, to 5kWp and now (2019) is at the 10kWp. However, the PV installed capacity needs to be equal to the annual house consumption in order to restrict the exports. For Scenario D, it is suggested to allow a larger PV system (maximum allowed capacity the existing PV allowance) if an ESS is installed at the house. Source: http://www.moa.gov.cy/moa/environment/environmentnew.nsf/all/8D6EF81F38772607C225829400343871/$file/NECP_190123_1320_clean.pdf?openelement

[8] For Scenario E, it is assumed that all the benefits associated with a residential ESS installation (as quantified in Section 4.3.1) can be exploited, and hence, the installed ESS can be fully utilised by offering the unexploited battery capacity to the power grid for providing services and getting financially rewarded.

The existing Net-Billing[9] and Self-consumption[10] schemes are currently available only for the industrial and commercial consumers with an installed PV system. For the needs of this study, it was assumed that the examined residential systems are under these two existing schemes (similar to Italy, the residential ESS pilots of Cyprus are currently under the Net-Metering scheme).

The current Self-consumption scheme does not reward the energy exported to the power grid, and does not charge the self-consumed energy – only charges the imported energy. On the other hand, the current Net-Billing scheme has three tariffs: 1) the imported tariff, which is applied on the imported energy, 2) the exported tariff, which is applied on the exported energy and 3) the self-consumption tariff, which is applied on the self-consumed energy[11]. For systems with only PVs, the self-consumed energy is defined as the instant self-consumed energy from the power loads, and it can be calculated by subtracting the generation and the exported energy. When an ESS is installed, there are two types of self-consumption; the instant self-consumption (generation that is instantly consumed by the loads - as for the systems with only PV) and the self-consumption occurred by the ESS installation due to the stored generated energy, which will be consumed by the house later, when it is needed.

In order to identify the impact on the electricity cost when a) only the instant self-consumption is charged and b) when both the instant and stored self-consumption are charged, for Scenarios B-D, the electricity cost for the two different energy charging cases was calculated. Additionally, for the same scenarios, for each of the two energy charging cases, three possible self-consumption pricing tariffs are applied: i) including levies and VAT, ii) excluding levies and include VAT, and iii) excluding levies and VAT.

From the undertaken analysis, it was found that:

- An ESS under the Self-consumption scheme can gain more financial benefits than a system under the Net-Billing scheme. This is due to the decrease of the imported revenues for a PV system, which strongly affects the electricity cost for an ESS under the Self-consumption scheme.
- By charging the stored energy under the self-consumption tariff of the Net-Billing scheme, the annual electricity cost was calculated to

[9] Net-Billing scheme description can be found at: https://www.eac.com.cy/EN/EAC/RenewableEnergySources/Pages/netmetering.aspx

[10] Self-consumption scheme description can be found at: eac.com.cy/EN/CustomerService/Tariffs/Documents/Διατιμήσεις%20Εμπορικής%20και%20Βιομηχανικής%20χρήσης%20από%20Σεπτέμβριο%202017%20μηνιαίες%20από%20Νοέμβριο%202017%20διμηνιαίες.pdf

[11] The self-consumption tariff is charged in order to cover the standby costs of the power grid.

be 12-19% higher (lower difference for the lower self-consumption tariff case) than when only the instant self-consumption is charged.
- For Scenario B - Case i) (ESS is under the current Net-Billing scheme and the levies and the VAT are included to the self-consumption tariff), when both the instant self-consumption and stored energy are charged, it was found that, the benefits received from the ESS installation cannot cover the OPEX over the system operation lifetime (20 years).
- It was quantified that by applying a different variable pricing scheme under the same pricing principles, the annual electricity cost does not vary significantly (annual electricity difference between Scenario B – Net-Billing and Scenario C for the power profile under investigation: €3). More specifically, for October-February, the electricity cost was found to be lower for the existing Net-Billing, for March-June, the electricity cost was the same for both schemes as it was equal to the constant costs due to the excess exported energy, and for July-September, the electricity cost was lower for the proposed pricing scheme.
- Scenario D provides the lowest electricity cost to the end-users and hence, the highest difference compared to Scenario A. However, there are extra costs associated with the purchase and installation of the additional PV capacity that need to be included in the CBA.
- By offering the unutilized battery capacity to the power grid (Scenario E), it was calculated that €408 per year could be offered to the end-users, in addition to the benefits received from the self-consumption. Again, there are costs associated with this Scenario, such as purchasing and installing the required power electronics, controllers, etc., that need to be included in the costs.

11.3.4 Costs and benefits comparisons

The NPV for all the examined cases (Scenarios B-D) found to be negative ($\sim 10^3$ for the Net-Billing scheme, and $\sim 10^2$ for the Self-consumption scheme), and hence, they could not offer any financial benefits to the end-users over the system lifetime with the current examined conditions.

Combining the benefits received from Scenario E (utilisation of the unusable battery capacity to offer services to the power grid), could potentially create a positive NPV for the examined scenarios, and hence, to offer a profitable investment. Among the examined scenarios and cases, the ones that after being combined with Scenario E have still a negative NPV found to be: Scenario B i) and ii) and Scenario C i)-iii), when both the instant self-consumption and stored energy are charged.

Figures 9 and 10 illustrate the average cumulative costs and benefits for Scenario B under the Net-Billing scheme, by assuming an installed ESS at the beginning of 2019, which operates for 20 years. Figure 9 presents the costs and benefits, if only the instant self-consumption is charged for the three examined self-consumption cases: **i)** the current Net-Billing scheme is applied, **ii)** the levies are excluded from the self-consumption tariff, and **iii)** the levies and the VAT are excluded from the self-consumption tariff. Figure 10 illustrates the cumulative costs and benefits when both the instant self-consumption and the stored energy are charged. Similarly, Figure 11 shows the cumulative costs and benefits for Scenario B under the Self-consumption scheme. Then, Figures 12 and 13 show the cumulative costs and benefits of Scenario C, when only the instant self-consumption is charged (instant) and when both the instant self-consumption and the stored energy are charged ("Both") respectively.

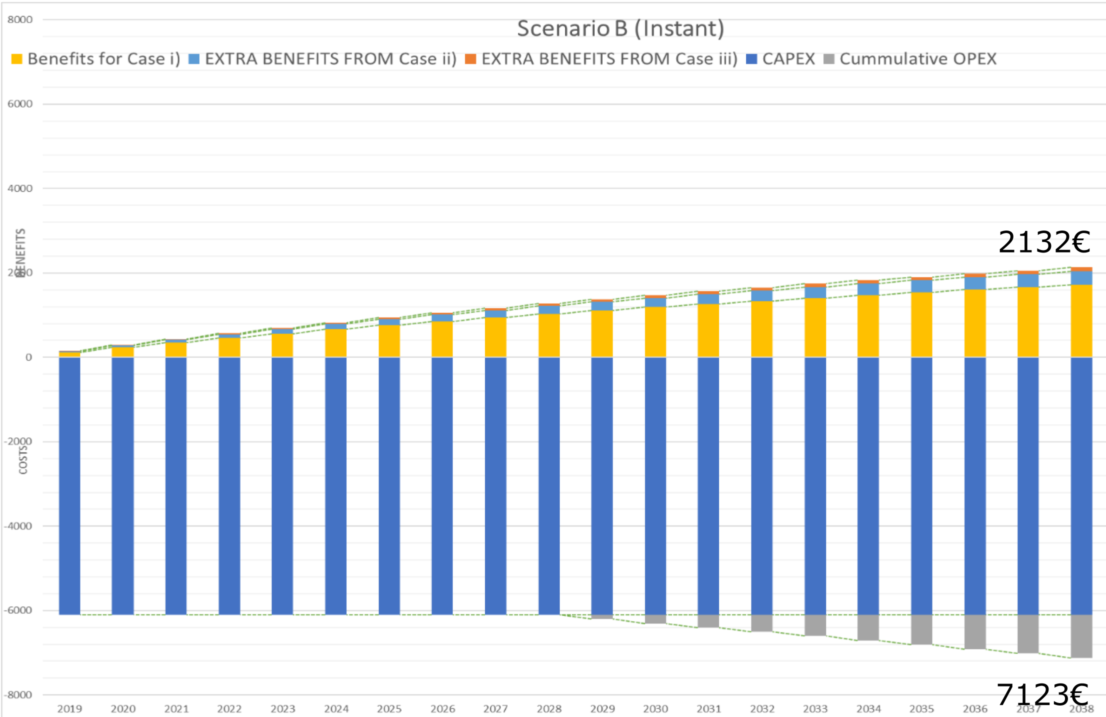

Figure 9: Cumulative costs and benefits for Scenario B under the Net-Billing scheme when only the instant self-consumption is charged (Cyprus)

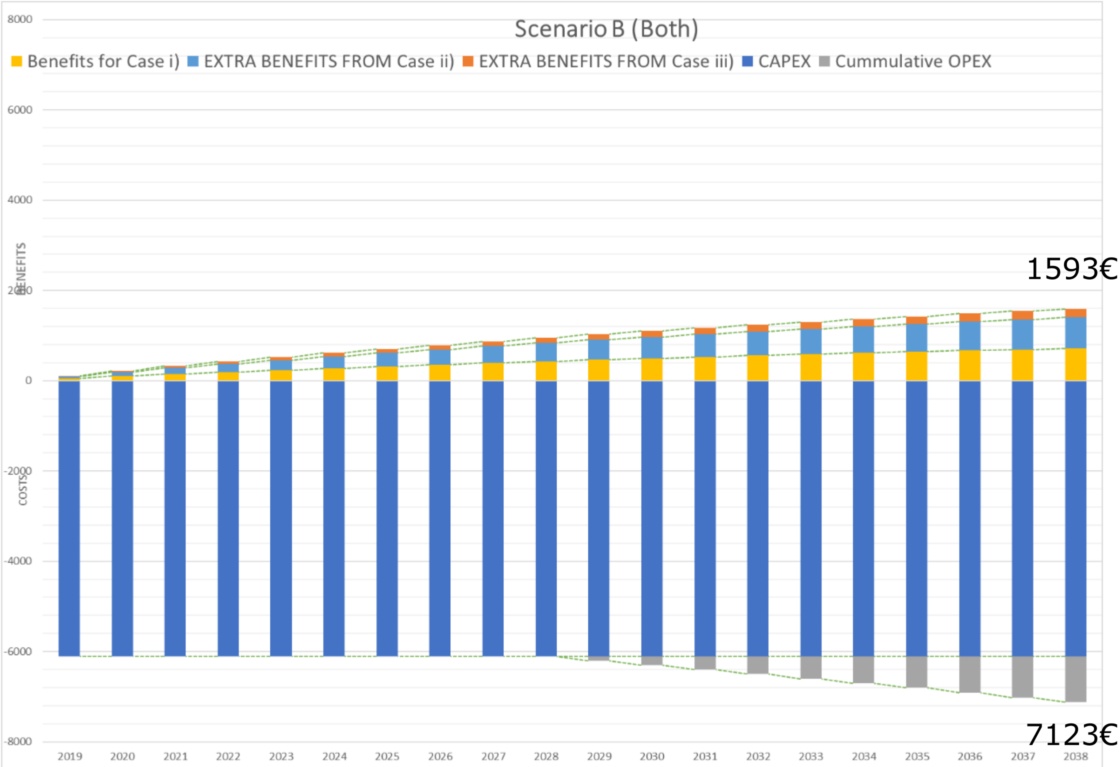

Figure 10: Cumulative costs and benefits for Scenario B under the Net-Billing scheme when both the instant self-consumption and stored energy are charged (Cyprus)

