4E Efficient, Demand Flexible Networked Appliances EDNA

Plug-in Battery Energy Storage Systems

JULY 2026

Technology Collaboration Programme
by iea

About the IEA 4E Efficient, Demand Flexible Networked Appliances Platform of 4E (EDNA)

The Efficient, Demand Flexible Networked Appliances Platform of 4E (EDNA) Platform provides analysis and policy guidance to members and other governments aimed at improving the energy efficiency and demand flexibility of connected devices and networks. Further information on EDNA is available from: www.iea-4e.org/edna

About the IEA Implementing Agreement on Energy Efficient End-Use Equipment (4E):

The Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E TCP), has been supporting governments to co-ordinate effective energy efficiency policies since 2008. Fourteen countries and one region have joined together under the 4E TCP platform to exchange technical and policy information focused on increasing the production and trade in efficient end-use equipment. However, the 4E TCP is more than a forum for sharing information: it pools resources and expertise on a wide a range of projects designed to meet the policy needs of participating governments. Members of 4E find this an efficient use of scarce funds which results in outcomes that are far more comprehensive and authoritative than can be achieved by individual jurisdictions. The 4E TCP is established under the auspices of the International Energy Agency (IEA) as a functionally and legally autonomous body.

Current members of 4E TCP are: Australia, Austria, Canada, China, Denmark, European Commission, France, Japan, Korea, Netherlands, New Zealand, Switzerland, Sweden, United Kingdom and the United States. The main collaborative research and development platforms under 4E include:

- Electric Motor Systems (EMSA)
- Smart Sustainability in Lighting and Controls (SSLC)
- Efficient, Demand Flexible Networked Appliances (EDNA)
- Power Electronic Conversion Technology (PECTA)

Further information on the 4E TCP is available from: www.iea-4e.org

EDNA has made its best endeavours to ensure the accuracy and reliability of the data used herein, however makes no warranties as to the accuracy of data herein nor accepts any liability for any action taken or decision made based on the contents of this report.

The views, conclusions and recommendations are solely those of the authors and do not state or reflect those of EDNA, the 4E TCP or its member countries. Views, findings and publications of EDNA and the 4E TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

Plug-in Battery Energy Storage Systems

This report was commissioned by the IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E) – Efficient, Demand-flexible Networked Appliances (EDNA).

Main authors

The report was prepared by the Institute for Sustainable Futures (ISF), an interdisciplinary research and consulting organisation at the University of Technology Sydney. The main contributing authors are Rusty Langdon, Sarah Niklas, and Jamie Chen.

Disclaimer

Acknowledgement of country

UTS acknowledges the Gadigal People of the Eora Nation, the Boorooberongal People of the Dharug Nation, the Bidiagal People and the Gamaygal People upon whose ancestral lands our university stands. We would also like to pay respect to the Elders past, present and future, acknowledging them as the traditional custodians of knowledge for these lands.

Abstract

Plug-in battery energy storage systems (plug-in BESS), often connected with plug-in solar photovoltaic or 'balcony solar' systems, are the latest innovation in distributed energy resources technology. Plug-in BESS are smaller capacity batteries usually under 3kWh in storage capacity per unit. They are a do-it-yourself solution to home solar generation and storage that can be plugged into standard wall sockets and enabling consumers to start generating and storing renewable, affordable electricity. The ability for consumers to plug-in solar PV and BESS at home unlocks more equitable access to clean, affordable, and reliable energy. This is particularly important for energy consumers that may have previously been shut out of the market such as renters or apartment dwellers. Plug-in systems have the added benefit of reducing pressure on qualified electricians and solar PV installers, skilled occupations in high demand and in shortage globally. Due to the emerging nature of the plug-in BESS market, the technical capabilities, limitations, and performance characteristics are not well understood. The report indicates that there is a need for policy action to improve transparency and comparability of the performance of plug-in BESS units.

