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Net-Metering Compared to Battery-Based Electricity Storage in a Single-Case PV Application Study Considering the Lithuanian Context

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Received: 21 March 2020; Accepted: 26 April 2020; Published: 5 May 2020

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Abstract: Further increases in the number of photovoltaic installations in industry and residential buildings will require technologically and economically flexible energy storage solutions. Some countries utilize net-metering strategies, which use national networks as "virtual batteries." Despite the financial attractiveness, net-metering faces many technological and economical challenges. It could also lead to the negative tendencies in prosumer behavior, such as a decrease in motivation for the self-consumption of photovoltaic (PV)-generated electricity. Batteries, which are installed on the prosumer's premises, could be a solution in a particular case. However, the price for battery-based storage solutions is currently sufficiently unattractive for the average prosumer. This paper aimed to present a comparison of the economic and energy related aspects between net-metering and batteries for a single case study by considering the Lithuanian context. The net present value, degree of self-sufficiency, internal rate of return, payback time, and quantified reduction of carbon emission were calculated using a specially developed Prosumer solution simulation tool (Version 1.1, Delloite, Madrid, Spain) for both the PV and net-metering and PV and batteries cases. The received results highlight that the battery-based energy storage systems are currently not an attractive alternative in terms of price where net-metering is available; a rather radical decrease in the installation price for batteries is required.

Keywords: photovoltaics; net-metering; batteries

1. Introduction

Photovoltaics has become a field with a very rapid development due to the possibility of decreasing greenhouse gas emissions during electricity production, the reduction of the dependence on fossil fuels, and as a result, an increase in a country's energy security and growth of new jobs. Lots of different economical mechanisms, such as feed in tariffs, net-metering, and net purchase and sale, have been developed all around the world to support photovoltaic (PV) penetration in the energy market [1].

Despite all its benefits, photovoltaics is very unstable, highly dependent on weather conditions, and needs technological solutions to be able to provide a stable source of power. A surplus of electricity produced by the PV plant should be supplied to the grid or stored in house using energy storage technologies, such as batteries [2] and battery and supercapacitor combinations [3], or approaches such as power-to-gas could be used in urban areas [4]. The attractiveness of PV technologies increases with the increase of capabilities to use the produced electricity for self-demands and with the connection of PV technology to the proper energy storage solutions. The in house batteries or net-metering schemes could be excellent solutions to support further photovoltaics penetration; however, both options have clear economic and technological challenges [5].

The net-metering system is usually financially more attractive than a net feed-in tariff. Therefore, together with the rapid reduction of the costs of PV systems, a net metering policy reduces simple payback times for PV systems and strongly promotes the capacity growth of these systems [6]. If there is a small number of energy prosumers, the aggregate effect of net-metering policies on utilities is insignificant. However, the rapid increase of energy prosumers requires addressing the efficiency and equity of net metering. Doubts have been raised regarding the net-metering scheme's long-term sustainability [7].

In the academic literature, the many disadvantages of a net-metering system can be found. First, the net-metering scheme allows prosumers to not have to pay their full share of the fixed utility infrastructure costs, which means requiring the utility to raise retail prices for all customers [5,8,9]. For this reason, the net-metering policy is not fair to customers with and without distributed generation. Net metering schemes can result in the subsidization of energy prosumers by regular energy customers [10]. Second, net metering is not fair to utilities. The rapid growth of energy prosumers adds additional risk to utilities, thus it can lead to increasing the necessary expenses related to the national grid. In the long-term, net-metering could lead to challenges related to utilities' load balancing requirements [10]. Third, additional metering and power-quality costs exist related to the new facilities needed to accommodate the energy prosumer side [9]. Fourth, as the number of PV systems using net-metering is increasing, this can result in the government suffering significant income tax losses [6]. Fifth, as the prices of PV systems are constantly falling, net metering can lead to overstimulation because of an overly profitable financial case. Sixth, net-metering has a low impact on energy prosumers' level of self-consumption and thereby reduction in their use of the power grid capacity [6].

Batteries, which are installed on the prosumer's premises, could be a solution in this case. Appropriate PV system design can be complex, especially when one introduces an additional element to the system, which is the battery. With PV system development, energy storage systems have gained increasing interest in serving grid support and have evolved rapidly. The most popular type of battery, especially in modern power grids, is the lithium-ion battery [11]. In comparison with a lead-acid battery, it was found that a lithium-ion battery generally has a lower levelized cost of electricity (LCOE). This is related to the longer lifetime of lithium-ion batteries and the reduction of the price of batteries as a result of significantly increasing global production scales [12]. Other types of batteries, e.g., nickel-cadmium, sodium-sulfur, and metal-air batteries, also have disadvantages in comparison to lithium-ion batteries: nickel-cadmium batteries have a relatively high cost due to the expensive manufacturing process; sodium-sulfur batteries need to operate at a high temperature (from 290 to 360 °C); and for metal-air batteries, the high reactivity of lithium with air and humidity can cause a fire, which is a high safety risk [13].

To provide a proper battery storage size for grid-connected PV systems, appropriate technical and economic aspects should be maintained. Generally, the main objective is to choose an appropriate battery size while minimizing the electricity purchase cost from the grid [14]. Furthermore, appropriate assumptions for battery aging are necessary to reliably estimate the financial benefits of storage in PV systems [15,16]. By making proper assumptions regarding battery aging, this not only allows for cost savings, but energy savings can also be achieved [17]. An appropriate battery management algorithm for the charging and discharging process should be used to achieve the abovementioned goals [18]. It should also be mentioned that the aging of a PV module could impact the performance of a grid connected PV system [19].

An important aspect to consider when selecting the proper storage size is the household's energy self consumption. Batteries that are optimally sized for household self-consumption could increase the system's self-sufficiency ratio (SSR) and net present value (NPV) of the investment [20,21]. According to economic analyses, the most important goal is to maximize the system's SSR and NPV. Many PV system's design algorithms are based on that goal [22], but also incorporate the minimization of the LCOE and payback-period time [23]. The main advantage of PV systems with batteries is reducing the customers' reliance on grid electricity [24,25], but this also depends on the country's legal regulations, e.g., different tariff structures [26].