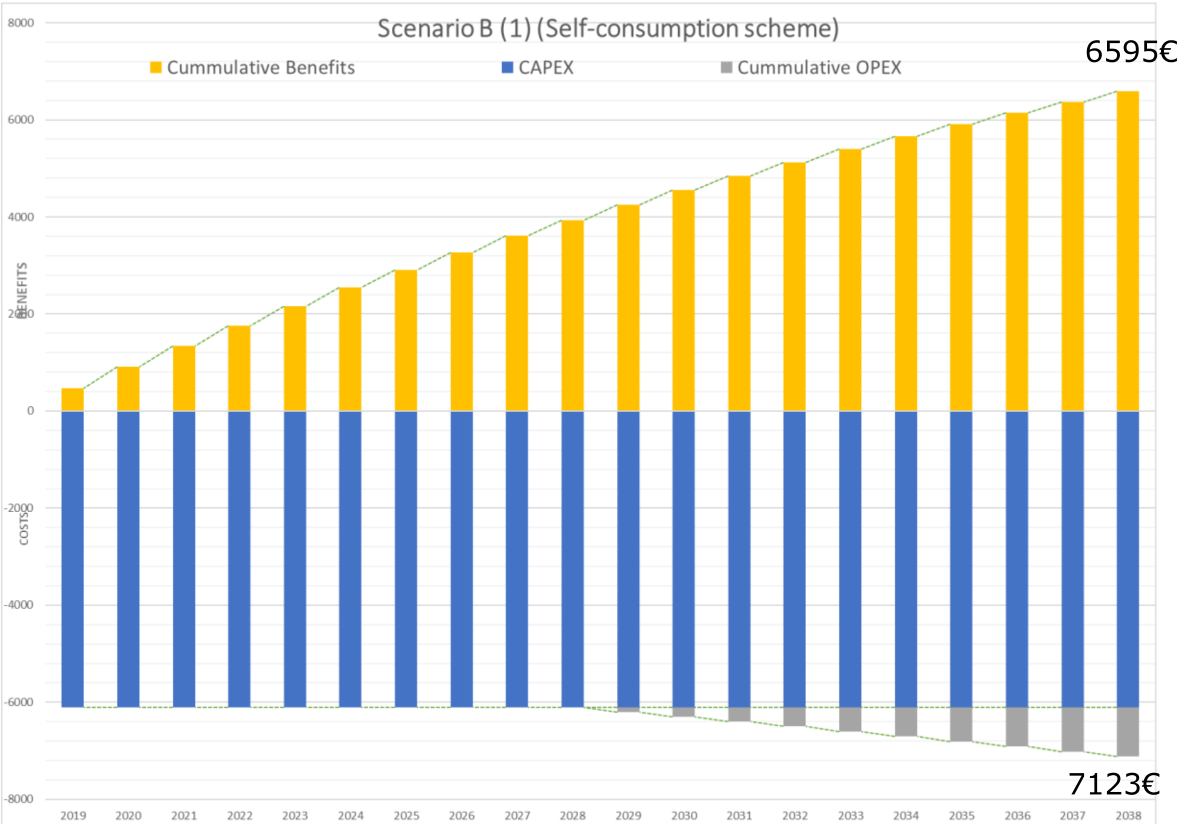

Figure 11: Cumulative costs and benefits for Scenario B under the Self-consumption scheme (Cyprus)

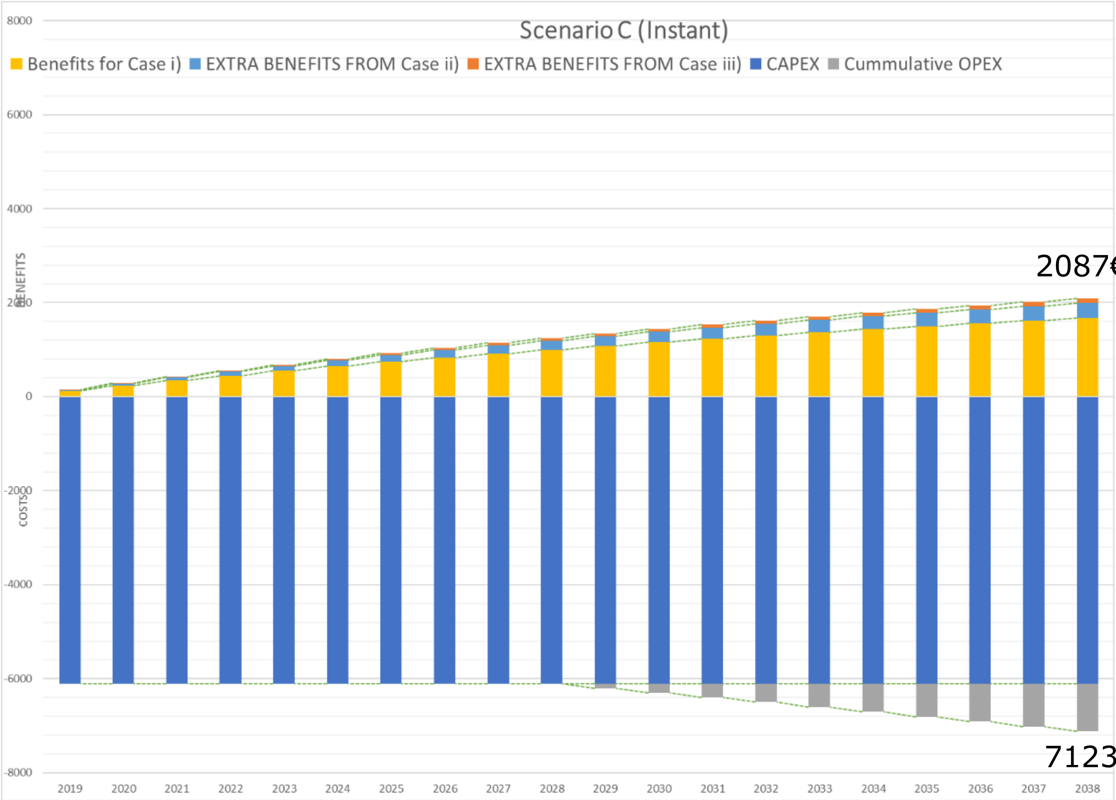

Figure 12: Cumulative costs and benefits for Scenario C when only the instant self-consumption is charged (Cyprus)

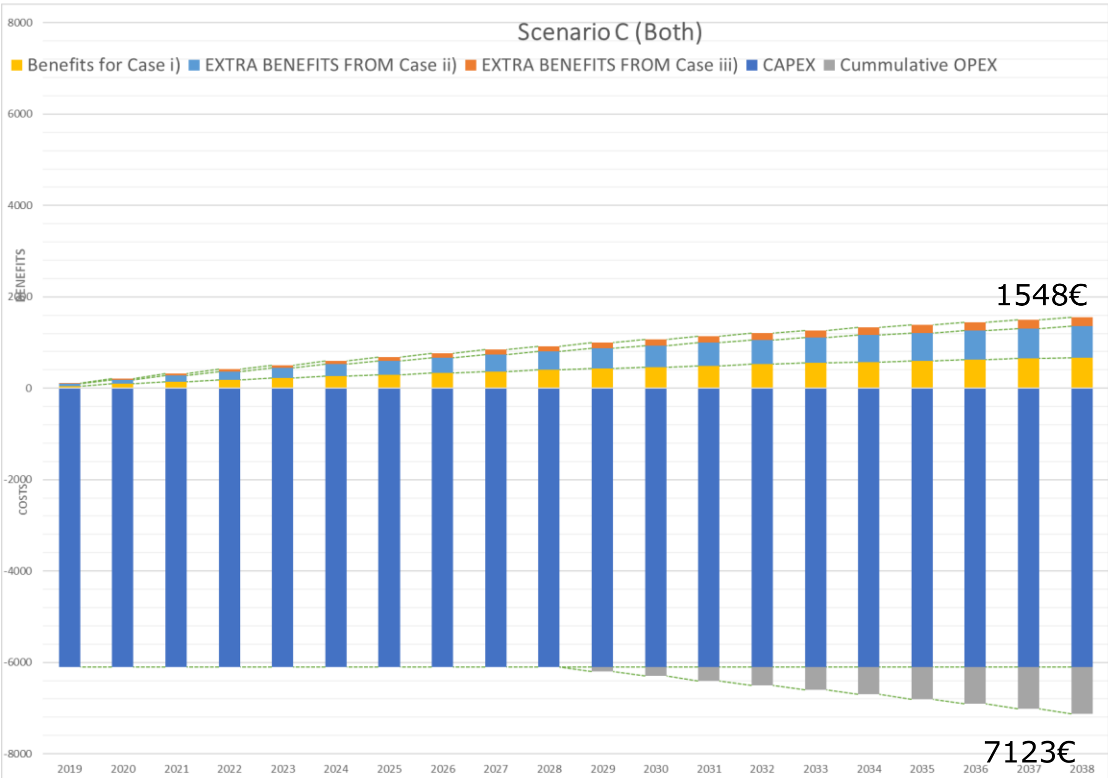

Figure 13: Cumulative costs and benefits for Scenario C when only the instant self-consumption is charged (Cyprus)

For Scenario D, in addition to the ESS CAPEX, the extra installed PV capacity was included in the costs. Figures 14 and 15 depict the cumulative costs and benefits for Scenario D for the three examined pricing cases for the Net-Billing scheme. As illustrated in Figure 14, there are no extra benefits for excluding the levies and the VAT from the self-consumption tariff. This is due to the annual electricity cost that is equal to the constant costs because of the high excess PV energy.