Contents

LIST OF FIGURES

LIST OF TABLES

1. Introduction

Plug-in battery energy storage systems (plug-in BESS), often connected with plug-in solar photovoltaic (plug-in solar PV) or ‘balcony solar’ systems, are the latest innovation in distributed energy resources (DERs) technology. Plug-in BESS are smaller capacity batteries usually under 3kWh in storage capacity per unit. An estimated total of 113,703 plug-in BESS (e.g., systems under 2kWh) are estimated to be installed in Germany [1]. The ability for consumers to plug-in solar PV and BESS at home unlocks more equitable access to clean, affordable, and reliable energy. This is particularly important for energy consumers that may have previously been shut out of the market such as renters or apartment dwellers. Plug-in solar PV and BESS systems are considered a do-it-yourself (DIY) solution to home solar generation and storage, just purchase a system online, plug it into a standard wall socket and perform some simple setups to start generating and storing renewable, affordable electricity. Plug-in systems have the added benefit of reducing pressure on qualified electricians and solar PV installers, skilled occupations in high demand and in shortage globally [2]. Due to the emerging nature of the plug-in BESS market, the technical capabilities, limitations, and performance characteristics are not well understood. Additionally, emerging approaches to regulation and performance testing of plug-in BESS need to be identified to enable the development of regulation and standards in new markets. In the absence of comprehensive understanding of performance characteristics, relevant standards and legal frameworks for Plug-in BESS, there is a risk that products placed on market are not meeting minimum technical and performance standards,or are being installed by consumers in an unsafe way.

The Efficient, Demand Flexible Networked Appliances (EDNA) as part of the 4E Technology Collaboration Programme of the International Energy Agency commissioned the Institute for Sustainable Futures to research the status of the plug-in BESS market, including technical capabilities, limitations and performance characteristics, paying particular attention to energy efficiency performance, and to identify relevant technical standards and regulation relevant to plug-in BESS adoption.

About the research

This research uses both desktop methods and stakeholder engagement to explore the status of plug-in BESS and identify opportunities and gaps for future policy development. An initial desktop review of the technical capabilities, system configurations and installation requirements of typical plug-in BESS available on the market was performed. This was followed by a desktop analysis of standards and regulations that cover both plug-in BESS and plug-in solar PV systems, to identify current frameworks and identify gaps. Desktop research was supplemented with stakeholder engagement via expert interviews with standards development bodies, end-of-life and emergency response representatives, battery wholesalers/importers and a plug-in battery manufacturer. Insights were gathered from interviewees on the opportunities and barriers to adoption of plug-in batteries. Insights from interviews and desktop research are used to identify where standards are already addressing the requirements of plug-in BESS, highlight technical and safety gaps, and to identify regulation and standards for adoption in emerging markets. A case study of Germany is presented to showcase drivers that have influenced growth in the balcony power plants (e.g., plug-in PV and BESS) market and to inform the potential uptake in future markets.

A mixed methods research approach is adopted, performed in four stages:

- **Rapid literature review:** A scan of reports, journal articles, standards/regulations, product reviews, and product datasheets on plug-in BESS was performed. Noting that this approach to literature review is designed to identify the most relevant and up to date information on the topic, it does not represent a comprehensive overview of all available literature.
- **Market scan:** Data was collected on plug-in BESS available on the market to understand product characteristics, categories, use cases and capabilities.

- **Internal workshop:** A workshop was conducted with the research team to identify product similarities and differences, to finalise a definition of what is considered a plug-in BESS for the purpose of the research and to agree on the report structure.
- **Stakeholder engagement:** Interviews were performed with a total of eight expert stakeholders across the battery market including product manufacturers, product importers/wholesalers, standards setting organisations, independent bodies with an interest in distributed renewable energy development, battery related government bodies, fire and safety standards development bodies, and end-of-life management organisations.

The report is organised into 5 key sections, starting with a definition of plug-in BESS, technical characteristics, use cases, capabilities and technical limitations. This is followed by an overview of adoption in the German market, as a case study on rapid plug-in solar PV and BESS adoption. The fourth section provides an overview of the current policy framework, emerging technical regulations and product standards for plug-in BESS this is followed by identification of policy gaps. Chapter 5 provides recommendations for future policy and standards development. The last section summarises findings and finishes with a policy outlook.

