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The financial impact of policy schemes on PV+Battery systems in residential buildings: A case study in Cyprus

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Abstract. The number of grid-connected Photovoltaic (PV) systems continues to increase, especially in the building sector, due to both the vast cost reduction observed and the existence of direct policy intervention through various compensation mechanisms. As a result, several security and stability issues to the grid are expected to arise, mainly due to the mismatch of PV production and building demand. This paper addresses the integration of Battery Energy Storage Systems (BESSs) in three residential buildings equipped with PVs in Cyprus, as a means to tackle the aforementioned issues by increasing energy self-consumption. Furthermore, it focuses on the impact of various policy schemes, such as Net-Metering and Net-Billing, on the financial feasibility of PV+Battery installations in residences, by analysing the pilot operation under various compensation mechanisms, during the first year since the Net-Metering amendment in Cyprus, which stems from the latest EU guidelines for more sustainable and cost-effective Renewable Energy Sources at the building side[a].

Keywords: Photovoltaic, Battery Energy Storage System, Self-consumption, Net-Metering, Net-Billing.

1 Introduction

In light of the continuous quest for a sustainable and environmentally friendly energy sector, the world has observed a notable increase in grid-connected Photovoltaic (PV) installations in recent years, both at the building side and the utility scale [1], mainly due to the continuously falling cost of the PV technology [2]. The latter enabled PV systems to reach grid parity in numerous countries worldwide [3, 4]; one of them is Cyprus [5].

For the case of Cyprus, this relies on the high solar resource [5], which yields high PV production, as well as the presence of various recent policy schemes in the form of supporting mechanisms, such as Feed-in Tariff (FiT) and Net-Metering, targeting especially buildings and mostly, residential premises. Net-Metering replaced FiT in

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2013, following the significant reduction in PV cost, which enhanced the competitiveness of PV systems, thus making their support in the form of FiT unnecessary. Moreover, the installed PV capacity under Net-Metering in the building sector accounted for about 63 MWp in early 2021, having a significant share of the total installed PV capacity in Cyprus (approximately 25%) [6].

Yet, the rising penetration of residential PVs in the Low-Voltage distribution grid of Cyprus could possibly lead to various stability and security issues, mainly due to the mismatch of PV production and building demand, which generally stresses the cabling infrastructure and accelerates voltage variations [7, 8]. The integration of a Battery Energy Storage System (BESS) with the on-site PV system is regarded as a solution to the aforementioned issues, as it decreases both the grid imported and exported energy by storing surplus PV production, which cannot be directly consumed by the building, for later use. Therefore, the energy self-consumption is increased resulting in more self-sufficient buildings [7-9].

For the case of Cyprus, there are a handful hybrid PV+Battery systems, implemented as pilots in residential buildings between 2018-2019 [3, 7, 8]. So far, their operation was primarily studied with regards to their sizing for self-consumption and self-sufficiency maximisation and as a possible solution for grid export limitation without affecting the load demand of the building residents or curtailing PV generation [7, 8]. In general, various studies investigated the operation of residential PV+Battery systems for optimal system sizing in respect to their payback period [10, 11], while others, focusing on grid-scale systems, addressed the financial feasibility of different BESS technologies [12, 13]. Moreover, the competitiveness of residential PV+Battery systems under a specific mode of operation was explored with the use of a dedicated financial index in [4].

Nonetheless, none of the above investigated the impact of policy intervention on PV+Battery systems in buildings, especially in Cyprus. Given the recent amendment in the Net-Metering scheme in Cyprus, which is to-date the sole supporting mechanism for PVs in residential buildings in Cyprus [14], the current study was conducted. This amendment stems from the latest Directive (EU) 2019/944 of the European Parliament and of the Council of 5th June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU [15]. The Directive aims to establish common rules for the generation, transmission, distribution, energy storage and the supply of electricity, along with consumer protection provisions that seek to create integrated, competitive, consumer-centred, flexible, fair and transparent electricity markets in the EU.