This study aimed to compare the economic- and energy-related aspects between net-metering and batteries for a single case study considering the Lithuanian context. All the simulations were performed in hourly time steps. This increased the accuracy of the results and provided in depth insights for wider discussions and future energy policy developments. Net present value, degree of self sufficiency, internal rate of return, payback time, and quantified reduction of carbon emission were calculated using a specially developed Prosumer solution simulation tool for both the PV and net-metering and PV and batteries cases.

2. Study Object and Method

2.1. Study Object

Lithuanian Energy Institute (a prosumer), which is in Kaunas, Lithuania, was analyzed in the case study. The prosumer was selected due to the availability of demand profiles on an hourly basis for a few years and the consumption history up to 10 years before the current investigations. The electricity consumption of the prosumer was about 1 GWh per year. The average electricity price paid was 94.9 €/MWh. PV electricity was consumed when possible and excess electricity was stored in a battery system or was exported to the low-voltage grid and temporarily stored using net-metering. The total available space for optimal (optimal orientation, installation angle, no shadows during the daytime, and the possibility for easy maintenance) PV power plant installation on the building's roof was approximately 800 m^2. The demand profile with an hourly time step is provided in Figure 1. The monitoring system for the prosumer data started on 1 January 2018 and ended on 31 December 2018.

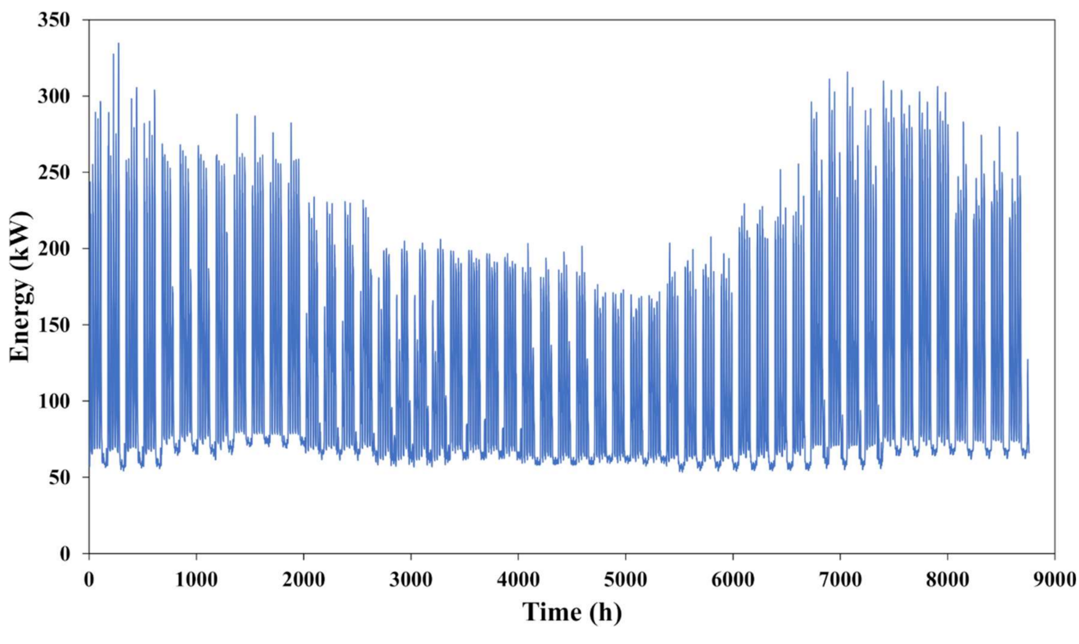

Figure 1. Yearly demand of the studied prosumer in Kaunas, Lithuania.

A fixed installation cost of €1000 per kW, a fixed battery cost of €600 per kW, and a discount rate of 6.5% were assumed for the economic analysis. Furthermore, the analysis also included fixed governmental support of 323.00 €/kW of PV power installed.

The radiation profiles (Figure 2) for the year 2018 were obtained from the solar radiation database CMSAF-PVGIS (©PVGIS © European Communities, 2001–2017) [27]. For the obtained data, a slope of 30° and an azimuth of 0° (south) were chosen.

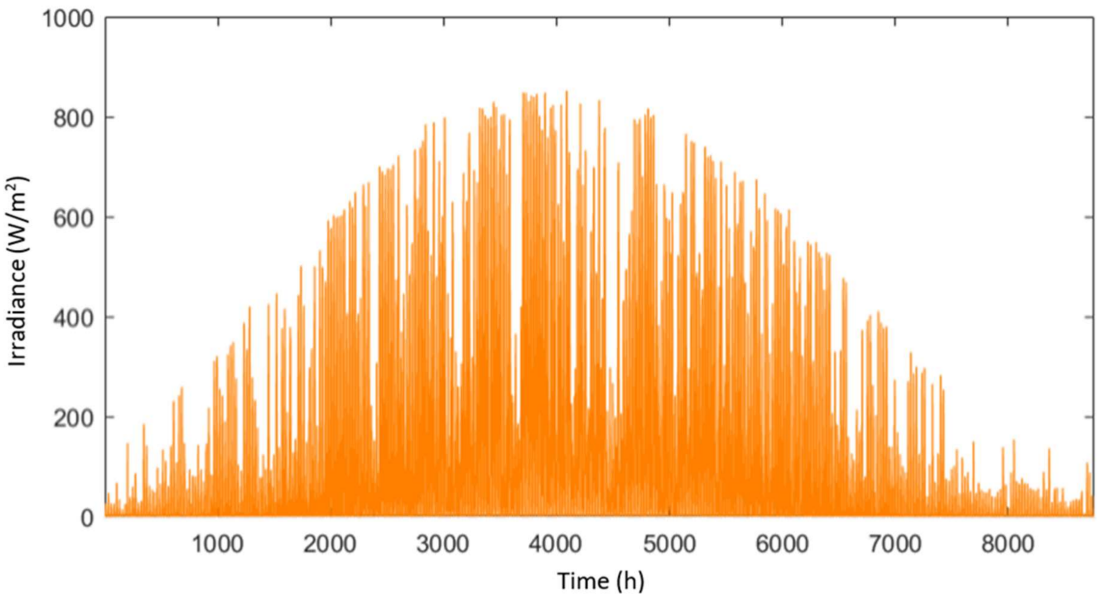

Figure 2. Yearly radiation in Kaunas, Lithuania.