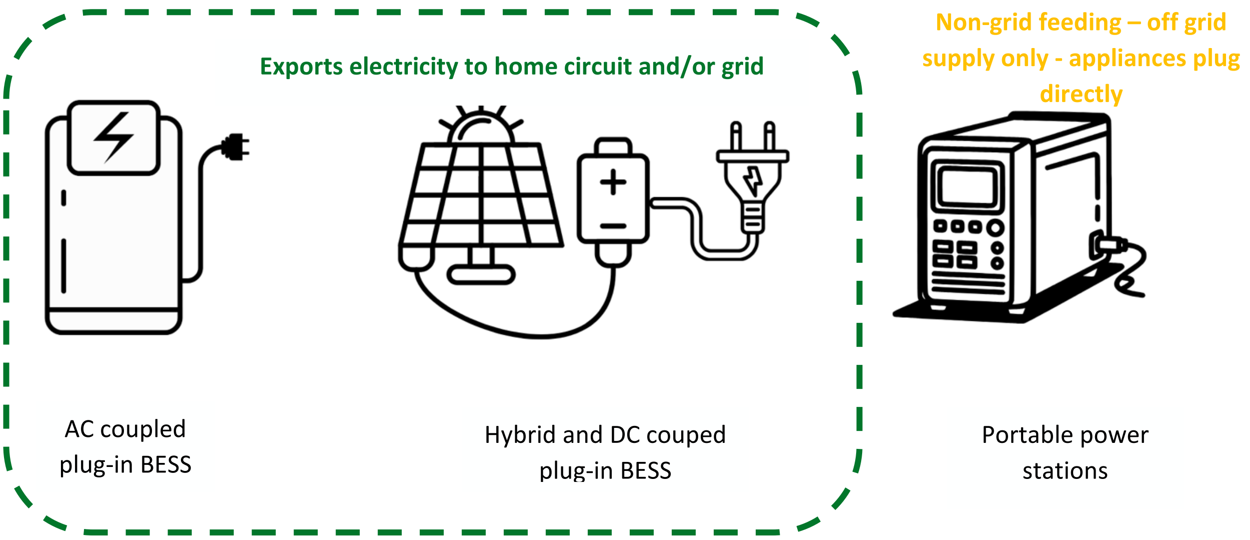
2. Plug-in BESS

This section defines the products considered plug-in BESS for the purpose of this research. Four key parameters were used to define plug-in BESS, these parameters included batteries that are:

- Stationary battery energy storage systems (BESS),
- Designed for the residential market or being used in residential applications,
- Can be plugged into a standard residential power outlet,
- Can export electricity to the home circuit and/or grid through the standard power outlet,
- Can be installed without electrical qualifications (noting that circuits may need to be verified for safety by a qualified electrician before a plug-in BESS can be installed by the consumer).

Products that fit this scope are circled in the green dotted line in Figure 1 below. While portable power stations are not grid-feeding, they are increasingly being used for energy back up support in the home during power outages and are being marketed for in-home use. The focus of this research is on plug-in BESS with the capability to export electricity to the home circuit and/or grid, however, some information and data was collected on portable power station batteries in the early stages of product definition. It is recommended that further research is performed to explore the portable power station category in more detail, however, this research is limited in the coverage of portable power stations.

Figure 1 Plug-in BESS product definition and research scope



2.1. Technical specifications

This section outlines the technical specifications of a representative sample of plug-in BESS currently available on the market. A search and review was performed using keywords, such as 'plug-in', 'balcony', 'plug and play', 'plug in only' and 'no installation' to identify plug-in BESS within the identified research scope. Technical and performance data was collected from product websites, product datasheets, and product installation and owner's manuals, representing a total of 23 products.

Battery datasheets are the primary form of communicating technical details about plug-in BESS, however, product datasheets were not available for all plug-in BESS analysed. In cases where datasheets were not available, information was collected from product websites, where information is scattered, presented in an image format with a marketing focus and lacks information on the testing standards used to back up claims.

The plug-in BESS market would benefit from a standardised approach to performance data provision. The lack of transparent information on performance testing methods used to generate claimed performance data and the high variability in the quality of performance information provided makes it very difficult for consumers to make informed performance-based choices.

A total of 10 plug-in BESS models were selected to showcase the range of technical and performance characteristics and to demonstrate the range of use cases. The section starts with a technical summary of system features across the plug-in BESS market. Following this, detailed data is provided on the technical characteristics, limitations and use cases, according to the categories of AC coupled, hybrid, DC coupled and portable power stations. Several brands are represented that showcase a range of capabilities and use cases, including Zendure, Marstek Energy, Anker, EcoFlow and BigBlue.