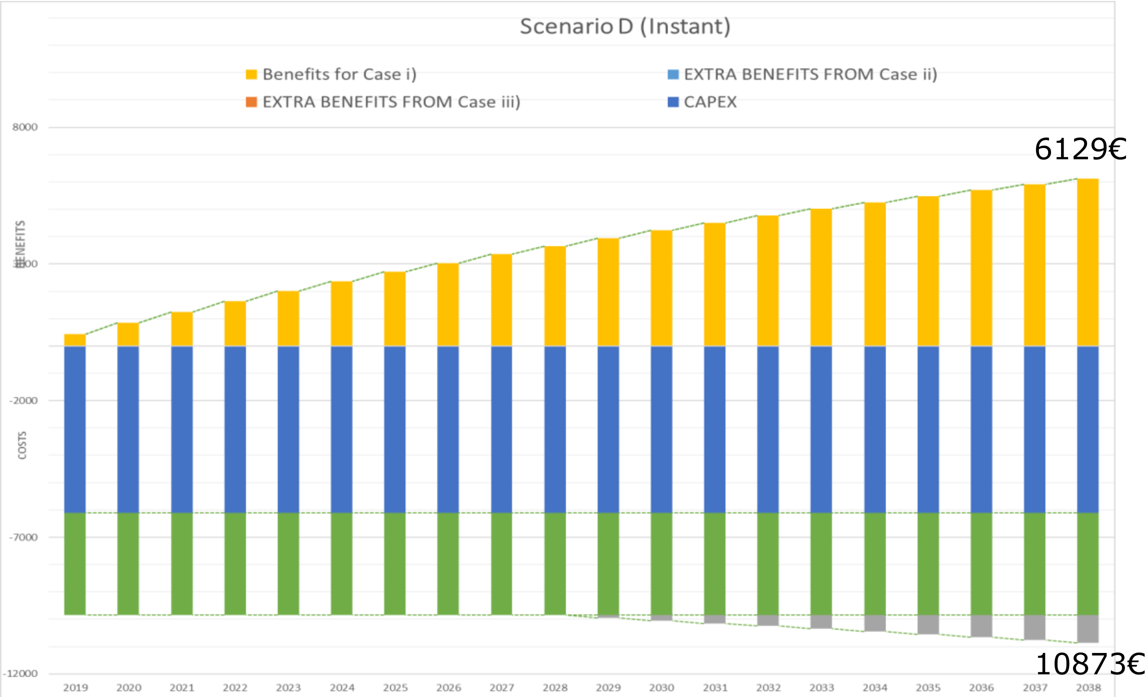

Figure 14: Cumulative costs and benefits for Scenario D when only the instant self-consumption is charged (Cyprus)

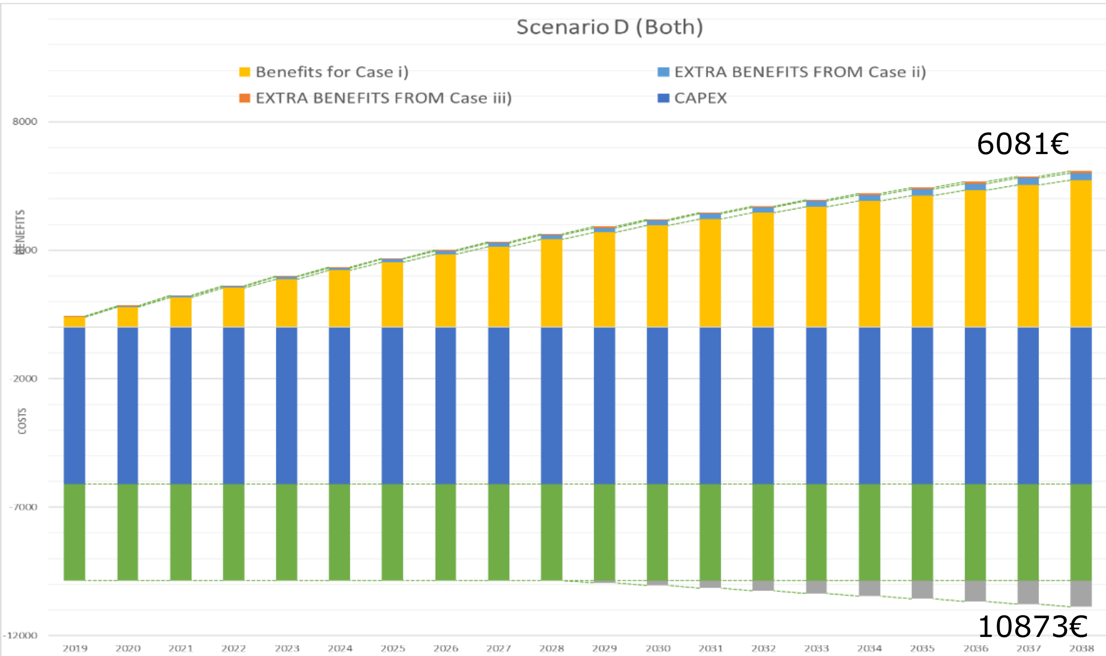

Figure 15: Cumulative costs and benefits for Scenario D when only the instant self-consumption is charged (Cyprus)

12. Sensitivity Analysis

A CBA is based on predictions and estimated variables, such as costs associated with the installation, financial benefits, discount rate, etc. The values of these indicators used are those predicted to be the most probable to occur in the near and long future based on the current literature, existing conditions, statistics and forecast techniques. However, as the prediction period is long (20 years) and some of the scenarios are potential future scenarios, the estimated values could differ significantly from the values actually realised. Further ESS development depends on a great number of factors, which is the reason of taking into consideration changes in key variables and of the profitability of the project. Thus, a sensitivity analysis is performed in order to identify the impact of the critical parameters to the system financials. A sensitivity analysis indicates to what extent the profitability of a project is affected by variations in key quantifiable variables. The goal of the sensitivity analysis is to find the range of variables leading to a positive outcome of a CBA. This requires to identify the switching value of the main critical values.

The sensitivity analysis of this study took as benchmark, the parameters of the year 2019and the assumptions listed in Appendix A.

12.1 Capital expenditure

From the literature, it was found that the CAPEX of the batteries has fallen and it is predicted that it will keep falling by an average of 8% each year (discussion can be found in Section 8.2.1). The reduction of the CAPEX was investigated, in order to identify the percentage decrease, which offers positive revenues to the end-users for a residential ESS installation in 2019. Figure 16 illustrates the NPVs for Scenarios B-D by assuming a yearly 8% CAPEX reduction for a 20-year operational period. It was found that only two scenarios can provide a positive NPV for a reasonable CAPEX reduction (maximum CAPEX reduction examined compared to the 2019 price: 65%). More specifically, Scenario B under the Self-consumption scheme can provide revenues to the end-users, if the CAPEX falls by 12% compared to the 2019 prices – this percentage drop is estimated to happen in mid-2020. On the other hand, Scenario D can be profitable with the CAPEX estimated to occur in 2027 and 2028 (a 49% and a 53% reduction respectively compared to the 2019 CAPEX level) depending on the self-consumption tariff applied and on which energy is under the self-consumption tariff. For Scenario D, it was assumed that both the battery and the PV CAPEX reduce with the same rate over the years.