Different PV power plant sizes (20, 40, 60, 80, 100, and 500 kW) were evaluated. Two different scenarios were simulated:

- A PV system without battery storage but with net-metering (first).
- A PV system with battery storage but without net-metering (second).

The net-metering was used to monitor the stored electricity that was produced by renewables. The National energy independence strategy (approved by the Lithuanian Parliament in 2018) [28] sets the following goals: in 2020, 30% of the country's total final electricity consumption should be from renewable energy sources, which increases to 45% by 2030 and 80% by 2050.

Residential PV installations can be up to 10 kW for homeowners and up to 500 kW for companies. Several algorithms for net-metering were proposed by the Lithuanian national electricity distribution company ESO (Energijos skirstymo operatorius, AB). The main algorithm is related to a 0.4 kV grid:

1. Fixed payment for energy storage at 0.042592 €/kWh (scenario I in further simulations).
2. Fixed payment for the installed PV power at 2.022 €/kW/month. (scenario II).
3. Mixed method that comprises payment for energy storage at 0.01938 €/kWh and payment for the installed PV power at 1.012 €/kW/month (scenario III).
4. ESO uses 36% of its produced electricity to cover expenses related to energy storage and the prosumer uses 64% for its needs (scenario IV).

2.2. Simulation Method

The Prosumer Simulation Tool [29] was used for the scenario simulations. The simulation tool was successfully verified for different cases (industry, services, residential sectors) in Germany, Greece, Poland, and Spain. It considers an electricity self-consumption environment and simulates the generation of distributed solar PV according to the historical radiation profile at the consumption site, along with its capacity to attend to the demand profile (examples of consumers: residential, different manufactures, agriculture, and companies of the service sector). The tool also allows for simulating the behavior of the installation of batteries to maximize the self-consumption. Based on these energy flows, the cash flows are estimated by considering the necessary investments, the savings due to substituting the current electricity supply from the grid with solar PV production, the additional revenues due to an excess of production, and the maintenance costs.

The study horizon for all the cases was 20 years. It is worth mentioning some limitations of the simulation tool used in these calculations. These limitations are related to the volatility of the radiation profiles since they could slightly change in the study location due to the global climate changes over the 20 years. The same could be said about the consumer demand profile: it could change over the 20 years. However, we verified the consumption of the prosumer, whose data were used in this study, and found that the deviations were relatively small in the past (approximately ±4% every year over the last 10 years). There could also be a minor uncertainty related to the panel price changes with the changes in the installation date.

The parameters that are considered in this paper are described below.

2.2.1. Fed-In Energy Loss

The electricity surplus produced by the prosumer the preceding year must be used by 31 March of the next year. Surplus electricity left unused after this date will be lost. This unused electricity is defined as the "fed-in energy loss" in further simulations.

2.2.2. Payback Time

The payback time (PB) is defined as the length of time required to recover the cost of investment:

$$\mathrm{PB} = \frac{C_0}{\sum_{t=1}^{T} \frac{C_t}{(1+i)^t}}, \tag{1}$$

where C_t is the net cash inflow during the period t, C_0 is the total initial investment cost, and i is the discount rate.

2.2.3. Net Present Value (NPV)

Net present value (NPV) describes the difference between the present value of cash inflows and the present value of cash outflows:

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+i)^t} - C_0, \tag{2}$$

where C_t is net cash inflow during the period t, C_0 is the total initial investment cost, and i is the discount rate.

2.2.4. Degree of Self-Sufficiency

The self-sufficiency ratio is the level of electricity consumption that is covered by the distributed solar PV generation located in the consumption site:

$$\mathrm{SS} = \frac{\mathrm{EC_{PV}}}{\mathrm{EC_{Total}}} \tag{3}$$

where SS is self-sufficiency ratio, EC_{PV} is electricity consumption from the solar panels production and EC_{Total} is the total electricity consumption.

2.2.5. Internal Rate of Return (IRR)

The internal rate of return (IRR) is a financial ratio that measures the level of return of a project relative to the investment. This ratio is calculated using the projected cash flows: IRR is the discount rate that sets the net present value of the project's cash flow equal to zero:

$$0 = \sum_{t+1}^{T} \frac{C_t}{(1+\mathrm{IRR})^t} - C_0. \tag{4}$$

2.2.6. Quantified Reduction of Carbon Emissions

Electricity self consumption based on solar PV is a substitute for the purchase of electricity from the power grid. In most countries, a relevant percentage of this electricity in the power grid is produced by fossil-fuel power plants. Therefore, the simulation of the avoided carbon emissions due to the distributed solar PV generation can be estimated by multiplying the self consumption production by the average emissions of the power plants in the country:

$$\mathrm{eCO2}_{\mathrm{avoided}} = \mathrm{EC}_{\mathrm{PV}} \times \mathrm{eCO2}_{\mathrm{factor}} \tag{5}$$

where $\mathrm{eCO2}_{\mathrm{avoided}}$ are the CO_2 emissions avoided in $kgCO_2$, $\mathrm{EC}_{\mathrm{PV}}$ is electricity consumption from the solar panels production in kWh and $\mathrm{eCO2}_{\mathrm{factor}}$ is the average coefficient of emissions of the power plants in the country in CO_2/kWh.

3. Results and Discussions

3.1. Case Study with Net-Metering

To find the appropriate size for the PV installation, different sizes (from 20 to 500 kW) were tested by considering the payback time and fed-in energy loss (Figure 3). The simulated results showed that fed-in losses appeared for the plants that were larger than 300 kW. However, if the payback time must be less than 10 years, the optimal PV power capacity was in the range of 100–200 kW.