The aim of this paper is twofold. Firstly, to assess the operation of three pilots in Cyprus under various compensation mechanisms during the first year of operation since the Net-Metering amendment from a financial point of view. Secondly, to propose actions for further BESS exploitation in the island’s building sector. It is foreseen that residential PVs will continue to be exploited largely in Cyprus due to the suitability of the environmental conditions, hence, this study discusses the need for enabling the integration of BESS through appropriate supporting mechanisms (similarly to the case of PVs under Net-Metering in previous years), to enable more sustainable buildings.

2 Methodology

2.1 Pilot description & Mode of operation

Three PV+Battery systems were commissioned in residential premises in the wider area of Nicosia in 2019, being among the first (and only few) such grid-connected installations in Cyprus. Each system consists of a 2.5 kW / 9.8 kWh BESS (including a dedicated bidirectional battery converter and a High-Voltage Lithium-ion battery unit) and a 3 kWp crystalline-silicon rooftop PV system. As it can be seen in Fig. 1, both components are linked at a common AC-bus and installed behind the building's utility meter, resulting in a Behind-the-Meter (BtM) AC-coupled system. Both system monitoring and data collection are achieved via a dedicated metering infrastructure integrated with the aforementioned components.

The systems are operated by default in a mode aiming to increase the building's energy self-consumption, as shown in Fig. 2. Notably, the BESS' battery unit is charged through its dedicated battery converter only by any surplus energy produced by the PV system, i.e. when PV production exceeds the building demand, while it is discharged when the PV production cannot meet the building demand, e.g. during the night. As the systems are grid-connected, any excess PV production that cannot be absorbed by the BESS (i.e. battery full) is exported to the grid, while any deficit that cannot be covered by the BESS (i.e. battery empty) is imported from the grid. As the pilots operate under Net-Metering, grid export is credited to the next billing period (i.e. not remunerated) and grid import is debited at the retail electricity price.

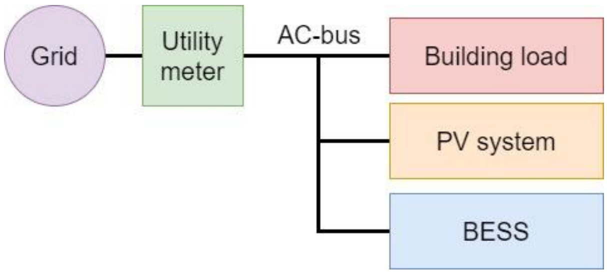

Fig. 1. Single-line diagram of the hybrid BtM AC-coupled PV+Battery at each building.

2.2 Net-Metering amendment & Financial considerations

Since March 2020, an amendment in the way buildings with PVs under Net-Metering are charged in Cyprus was performed, following the local Regulator's decision [14], after the latest EU guidelines for the direct promotion of energy self-consumption in buildings, which in turn indirectly promotes the concept of energy storage. Specifically, this decision was made in light of the EU scope which sets as the main parameter that the owners of such systems should not face discriminatory or disproportionate burden and costs, nor unjustified charges due to the operation of their systems.

As a result, no fixed charges apply anymore for the use of the grid for PV systems, as in the previous pricing methodology the building owner was subject to a fixed charge depending on the PV system installed capacity, i.e. 4.325 €/kWp per month. The above did not consider important parameters that influence significantly the production of a PV system, although the charge remained constant, such as the system orientation, any temporary reduction of production (e.g. due to soiling, dust, etc.) and the exact installed capacity (e.g. a 3.14 kWp PV system instead of a 3 kWp one).

The new way of pricing is now based on the net-consumption profile of the owner, specifically on when the produced energy is consumed and, as a result, when the grid is used for importing or exporting energy. For the surplus PV energy exported to the grid, but taken back when needed (e.g. overnight) there is a charge of 0.043 €/kWh, which reflects the cost for Grid usage. This charge is applied only on the imported and not on the exported energy. Additional energy (not from the credited amount) that is imported from the grid, is charged normally (as before the amendment) at the retail electricity price, i.e. 0.2133 €/kWh [16].