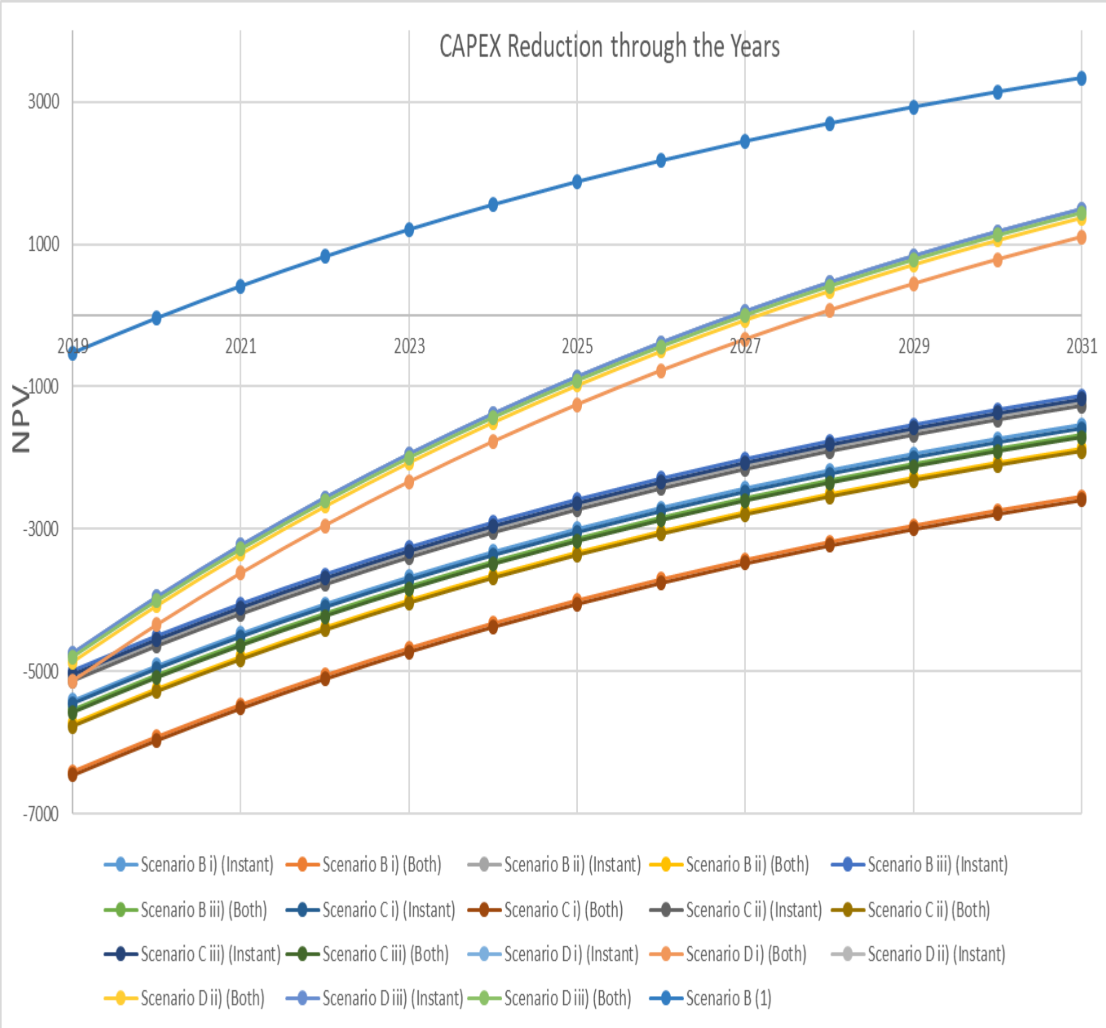

Figure 16: Sensitivity analysis on ESS CAPEX

12.2 Discount rate

The discount rate is an important factor to be examined as it accounts for the rate of return used in a discounted cash flow analysis in order to determine the present value of the future cash flows. For this reason, a sensitivity analysis was obtained on the discount rate of this study. The baseline discount rate was considered to be 4% (discussion can be found in Section 5.1). For the sensitivity analysis, the range of the discount rate considered was 0-8% (the 0% discount rate was investigated in order to depict the existing negative interest rated in some EU countries). Figure 17 illustrates the NPVs for Scenarios B-D for different discount rates. As it can be seen, for all the examined scenarios except Scenario B under the Self-consumption scheme, the NPV at the end of the system lifetime (20 years) is negative, and hence, a reduction of the discount rate is not enough in order to provide profitability for such investment and the examined conditions. For Scenario B under the Self-consumption scheme, if the discount rate is 3% or less, then the installation of an ESS would be beneficial.

In addition, as it can be seen from the figure, except Scenario B under the Self-consumption scheme and Scenario D, for the rest scenarios, the NPVs slightly increase with the increase of the discount rate. This is because the overall financial benefits received do not compensate the OPEXs. As the OPEX associated with the equipment degradation occurs after the 10th operational year, an increase on the discount rate results to a less impact of the OPEX on the NPV.

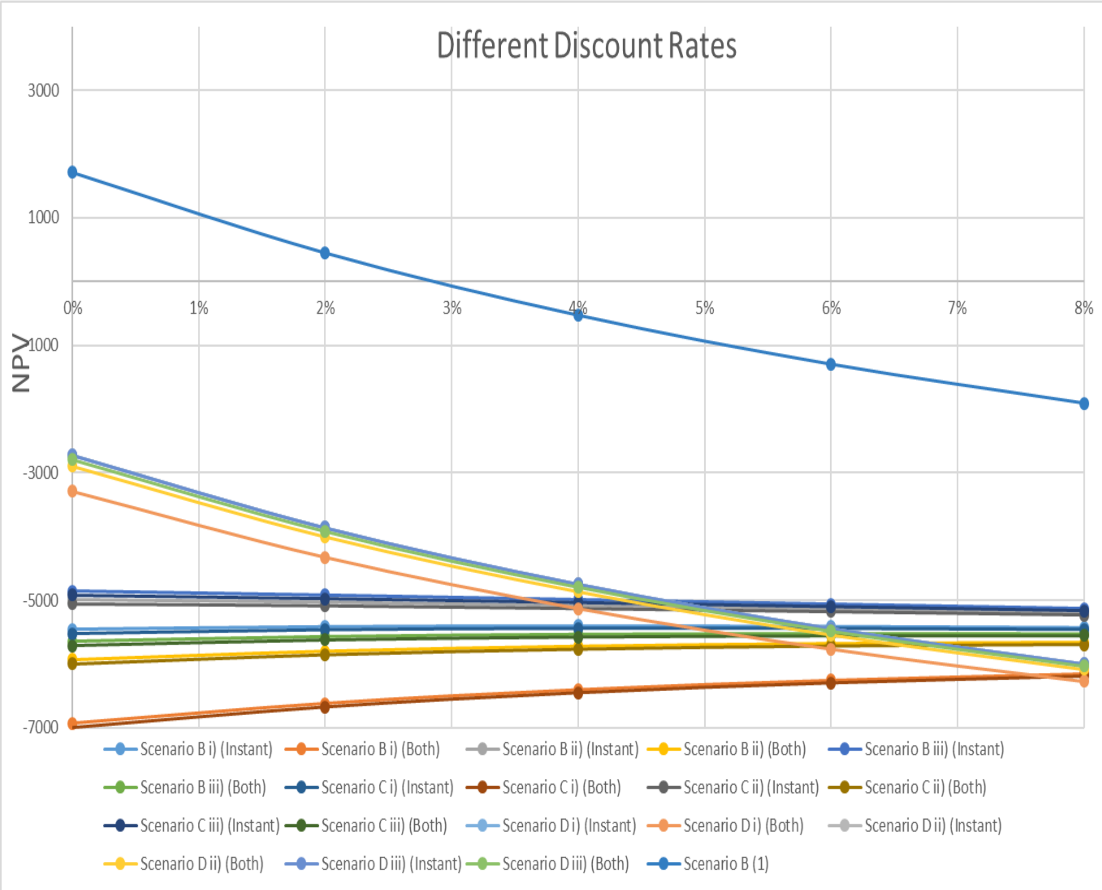

Figure 17: Sensitivity analysis on the discount rate

12.3 Power profile

The power profile significantly affects the outcome of the CBA, as depending on the consumption and generation power profile, the battery charging pattern varies, and so the benefits received from the ESS installation. In order to understand the impact of the power profile on the CBA outcomes, the typical consumption and generation power profile for Cyprus[12] is examined under Scenario B. Similar to Figures 9 and 10, which illustrate the cumulative costs and benefits for the StoRES pilots, Figures 18 and 19 show the cumulative costs and benefits for the typical power profile in Cyprus, for the instant self-consumption charging (Figure 18) and when

[12] The typical power profile for Cyprus was extracted from the SmartPV project.

both the instant self-consumption and the stored energy are charged (Figure 19). It was calculated that the overall difference on the financial benefits received from the ESS over the 20 years of the system operation for the two examined power profiles lays between €110 and €220, depending on the self-consumption charged energy and the applied tariff.

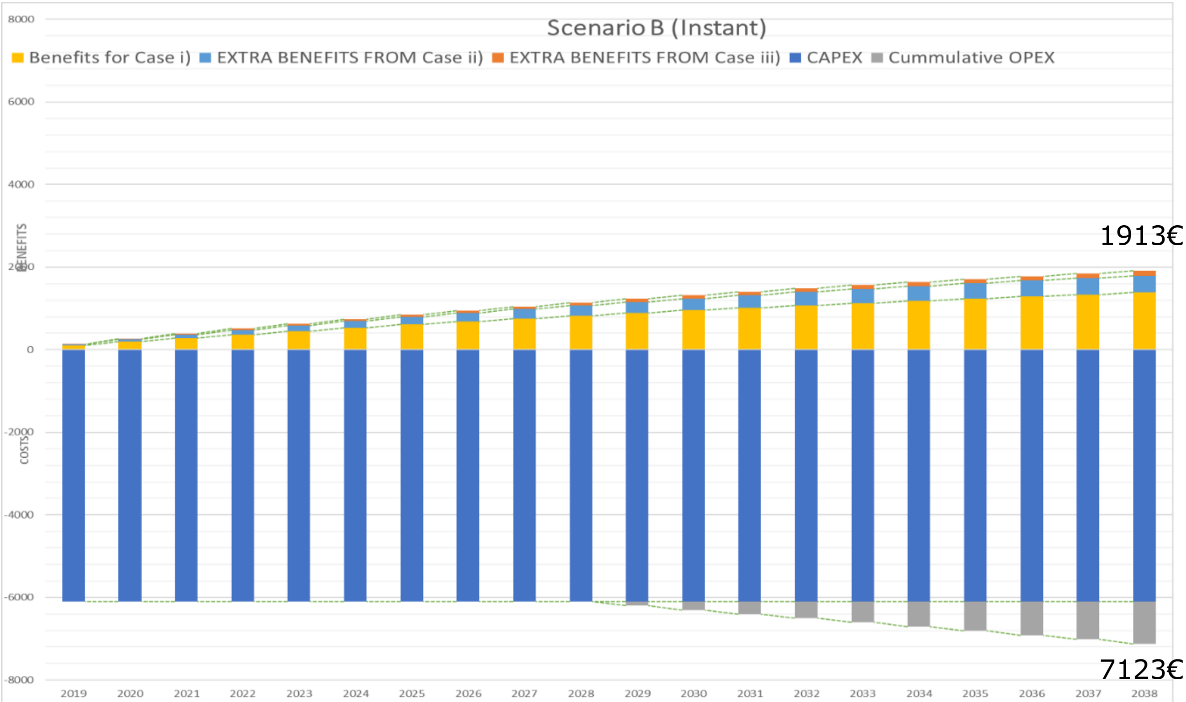

Figure 18: Cumulative costs and benefits for Scenario B under the Net-Billing scheme when only the instant self-consumption is charged – Typical power profile (Cyprus)

