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Communication

Techno-Economics of Using Second Life BEV Traction Batteries as BESS in Domestic RES Installations

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Abstract

This article analyses the possibility of using Li-ion batteries removed from battery electric vehicles (BEVs) as short-term energy storage devices in a near-zero energy building (nZEB) in conjunction with a rooftop photovoltaic (PV) system. The technical and economic feasibility of this solution was compared to that of a standard commercial LIB (Lithium-Ion battery) BESS Battery Energy Storage System). Two generations of the same BEV model battery were tested to analyse their suitability for powering a building. The necessary changes to the setup of such a battery for building power supply purposes were analysed, as well as its suitability. As a result, analyses of profitability over the predicted life span and NPV (net present value) of SLEVBs (second-life BEV batteries) for building power were carried out. The study also conducted preliminary research on the effectiveness of such projects and their pros and cons in terms of security. The author calculates the profitability of a ready-made PV BESS with a set of SLEVBs, estimating the payback periods for such investments relative to electricity prices in Poland. The article concludes on the potential of SLEVBs to support self-consumption in nZEB buildings and its environmental impact on the European circular economy.

Keywords: BESS profitability; BEV battery reuse; LIB battery second life; SLEVB; PV storage

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1. Introduction

The future of LIB batteries: While the almost exponential growth in the number of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) in use in Europe is cause for optimism due to the improvement in air quality caused by the reduction in cars with alternative internal combustion engines, it also raises concerns about what will happen to the millions of traction lithium-ion (LIB) batteries once these EVs reach the end of their service life. Meanwhile, there is an increasing demand for high-capacity LIB batteries to store energy from renewable energy sources (RESs) on a daily or multi-day basis. However, the new ready-to-use battery energy storage system (BESS) kits (also based on LIBs) are too expensive in most countries to store surplus energy effectively. Used BEV batteries, also known as SLBEVs (second-life electric vehicle batteries), which are suitable for energy storage in home PV installations, can be sourced from BEVs at various stages in their life cycle. This significantly impacts their usefulness as DIY (Do It Yourself) BESS. Author proposes introducing a typology of SLEVB usefulness, i.e., types A, B and C.

The first category (Type A) concerns LIBs from EVs/PHEVs that are a few years old and so damaged that they cannot be returned to road use. This includes cars that have been scrapped for technical reasons, including loss of market value as assessed by the insurer. However, the traction batteries are still in good condition. Batteries from BEVs that are

so old they are naturally scrapped after 15–20 years of use can be described as Type C. These completely worn-out batteries shall not be considered for DIY BESSs and must be recycled as soon as possible. Type B batteries would cover those from vehicles that are just a few years old, whose capacity is difficult to determine, although their condition and current SOH (state of health) parameter predestines them for further use as BESSs. Type A and B batteries still have significant energy storage capacity and can and should be reused within the circular economy. In 2023, the European Union introduced Directive 1542 [1], which takes the reuse and remastering of LIBs very seriously and encourages EU (European Union) member states to introduce appropriate legislation for such activities within their countries. Restoring them for reuse, a process sometimes known as 'remanufacturing of LIBs' [1] (definition, see: Appendix A), is challenging in the case of BEV batteries. The repurposing of BEV batteries has also been defined there (see Appendix A). However, it can be an important element of Europe's closed-loop economy, as noted in [1]. Previous research conducted by the Author and a group of Polish scientists indicated that the technical problems of restoring the efficiency of such batteries (Type B or even C) could be solved by replacing the cells [2], provided that such cells are still available. The lack of spare parts, especially cells, is one of the most serious issues when it comes to giving batteries a second life. Rapid progress in the EV market means that manufacturers are introducing new generations of cells quite quickly without considering their availability after the EV warranty period. This issue will be discussed in more detail in the comparative studies of DIY_EV 1 and 2. Another publication indicates that the biggest problem for the second life of BEVs will be how to guarantee their continued use and under what conditions. Furthermore, numerous sources [3–6] suggest that the increasing number of BEV/PHEVs in Europe could present challenges in terms of the disposal and safe management of LIBs. According to analyses carried out in Sweden, EV battery gigafactory operator Northvolt declares that they 'will strive to recover more than half of the raw materials for new batteries from BEV batteries by 2030'. If this succeeds, it will account for half of the small proportion of BEV/PHEV batteries produced in Europe. But what about cars imported from the USA, China, and India? In other words, an increase in the supply of cars will lead to an increase in the supply of used batteries from electric vehicles (BEVs and PHEVs) across Europe. The author doubts that these batteries will be re-imported to the countries in which they were manufactured. The high prices of new BESS batteries for domestic use have already created a domestic market for retrofitting EV batteries in Europe, resulting in a significant influx and a creative approach from IT (Information Technology) specialists. This has led to the emergence of a separate and significant market for used battery packs from end-of-life vehicles in Europe, involving many small companies and giving a second life to thousands of EV/PHEV batteries [7]. The economics of using and decommissioning such batteries are therefore becoming very important [8]. This makes sense because Type A or B LIBs in scrap yards today have much better performance parameters (e.g., capacity and durability) than most lead-based VRLA batteries used in UPSs to date. On the other hand, there are legitimate concerns about the safety of using batteries over a longer period of time [9]. For used Nissan Leaf batteries from 2016, an empirically confirmed value of 75–76.5% has been adopted for storing energy from RESs, which is still very favourable [2]. The safety of BESSs will become a key issue as soon as LIB-based BESS batteries start to explode on the market. Considering the fires that have occurred in the EV/PHEV's, this is a legitimate concern. The issue of thermal runaway is described in detail in [9], and possible BESS design solutions are discussed in [10–12]. The easiest solution would be to recommend LIB chemistry with the lowest susceptibility to thermal runaway, e.g., LFP (Lithium iron phosphate). However, this does not solve the general problem with LIBs, which are sensitive to mechanical damage, overheating and overcharging. The basic principles of preventing thermal runaway in