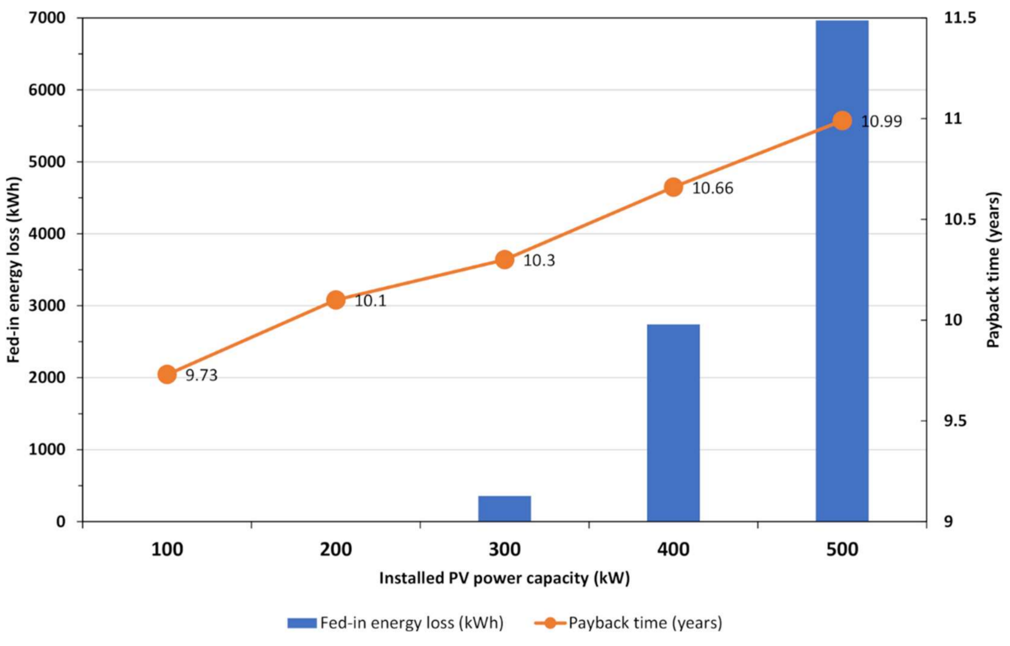

Figure 3. The fed-in loss (blue bars) and payback time (orange lines) of a PV power plant for different installed photovoltaic (PV) power capacities.

It is also very important to keep in mind the total available space for an optimal PV power plant installation on the prosumer building's roof (in our case, it was approximately 800 m^2). If the PV power plant will be built using panels with 250 W of power and a panel size of 1.7 m^2, 680 m^2 will be needed to install 400 panels and it will provide 100 kW in installed PV power capacity. Following all these considerations, PV plants with a maximum of 100 kW PV power capacity were selected for all further simulations.

The NPV analysis shows that it was highly sensitive to the net-metering payment option chosen (Figure 4). If the first scenario was chosen, the NPV increased as the PV power capacity was increased. The second scenario showed negative values and the NPV dropped as the size of the PV system increased. The third scenario showed positive NPV values, though they were relatively low, and they did not undergo great fluctuations when the PV power capacity was modified. The fourth scenario gave results that were similar to the first scenario.

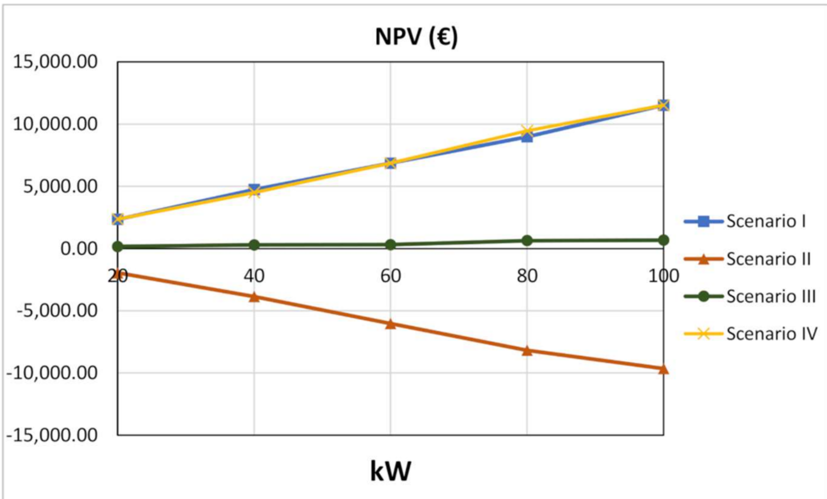

Figure 4. The net present value (NPV) of the different PV system configurations and payment options.

The underlying reason for the poor performance of scenario II was that this prosumer satisfied almost all their energy needs using energy generated from the panels. Consequently, paying for installed capacity was a fixed cost that did add any value to the solution as grid storage was not employed in this case. It can be observed that scenarios I and IV, where payment was only required for each unit of energy stored in the grid, was the most profitable option.

The IRR analysis (Figure 5) showed convergent results with the NPV, where the highest profitability of potential investments took place when scenarios I or IV were used for net-metering. The IRR remained constant for the different net-metering payment options irrespective of the installed PV capacity. The lowest IRR corresponded to scenario II.

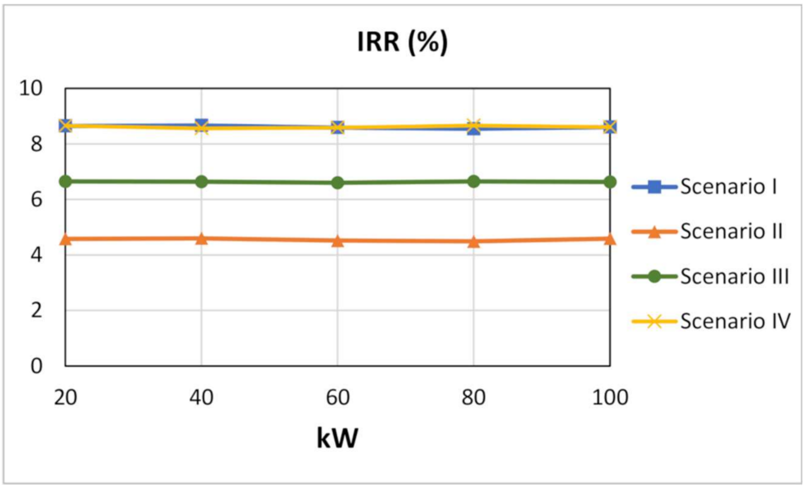

Figure 5. The internal rate of return (IRR) of the different PV system configurations and payment options.