Technical summary

Only two products reported a round trip efficiency (RTE), the Zendure SolarFlow 2400 AC at 93% claimed AC RTE and the Marsek Venus E Gen 3.0 at 85% claimed RTE. Neither product specified the performance testing method or standard used and it is unclear whether the Marstek 85% RTE claimed is AC or DC.

It is positive to see an estimated lifetime data available for most products, represented as total cycles, however, only one plug-in BESS specified the estimated product health after this lifetime. Of the plug-in BESS under study in this research, most claim battery lifespans of 6,000 cycles, with one product noting an 80% battery health at the end of the estimated lifetime. Warranty periods range between 10 and 15 years.

Plug-in BESS are highly modular, with individual battery units starting at between 1.5kWh and 5kWh capacity. Battery stacking, which describes putting multiple batteries on top of each other to increase total storage capacity, can achieve over 20kWh of useable storage. Individual plug-in BESS unit weights range between 20 and 30 kilograms, most systems can stack up to 6 units totalling over 100kg. Several stacked battery units can be supported on one home circuit. For example, the Zendure SolarFlow system can support up to 6 stacks of 6 battery units per home, with total maximum exports managed through the Zendure app.

Plug-in BESS entry level pricing is between 1,000 and 2,000 Euros per unit, stacked costs are not linear, once the inverter unit is purchased, lower cost battery modules can then be stacked or connected in parallel. The cost for a stacked system, consisting of 6 battery modules and an inverter unit, ranges between 3,700 and 4,700 Euros.

To maximise energy savings and to meet zero feed-in regulations in some countries, plug-in BESS are designed to control total electricity exported to the grid using a combination of maximum export limits, smart meters and energy management apps. Most grid-connected plug-in BESS have a default export limit of 800W, but export limits can reach as much as 2400W for some products.

The ingress protection rating (IP rating) specifies the level of protection from water and dust ingress. All products featured an IP65 rating or higher, which makes them appropriate for outdoor installation, however, most manufacturers recommend the installation of batteries in an area with good ventilation and protection from rain and full sun. Many products feature between 2 and 4 MPPT solar PV connections, with total PV input ranging from 1,000W to 2,000W. Electrical connections are also IP65 rated. Automatic self-heating during periods of low outdoor temperatures is a common design feature, as products are designed to be installed in outdoor environments.

Smart home energy management

All plug-in BESS products identified during market analysis featured home energy management system (HEMS) apps to monitor total energy use and battery state of charge. Plug-in BESS connect to apps and smart products through WiFi, Bluetooth, or LAN connection. Without the use of smart metering devices, energy management functionality is limited to basic on/off timing of charge/discharge cycles which means that excess energy is exported to the grid. Grid export is banned in some countries, therefore a smart metering device is needed to ensure electricity export is kept to zero.

Smart metering devices and HEMS apps enable more sophisticated energy management capabilities, including the ability to monitor local electricity tariffs and set charge and discharge cycles to align with price variations. Product apps integrate a period of machine learning powered by artificial intelligence (AI) to establish home energy use patterns and align battery charge/discharge cycles to user needs and electricity pricing structures. Products also leverage AI to discharge the battery intelligently, based on the weather forecast, storage levels and energy use patterns.

Several smart energy meters are compatible across a range of plug-in BESS, these meters are highlighted in Figure 2. Shelly smart meters use CT clamps to monitor electricity flow through the switchboard. The Everhome and SmartWizard dongle systems connect to the P1 port of the distribution panel smart meter and integrate with smart sockets to monitor home energy loads. In addition to the smart meters highlighted here, branded smart meters are also available directly through plug-in BESS companies.

Figure 2 Smart meter devices compatible with plug-in BESS

Shelly smart meter installed in switchboard using CT clamps to monitor electricity flow

P1 smart meters connect directly into the electricity meter P1 port (not all jurisdictions have a P1 port) and enable management through smart sockets

Smart sockets monitor energy demand from connected appliances

Source: Images sourced from [4-15].