LIBs include preventing overheating (author believes this is easier to achieve in domestic conditions than in a vehicle), protecting the casing from punctures (same as above) and ensuring proper use, e.g., not exceeding charging voltages and currents, by using a proper BMS (Battery Management System). Concerns about the safety of such solutions have so far proved unfounded, as Author's own research shows that automotive batteries are much better protected against atmospheric influences (they are designed for outdoor use, unlike most domestic BESSs) and punctures. It is worth mentioning that, due to their large size and weight, they are usually kept outside residential buildings, which increases their overall safety. The design of the BEV's internal EV BMS also shows that it disconnects from the associated power supplier (e.g., a PV inverter) much easier/faster than a stationary BESS does—e.g., in the event of "suspicious activity", including opening the housing. Author has already examined some of these features in publication [10]. Finally, mass production of LIBs for BEVs has led to batteries manufactured for the automotive market setting quality standards for the entire electricity storage market, consistently ranking among the most durable and efficient solutions. It is a shame to scrap or recycle type A or B batteries today, given their significant utility and market value. However, publication [9] rightly points out that there is a lack of uniform testing and certification methods for BEV and BESS batteries. As mentioned in Directive [1], the EU states that requirements for the end-of-life stage are necessary to address the environmental impact of batteries and, in particular, to support the creation of markets for battery recycling and for secondary raw materials from waste batteries. Directive 2006/66 should therefore be replaced by a local regulation. The newer version of this directive even suggests introducing new EU rules, anticipating that 'batteries for electric vehicles represent the market segment with the highest expected growth in the coming years', and that these rules should 'establish specific sustainability requirements for rechargeable batteries with a capacity greater than 2 kWh'. Author hopes that the EU will call for greater attention to be paid to what happens to LIB batteries in vehicles, in terms of safety tests and certificates, as well as when they are reused as SLBEVs in BESSs as a result of their 'conscious withdrawal' from use. This will help to increase the safety of LIBs in the future. Hopefully, standards for their use will already have been developed before the first serious accidents occur as a result of improper use of SLBEVs. Regardless of the business models that would need to be developed for this type of product (e.g., warranty or liability issues relating to the safe use of SLBEV-based BESSs), this article focuses on testing the technical usability of such systems in nZEB, PV-powered buildings, as well as the potential payback periods in relation to the value of the stored electricity.

The objectives of the research were as follows: Author posed three fundamental research questions:

1. Will every used battery (type A or B) removed from an EV be suitable for use as a BESS in a residential building, and how will its performance parameters compare to those of a commonly available PV BESS?
2. What will the cost be of converting a BEV battery to a BESS battery? What will the real (not Simple Pay Back Time) payback period be? The payback calculation should take into account the cost of money, the degree of actual use of the BESS, and the degree of degradation of the SLBEV, i.e., an NPV calculation should be performed. How sensitive is NPV calculation to the market value of electricity (including that from renewable energy sources)?
3. Are there any other factors to consider, such as safety or environmental impact, when comparing these two solutions (SLBEV vs. BESS)?

2. Materials and Methods

The author believes that the fundamental question concerning the economics of using BESSs is: what is the appropriate battery capacity (E_max) for a household, and what will the acquisition and usage costs be? Opinions are divided on this issue, and ultimately it comes down to how energy storage is intended to be used. Author has performed numerous simulations in PVSyst software regarding this issue, but these will be published in a subsequent article determining optimal values. The optimal E_max capacity will be described later in this text and adopted as a constant—appropriate for the test building in which the BESS storage units were installed. The next important question is, if energy is to be stored locally, what should its market value be? These are fundamental questions regarding a country's strategy for harnessing and storing renewable energy from RES sources. Looking at the problem from the prosumer's perspective, Author's previous research indicates that E_min (the minimum reasonable real value of energy available from the BESS for given household) should be at least equal to a household's energy demand from one solar day to the next (in summer, this can be assumed to be from dusk until morning or noon the following day). Further research has shown that, if it is not possible to feed surplus energy from PV into the grid either technically or economically, the power and capacity of the BESS should be sized so that E_max (the maximum reasonable real value of energy available from the BESS) allows the entire daily solar energy surplus (assuming 100% possible self-consumption) to be collected and stored for as long as possible for subsequent potentially cloudy days. In practice, if the value of the energy stored in the BESS (taking into account its net present value (NPV) over its lifetime) is lower than the price of purchasing energy from the grid, it is profitable for the prosumer to store as much energy as possible in the household and even to switch other energy sources to stored electricity from renewable energy sources (RES) (e.g., fuel for vehicles or gas for cooking). Therefore, SLBEV batteries may be particularly attractive, as they offer 2–4 times the capacity of BESSs for the same purchase price. This will be analysed in detail later in the article. For the purposes of this article, a given household was assumed to have an E_min of 8 kWh, which is considered a reasonable minimum in the Polish PV industry for a household preparing DHW from electricity from late spring to early autumn. In the first stage of the experiment, a BESS set (E_max = 22 kWh) consisting of seven modules and a BMS control module (BESS_1), manufactured by Pylontech and described in detail in Table 1, was purchased. Next, a complete EV battery with a nominal capacity of 24 kWh, was purchased from a car scrapped in 2012 and named DIY EVB_1. This increased the theoretical total local Energy Storage to 46 kWh (the output of the PVSyst optimisation). After assembling and programming the measuring system to work with two Goodwe ET10 kW PV inverters it was found that the DIY EVB_1 battery (see Figure 1) was practically unsuitable for comparative tests as its available capacity was significantly lower than the nominal capacity, and it also showed a loss of power over time. Following literature research and tests carried out by Author on dismantled cells of this battery, it emerged that batteries of this type, based on hybrid chemistry ($LiMn_2O_4$ + NMC (lithium nickel manganese cobalt oxide)), proved to be an unstable solution on the automotive market, with production being discontinued in 2016. The purchased battery had a real capacity of ~15 kWh and showed signs of typical permanent damage for this model (e.g., swollen cells, see Figure 1), which made it practically impossible to conduct tests, as the battery heated up and was unable to store a comparable amount of energy to the new BESS_1's nominal 24 kWh. In earlier work, the replacement of individual cells was found to be an effective way of regaining LIB capacity, as described in [2,10]. In this case, Author replaced four modules of the battery (see Table 1), achieving an E_max of 21–22 kWh, but still not achieving comparable charging results for the entire set. In this case, a newer