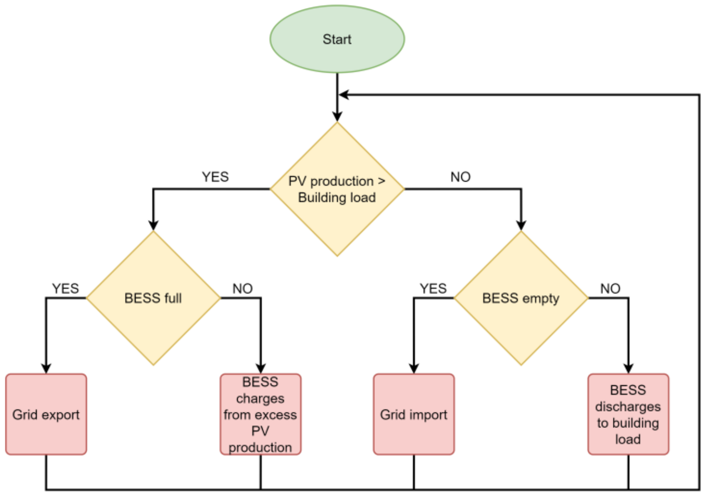

Fig. 2. PV+Battery system mode of operation (i.e. to increase the building's self-consumption).

2.3 Available data for analysis & Scenarios addressed

A set of yearly energy data (March 2020 – February 2021) was made available for the purpose of this work after suitable processing, i.e. power to energy values conversion. These sets include PV production, building consumption, direct consumption from the PV system, BESS charge and discharge, as well as grid import and export for each of the three buildings.

For all pilots, the monthly Self-Consumption Rate (SCR) and the monthly Self-Sufficiency Rate (SSR), as well as their yearly average, were estimated. The SCR corresponds to the portion of PV production that is consumed locally (i.e. by the building), as seen in (1), while the SSR represents the portion of building load that is covered by the PV production, as seen in (2). It is evident that the integration of a BESS with a PV system increases both metrics, as a greater amount of PV production can be utilised by the building through the charging and discharging processes.

$$SCR\ (\%) = \frac{Direct\ PV\ consumption + BESS\ charge}{PV\ production} \quad (1)$$

$$SSR\ (\%) = \frac{Direct\ PV\ consumption + BESS\ discharge}{Building\ consumption} \quad (2)$$

Moreover, four different scenarios were exploited and the total electricity cost of the pilot buildings under each scenario (S) was calculated. Notably, S1 addresses the case of a residential building without a PV or a BESS, S2 considers the case of a hybrid PV+Battery system under the previous form of the Net-Metering scheme, S3 exploits the case of a hybrid system under the current (amended) Net-Metering scheme, whereas S4 explores the system's operation under the consideration of a possible Net-Billing scheme with two different time slots (Peak and Off-Peak periods).

For S1, S2 and S3, the total electricity cost was calculated based on the energy exchange with the grid, i.e. grid import and export, and the relevant electricity price as explained in Section 2.2. For S4 however, the retail electricity price is categorised to Peak Tariff (i.e. 0.2133 €/kWh) between 09:00 – 23:00 and Off-Peak Tariff (i.e. 0.1741 €/kWh) between 23:00 – 09:00 for each day of the year, whereas the Grid Export price (i.e. remuneration for any surplus PV production injected to the grid) is at a constant value of 0.0711 €/kWh [17].

3 Results

3.1 Analysis results

Fig. 3 demonstrates the monthly SCR and SSR results obtained for each building. It can be seen that a significant increase was achieved in both metrics for every pilot for each month of the year under study, confirming the immediate impact of BESS integration with PVs on a building's self-consumption and self-sufficiency and in turn, the significant reduction of energy exchange between the building and the grid, resulting in more sustainable buildings.