The degree of self-sufficiency is one of the key performance indicators representing the prosumer's independence from the grid. As presented in Figure 6, the self-sufficiency increased linearly with the increase in PV power plant size and reached up to 10 % with the installed PV power capacity 100 kW.

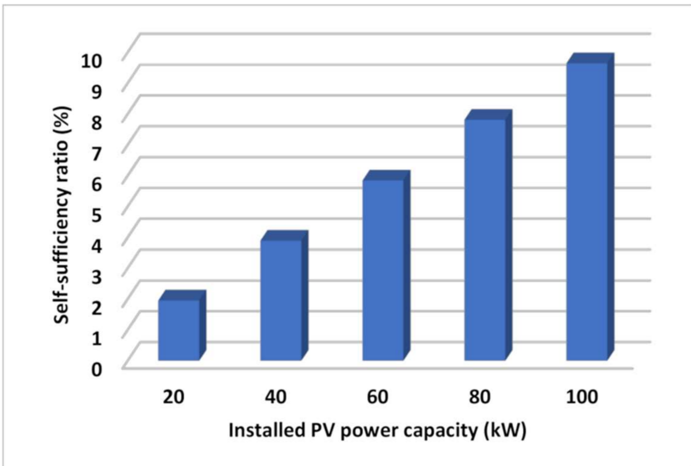

Figure 6. Self-sufficiency ratio for different PV installation sizes.

The amount of reduced carbon emissions increased with installed PV power capacity (Figure 7). As the installed capacity increased, the plant used less energy from a conventional energy source.

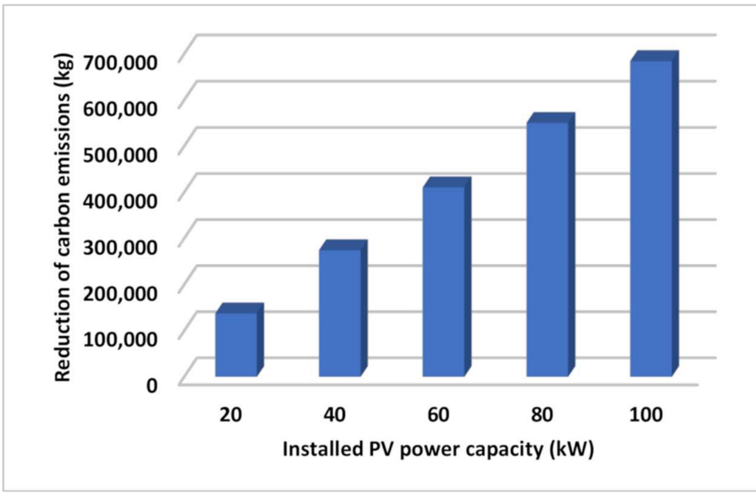

Figure 7. Reduction of carbon emission for different installed PV power capacities.

3.2. PV System with Battery Storage

Similar to the simulations presented in Section 3.1 (case study with net-metering), five different PV power plant sizes were also evaluated when considering a PV system with battery storage. For every PV power plant size (peak power P_p in kW), three different battery capacities were pre-proposed (Table 1), namely 0.25, 0.5, and 1 kWh/kW. It was also assumed that in the case of a PV system with batteries, net-metering was not applicable anymore and all electricity that was produced and not consumed by the prosumer was lost. The following default values were used for the lithium ion batteries in our simulations: efficiency—90%, depth of discharge—80%, time for the batteries replacement—10 years, degradation rate—5%, replacement cost—70%, and the discharge and charge rate was adjusted to 2/3 of the nominal capacity.

Table 1. Pre-proposed battery capacities for five different PV power plant sizes.

Battery Capacity for PV Power Plant Size	PV Power Plant Size P_p (kW)				
	20	**40**	**60**	**80**	**100**
Battery capacity (kWh)	5	10	15	20	25
	10	20	30	40	50
	20	40	60	80	100

The PV power plant sizes of 20, 40, and 60 kW were eliminated from further simulations. The prosumer had a huge demand for energy and the energy produced from the PV panels was consumed directly for use in the prosumer facilities. It did not make any sense to install batteries because the benefits from the storage system usage were small at best. The NPV factor was negative; thus, there was no need (economical issue) to install systems with a battery capacity in the range of 0.5–1.0 kWh/1 kW (Table A1, Appendix A). The lower capacities were used for further simulations. For the object with a huge energy demand, the prosumer battery capacity should be lower than 0.25 kWh/kW. For the main simulation, lower battery capacities were used (Table A2, Appendix A).

Figure 8 shows that the best solution was an 80 kW power plant with a battery capacity of 35 kWh. However, for the final decision, the payback time, NPV factor, IRR, and degree of self-sufficiency should also be verified. For the 80 kW and 100 kW power plants, the payback time increased as the battery capacity increased. This is logical since a system with batteries is more expensive. There was no significant change in the fed-in energy loss in the 80 kW power plant compared to the 100 kW power plant. In both cases, the fed-in energy loss decreased with increasing energy storage capacity (Figure 8).

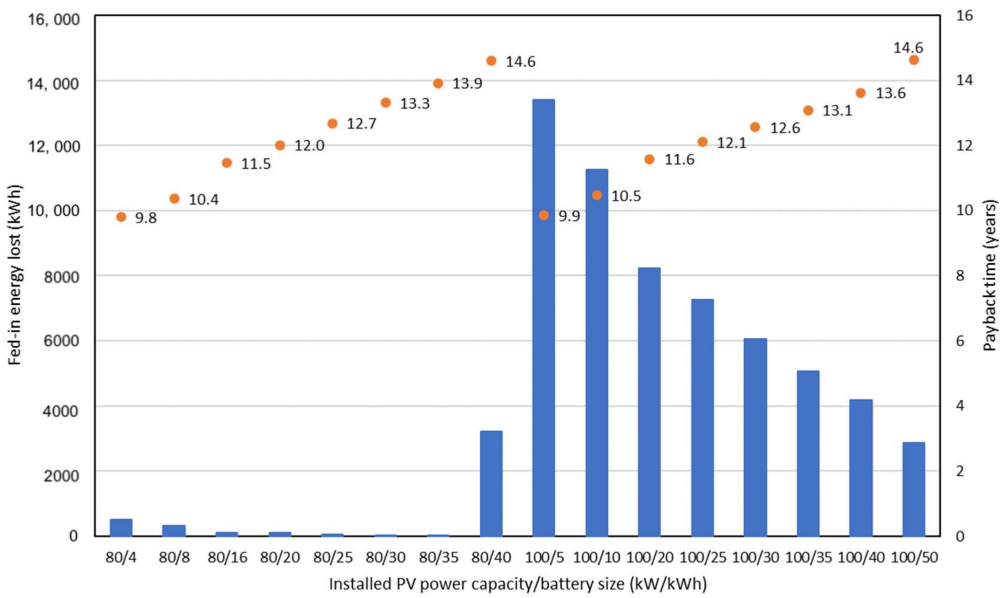

Figure 8. Fed-in energy loss (blue bars) and payback period (orange dots) of the PV system and battery capacity combinations.