version of the DIY battery was purchased from the same supplier of used car parts with a nominal capacity of 24 kWh. This battery, which is the same shape as the previous one and was manufactured in 2016, is built on the basis of new NMC chemistry (although the external dimensions and weight remain almost identical, see Table 1). This unit has already reached 95% of its nominal 24 kWh capacity (i.e., approx. 23 kWh) and has been named DIY EVB_2. This is compared to BESS_1, which has software limitations on capacity usage (approximately 10% of the nominal capacity must remain in the battery, hence E_max = 22 kWh). Consequently, while the two batteries did not differ in terms of available capacity, they did differ significantly in terms of purchase price and home installation options (see Tables 2 and 3). The first battery (BESS_1) was chosen because it can work with at least five different types of PV inverter, including the GoodWe 10 ET (used in tests), on almost a plug-and-play basis. However, connecting the DIY EVB_2 kit to the other GoodWe 10ET inverter required the installation of a special interface called a 'CAN bridge', which safely translates commands between the battery's BMS and the PV inverter. The test bed was almost identical to that used in work [11]: a series-connected PV inverter, CAN bridge and DIY EVB_2. The system only required an additional 12 V DC power supply (for automation only). In this case, Author used LillyGO hardware and widely available documentation to program the interface to work with this type of LIB [7]. This resulted in a universal CAN bridge that will allow many different types of batteries to be connected to EVs LIB in future, particularly the DIY EVB_1 and 2, which have identical cooperation protocols. The purchase costs of individual sets are shown in Table 1.

Table 1. A summary of the three energy storage systems that were tested in the study.

Description	PylontechH1 Set. BESS_1 (Figure 2)	DIY EVB_1 24 kWh Y2012 Version	DIY EVB_2 24 kWh Y2016 Version
Chemistry	LFP	LMN + NMC	NMC
Nominal {real} capacity (kWh)	23.6 {20}	24 {15–22}	24 {24}
Voltage (V)	336 Vdc	350–410 Vdc	350–410 Vdc
Capacitance	70 Ah	37–54 * Ah	59 Ah
Communication	RS485, CAN	CAN	CAN
Working temperature	0–50 °C	−20–50 °C	−20–50 °C
Placement	Indoor only	Outdoor only	Outdoor only
Effectiveness	96%	65–80% *	90–95%
Weight [kg]	~286	~294	~280
Dimensions [mm]	1380 × 600 × 380	1600 × 1170 × 270	1600 × 1170 × 270
Cost [Euro]	k€8–12 Set	2500 Set **	2500 Set **
Guarantee	6000 cycles @25 °C	No	No
Estimated lifespan	6 years ***	0–6 years ****	8–10 years ****

* before and after replacement of 4 modules. **—incl. BMS and CAN bridge (interface to PV inverter). ***—manufacturer warranty. ****—estimated, depending on the climate in which the car was sold.

Table 2. Description of 3 battery set tested in the research.

Name	BESS	Nominal Capacity (kWh)	Initial Cost (Euro)	Set Description
1.	BESS-NEW Pylontech H1	24	k€8–12 [1]	Set of BES module, rack, 7 battery modules, cables

Table 2. *Cont.*

Name	BESS	Nominal Capacity (kWh)	Initial Cost (Euro)	Set Description
2.	DIY EV 24_1	24	2500 [2]	Set of EV battery incl. BMS, modules replacement, CAN emulator, cables
3.	DIY EV 24_2	25	2500	Set of EV battery incl. BMS, CAN BYD HVM emulator, cables

[1] k€8–12 Euro depending on country and delivery conditions. [2] 1500 Euro purchase cost plus 1000 Euro modules replacement (total 2500 Euro).

Table 3. Description of NPVs adopted for scenarios 1, 2 in the research.

Number	Parameter	NPV1	NPV2	Set Description
1.	Daily Energy Used	8 kWh	8 kWh	24 h energy stored and used from BESS
2.	Efficiency (η)	0.765	0.765	Charging (0.95)–discharging (0.8) efficiency
3.	Annual degradation (d)	4%	4%	Estimated battery capacity degradation (capacity)
4.	Annual maintenance (M)	€100	€100	Annual cost of maintenance (test and care)
5.	Discount Rate (r)	5.35%	5.35%	Current discount rate in Poland [13]
6.	Lifetime (N)	7	7	Based on a new BESS guarantee time and expected life time of SLBEVs or BESSs
7.	Initial Cost (€)	k€2.5	k€8–12	Calculation of DIY BESS based on used BEV battery compared to new BESSs



Figure 1. Opened used battery (DIY EV 24_1) (note: lower left cells are swallowed).



Figure 2. BESS_1 brand NEW Pylontech H1 24 kWh.

3. Results

3.1. Batteries Tests Results

The tests were performed over a period of six months in 2024, followed by calculations and conclusions. Initially, a DIY EV 24_1 battery was purchased. After replacing four LIB modules, many charging and discharging cycles were performed to balance the battery, but the capacity increased only slightly (from about 60% to 75%). Additionally, it was observed that the battery tended to overheat during charging; this problem was already found and described in [14]. It is worth noting that such a situation is very likely and may in practice disallow the reuse of EV LIBs, as postulated in [1] and described in [15]. The chemical composition used in this LIB battery was found to be unstable, as explicitly noted for this LIB model in [16]. However, the biggest problem is the uncertainty surrounding the future performance of such an SLBEV as a BESS. The tests indicated an SOH of approximately 70–80%, as well as significant unevenness in the resistance of the individual cells. There is therefore no rational reason to believe that this battery will be able to operate for another 6–7 years without further module replacement. Therefore, there is no technical justification for recommending such a solution for the future. It can already be concluded at this stage that, despite having almost identical purchase and connection costs to PV inverters (Goodwe ET series), the DIY EVB_1 set should not be compared to other sets (DIY EVB_2 and BESS_1), as its usefulness is negligible and it can only be classified as a Type C battery (scrap). Nevertheless, it should be noted that EV batteries with a specific manufacturing date are not generally unsuitable for regeneration. In practice, this depends not only on the aforementioned type (A, B or C), but also on the nominal capacity and internal design of the SLBEV. As part of the aforementioned research project [2], it was possible to regenerate older hybrid car batteries to an SOH of 85%. However, in that case it was feasible due to the significantly lower capacity of the hybrid car battery (e.g., 1 kWh) and the small number of cells this entailed.