Table 1 compares the yearly average SCR and SSR for each pilot. It can be seen that a significant increase is achieved in different magnitudes. The difference between each pilot is directly related to the occupants' energy behaviour, specifically their consumption profile. In addition, the increase in the SCR is greater than the increase in the SSR. Specifically, very high utilisation of PV production by the building is observed, i.e. approximately 84-88%. On the other hand, despite the significant increase in the SSR values, these are limited up to 48.7%, 67.5% and 65% for Pilot 1, Pilot 2 and Pilot 3 respectively, mainly as a result of the PV+Battery system size. In general, Table 1 verifies the direct impact of a BESS when integrated with a building equipped with PVs on both SCR and SSR metrics.

Table 2 depicts the financial outcome of each scenario addressed. It can be seen that investing in a hybrid PV+Battery system under any scheme (i.e. S2, S3 and S4) is by far a more profitable investment for the end-user rather than being solely dependent on the grid for the purchase of electricity at the retail price (i.e. S1). Moreover, given the new format of the Net-Metering scheme (i.e. after its amendment), the competitiveness of such installations is enhanced, as reduced electricity bills can be observed. Specifically, a growth of 13.3%, 18.2% and 21.7% in energy cost savings is achieved for Pilot 1, Pilot 2 and Pilot 3 respectively, as it can be seen in Table 3, when comparing S3 to S2. Yet, this decrease in electricity bills can be considered insufficient for higher BESS exploitation, given the still high cost of BESS [18].

Furthermore, S4 demonstrates that this specific Net-Billing format (i.e. two time slots with the aforementioned prices) is the most cost-effective option among the policy schemes addressed for Pilot 1, while it is the least cost-effective option for Pilot 2 and it has the same impact as S3 for Pilot 3, clearly showing that the financial feasibility of a hybrid PV+Battery system under Net-Billing is directly related to occupants' energy behaviour and mostly, the mode of operation (i.e. control scheme) of the system, specifically of the BESS. Notably, due to this specific mode of operation, the average imported energy for all pilots during Peak Period was 49.5%, while during Off-Peak Period was 50.5%. Thus, a mode of operation aiming to increase self-consumption is not the ideal for all buildings and mostly, the control scheme should be modified accordingly, preferably to charge the BESS during the Off-Peak Period rather than the Peak Period, resulting in additional cost savings under Net-Billing.