The IRR analysis showed convergent results with the NPV, as in the case of net-metering. In both cases, the NPV and IRR decreased as the battery capacity increased (Figures 9 and 10). The NPV was positive for only four cases:

- 80 kW power plant with a 4 or 8 kWh battery capacity, and
- 100 kW power plant with a 5 or 10 kWh battery capacity.

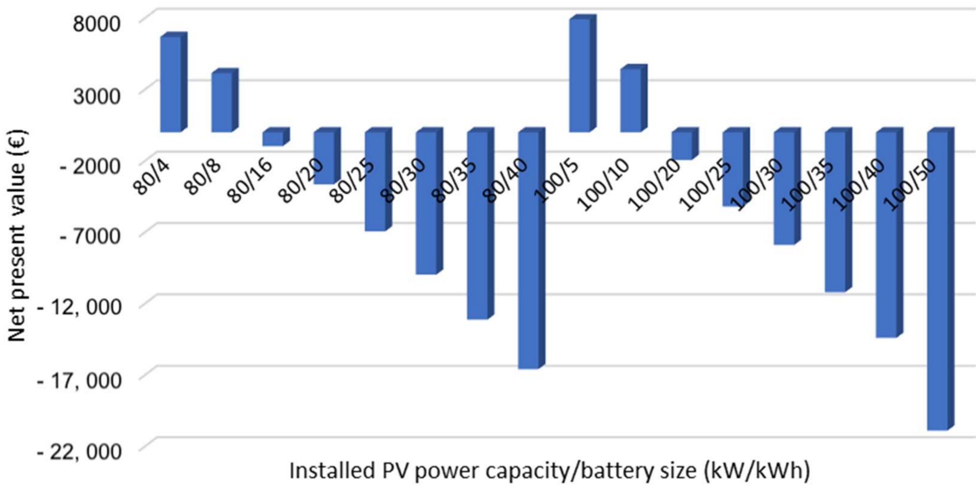

Figure 9. The NPV value for different PV system and battery capacity combinations.

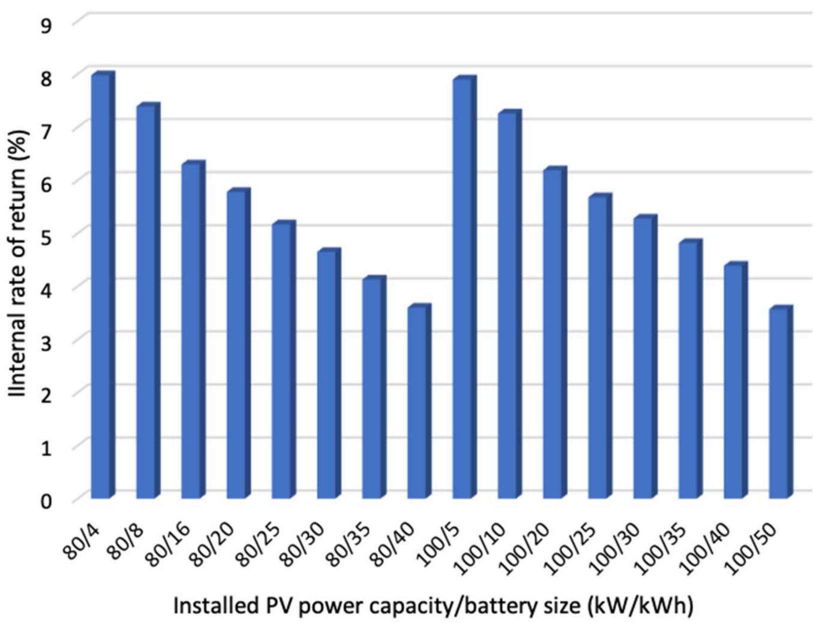

Figure 10. Internal rate of return for different PV system and battery capacity combinations.

The degree of self-sufficiency showed similar values independently of the battery capacity option chosen. There was no change in the degree of self-sufficiency for both cases of installed power plant capacity: for the 80 kW power plant, the degree of self-sufficiency was 7.8%, and for the 100 kW power plant, it was 9.7% (Figure 11).

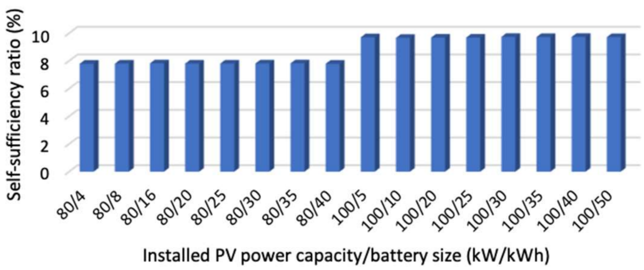

Figure 11. Degree of self-sufficiency for different PV system and battery capacity combinations.

There was no significant change in the value of the reduction in carbon emissions. It was approximately 550 and 690 tons of CO_2 emissions reductions for the 80 and 100 kW power plants, respectively, for each of the battery capacities (Figure 12).