Compared to the brand new BESS_1, only the DIY EVB_2 (Type B) produced stable, comparable output. Despite the theoretical difference in capacity, it is worth noting that DIY EVB_2 showed a higher E_max value throughout the entire test because BESS_1 had a

firmware-imposed discharge limit of 90% (DOD (Depth of Discharge)). This meant that the available E_max was 21.6 kWh per day. By contrast, the DIY EVB_2 battery, which had no such limitations (the DOD limits were set at 98% by Author in CAN-Bridge), operated at 98% with 24 kWh and could be charged up to 23.5 kWh. While the 1.9 kWh difference in capacity is not significant, for larger SLBEV capacities (e.g., a 60 kWh battery) it could provide an additional day of household operation on a DIY BESS. From a technical point of view, only the DIY EVB_2 and BESS_1 versions can be considered in this experiment, as they were selected to have similar available capacities and variable costs in the assumed analysis period. Periodic inspections are required for safety reasons, either by an authorised service centre or by the company that supplies the DIY BESS. As part of the monitoring process, it is assumed that this type of BESS should be managed remotely by the supplier (in Polish conditions, this is estimated to cost approximately €200 per year). The only significant differences are the purchase cost (see Table 1) and the possible location: the DIY EV 24_2 is located outside the building under a roof, while the BESS_1 is located inside the building.

In parallel, the NPV and sensitivity to market electricity prices were simulated, as described in Section 4. The results obtained during the calculations are economic rather than technical, as it can be presumed that both sets (BESS_1 and DIY EV 24_2) will perform similarly during the 7-year period under consideration.

Net present value (NPV) calculations were performed for investments in BESS_1 and DIY EV 24_2.

Author used the typical NPV Equation (1), modified by the annual degradation factor '*d*' and the price (tariff) difference '*P*', as follows:

$$\mathrm{NPV} = -C_{init} + \sum_{t=1}^{N}\left[\left(E_{daily}\cdot 365\cdot\eta\cdot(1-d)^{t}\cdot P - M\right)\cdot\frac{1}{(1+r)^{t}}\right] \quad (1)$$

where

C_{init} = Initial cost of BESS (e.g., €2500)
E_{daily} = Daily energy consumed by household (8 kWh)
η—Efficiency (0.765)
d—degradation annually (4%)
r—discount rate (in Poland 5.35%),
N—lifetime (expected BESS lifetime, let's consider 5, 7, 9, 11 Years), t—year
P—tariff difference ("avoided cost" * in € per kWh)
M—Cost of Maintenance (yearly in €)

The '*P*' factor in Equation (1) requires clarification and expansion. If P is equal to the current energy purchase tariff from the grid operator, the NPV will show how long it will take for the investment in the BESS (with assumed efficiency, purchase and maintenance costs, and degradation) to pay for itself, assuming that the 'charging energy' comes from PV during the day and is used after sunset. A comparison with the expected lifetime of the system will show whether purchasing such a system at the price of C_{init} will generate funds (a positive NPV) or result in a loss (a negative NPV) at a given purchase price after a period of '*N*' years.

Following this approach and assuming that '*P*' is the difference between the current purchase price of energy and the marginal cost of energy from PV (which, in the case of rooftop PV installations, can be assumed to be equal to zero), the result will be similar. However, if the PV system was specifically installed to increase energy self-consumption as an alternative to grid energy, its cost should be added to C_{init} and its other costs included in the calculation. In the case of Poland, considering the 2015 PV system (installed in 2015), by 2024, its purchase cost had already been fully amortised (written off in eight years), so it

can be assumed that the cost of the PV system does not affect the economics of the BESS. However, if there were a possibility of price arbitrage for prosumers in another country, whereby one could purchase energy at zero prices during the day and resell it to the grid at maximum prices in the evening, then the value of P would determine the value of the energy difference obtained. In the case of Poland, if such a possibility were to arise (it has already been announced), the value of the 'storage' energy between periods of negative prices during the daytime and evening price peaks would be approximately 300 euros per 1 MWh (0.3 euros per 1 kWh) without additional costs. The latest sensitivity analysis was performed for these values. Thus, let us consider the aforementioned price difference, 'Pd', as follows:

$$\mathrm{Pd} = \mathrm{Cepp} - \mathrm{Cerv} \quad (2)$$

where

Pd—tariff difference (in € per kWh)

Cepp—Current energy purchase price, i.e., the total cost (in € per kWh) delivered to household

Cerv—Current (value) of energy returned to grid–i.e., Value (in € per kWh) injected to grid by household.

For example: Pd = 0.23 − 0.032 = €0.198 per kWh (as it is currently in Poland).

3.2. Price Sensitivity Simulation Results

Figures 3 and 4 show the results of the calculations for the DIY EV 24_2, with service lifespans of 5 and 7 years, respectively. These figures show that a grid energy price of less than €0.34/kWh over 5 years and less than €0.28/kWh over 7 years would not justify such an investment. The current purchase price of energy from the grid in Poland is €0.25/kWh (price *P* in Equation (1)). Consequently, it can be concluded that BESS devices with the parameters described in Table 1 will not add value if their service life is less than seven years. In other words, if the effective operating time of a BESS with its assumed available capacity in kWh per day is less than seven years, investing in it would not be worthwhile, as storing energy in it would be more expensive than purchasing it from the grid. It is worth noting that most new BESSs analysed on the Polish market have a five-year warranty.