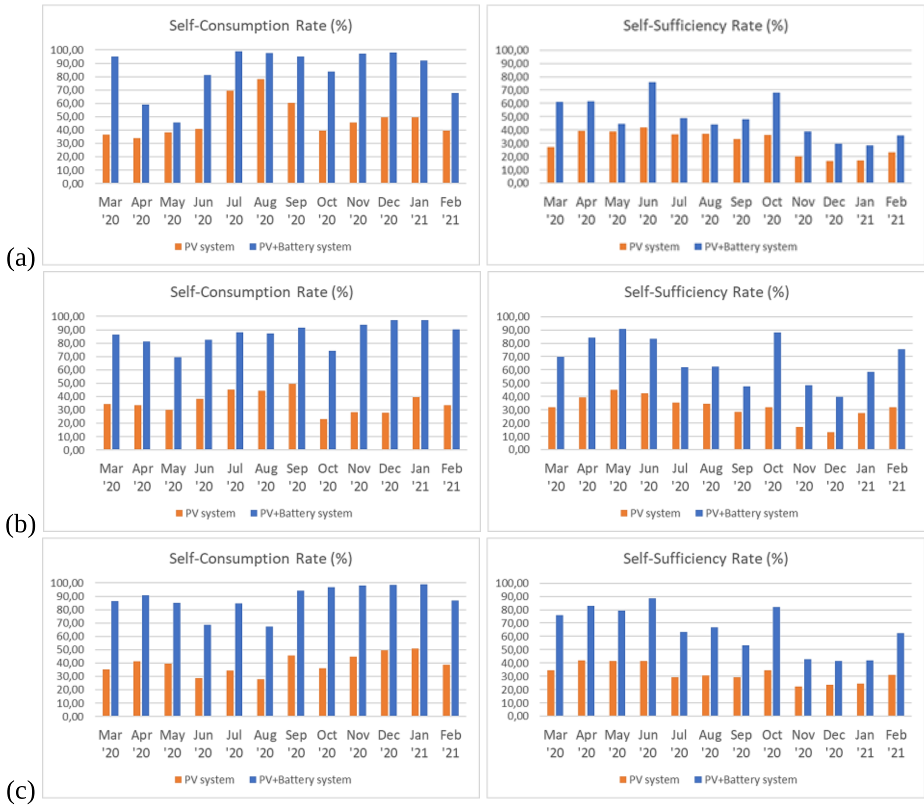

Fig. 3. Monthly SCR and SSR for (a) Pilot 1, (b) Pilot 2 and (c) Pilot 3.

Table 1. Yearly average SCR and SSR for all pilots and impact of BESS integration.

Pilot	Parameter	PV system	PV+Battery system	Percentage difference
#1	SCR (%)	48.5	84.2	+35.7%
	SSR (%)	30.6	48.7	+18.1%
#2	SCR (%)	35.7	86.6	+50.9%
	SSR (%)	31.6	67.5	+35.9%
#3	SCR (%)	39.4	88.0	+48.6%
	SSR (%)	32.1	65.0	+32.9%

Table 2. Total yearly electricity cost for all pilots for the four scenarios.

Pilot	S1: No PV+Battery	S2: PV+Battery (previous Net-Metering)	S3: PV+Battery (current Net-Metering)	S4: PV+Battery (Net-Billing)
#1	€1,647.76	€857.16	€742.91	€691.3
#2	€1,277.32	€449.17	€367.43	€484.5
#3	€1,279.46	€467.63	€366.22	€366.5

Table 3. Difference of the total yearly electricity cost for all pilots for the four scenarios.

Pilot	S2 vs S1	S3 vs S1	S4 vs S1	S3 vs S2
#1	-48.0%	-54.9%	-58.0%	-13.3%
#2	-64.8%	-71.2%	-62.1%	-18.2%
#3	-63.5%	-71.4%	-71.4%	-21.7%

Table 4 indicates the impact of the PV+Battery system implementation (i.e. S2, S3 and S4) on the buildings' environmental footprint during the year under study. Given the latest greenhouse gases (GHG) emissions factor (i.e. grid factor) of 0.71184 kgCO2/kWh, as published by the Electricity Authority of Cyprus (EAC) [19], all residences observed substantial reductions in their CO2 emissions, when compared to the no PV+Battery system scenario (i.e. S1). Specifically, the PV+Battery systems contribute in the reduction of GHG emissions by 57.4%, 77% and 75.6% for Pilot 1, Pilot 2 and Pilot 3 respectively, assisting in more environmentally friendly buildings.

Table 4. Impact of PV+Battery operation in buildings' CO2 emissions.

Pilot	S1: No PV+Battery (kgCO2)	S2/S3/S4: PV+Battery (kgCO2)	Percentage difference
#1	5,499.0	2,340.9	-57.4%
#2	4,262.7	979.4	-77.0%
#3	4,269.9	1,041.0	-75.6%

3.2 Discussion

The impact of the recent Net-Metering amendment on the financial feasibility of the three residential PV+Battery systems can be considered important, however it can only be regarded as a first step towards more supportive energy storage compensation mechanisms. Despite the recent amendment for the promotion of energy self-consumption, Net-Metering still remains a compensation mechanism that promotes higher PV production rather than increased PV self-consumption. This results from the fact that the grid can still be used as a virtual and cheap energy storage asset, mainly because energy can be exported to it for free and then imported back from it at a very low price, i.e. 0.043 €/kWh. As a result, the concept of BESS is not promoted adequately, as it is more beneficial for the building owner to export any excess PV production, rather than invest in a BESS.

However, it is evident that higher PV self-consumption under the current Net-Metering scheme is rewarded more than its previous form, even if the financial benefit (derived as energy cost savings in the form of reduced electricity bills) can be considered low. As a result, further actions are needed, yet this recent amendment showed that policy intervention is in any case in the right direction. With regards to these further actions, these primarily include the abolition of flat pricing, as well as the promotion of other tariff incentives.