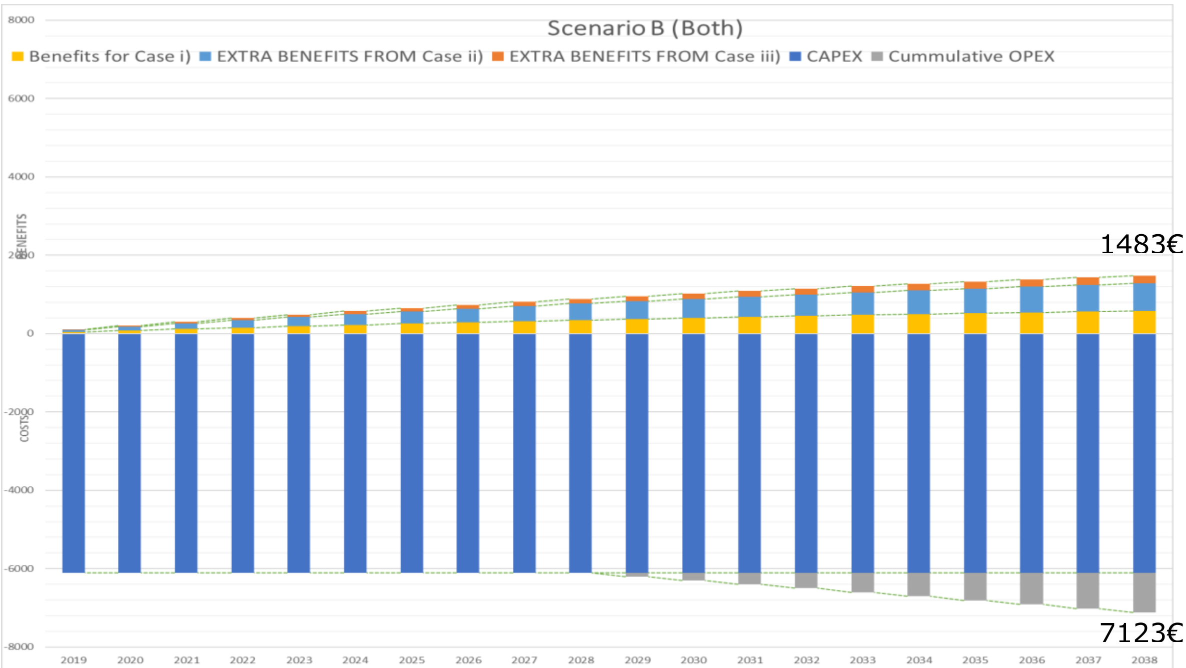

Figure 19: Cumulative costs and benefits for Scenario B under the Net-Billing scheme when both the instant self-consumption and stored energy are charged – Typical power profile (Cyprus)

13. Qualitative Impact Analysis

An overall project assessment should address both quantifiable and non-quantifiable benefits. Non-quantifiable benefits, i.e. consumer participation in their energy management, are difficult to be monetised and included in the CBA. Other aspects of the project such as job creation, social acceptance and improvement of resilient conditions should also be considered during the qualitative impact analysis. Furthermore, the CBA should include potential future applications and functionalities or the resulting of indirect benefits that are enabled by the ESS projects. For instance, new services enabled by the ESS equipment may include the increase of the power grid flexibility and reliability, aggregation of services (e.g. enabling Vehicle-to-Grid – V2G services, smart appliances, electric mobility, etc.), participation in real-time pricing schemes, etc. All these externalities represent important results that are enabled by the project and which have effects on the public and society. As they are very complex parameters, it is difficult to be quantified. Therefore, they are considered for the qualitative project assessment and complement the quantitative results of the CBA.

13.1 Performance assessment

To qualitatively capture the deployment merit of a residential ESS installation and complement the monetary quantification carried out during the CBA, the key performance indicators were defined based on [33] and smart grid eval software tool[13]. The qualitative benefits for this study were divided into five categories as shown below:

i) Services and grid operation:

- Reduction of network losses;
- Load levelling;
- Demand side participation / prosumers' active participation;
- Extension of grid infrastructures lifetime;
- Enabling additional aggregation services;
- Black-start;
- Increase grid components and network capacity availability.

ii) Supply security and quality:

- Increase system adequacy and resiliency;
- Increase the power system stability;

[13] The smart grid eval software combines the results of several CBAs with not monetary data. Available at: http://smartgrideval.infora.it/

- Decrease the duration and the frequency of interruptions;
- Improve voltage quality.

iii) Network connectivity:

- Reduce traffic congestions;
- Increase of power grid flexibility.

iv) Sustainability:

- Reduction of greenhouse gas emissions;
- Increase the country's percentage of energy received from decentralised energy sources;
- Positive environmental impact.

13.2 Social impact

Apart from addressing the deployment merit, externalities which are identified as costs and benefits spill over the project's lifetime into society which cannot be monetised, need to be included as physical terms in the qualitative analysis [33]. Social impacts represent a significant portion of the possible externalities of an ESS project; it is expected that society may benefit from ESS projects through the resulting improvement in areas like national security, environmental conditions, public health or economic growth. For instance, the national security can potentially be increased by reducing the national dependence of imported fossil fuels through the increased penetration of renewable sources, participation of the end-users into Demand Response schemes, reduction of carbon-based stand-by generation plans and decreased transmission and distribution power losses.

Although the social impact of ESS projects is difficult to be monetised and its costs and benefits are complex to be evaluated and included in the quantitative results of the CBA, it is essential to understand their importance for grasping the entire value of residential ESSs. Areas of potential social impact for the development of residential ESS installations as identified in this study are listed below:

- ❖ **Jobs**: Creation of new working positions with the direct and indirect impact on utility suppliers, manufacturers, communication providers, integrators, aggregators (in order for the residential ESSs to offer services to the power grid), new industry players, renewable suppliers, etc.
- ❖ **Safety**: Matter of domestic safety as residential batteries are a matter of new possible source of hazard – battery systems are associated with electrical and chemical risks (such as electric shock, fire, explosion, etc.). Hence, health and safety standards need to be considered before their wider spread.

- **Social acceptance**: As residential ESS is a relatively new technology at a non-mature stage, social resistance may arise due to concerns over safety, fair benefits sharing, transparency, policy regulations, bureaucracy, etc.
- **Privacy and security**: To fully utilise the installed capacity, bidirectional information flow needs to be in place. However, preventing measures must be developed in order to ensure data privacy and cyber-security.
- **Enabling new services/applications/market entry for third parties**: As discussed in Section 4.3, ESSs can create new services and provide multiple applications to the end-users and the power grid, as well as market entries for third parties. Some examples could be: the V2G services, services to the power grid, trading electricity market through energy arbitrage, etc.
- **Restore urban ecosystem**: It is a fact that the more exploitation and integration of renewable energy sources into the generation mixture will eventually lead to a restored and sustainable ecosystem. ESSs could significantly contribute to the increased penetration of renewable generation.
- **Supporting interconnections**: Through the ESSs, more services could potentially be exchanged through countries with the additional sources of flexibility, clean generated energy and services.

14. Conclusions

In this report, a Cost and Benefit Analysis (CBA) procedure suitable for analysing residential Energy Storage Systems (ESSs) has been developed. The developed stages include: 1) Project Characterisation which involves review and description of technologies, elements and goals of the project, and procedures for mapping assets onto functionalities, 2) Cost Estimation which quantifies the costs associated with the project, 3) Benefit Estimation through mapping the functionalities onto benefits, establish the baseline and monetise benefits, and 4) Comparison between the Costs and Benefits. The outcomes of the CBA were then refined through sensitivity analysis, with aim to identify the range of critical variables for which the CBA outcome is positive. The StoRES project, and more specifically, the residential pilots of Italy, Greece and Cyprus were used as case studies to fine-tune the developed CBA and to illustrate the proposed assessment framework.

Overall, it was found that the current frameworks, conditions and policies in combination with the existing pricing schemes do not allow any financial benefits to the end-users, and hence, a residential ESS installation is not a profitable investment now.

The main conclusions and remarks of the four pricing schemes investigated in this study are listed below:

- Installing an ESS under a Net-Metering scheme does not provide any financial benefits to the end-users, as because of the ESS losses, the monthly electricity cost increases. For Italy, three sub-categories of the Net-Metering scheme were investigated in this study. It was found that the greater financial loss is occurring when the electricity authority allows negative electricity bills (78% income loss) and the lowest one, when the top-up period starts in January (9% income loss).

- A partial Net-Metering scheme can potentially provide financial benefits to the end-users, as the imported tariff is higher than the exported revenue. In order to identify the financial revenues of a residential ESS under an existing partial Net-Metering scheme, the residential StoRES pilot of Greece was investigated by considering an increase of the imported and exported prices for energies above 2000 kWh per quarter. It was found that the financial benefits received from the ESS are not enough to cover the costs associated with the ESS installation, with the case where the imported and exported prices increase for energies greater than 2000kWh, to provide 7% higher financial benefits to the end-users compared to the case where the prices remain the same.

- A main difference between a Net-Metering scheme and a Net-Billing scheme is the self-consumption tariff. By assuming that the examined residential pilots in Cyprus are under the existing Net-Billing scheme, which is currently available only for the commercial and the industrial consumers, conclusions were drawn on the profitability of this pricing scheme. As the StoRES ESS pilots are the first-ever residential ESSs in Cyprus, the energy for which the self-consumption tariff is applied needs to be identified; charge only the instant self-consumption or both the instant self-consumption and the energy stored in the battery. It was found that by charging additionally to the instant self-consumption the stored energy, the financial benefits offered by the ESS installation will be reduced by 12-19% depending on the applied self-consumption price.

- The Self-consumption scheme was also investigated for the Cypriot pilots. This pricing scheme found to have the highest Net Present Value (NPV), as the exports are not financially rewarded and the self-consumption is not charged. Identically, the NPV for this pricing scheme found to be 10 times higher compared to the Net-Billing scheme. In addition, considering a 3% discount rate or an 8% reduction on the system CAPEX, a residential ESS installation could be a profitable investment under this pricing scheme.