Integrated protections

One of the main protection mechanisms incorporated into plug-in BESS is the default export limit, which limits the total amount of energy that can be exported to the home circuit at any one time. The typical default export limit for plug-in BESS is 800W, designed to be plugged straight into a standard power outlet by the consumer and start producing energy in minutes. The default export limit can also be manually adjusted down by the user in the supplied app, if say, the plug-in BESS is placed on a circuit with loads less than 800W, or if the unit is sold in a region that has a lower legal export limit.

The 800W export limit is considered low enough to be safe in most countries where plug-in BESS have been legalised. The primary safety concerns with plug-in PV and BESS are the potential for overloaded circuits and undetected electrical faults. The potential for circuit overload differs depending on the country, due to the differences in the way circuits are wired to the main switchboard. In Europe, where plug-in systems have been legalised, the 800W limit is considered safe in terms of circuit overload because circuits are wired in a radial pattern which limits the potential for overload due to the ability to selectively install on dedicated circuits. In countries like the UK where a ring pattern is used to connect power outlets, overload risks need to be carefully managed because risks can be hidden if circuit connections are broken or incorrectly modified. Several manufacturers recommended installing the plug-in BESS on a dedicated battery only circuit, however, in some cases it can be difficult for the average consumer to identify dedicated circuits in their home. In regions that use ring circuits, dedicated circuits may not be possible without electrical work.

An additional concern is with appropriate earth leakage fault detection in older homes that use type AC residual current devices (RCDs). Because AC RCDs only monitor electricity flow in one direction, they cannot appropriately detect earth leakage faults when a generating device is connected to the circuit. Best practice policy from the USA is to upgrade older RCDs to a type A RCD or to upgrade to a bi-directional residual current breaker with overcurrent protection (RCBO) which provides the added circuit overload protection, see Section 4 for more detail. Plug-in BESS systems also note several protection mechanisms in the battery unit including overvoltage, overcurrent, short circuit, and overheat protection

Several plug-in BESS systems, from Zendure and Marstek, allow for the total export limit to be increased, in some cases up to 2500W; however, increasing the export limit relies on confirmation from a qualified electrician that the associated electrical circuits are appropriately designed to safely handle the increased export limit. Installing a plug-in BESS with the maximum export limit would require a dedicated electrical circuit and appropriate bi-directional circuit protection.

Safe adoption of plug-in BESS is being managed through changes in wiring and grid connection rules, and through the introduction of dedicated product and testing standards. Approaches to regulation and standards differ between countries. An overview of regulations and standards is provided in .

2.2. System configurations and use cases

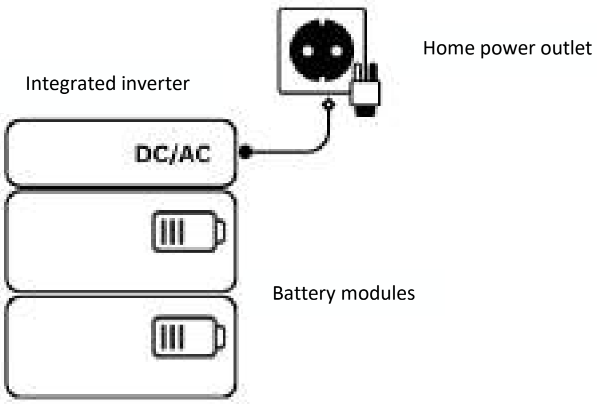
The plug-in BESS market is rapidly evolving to meet a range of site configurations and end use cases, plug in BESS are already widely available in Europe. Like hard-wired systems, plug-in BESS can be AC coupled, hybrid, or DC coupled to meet a range of system configurations and needs. Most plug-in BESS incorporate a micro inverter into the battery system, either by fully integrating the inverter and battery as one unit, or as a pluggable top unit that battery modules connect to. In DC coupled systems, inverters are a separate component to the battery with DC connection points for the battery modules and solar panels [3]. Several plug-in BESS support both grid-connected and off-grid operation.