Moreover, this transition requires the abolition of Net-Metering (in all their different types) or other similar schemes and the adoption of schemes suitable for energy storage exploitation at the building side, such as Net-Billing [20], which despite being very similar to Net-Metering, is distinguished by a major variation from it, constituting Net-Billing more proper for BESS than Net-Metering. Notably, within Net-Billing differing rates are used to value the excess PV production exported to the grid and the energy imported from it. The building user purchases energy at the retail electricity cost (including the network and all other regulated charges), which can be further classified by its cost (i.e. Peak/Off-Peak) and provides any excess PV production at an agreed price, usually less than the retail. Yet, the analysis results showed clearly that the control scheme of the PV+Battery system (specifically of the BESS) directly affects its financial feasibility, as value is created for the building user by utilising the difference between the two aforementioned prices to the greatest possible extent. This is achieved by storing energy during times of low retail electricity cost (i.e. Off-Peak Period) or excess PV production and using it during periods of high electricity cost (i.e. Peak Period). As a result, a control scheme that distinguishes the above in order to optimise the PV+Battery performance for reduced electricity bills is necessary under Net-Billing.

The aforementioned EU Directive states that more cost-oriented approaches should be encouraged within the EU. Thus, there is a clear need for establishing other pricing policies than flat pricing in Cyprus, as it is generally applicable until now. Tariff incentives such as Dynamic (e.g. Real-Time Pricing) and Static (e.g. Time-of-Use Tariffs) pricing models are considered the preferred option. Finally, the avoidance of any discriminatory charges (usually in the form of fixed charges) for PV+Battery system owners is highly recommended. These include added charges/levies applied, double taxation of the system owners both as consumers and producers, etc.

Conclusions

This paper addressed the integration of pilot BESSs in Cyprus, focusing on the impact of various policy schemes on the financial feasibility of hybrid PV+Battery systems in residential buildings, stemming from the recent EU guidelines for more sustainable and cost-effective Renewable Energy Sources at the building side. Specifically, the paper analysed the operation of three residential PV+Battery pilots during their first year of operation since the Net-Metering amendment in Cyprus from a financial point of view, while it also considered a Net-Billing scheme.

The new Net-Metering form indeed promotes energy self-consumption when compared to the previous form. However, further actions are needed as derived from the results. Specifically, the impact of the recent Net-Metering amendment on the financial feasibility of residential PV+Battery systems can be considered important, as significant energy cost savings for the building users are achieved. Yet, the use of the grid as a virtual and cheap energy storage asset does not promote adequately BESSs and the energy storage concept in general. However, it is evident that this transition is in the right direction and can be regarded as a first step towards more supportive to energy storage compensation mechanisms.

In addition, this work showed clearly that the financial feasibility of a hybrid PV+Battery system under Net-Billing is directly related to the occupants' energy behaviour and mostly, to the mode of operation (i.e. control scheme) of the system, specifically of the BESS. A mode of operation aiming to increase the building's self-consumption is not the ideal for all cases, as the control scheme should be modified accordingly, e.g. to charge the BESS during Off-Peak Periods rather than the Peak Periods, resulting in additional cost savings under Net-Billing. Finally, the environmental impact of the pilot PV+Battery systems is quantified. The results showed clearly that such investments reduce significantly building's environmental footprint, while they also increase its SCR and SSR, resulting in more sustainable buildings.