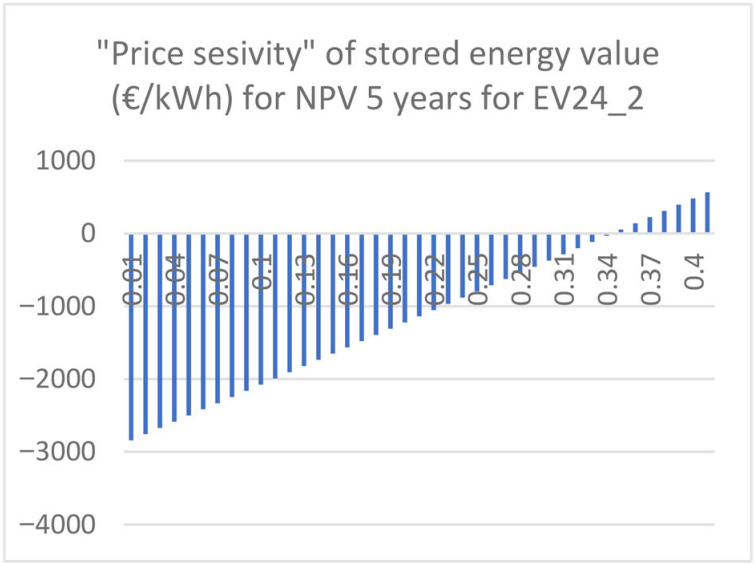


Figure 3. NPV price sensitivity for DIY EV 24_2 in 5 years.

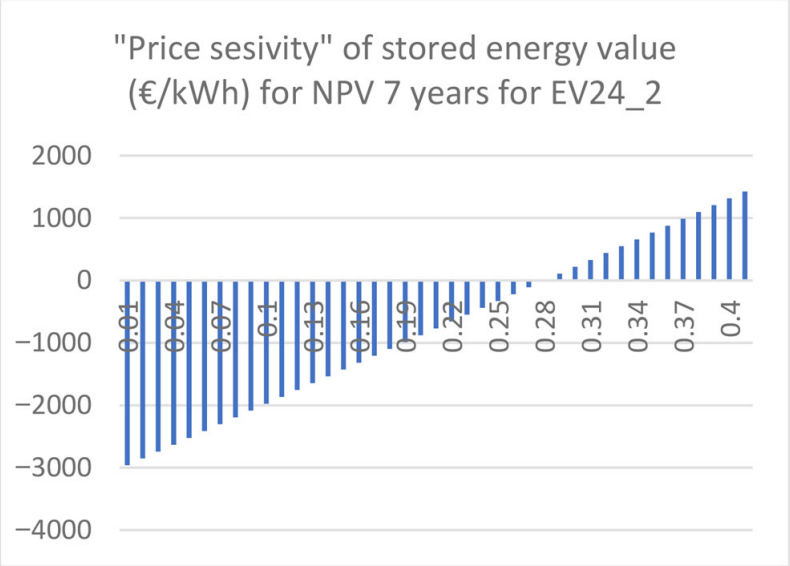


Figure 4. NPV price sensitivity for DIY EV 24_2 in 7 years.

Figures 5 and 6 show the NPV calculation results for the DIY EV 24_2, with service lifespans of 9 and 11 years, respectively. These figures show that the grid energy price of less than €0.25/kWh over 9 years and €0.23 over 11 years would not justify such an investment. It is worth noting that the current purchase price of energy from the grid (price P in Equation (1)) is €0.25/kWh and is likely to increase within the next 9–11 years. Consequently, it can be concluded that, given the current energy prices in Poland, only BESS devices based on used batteries from BEVs with the parameters described in Table 1 that will operate for at least nine years will represent a worthwhile investment. Otherwise, i.e., if they lose the ability to deliver at least 8 kWh per day or if their operating costs increase by more than €200 per year, they will be a poor investment as their costs will exceed the expected revenue. Consequently, investing in a BESS set made of SLEVBs that would work for less than 10 years for technical reasons or require major repairs within this timeframe would not make sense.

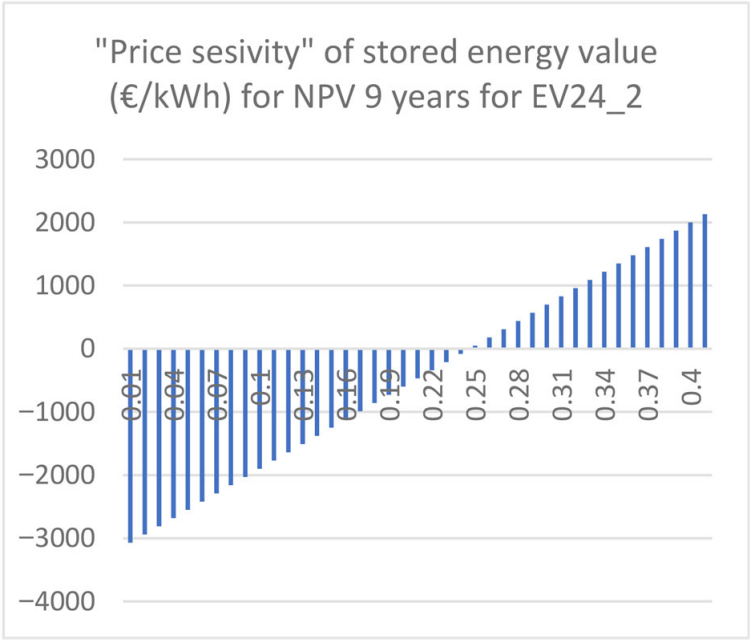


Figure 5. NPV price sensitivity for DIY EV 24_2 in 9 years.