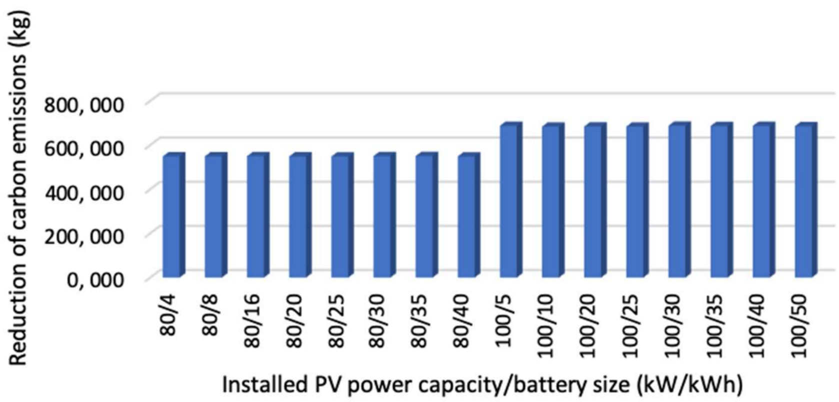

Figure 12. Reduction of carbon emissions for different PV system and battery capacity combinations.

The economic analysis based on the evaluation of the NPV and IRR for the different installed PV power capacities showed that with the increase of the battery size, the investment attractiveness decreased. On the other hand, when evaluating the fed-in loss, the situation was different: the fed-in loss decreased with increased battery size. The NPV and IRR were very sensitive to the price of batteries. When evaluating the case with the biggest battery sizes for both the 80 and 100 kW installations, it was clear that the price of batteries should be much lower than their current price (600 €/kWh for Li batteries) and reach payback time in less than 10 years to compete with net-metering (Figure 13).

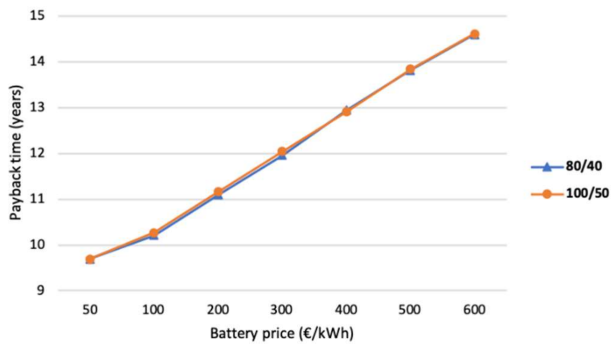

Figure 13. Payback time of the PV and batteries power plant for different battery prices.

Despite the current rather high prices for the Li-ion battery-based storage systems, the predictions are very optimistic.The growth of the battery-based energy storage market depends on tariff structures, incentives that are available for customers, proactivity of local retailers and system operators, and interventions by state/federal governments (e.g., upfront subsidies/rebates or funding of pilots) [30]. The system costs will continue to fall due to lots of ongoing R&D activities and economies of scale. It is expected that in the best-case scenarios, the installation cost for Li-ion batteries will reach 77 USD/kWh for lithium iron phosphate, 215 USD/kWh for lithium-titanate, 82 USD/kWh for Nickel Cobalt Aluminum, and 79 USD/kWh for Nickel Manganese Cobalt/ Lithium Manganese Oxide bateries technologies by the year 2030 [31], which will be competitive with current net-metering solutions.

4. Conclusions

This research compared net-metering and batteries-based energy storage for PV applications for a single case study in a Lithuanian context due to very ambitious plans stating that in 2020, 30% of the country's total final electricity consumption will be from renewable energy sources, which increases to 45% by 2030 and 80% by 2050.

The analysis of the NPV, IRR, and payback time for the net-metering case showed that it was very attractive in terms of investment and can give a payback time of fewer than 10 years with a study horizon of 20 years. Given the four different scenarios for net-metering that Lithuania has, it was found that for the single case study analyzed, the most profitable ones were these where payment was only required for each unit of energy stored in the grid. It was also found that self-sufficiency and the reduction of carbon emissions increased linearly with the increase of installed PV power capacity.

The analysis of the PV system with battery cases showed that the NPV was positive only for the cases when the batteries' capacity did not exceed 10 kWh and radically decreased with increasing battery capacity up to 40 kWh for 100 kW of installed PV power. The IRR analysis showed convergent results with the NPV.

The analysis of the degree of self-sufficiency and the reduction of carbon emissions remained stable with the increase of the batteries' capacity and depended only on the installed PV power, just as in the net-metering case.

The general conclusion of this work is that battery-based energy storage in the discussed single case study was not currently competitive with the possible net-metering options. To compete with net-metering, battery system prices should go down to less than about 100 €/kWh to support PV installations in Lithuania; support mechanisms for the batteries should also be proposed.

The main concern about the application of the net-metering approach is related to its impact on the electricity market cash flows. The consumers who install the solar PV equipment obtain a benefit from this mechanism when they take electricity from the system at a lower price than the traditional supply from the retailer, while the rest of the consumers support this benefit.

Author Contributions: Conceptualization, D.M., J.A.-G., and E.D.; methodology, E.D. and R.U; software, D.G.; calculations, D.G., D.M., and J.A.-G.; regulatory framework analysis, S.M. and J.K.; writing—original draft preparation, J.A.-G., D.M., S.M., and J.K.; writing—review and editing, R.U. and E.D. All authors have read and agreed to the published version of the manuscript.

Funding: This study is part of the project iDistributedPV. The project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 764452. Joanna Aleksiejuk-Gawron's participation in the research was financed from the scholarship fund of the Warsaw University of Life Sciences (decision no. BWM-315/2018).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Pre-proposed battery capacities simulation results.