15. Recommendations

From the undertaken CBA, it was concluded that the current conditions, including policies, pricing schemes, frameworks, costs, ESS utilisation, etc., do not allow any financial revenues to the end-users for adding Energy Storage to the existing PV system using AC coupling. Briefly, some points that could be considered to create a more suitable environment for a residential ESS installation to an existing PV system as drawn from this study are summarised below:

- The deployment of storage is strongly affected by financial support for renewable electricity production, especially when the support is based on the actual supply of electricity to the grid. Depending on the height and conditions of the support, these schemes make use of Energy Storage BtM unattractive. An example of this statement could be the current Net-Metering scheme which benefits the prosumers equally when they self-consumed the generated energy and export the excess energy to the power grid. When it is combined with a flat electricity tariff, potential benefits from the increase of self-consumption and the peak independency Energy Storage uses are both blocked. Hence, it is needed to consider moving from a Net-Metering scheme towards an asymmetric Net-Billing scheme, where the electricity that is fed into the power grid is purchased at a tariff below the marginal generation cost.

- Applying the Net-Billing scheme, which was originally created to support renewable energy sources to a system with an ES, will not benefit the ESS installation. The self-consumption tariff needs to be correctly priced (most suitable option is to exclude the levies and the VAT from the tariff) and properly define the energy that will be charged under this tariff (if only the instant self-consumption is charged, the financial benefits for the ESS installation will be greater compared to charge both the instant self-consumption and the stored energy).

- The current opportunities for the ESS exploitation do not fully utilise the Energy Storage capabilities of the installed capacity. Aggregators can control and manage any unexploited capacity of a number of residential ESSs, in order to provide services to the power grid and hence, to create additional financial benefits for a residential ESS installation (the potential benefits of the ESS installation were quantified in Scenario E). However, the current policy framework and the power grid infrastructures do not allow this full battery capacity exploitation. Modifications of the current policy legislations and electricity infrastructures need to be undertaken in order to minimise the requirements for the provision of ancillary services from residential ESSs.

- In order to control the exported energy injected to the power grid, the PV capacity allowance is typically equal to the house energy needs. However, with the installation of a residential ESS, the amount and quality of the exported energy can be controlled. In order for the end-users to actively participate in the energy market through energy trading, the PV allowance when a residential ESS is installed, needs to increase.

16. Future Work

This study could be seen as the first out of many steps for the mobilisation of stakeholders, policy makers, researchers, manufacturers, etc. for creating a more financially feasible environment for the residential ESSs. Future work of this study could be seen as:

- Dissemination of the outcome of this study:
  - Publication of the methodology developed and of the main results of this study via a journal paper,
  - Workshop open to the stakeholders, policy makers, and relevant companies in order to emphasis the importance of ESSs, explaining the current conditions of a residential installation and discuss potential ways of a further utilisation and exploitation of the usable battery capacity.

- Apply the developed methodology to more pilots: Currently in Cyprus, there are five more ESS pilots fall into another research project. The methodology developed in study will be applied in order to generalise conclusions.

- Extend the sensitivity analysis: Extra complex critical parameters could be investigated in order to derive more outcome, i.e. size of the ESS (battery and power inverter), overnight charging of the battery, optimal battery percentage offered to the power grid for each service, etc.

- Investigate the benefit offered by each service: Currently, the very few existing benefit schemes for providing services to the power grid concern only ESS installations on the transmission, distribution or generation level. As the BtM ESSs could also offer services to the power grid, a suitable pricing scheme needs to be developed.

- Technical aspects: Up-to-now, the ESSs charge/discharge only for one purpose, i.e. for the residential sector, to satisfy the needs of the house, for the distribution sector, to provide frequency regulation, etc. As a full usage of the installed capacity is the key for a financially beneficial ESS investment, the ESS will be called to combine services. Technical barriers need to be overcome in order for the further battery capacity utilisation to become a reality. Few examples of the technical aspects which would be needed to addressed are: strategies for suitable energy management, techniques for proper power flow control, a win-win action priority, etc. In addition, the optimal sizing is an open question, as it is not yet clear how the best battery and power inverter pair for this kind of ESS utilisation will be defined.

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Appendix A

Appendix A lists the assumptions considered for estimating the costs and monetarising the benefits for the undertaken analysis of Section 6.

- Maximum lifetime duration of the project: **20years**.
- **CAPEX** was paid at the beginning of the installation. The PV purchased cost was not included in the CAPEX as it was assumed that the PV system existed in prior of the ESS project. However, for Scenario D (Cyprus), the cost of the extra PV capacity was included in the CAPEX of the investment. It was assumed that CAPEX decreases by **8%** each year.
- The extra **OPEX** occurred by the equipment degradation was considered to be zero for the first 10 years of the system operation and then starting from 2% of the investment cost to increase by **5%** each year. This assumption was based on the fact that the battery degradation is significantly higher after the 50% of the battery lifetime.
- The costs associated with the ESS installation considered to be the same for all examined scenarios in each country and be included in the CAPEX and OPEX.
- It was assumed that the same electricity pricing scheme will be used for the whole examined operational period, i.e. the end-users will not switch from the Net-Billing scheme to a real-time pricing scheme.
- The discount rate taken to be **4%**.
- For Scenario E, it was assumed that the residential ESSs could provide services to the power grid by being aggregated. It was also assumed that the financial benefits will be equally distributed to the ESS holders and no costs are applied to the end-users for being aggregated.
- The financial benefits received for providing services to the power grid were assumed to be constant through the project lifetime. It was also assumed that the end-users provide services to the power grid constantly for the whole year.
- It was assumed that the end-users benefit for providing services to the power grid as follows: **1.456c** per kW per year for ancillary services, **2.6c** per kW per year for congestion relieve, and **0.34c** per kW per year for transmission support. Equal share between the three applications were assumed.
- **Currency rate** considered for the study:

- £1 = 1.16€
- $1 = 0.89€

The **Net-Billing** prices considered:

- **Import Tariff (Euro cent/kWh)**:
  - Energy cost:

October - May			June - September		
	Weekdays	Weekends		Weekdays	Weekends
Peak (16:00-23:00)	8,72	8,38	Peak (9:00-23:00)	13,83	8,45
Off-peak (23:00-16:00)	7,49	7,12	Off-peak (23:00-9:00)	8,34	8,15

  - Network cost: 3.21
  - Ancillary services: 0.66
  - Fuel adjustment: 4.706
  - VAT: 19%
  - Green fee:1
  - Measurement cost: 0.08166 fixed cost per month
  - Trading cost: 0.3966 fixed cost per month

- **Exported Tariff**:
  - RES cost: 12.11
  - With 19% VAT: 14.4109

- **Self-consumption Tariff**:
  - Net-Billing: 1.63
  - Levies: 0.083
  - Green fee: 1
    - Current Net-Billing: 3.038
    - Without Levies: 1.9397
    - Without levies and VAT: 1.63

The **Partial Net-Metering** prices considered:

	<2000kWh	>2000kWh
Imported	15,582	16,4512
Exported	10,0276	10,86712

The prices for **Scenario C Greece** considered:

Tariff level	Winter	Summer	Middle	Tariff
Peak	16:00 – 21:59	11:00 – 20:59	16:00 – 20:59	20.15
Shoulder	06:00 – 15:59 22:00 – 23:59	07:00 – 10:59 21:00 – 00:59	06:00 – 15:59 21:00 – 23:59	15.88
Off-peak	00:00 – 05:59	01:00 – 06:59	00:00 – 05:59	11.6

The prices for **Scenario C Cyprus** considered:

December - February		June- August		March-May + September-November	
16:00-22:00	23,360695	11:00-21:00	23,360695	16:00 - 21:00	23,360695
06:00-16:00 + 22:00-00:00	21,78811	07:00-11:00 + 21:00 -01:00	21,78811	06:00-16:00 + 21:00-00:00	21,78811
00:00-06:00	20,215525	01:00-06:00	20,215525	00:00 - 06:00	20,215525

The energy cost for the **Self-consumption scheme**:

October - May			June - September		
	Weekdays	Weekends		Weekdays	Weekends
Peak (16:00-23:00)	8,82	8,48	Peak (9:00-23:00)	14,25	8,59
Off-peak (23:00-16:00)	7,63	7,26	Off-peak (23:00-9:00)	8,44	8,26

Appendix B

A) Italy:

Scenario A: Presents the baseline conditions that reflect to what the system condition would have been *without* the ESS (house contains only the installed rooftop PV system (3kWp) - BaU)

Case i): Electricity authority allows negative monthly electricity bills

	Imports	Exports	Constant costs	Bill
January	52,94	11,99	4	44,95
February	36,11	36,95	4	3,16
March	35,05	55,81	4	-16,76
April	38,88	61,27	4	-18,39
May	23,72	81,56	4	-53,83
June	22,54	86,42	4	-59,88
July	25,46	88,43	4	-58,98
August	28,22	58,46	4	-26,24
September	24,73	56,94	4	-28,22
October	30,83	34,49	4	0,34
November	31,86	17,48	4	18,38
December	37,31	16,79	4	24,52
			TOTAL	**-170,93**

Case ii): Top-up month is October

	Imports	Exports	Constant cos	Bill
January	52,94	11,99	4	44,95
February	36,11	36,95	4	4
March	35,05	55,81	4	4
April	38,88	61,27	4	4
May	23,72	81,56	4	4
June	22,54	86,42	4	4
July	25,46	88,43	4	4
August	28,22	58,46	4	4
September	24,73	56,94	4	4
October	30,83	34,49	4	4
November	31,86	17,48	4	10,72
December	37,31	16,79	4	24,52
			SUM	**116,19**

Case iii): Top-up month is January

	Imports	Exports	Constant c	Bill
January	52,93561	11,9861	4	44,949505
February	36,11146	36,94777	4	4
March	35,05177	55,8109	4	4
April	38,88255	61,26911	4	4
May	23,72302	81,55576	4	4
June	22,53531	86,41556	4	4
July	25,45663	88,43331	4	4
August	28,22046	58,46027	4	4
September	24,72749	56,94366	4	4
October	30,83411	34,49019	4	4
November	31,8632	17,4822	4	4
December	37,31234	16,7925	4	4
			SUM	**88,949505**

Scenario B: Illustrates the realised and measured conditions with the ESS (current StoRES house with PV and ESS)

Case i): Electricity authority allows negative monthly electricity bills

	Imports	Exports	Constant co	Electricity Bill
January	43,68	0	4	47,68
February	7,97	1,24	4	10,72
March	1,82	14,07	4	-8,25
April	2,86	16,93	4	-10,07
May	0	48,03	4	-44,03
June	0	13,21	4	-9,21
July	0	52,41	4	-48,41
August	0	21,07	4	-17,07
September	0	22,96	4	-18,96
October	4,99	0,86	4	8,14
November	18,70	0	4	22,70
December	24,59	0	4	28,59
			SUM	**-38,17**