AC coupled plug-in BESS

AC coupled plug-in BESS are fully integrated systems containing all battery management, power conversion, and inverter equipment, see Figure 3. AC coupled systems do not feature the maximum power point tracking connectors (MPPT) required to connect solar PV panels. A handful of product systems feature an AC coupling input for the purpose of connecting an existing plug-in PV micro inverter, which is useful if operating the BESS in off grid mode. However, using an AC coupler to connect solar PV to charge an AC coupled battery reduces energy conversion efficiency due to several AC-DC-AC conversions required before energy can be used in the home.

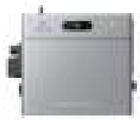
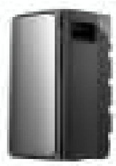
A stand-alone AC coupled plug-in BESS is designed for a home that already has solar PV installed or is intending to use the BESS without solar PV, usually for the purpose of electricity tariff arbitrage (for example, to purchase electricity at cheaper off-peak times and use this electricity in the home during peak times when energy costs are high). Some AC coupled plug-in BESS require the installation of a smart meter device in the home switchboard and a compatible energy management system in the form of a product branded app. Not all products identified in this study noted a smart meter as a requirement. AC coupled plug-in BESS often feature AC power outlets on the battery unit that can be used to plug in appliances during power outages. A representative sample of AC-coupled plug-in BESS products are presented in Table 1.

Figure 3 AC coupled plug-in BESS system configuration



Source: Created by author.

Table 1 AC coupled plug-in BESS example products

Product				
Brand	Zendure	Zendure	Marstek	EcoFlow
Model	SolarFlow 1600 AC+[4]	SolarFlow 2400 AC[5]	Venus E Gen 3.0[6]	STREAM AC Pro[7]
Chemistry	LFP			
Default export limit (W)	800			
Maximum export limit – grid tied (W)	1600	2400	2500	800
Capacity per unit (kWh)	1.92	2.88	5.12	1.92
Maximum stacked capacity (kWh)	11.52	17.28	15.36	11.52
Round trip efficiency (%)	No data	93% AC RTE (claimed)	85% RTE 93.5% Battery AC efficiency (claimed)	No data
Lifetime (cycles)	6000			
Entry level cost (1 battery unit)	€ 779.00	€ 1,199.00	€ 1,999.00	€ 799.00

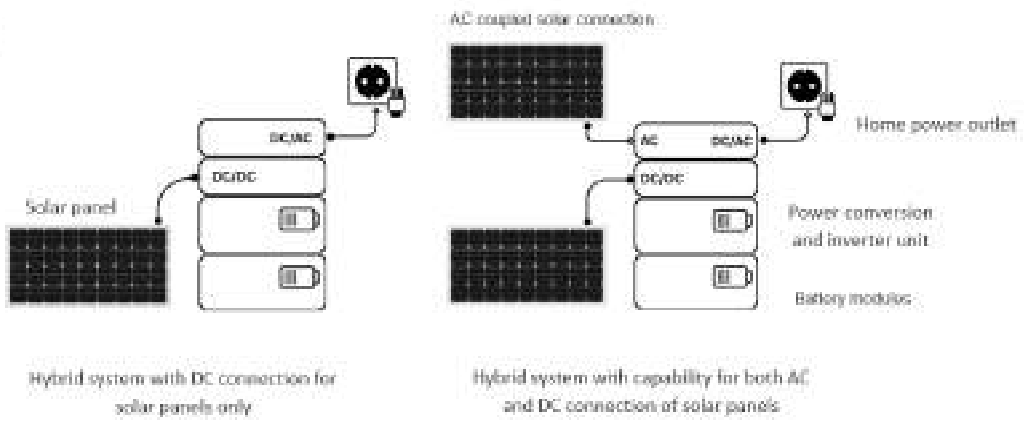
Source: Data and images sourced from [4-7]

Hybrid plug-in BESS

Hybrid plug-in BESS integrate an inverter and power conversion equipment into the battery unit; Figure 4 shows the different system configurations. Hybrid plug-in BESS feature MPPT connections where solar PV can be plugged directly into the battery unit. Each of the products in feature 4 x MPPT inputs to connect solar panels with total input capacity ranging between 2kW and 3.6kW, see Table 2. The SolarFlow 2400 Pro also allows a solar micro inverter to be plugged into an AC coupling socket input, increasing solar input capacity to 4.8kW. However, as discussed in the AC coupled systems, connecting a solar system via AC coupling significantly lowers energy efficiency if used to charge the battery, due to additional conversion steps.