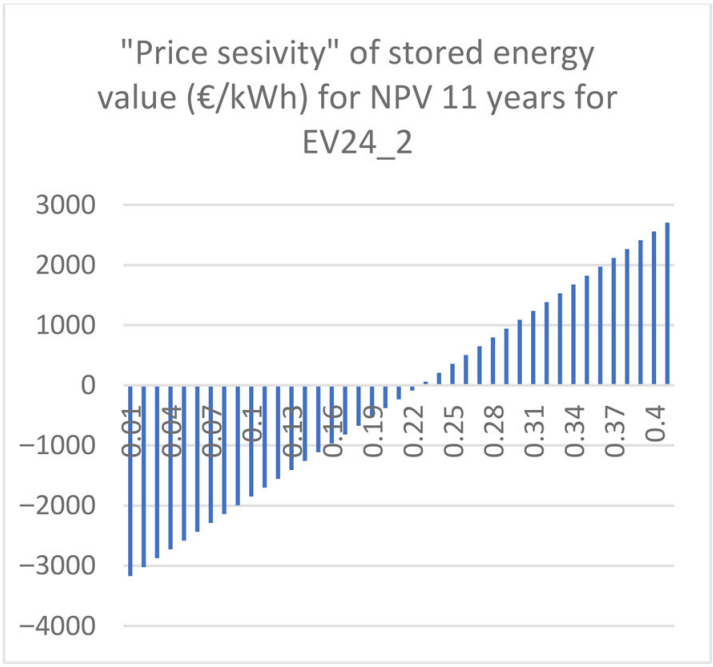


Figure 6. NPV price sensitivity for DIY EV 24_2 in 11 years.

Figure 7 shows the results of the calculations for the BESS_1 set, with service lifespans of 5 and 7 years, respectively. They demonstrate that a grid energy price of €0.34/kWh over 5 years and €0.28 over 7 years would not justify such an investment. The current purchase price of energy from the grid in Poland (price P in Equation (1)) is €0.25/kWh.

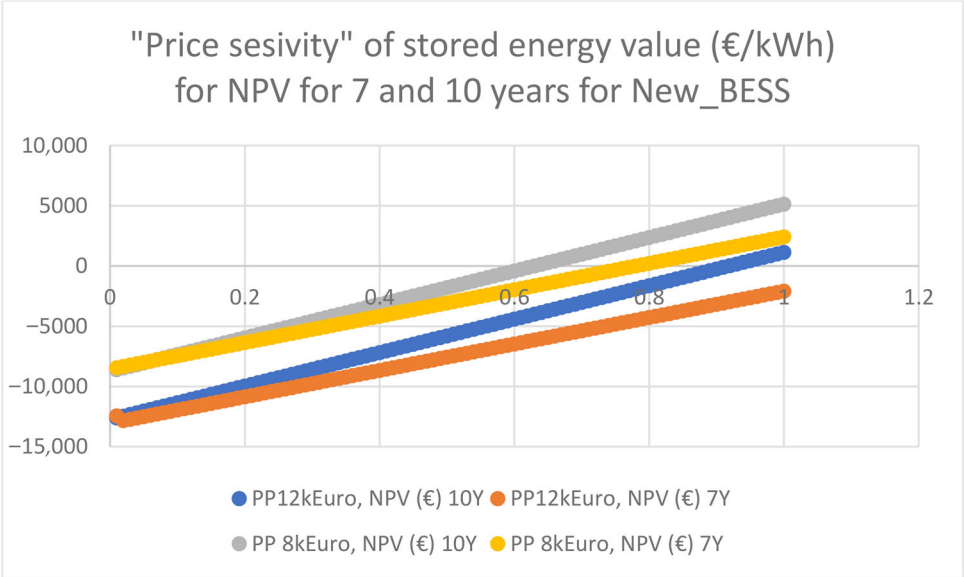


Figure 7. NPV price sensitivity for BESS_1 in 5–7 years with C_{init} = €8000 and C_{init} = €10,000 PP (Purchase Price).

Similarly to the DIY EV24_2, an NPV sensitivity analysis was performed for the new BESS_1 (Pylontech H1 24 kWh) device at the current market energy price of €0.25/kWh. Depending on the purchase and delivery terms, the device's price (C_{init}) in Poland ranges from €8000 to €12,000. This price range does not allow for amortisation before the price reaches €1/kWh. At a purchase price of up to €8000, the graphs are yellow (€0.8/kWh with 7-year amortisation) and grey (€0.6/kWh with 10-year amortisation). This process was repeated until the current energy price in Poland was reached in Section 3.2.

Interpreting Figure 8 leads to the conclusion that, assuming the price difference (Pd) in Equation (1) instead of the price of energy supplied, the NPV economic calculation indicates that, in a 11-year perspective, current tariffs in Poland are not profitable.

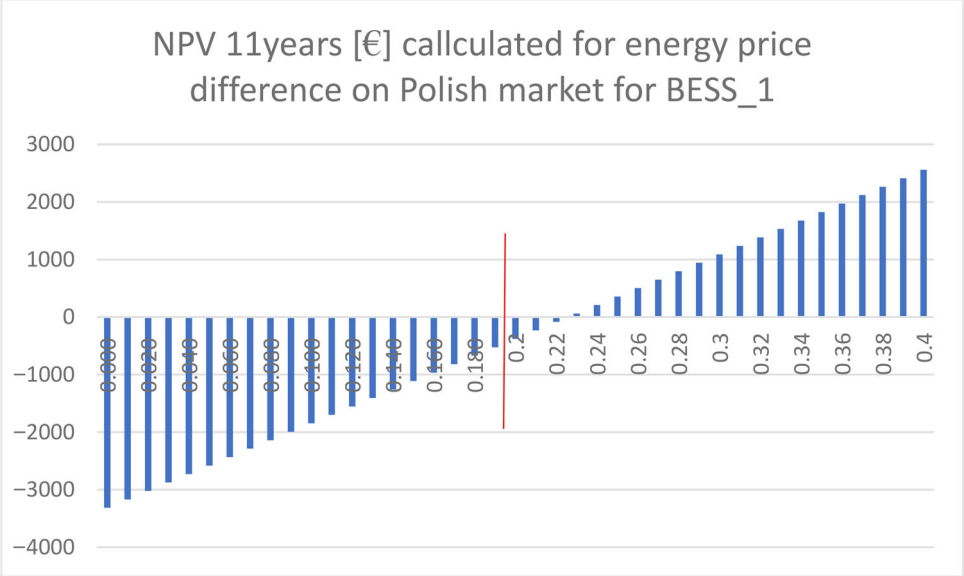


Figure 8. BESS_1 (Pylontech 24 kWh) set price difference "Pd (0.198 Euro)".

4. Discussion

The results obtained should stimulate discussion about the economic justification for purchasing home energy storage systems in residential buildings, particularly if they are partially subsidised by the government. This applies to stand-alone home devices and BESSs based on batteries from BEVs (SLBEV).