Case ii): Top-up month is October

	Imports	Exports	Constant (	Electricity
January	43,68	0	4	47,68
February	7,97	1,24	4	10,72
March	1,82	14,07	4	4
April	2,86	16,93	4	4
May	0	48,03	4	4
June	0	13,21	4	4
July	0	52,41	4	4
August	0	21,07	4	4
September	0	22,96	4	4
October	4,99	0,86	4	8,14
November	18,70	0	4	22,70
December	24,59	0	4	28,59
			SUM	**145,83**

Case iii): Top-up month is January

	Imports	Exports	Constant (	Electricity
January	43,68	0	4	47,68
February	7,97	1,24	4	10,72
March	1,82	14,07	4	4
April	2,86	16,93	4	4
May	0	48,03	4	4
June	0	13,21	4	4
July	0	52,41	4	4
August	0	21,07	4	4
September	0	22,96	4	4
October	4,99	0,86	4	4
November	18,70	0	4	4
December	24,59	0	4	4
			SUM	**98,40**

B) Greece:

Scenario A: Presents the baseline conditions that reflect to what the system condition would have been without the ESS (house contains only the installed rooftop PV system (5kWp) - BaU)

Case i): without considering the increase of the prices

	Imports	Exports	Constant c	Bill	
January	394,6932	0,505396	2,595833	396,78367	
February	228,5795	11,31415	2,595833	219,86121	
March	141,4649	31,08494	2,595833	112,97575	
April	110,8327	55,52192	2,595833	57,906647	
May	89,49616	72,63742	2,595833	19,454572	
June	48,5994	62,79386	2,595833	-11,59863	
July	61,47494	73,57481	2,595833	-9,504036	
August	50,15334	80,74277	2,595833	-27,9936	
September	54,66941	44,04769	2,595833	13,217551	
October	106,7267	48,26782	2,595833	61,054682	
November	174,0005	30,33109	2,595833	146,26521	
December	333,8117	21,21283	2,595833	315,19469	
				SUM	**1293,6177**

Case ii): by considering the increase of the prices for energies above 2000 kWh per quarter

	1st Quarter		2nd Quarter		3rd Quarder	
	Import kWh	Export kWh	Import kWh	Export kWh	Import kWh	Export kWh
	5619,11411	981,554993	1602,643	2889,51348	4294,75188	1434,63484
>2000kWh	2000	981,554993	1602,643	2000	2000	1434,63484
<2000kWh	3619,11411	0	0	889,513485	2294,75188	0
Electricity cost	818,984625		-37,1093322		555,678111	
	TOTAL ELECT	**1337,5534**				

Scenario B: Illustrates the realised and measured conditions with the ESS (current StoRES house with PV and ESS under the partial Net-Metering scheme)

Case i): without considering the increase of the prices

	Imports	Exports	Constant co	Electricity Bill	
January	392,9796	0	2,5958333	395,5754035	
February	211,5951	0,0761696	2,5958333	214,1148094	
March	111,0732	8,3274144	2,5958333	105,3416628	
April	84,83194	33,64127	2,5958333	53,78650535	
May	59,61082	50,159812	2,5958333	12,04684305	
June	21,0846	40,146919	2,5958333	-16,46648976	
July	32,73816	49,502392	2,5958333	-14,16839913	
August	23,15744	57,468782	2,5958333	-31,71551032	
September	26,34886	22,028568	2,5958333	6,916121281	
October	76,45059	25,324493	2,5958333	53,72192843	
November	141,4939	7,2013262	2,5958333	136,8884537	
December	305,4805	3,3632891	2,5958333	304,7130902	
				SUM	**1220,754419**

Case ii): by considering the increase of the prices for energies above 2000 kWh per quarter

	1st Quarter		2nd Quarter		3rd Quarder	
	Import kW	Export kW	Import kW	Export kW	Import kW	Export kW
	5137,209	419,2913	876,5949	1967,349	3528,263	577,5826
>2000kWh	2000	419,2913	876,5949	1967,349	2000	577,5826
<2000kWh	3137,209				1528,263	
Electricity co	785,7037		-60,6869		505,1399	
	TOTAL ELE	1261,307				

Scenario C: Proposes a revised electricity scheme based on the charging time-slots suggested from SmartPV project

	Imports	Exports	Constant cc	Bill	
January	417,82278	0	2,5958333	420,41861	395,5754
February	212,51344	0,0761696	2,5958333	215,03311	214,11481
March	108,00871	8,3274144	2,5958333	102,27713	105,34166
April	88,226367	33,64127	2,5958333	57,180931	53,786505
May	56,726717	50,159812	2,5958333	9,1627387	12,046843
June	18,253784	40,146919	2,5958333	-19,2973	-16,46649
July	29,056256	49,502392	2,5958333	-17,8503	-14,168399
August	20,900456	57,468782	2,5958333	-33,97249	-31,71551
September	23,972801	22,028568	2,5958333	4,540066	6,9161213
October	77,96973	25,324493	2,5958333	55,24107	53,721928
November	140,74619	7,2013262	2,5958333	136,1407	136,88845
December	316,70033	3,3632891	2,5958333	315,93287	304,71309
				SUM	**1244,8071**

C) Cyprus:

Scenario A: Presents the baseline conditions that reflect to what the system condition would have been *without* the ESS (house contains only the installed rooftop PV system (3kWp) - BaU)

1) Net-Billing scheme:

	Imports	Exports	Constant costs	Bill
January	85,88769	19,52624	0,478333333	70,22816951
February	67,03533	25,96217	0,478333333	45,29908142
March	43,173	47,96915	0,478333333	0,478333333
April	40,94098	49,15568	0,478333333	0,478333333
May	42,35956	48,35713	0,478333333	0,478333333
June	60,59873	39,12232	0,478333333	24,61054606
July	90,88452	26,55668	0,478333333	74,7173631
August	85,3647	24,46874	0,478333333	71,41127708
September	70,88436	35,53451	0,478333333	42,13891168
October	51,25173	31,97473	0,478333333	23,61857906
November	59,20721	24,43516	0,478333333	38,38906892
December	81,0278	19,59853	0,478333333	64,90164937
			SUM	**456,7496462**

2) Self-consumption scheme:

	Imports	Exports	Constant costs	Bill
January	86,43767	0	0,478333333	86,91599883
February	67,46095	0	0,478333333	67,93928336
March	43,45228	0	0,478333333	43,93061534
April	41,22059	0	0,478333333	41,69892171
May	42,65073	0	0,478333333	43,12906765
June	61,26089	0	0,478333333	61,73922517
July	91,88349	0	0,478333333	92,36181968
August	86,27448	0	0,478333333	86,75281198
September	71,6402	0	0,478333333	72,11853723
October	51,59985	0	0,478333333	52,0781839
November	59,59332	0	0,478333333	60,07165672
December	81,54698	0	0,478333333	82,02531477
			SUM	**790,7614363**

Scenario B: Illustrates the *realised and measured conditions with the ESS* (current StoRES house with PV and ESS under either the Net-Billing scheme or the Self-consumption scheme)

1) Net-Billing scheme:

Case i): including levies and VAT

		Self consumption				Electricity Bill	
	Imports	Instant	Both	Exports	Constant costs	Instant	Both
January	60,48792	3,38839084	7,5054068	0	0,478333333	64,35464	68,47166
February	34,34303	3,747589648	8,8809009	0	0,478333333	38,56896	43,70227
March	0	3,677969185	11,281353	11,90771	0,478333333	0,478333	0,478333
April	0	4,279469264	11,874403	12,67303	0,478333333	0,478333	0,478333
May	0	5,951463343	13,541865	12,35726	0,478333333	0,478333	0,478333
June	3,832782	7,755328539	15,519522	1,462232	0,478333333	0,478333	18,12802
July	51,40294	9,911189851	15,51054	0	0,478333333	48,88924	67,39181
August	39,77942	10,03697795	15,196095	0	0,478333333	50,29474	55,45385
September	12,4587	6,310728997	13,659587	0	0,478333333	19,24777	26,59662
October	12,3284	3,863250528	10,604971	0	0,478333333	16,66998	23,4117
November	27,74598	3,138686337	8,219391	0	0,478333333	31,363	36,44371
December	55,27554	2,994047569	7,1263045	0	0,478333333	58,74792	62,88018
					SUM	**330,0496**	**403,9148**

Case ii): excluding levies and include VAT

		Self consumption				Electricity Bill	
	Imports	Instant	Both	Exports	Constant costs	Instant	Both
January	60,48792	2,163082641	4,7913053	0	0,478333333	63,12933	65,75755
February	34,34303	2,392388156	5,669394	0	0,478333333	37,21375	40,49076
March	0	2,34794381	7,2017956	11,90771	0,478333333	0,478333	0,478333
April	0	2,731929731	7,5803876	12,67303	0,478333333	0,478333	0,478333
May	0	3,799298149	8,6448627	12,35726	0,478333333	0,478333	0,478333
June	3,832782	4,950850516	9,9073602	1,462232	0,478333333	0,478333	0,478333
July	51,40294	6,32711034	9,9016264	0	0,478333333	37,47095	60,54985
August	39,77942	6,40741101	9,7008907	0	0,478333333	46,66517	49,95865
September	12,4587	4,028646337	8,7200142	0	0,478333333	16,96568	21,65705
October	12,3284	2,466223806	6,7700069	0	0,478333333	15,27296	19,57674
November	27,74598	2,003676155	5,247099	0	0,478333333	30,22799	33,47141
December	55,27554	1,911341586	4,5492938	0	0,478333333	57,66521	60,30317
					SUM	**306,5244**	**353,6785**