References

1. Briano, J. I., Pardo, I. P. and Denoyes, C. R., 2018. PV Grid Parity Monitor Commercial Sector 5th issue, Creara Energy Experts.
2. von Appen, J., Braun, M., Stetz, T., Diwold, K. and Geibel, D., 2013. Time in the Sun: The Challenge of High PV Penetration in the German Electric Grid, *IEEE Power Energy Mag.*, vol. 11, no. 2, pp. 55–64.
3. Chatzigeorgiou, N., Afxentis, S. and Georghiou, G.E., 2019. Analysis of "Increase Self-Consumption" Battery Energy Storage System Use - A Residential Case Study in Cyprus - IEEE Conference Publication. (2019). 1st International Conference on Energy Transition in the Mediterranean Area – SyNERGY MED 2019.
4. Barzegkar-Ntovom, G., Chatzigeorgiou, N., Nousdilis, A., Vomva, S., Kryonidis, G., Kontis, E., Georghiou, G., Christoforidis, G. and Papagiannis, G., 2020. Assessing the viability

of battery energy storage systems coupled with photovoltaics under a pure self-consumption scheme. Renewable Energy, 152, pp.1302-1309.

5. Jäger-Waldau, A., 2019. *PV Status Report 2019 – EU Science Hub – European Commission*. [online] EU Science Hub – European Commission. Available at: <https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/pv-status-report-2019> [Accessed 12 March 2021].
6. Ministry of Energy, Commerce and Industry – Energy Service, Plan for Electricity Production from Renewable Energy Sources (RES) for own use, Cyprus (2018).
7. Chatzigeorgiou, N., Yerasimou, Y., Florides, M. and Georghiou, G. E., 2020. "Grid export reduction based on time-scheduled charging of residential Battery Energy Storage Systems – A case study in Cyprus". The 12th International Conference on Sustainability in Energy and Buildings (SEB-20), 9-11 September, Split, Croatia.
8. Chatzigeorgiou, N., Poize, N., Florides, M. and Georghiou, G. E., 2020. "Analysing the operation of residential Photovoltaic – Battery Storage Systems in Cyprus". The 12th Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion (MEDPOWER2020), 9-12 November, Pafos, Cyprus
9. Kousksou, T., Bruel, P., Jamil, A., El Rhafiki, T. and Zeraouli, Y., 2014. "Review: energy storage: applications and challenges", Sol. Energy Mater. Sol. Cells 120 (Part A) 59-80.
10. Santos, J.M., Moura, P.S. & Almeida, A.T.D. 2014, "Technical and economic impact of residential electricity storage at local and grid level for Portugal", Applied Energy, vol. 128, pp. 254-264.
11. Wang, Y., Lin, X. & Pedram, M. 2014, "Adaptive control for energy storage systems in households with photovoltaic modules", IEEE Transactions on Smart Grid, vol. 5, no. 2, pp. 992-1001.
12. Khalilpour, K.R. & Vassallo, A. 2016, "Technoeconomic parametric analysis of PV-battery systems", Renewable Energy, vol. 97, pp. 757-768.
13. Marchi, B., Pasetti, M. & Zanoni, S. 2017, "Life Cycle Cost Analysis for BESS Optimal Sizing", Energy Procedia, pp. 127.
14. Cyprus Energy Regulatory Authority (CERA) Homepage, https://www.cera.org.cy/en-gb/apofasis/details/apofasi-28-2020, last accessed 2021/03/12.
15. EUR-Lex, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944, last accessed 2021/03/12.
16. EUROSTAT Homepage, https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics, last accessed 2021/03/12.
17. Electricity Authority of Cyprus (EAC) Homepage, https://www.eac.com.cy/EL/RegulatedActivities/Supply/tariffs/Pages/supply-tariffs.aspx, last accessed 2021/03/12.
18. EU Science Hub Homepage, https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/pv-status-report-2019, last accessed 2021/03/12.
19. Electricity Authority of Cyprus (EAC) Homepage, https://www.eac.com.cy/EN/EAC/Sustainability/Pages/ContributionOfEnergySources.aspx, last accessed 2021/03/12.
20. Interreg MED StoRES, https://stores.interreg-med.eu/what-we-achieve/deliverable-li-brary/detail/?tx_elibrary_pi1%5Blivrable%5D=8870&tx_elibrary_pi1%5Baction%5D=show&tx_elibrary_pi1%5Bcontroller%5D=Frontend%5CLivrable&cHash=30d79a1f6a3bc928b2251f304e3c5816, last accessed 2021/03/12.