Firstly, it should be noted that the two LIB chemistry technologies used by the car manufacturer categorise potential applications as either 'old batteries' (such as DIY EVB_1) or 'modern batteries' (DIY EVB_2). Although these batteries come from the same car model, they are from different years of production and differ fundamentally. As tests have shown, 'old batteries' (Type C) are widely available today, and they are very affordable. However, due to the unstable chemical composition of the cells, they should not be used for home BESSs as they cannot be regenerated practically (no new spare parts are available from the original manufacturer). The modules available for this battery type mainly come from used batteries and can therefore only improve its performance slightly. Conversely, the Type B battery could be very attractive for use in BESS, as confirmed by the above experiment. Degradation at a rate of 4% per year will probably allow the Type B battery to be used for 12–18 years. The NPV level of 11 years assumed in the calculations can therefore be considered safe and economically justified. This data (4%) is also confirmed by EV repair shops in Poland (unpublished data). The lack of plug-and-play capability and the need to use a CAN bridge (or other interfaces) is not a drawback, as information about them is widely and freely available online from BEV battery specialists worldwide. This part of the study leads to the general observation that, on the one hand, the automotive market is learning very quickly how to optimise the selection of battery compositions for their vehicles. However, they are reluctant to share their R&D progress, nor do they want to facilitate a 'second life' for batteries outside their vehicles, nor do they want to collect waste batteries. This behaviour appears inconsistent with the requirements of the European Directive [1], which clearly states that "All . . .waste electric vehicles batteries should be collected. For that purpose, the producers of electric vehicle batteries should be rrequired

to accept and take back free of charge, all waste batteries for their respective category from end-users".

The second key issue concerns the current tariffs for storage energy and its impact on the profitability of purchasing energy storage BESSs (same for re-used BEV). Literature sources discuss various solutions for the optimal model of cooperation with DSOs (Distribution System Operator), and the energy storage process can be either very profitable or completely unprofitable from the point of investment economics of prosumer. This is shown in Figures 3–8 by conducting an NPV sensitivity analysis in relation to energy pricing. With an average investment in BES of around 2500 to 12,000 EUR (for 24 kWh capacity set) and energy prices below 0.25 EUR/kWh, from the prosumer's point of view, there is no justification for purchasing a BESS. When the price at which energy is repurchased from the prosumer is too low in relation to the price of energy purchased from the grid, storing energy instead of feeding it into the grid is not economically viable. Therefore, in countries such as Poland where the government has not carried out an NPV calculation to support the purchase of energy storage facilities, installing BESS (unless fully sponsored) is unattractive, resulting in people feeding energy into the grid on a massive scale and putting the national grid on the verge of collapse every summer. One solution could be to offer much more favourable energy buy-back prices, or to use cheaper energy storage methods such as SLBEV.

The third key factor in the discussion on the warranty, and what prosumers should do with fully depleted LIB batteries, is also important. For 'new BESS', there are several 'warranty schemes' on the market that are not compatible with each other. The most common is a time-period warranty (e.g., 5–7 years, as with the Pylontech 24 kWh model), which guarantees a minimum performance level of 70% of the battery's capacity, but does not guarantee the available power level. The second type is a 'cycle count-based warranty' (e.g., 5000 cycles), which is difficult to verify in the event of a warranty claim. Finally, the most convincing warranty is that of charged/discharged energy volume. This guarantees an exact energy volume (e.g., 16.5 MWh) that can be obtained from the storage system before significant degradation occurs (e.g., 30–40%). Only the latter can be used for reliable economic calculations, assuming that the supplier will be able to comply with it. Of course, all above calculations were made for the new BESS's warranty period, and one could argue that it can operate beyond this period. However, experience with LIB batteries in mobile phones (which use the same technology) shows that, once the warranty period has expired, they usually become useless because they require much more frequent charging.

In the case of a home BESS, although it may still have (e.g.) 60% of its nominal capacity, it may no longer be able to provide sufficient power for household appliances. This is much less likely to happen with a DIY BESS based on SLBEV, because the output power of these batteries has been designed to be much higher.

All users of new BESSs hope that, after a period of use, they will be taken away at no additional cost. In the case of SLBEV, however, there will be no such guarantee, only an estimation of remaining life based on market research into the wear and tear of certain car batteries. Author used this method, being aware that the results should be verified and are only assumptions at this stage of the experiment. Author concludes that older batteries in some EV models are not suitable for further use, as they were designed to last for the duration of the car's warranty (e.g., six years), and are now nothing more than difficult-to-dispose-of scrap. This was the case with the DIY EVB_1 battery, which poses a potential risk to prosumers. In Author's opinion, if BEV manufacturers had complied with Directive [1] and properly described and published data on the possibility of giving the battery a second life, there would not have been so many spontaneous purchases of these batteries by prosumers. They will have a much bigger problem with the proper recycling

of the batteries than professional car repair shops will, perhaps after only a year of trying to use them as BESSs.

The fourth issue is the relationship between grid energy prices in European markets and the cost of individual (home) energy storage. The lack of reliable calculations on the profitability of purchasing new or used BESSs in Europe (including Poland) results in 'marketing' rather than 'economics'-driven purchasing decisions by prosumers. Sellers of new BESSs often fail to consider the fundamental limitations of LIB battery technology and the necessary oversizing of PV systems for BESSs, as well as the actual energy prices in a given market. In Poland, the current value of surplus energy from new PV installations sold to the grid is €0.052/kWh (old installations use the net-metering system), while the cost of purchasing energy from the grid is €0.25/kWh (difference = €0.198). Even assuming a very optimistic scenario of 11 years of BESS use with full capacity (25 kWh) and average daily use of 8 kWh, the NPV sensitivity analysis shows that the purchase of a BESS would not pay for itself during the battery's lifetime (see Figure 7). A positive NPV would be obtained if the grid's repurchase price were €0.22/kWh instead of the current €0.052/kWh (Equations (1) and (2)). The current difference of €0.198 creates added value when energy is fed back into the grid because even a BESS at a quarter of the purchase price of a new one would not recoup the investment during its expected lifetime (see Figures 7 and 8).