Case iii): excluding levies and VAT

		Self consumption				Electricity Bill	
	Imports	Instant	Both	Exports	Constant costs	Instant	Both
January	60,48792	1,817716505	4,026307	0	0,478333333	62,78397	64,99256
February	34,34303	2,010410215	4,7641966	0	0,478333333	36,83178	39,58556
March	0	1,973062025	6,051929	11,90771	0,478333333	0,478333	0,478333
April	0	2,29573927	6,3700736	12,67303	0,478333333	0,478333	0,478333
May	0	3,19268752	7,2645905	12,35726	0,478333333	0,478333	0,478333
June	3,832782	4,160378585	8,3255127	1,462232	0,478333333	0,478333	0,478333
July	51,40294	5,316899445	8,3206944	0	0,478333333	34,25258	53,64662
August	39,77942	5,384379	8,152009	0	0,478333333	45,64214	48,40977
September	12,4587	3,38541709	7,327743	0	0,478333333	16,32245	20,26478
October	12,3284	2,07245698	5,6890814	0	0,478333333	14,87919	18,49581
November	27,74598	1,683761475	4,4093269	0	0,478333333	29,90808	32,63364
December	55,27554	1,6061694	3,822936	0	0,478333333	57,36004	59,57681
					SUM	**299,8936**	**339,5189**

2) Self-consumption scheme:

	Imports (€)	**Constant cost**	**Electricity Bill**	
January	60,89	0,4783	61,37	
February	34,59	0,4783	35,07	
March	0,00	0,4783	0,48	
April	0,00	0,4783	0,48	
May	0,00	0,4783	0,48	
June	3,85	0,4783	4,33	
July	51,82	0,4783	52,30	
August	40,05	0,4783	40,53	
September	12,53	0,4783	13,01	
October	12,43	0,4783	12,91	
November	27,96	0,4783	28,43	
December	55,65	0,4783	56,13	
		Annual Electricity Cost		**305,51**

Scenario C: Proposes a *revised electricity scheme* based on the charging time-slots suggested from SmartPV project

Case i): including levies and VAT

		Self consumption				Electricity Bill	
	Imports	Instant	Both	Exports	Constant costs	Instant	Both
January	63,10157	3,38839084	7,5054068	0	0,478333333	66,9683	71,08531
February	35,11181	3,747589648	8,8809009	0	0,478333333	39,33774	44,47105
March	0	3,677969185	11,281353	11,90771	0,478333333	0,478333	0,478333
April	0	4,279469264	11,874403	12,67303	0,478333333	0,478333	0,478333
May	0	5,951463343	13,541865	12,35726	0,478333333	0,478333	0,478333
June	3,901388	7,755328539	15,519522	1,462232	0,478333333	0,478333	18,19663
July	48,70515	9,911189851	15,51054	0	0,478333333	46,26006	64,69402
August	38,66877	10,03697795	15,196095	0	0,478333333	49,18408	54,3432
September	12,33593	6,310728997	13,659587	0	0,478333333	19,12499	26,47385
October	12,86529	3,863250528	10,604971	0	0,478333333	17,20687	23,94859
November	29,00204	3,138686337	8,219391	0	0,478333333	32,61905	37,69976
December	57,30733	2,994047569	7,1263045	0	0,478333333	60,77971	64,91197
					SUM	**333,3941**	**407,2594**

Case ii): excluding levies and include VAT

		Self consumption				Electricity Bill	
	Imports	Instant	Both	Exports	Constant costs	Instant	Both
January	63,10157	2,163082641	4,7913053	0	0,478333333	65,74299	68,37121
February	35,11181	2,392388156	5,669394	0	0,478333333	37,98253	41,25954
March	0	2,34794381	7,2017956	11,90771	0,478333333	0,478333	0,478333
April	0	2,731929731	7,5803876	12,67303	0,478333333	0,478333	0,478333
May	0	3,799298149	8,6448627	12,35726	0,478333333	0,478333	0,478333
June	3,901388	4,950850516	9,9073602	1,462232	0,478333333	0,478333	0,478333
July	48,70515	6,32711034	9,9016264	0	0,478333333	34,84177	57,92067
August	38,66877	6,40741101	9,7008907	0	0,478333333	45,55451	48,84799
September	12,33593	4,028646337	8,7200142	0	0,478333333	16,84291	21,53428
October	12,86529	2,466223806	6,7700069	0	0,478333333	15,80985	20,11363
November	29,00204	2,003676155	5,247099	0	0,478333333	31,48404	34,72747
December	57,30733	1,911341586	4,5492938	0	0,478333333	59,697	62,33495
					SUM	**309,8689**	**357,0231**

Case iii): excluding levies and VAT

		Self consumption				Electricity Bill	
	Imports	Instant	Both	Exports	Constant costs	Instant	Both
January	63,10157	1,817716505	4,026307	0	0,478333333	65,39762	67,60621
February	35,11181	2,010410215	4,7641966	0	0,478333333	37,60056	40,35434
March	0	1,973062025	6,051929	11,90771	0,478333333	0,478333	0,478333
April	0	2,29573927	6,3700736	12,67303	0,478333333	0,478333	0,478333
May	0	3,19268752	7,2645905	12,35726	0,478333333	0,478333	0,478333
June	3,901388	4,160378585	8,3255127	1,462232	0,478333333	0,478333	0,478333
July	48,70515	5,316899445	8,3206944	0	0,478333333	31,6234	51,01744
August	38,66877	5,384379	8,152009	0	0,478333333	44,53148	47,29911
September	12,33593	3,38541709	7,327743	0	0,478333333	16,19968	20,14201
October	12,86529	2,07245698	5,6890814	0	0,478333333	15,41608	19,0327
November	29,00204	1,683761475	4,4093269	0	0,478333333	31,16413	33,8897
December	57,30733	1,6061694	3,822936	0	0,478333333	59,39183	61,6086
					SUM	**303,2381**	**342,8634**

Scenario D: Investigates a *revised PV capacity installed allowance* when adding a residential ESS to an existing PV system

Case i): including levies and VAT

		Self consumption				Electricity Bill	
	Imports	Instant	Both	Exports	Constant costs	Instant	Both
January	26,59729	3,944268292	12,966148	9,72537	0,478333333	0,478333	27,44643
February	16,35325	3,713800342	12,077493	26,98441	0,478333333	0,478333	1,924664
March	0	3,917830564	11,759237	75,08249	0,478333333	0,478333	0,478333
April	0	4,490323889	11,870997	81,70634	0,478333333	0,478333	0,478333
May	0	6,43496292	13,953218	87,01959	0,478333333	0,478333	0,478333
June	0	8,227622239	17,355207	67,85643	0,478333333	0,478333	0,478333
July	19,5081	11,01935176	20,424959	50,28984	0,478333333	0,478333	0,478333
August	17,47332	10,80838471	20,39412	47,45307	0,478333333	0,478333	0,478333
September	9,334837	6,532906481	15,643895	55,39739	0,478333333	0,478333	0,478333
October	0	4,255270889	12,769422	40,05497	0,478333333	0,478333	0,478333
November	4,403843	3,376823385	12,379287	19,27388	0,478333333	0,478333	0,478333
December	23,6353	3,402177897	12,34449	9,073473	0,478333333	0,478333	0,478333
					SUM	**5,74**	**34,15443**

Case ii): excluding levies and include VAT

		Self consumption				Electricity Bill	
	Imports	Instant	Both	Exports	Constant costs	Instant	Both
January	26,59729	2,517943967	8,2773359	9,72537	0,478333333	0,478333	9,199348
February	16,35325	2,370817722	7,7100359	26,98441	0,478333333	0,478333	0,478333
March	0	2,501066637	7,5068677	75,08249	0,478333333	0,478333	0,478333
April	0	2,866535213	7,5782127	81,70634	0,478333333	0,478333	0,478333
May	0	4,107954851	8,907462	87,01959	0,478333333	0,478333	0,478333
June	0	5,252353605	11,079226	67,85643	0,478333333	0,478333	0,478333
July	19,5081	7,034539296	13,038896	50,28984	0,478333333	0,478333	0,478333
August	17,47332	6,899862046	13,019208	47,45307	0,478333333	0,478333	0,478333
September	9,334837	4,170480111	9,9867575	55,39739	0,478333333	0,478333	0,478333
October	0	2,716481961	8,1517502	40,05497	0,478333333	0,478333	0,478333
November	4,403843	2,155698203	7,9026955	19,27388	0,478333333	0,478333	0,478333
December	23,6353	2,17188403	7,8804818	9,073473	0,478333333	0,478333	0,478333
					SUM	**5,74**	**14,46101**

Case iii): excluding levies and VAT

		Self consumption				Electricity Bill	
	Imports	Instant	Both	Exports	Constant costs	Instant	Both
January	26,59729	2,1159193	6,9557445	9,72537	0,478333333	0,478333	4,056213
February	16,35325	1,9922838	6,4790218	26,98441	0,478333333	0,478333	0,478333
March	0	2,10173667	6,3082922	75,08249	0,478333333	0,478333	0,478333
April	0	2,40885312	6,368246	81,70634	0,478333333	0,478333	0,478333
May	0	3,4520629	7,4852622	87,01959	0,478333333	0,478333	0,478333
June	0	4,413742525	9,3102737	67,85643	0,478333333	0,478333	0,478333
July	19,5081	5,91137756	10,957055	50,28984	0,478333333	0,478333	0,478333
August	17,47332	5,7982034	10,940511	47,45307	0,478333333	0,478333	0,478333
September	9,334837	3,504605135	8,3922332	55,39739	0,478333333	0,478333	0,478333
October	0	2,28275795	6,8502103	40,05497	0,478333333	0,478333	0,478333
November	4,403843	1,811511095	6,6409206	19,27388	0,478333333	0,478333	0,478333
December	23,6353	1,82511263	6,6222536	9,073473	0,478333333	0,478333	0,478333
					SUM	**5,74**	**9,31788**

Scenario E: Suggests a f*ull exploitation of the installed battery capacity* by stacking the battery benefits in order to use the unutilised battery capacity to provide services to the power grid

	Unexploited SOC	Capacity (kWh)	Benefits received
January	60%	5,58	60,93
February	40%	3,72	40,62
March	20%	1,86	20,31
April	20%	1,86	20,31
May	20%	1,86	20,31
June	10%	0,93	10,16
July	30%	2,79	30,47
August	45%	4,185	45,70
Septembe	20%	1,86	20,31
October	25%	2,325	25,39
Novembe	45%	4,185	45,70
Decembe	55%	5,115	55,86
		Annual Benefits	**407,68**