Installed Capacity of PV/Battery Capacity (kW/kWh)	Economic Outputs							Technical Outputs							Environmental Outputs and Other Indicators		
	System Price (Thousand €)	IRR (%)	NPV (Thousand €)	Payback (Years)	Cost of Energy Purchased from the Grid (Thousand €)	Benefits from Storage System Usage (Thousand €)	Benefits from Panels Usage (Thousand €)	Solar Generation (Thousand kWh)	Cycles of the Storage System Consumed (Cycles)	Energy Bought from the Grid (Thousand kWh)	Energy Consumed from Storage System (Thousand kWh)	Energy Consumed from Panels (Thousand kWh)	Energy Exported to the Grid (Thousand kWh)	Fed-In Energy Lost (Thousand kWh)	Reduction of Carbon Emissions (Thousand kg)	Degree of Self-Sufficiency (%)	LCOE (cts/kWh)
20/5	16.54	5.8	−0.91	12.0	1820	0.0	36.2	382	0	19,180	0.0	382	0.0	0.0	137.4	2.0	7.1
20/10	19.54	3.6	−4.14	14.6	1821	0.0	36.2	381	0	19,190	0.0	381	0.0	0.0	137.2	2.0	7.1
20/20	25.54	0.4	−10.58	>20	1819	0.0	36.2	382	0	19,170	0.0	382	0.0	0.0	137.4	2.0	7.1
40/10	33.08	5.8	−1.88	12.1	1781	0.0	72.3	762	0	18,770	0.0	762	0.0	0.0	274.3	3.9	7.1
40/20	39.08	3.6	−8.34	14.6	1785	0.0	72.3	762	0	18,810	0.0	762	0.0	0.0	274.2	3.9	7.1
40/40	51.08	0.4	−21.18	>20	1784	0.0	72.5	764	0	18,800	0.0	764	0.0	0.0	274.9	3.9	7.1
60/15	49.62	5.8	−2.67	12.0	1746	0.0	108.6	1145	0	18,400	0.0	1145	0.0	0.0	412.1	5.9	7.1
60/30	58.62	3.6	−12.62	14.7	1748	0.0	108.1	1139	0	18,420	0.0	1139	0.0	0.0	410.2	5.8	7.1
60/60	76.62	0.4	−31.77	>20	1747	0.0	108.6	1144	0	18,410	0.0	1144	0.0	0.0	412.0	5.9	7.1
80/20	66.16	5.8	−3.64	12.0	1710	0.071	144.7	1525	37	18,020	0.7	1524	95	95	549.1	7.8	7.1
80/40	78.16	3.6	−16.58	14.6	1712	0.077	144.7	1525	20	18,040	0.8	1524	3.2	3.2	549.1	7.8	7.1
80/80	102.2	0.4	−42.42	>20	1712	0.074	144.5	1524	10	18,040	0.8	1523	0.0	0.0	548.5	7.8	7.1
100/25	82.70	5.7	−5.19	12.1	1675	0.734	178.8	1900	310	17,650	7.7	1885	7267	7267	684.2	9.7	7.1
100/50	97.70	3.6	−20.89	14.6	1678	1.092	179.4	1906	230	17,650	11.5	1890	2878	2878	686.2	9.7	7.1
100/100	127.7	0.4	−53.09	>20	1675	1.344	179.5	1908	142	17,650	14.2	1892	246	246	686.9	9.8	7.1

Table A2. Main simulation results.

Installed Capacity of PV/Battery Capacity (kW/kWh)	Economic Outputs							Technical Outputs							Environmental Outputs and Other Indicators		
	System Price (Thousand €)	IRR (%)	NPV (Thousand €)	Payback (Years)	Cost of Energy Purchased from the Grid (Thousand €)	Benefits from Storage System Usage (Thousand €)	Benefits from Panels Usage (Thousand €)	Solar Generation (Thousand kWh)	Cycles of the Storage System Consumed (Cycles)	Energy Bought from the Grid (Thousand kWh)	Energy Consumed from Storage System (Thousand kWh)	Energy Consumed from Panels (Thousand kWh)	Energy Exported to the Grid (Thousand kWh)	Fed-In Energy Lost (Thousand kWh)	Reduction of Carbon Emissions (Thousand kg)	Degree of Self-Sufficiency (%)	LCOE (cts/kWh)
80/4	56.56	8.0	6.68	9.8	1713	0.031	144.7	1526	84	18,050	0.3	1525	0.490	0.499	549.2	7.8	7.1
80/8	58.96	7.4	4.15	10.4	1712	0.501	144.8	1527	66	18,040	0.5	1526	0.320	0.320	549.7	7.8	7.1
80/16	63.76	6.3	−0.96	11.5	1709	0.066	144.9	1528	44	18,010	0.7	1527	0.121	0.121	550.0	7.8	7.1
80/20	66.16	5.8	−3.64	12.0	1710	0.707	144.7	1525	37	18,020	0.7	1524	0.095	0.095	549.1	7.8	7.1
80/25	69.16	5.2	−6.94	12.7	1710	0.070	144.5	1524	29	18,020	0.7	1523	0.048	0.048	548.6	7.8	7.1
80/30	72.16	4.7	−9.97	13.3	1712	0.074	145.0	1529	26	18,040	0.8	1528	0.014	0.014	550.4	7.8	7.1
80/35	75.16	4.1	−13.12	13.9	1712	0.075	145.1	1530	22	18,040	0.8	1529	0.010	0.010	550.7	7.8	7.1
80/40	78.16	3.6	−16.58	14.6	1712	0.077	144.7	1525	20	18,040	0.8	1524	0.003	3.210	549.1	7.8	7.1
100/5	70.70	7.9	7.92	9.9	1677	0.196	179.8	1911	425	17,670	2.1	1895	13.39	13.39	687.8	9.7	7.1
100/10	73.70	7.3	4.42	10.5	1676	0.356	178.9	1900	380	17,660	3.8	1885	11.27	11.27	684.2	9.7	7.1
100/20	79.70	6.2	−1.93	11.6	1676	0.623	179.0	1902	329	17,660	6.6	1886	8.238	8.238	684.7	9.7	7.1
100/25	82.70	5.7	−5.19	12.1	1675	0.734	178.8	1900	310	17,650	7.7	1885	7.267	7.267	684.2	9.7	7.1
100/30	85.70	5.3	−7.89	12.6	1676	0.823	179.9	1911	289	17,660	8.7	1895	6.067	6.067	688.0	9.7	7.1
100/35	88.70	4.8	−11.19	13.1	1,676	0.897	179.6	1908	270	17,660	9.4	1892	5.054	5.054	686.9	9.7	7.1
100/40	91.70	4.4	−14.40	13.6	1677	0.974	179.7	1909	257	17,670	10.3	1894	4.194	4.194	687.3	9.7	7.1
100/50	97.70	3.6	−20.89	14.6	1678	1.092	179.4	1906	230	17,650	11.5	1890	2.878	2.878	686.2	9.7	7.1

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