5. Conclusions

1. BEV battery packs, when combined with small interfaces (CAN Bridge), offer an interesting price alternative to the 'ready-made' BESS kits available on the market. They offer significantly higher capacities at a lower purchase price, providing a much shorter payback time than ready-made home BESS kits. LIB technology is definitely better for energy storage than lead-acid batteries [17]. In order to ensure the safe use of LIBs, however, it is necessary to ensure a safer location for such a battery facility (preferably in a separate fire zone) [14,18].
2. The increasing popularity of BEVs, coupled with the statistical withdrawal of vehicles from circulation, provides a natural supply of batteries to the secondary market. This encourages independent companies to establish a market for battery repair and reintroduction into the circular economy, as recommended in EU Directive 2023/1542 [1]. Reusing LIB EV batteries as home BESSs has the potential to significantly increase the self-consumption of RES energy in households, as well as using EBEV cars as mobile storage V2G (vehicle-to-grid) and V2H (vehicle-to-home) as described in the author's latest publication [19].
3. Due to dynamic progress in automotive battery solutions, even traction batteries from the same car model but with different years of manufacture can be a useful or completely useless source of DIY BESSs for domestic applications depending on the production chemistry. However, for marketing reasons, car manufacturers do not publish this data.
4. Advantages of BEV battery packs over domestic BESSs include:
    a. A significantly wider operating temperature range, meaning they can be used without heating or cooling systems, making them attractive for outdoor BESSs (safety considerations);
    b. A sealed construction;
    c. Resistance to environmental factors;
    d. Flame-retardant housing.
    e. Significantly higher capacity compared to regular domestic BESSs.
    f. A purchase price several times lower, especially in relation to EUR/kWh

g. Another important technical advantage is that BEV batteries have been designed to operate with significantly higher currents in vehicles, meaning that powering buildings is exceptionally easy and non-destructive for them.

Compared to BESS, two major drawbacks can be identified: the lack of a manufacturer's warranty and unfavourable dimensions and significant weight.

5. The attractiveness of BESSs in a given market depends heavily on the current relationship between the price of electricity purchased from and fed into the grid. Research has revealed that, if the energy price in a given market is too low, ready-made BESS kits will be too expensive in relation to the stored energy's value. Consequently, the energy storage market will not develop. One solution is to use high-quality vehicle batteries, which, when properly selected, can be given a second life (SLBEV).
6. As a result, Author provides answers to the following research questions:

Q1: Will every used battery removed from a functioning electric vehicle (EV) be suitable for use as a battery energy storage system (BESS) in a residential building, and what will its performance parameters be compared to those of BESSs commonly available for sale?

In light of the experiments and calculations conducted, this research question can be answered in the affirmative–it is both technically and economically feasible. However, implementation is not straightforward and, until specialist companies offering such retrofitting services are established, it may be challenging for prosumers who do not regularly work with LIB HV batteries.

Q2: What will the cost of converting a BEV battery to a BESS battery be? What will the real payback time be? How sensitive will the NPV of such a retrofit be to the market valuation of electricity from RES?

The initial cost of a BESS based on batteries from a BEV can be three to four times lower than the cost of purchasing a brand new PV-BESS. However, it can provide a storage system with significantly better parameters (e.g., capacity) and offer a faster return on investment, even when current electricity prices in European countries are taken into account.

Q3: Are there any other factors to consider, such as safety or environmental impact, when comparing these two solutions? Some factors, such as safety and environmental impact, work in favour of BESS solutions based on SLBEVs. In terms of safety, the fact that BESSs should be located outside the home, perhaps in a separate fire protection zone, could increase the safety of such storage facilities, as recommended for BEV LIB batteries in [14,19,20]. From an environmental point of view, reusing millions of BEV batteries, which could otherwise pose an environmental threat, is a worthwhile consideration, and EU directives strongly recommend it.

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Acknowledgments: Author deliberately does not specify the exact models of cars from which batteries suitable for further use could be obtained, in particular the models from which the EV1 and EV2 batteries were obtained, although for specialists in this field, their source is obvious from the figures provided. The reason for this is concern about the potential legal consequences (claims) that this article could cause in the event of dissatisfied owners of these car models, who could conclude from this manuscript that the BEV manufacturer has released a BEV with battery model that is in definite need of improvement.

Conflicts of Interest: The author declares no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EV/BEV	Electric vehicle/Battery Electric Vehicle
BESS	Battery Energy Storage System
SOH	State of Health–parameter describing battery wear out level
PHEV	Plug-in Electricity Vehicle, a Vehicle with ICE engine and electric engine

Appendix A

Appendix A.1 Quotes from EU Directive [1]

1. Author believes that, to stimulate the circular economy in Europe, this information should be clearly stated on every battery electric vehicle (BEV) battery, as encouraged by the EU Directive [1]. This Directive stats (Preface) *"... electric vehicle batteries that are incorporated in motor vehicles should be removable and replaceable by independent professionals. It is appropriate to consider revising Directive 2000/53/EC to ensure that those batteries can be removed, replaced and disassembled, including as regards joining, fastening and sealing elements. For the purposes of the design, manufacturing and the repair of ... electric vehicle batteries, manufacturers should provide the relevant vehicle on-board diagnostic information and vehicle repair and maintenance information on a non-discriminatory basis to any interested manufacturer, installer or repairer of equipment for vehicles..., as provided for in Regulation (EU) 2018/858/"*
2. Definitions (31) *'Repurposing' means any operation that results in a battery, that is not a waste battery, or parts thereof being used for a purpose or application other than that for which the battery was originally designed;*
3. Definitions (32) *"Remanufacturing" means any technical operation on a used battery that includes the disassembly and evaluation of all its battery cells and modules and the use of a certain number of battery cells and modules that are new, used or recovered from waste, or other battery components, to restore the battery capacity to at least 90% of the original rated capacity, and where the state of health of all individual battery cells does not differ more than 3% between cells, and results in the battery being used for the same purpose or application as the one for which the battery was originally designed.*

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