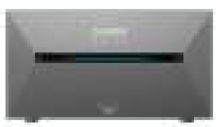
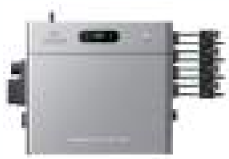
Hybrid plug-in BESS systems are more efficient than AC coupled systems when combined with solar PV. The integrated power conversion and inverter equipment enables solar energy to flow directly to the battery in DC form increasing energy efficiency by reducing conversion/inversion steps. Hybrid plug-in BESS often feature AC power outlets for the direct connection of appliances in off grid mode during power outages.

Figure 4 Hybrid plug-in BESS system configurations



Source: Created by author

Table 2 Hybrid plug-in BESS example products

Product				
Brand	Anker	EcoFlow	Anker	Zendure
Model	Solix Solarbank 3 E2700 Pro[8]	STREAM Ultra X[9]	Solix Solarbank 2 E1600 Pro[10]	SolarFlow 2400 Pro[11]
Chemistry	LFP			
Default export limit – grid tied (W)	800			
Maximum export limit – grid tied (W)	1200	1200	800	2400

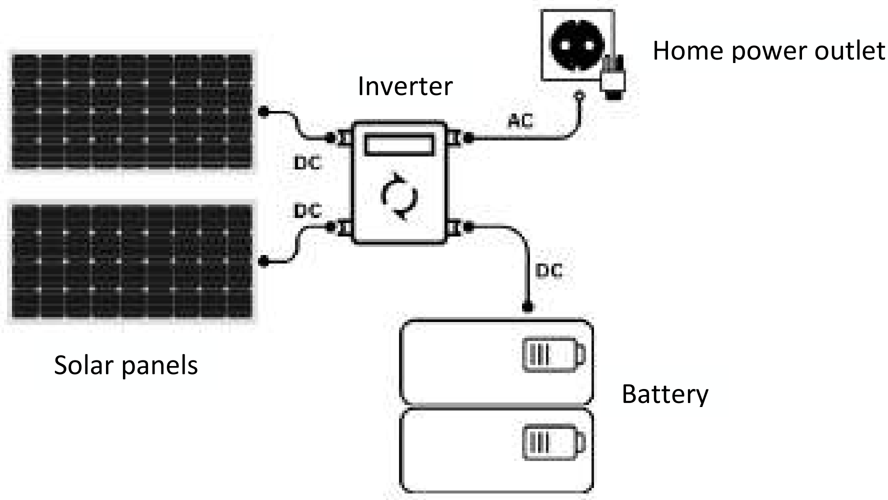
Capacity per unit (kWh)	2.6	3.8	1.6	2.4
Maximum stacked capacity (kWh)	16.12	23.04	9.6	16.8
Round trip efficiency (%)	No data	No data	No data	No data
Lifetime (cycles)	No data	6000		
No. of MPPT connections	4 @ 3.6kW total input	4 @ 2kW total input	4 @ 2.4kW total input	4 @ 3kW total input
Entry level cost (1 battery unit)	€ 1,199.00	€ 1,427.00	€ 799.00	€ 741.67

Source: Data and images sourced from [8-11]

DC coupled plug-in BESS

DC coupled plug-in BESS do not incorporate the conversion equipment and inverter into the battery, see Figure 5. Power conversion and inverter equipment can sit as separate units or they can be incorporated together in a micro inverter unit. DC coupled systems are often designed to expand existing plug-in AC coupled solar PV systems. For example, the BigBlue PowaFree DC coupled plug-in BESS in Table 3 comes with a DC router with inputs for both the solar and battery DC connections. An additional micro inverter is needed to AC couple the system and connect to the home circuit. A micro inverter is not supplied but the system is compatible with a range of micro inverters within the provided specifications. The Zendure SolarFlow 800 is supplied with a micro inverter and designed to accept a range of solar PV panels, within required specifications. DC coupled plug-in BESS do not feature AC power outlets for off grid use. Some DC-coupled systems cannot be charged by the grid [12,13].

Figure 5 DC coupled plug-in BESS system configuration



Source: Created by author.

Table 3 DC coupled plug-in BESS example products

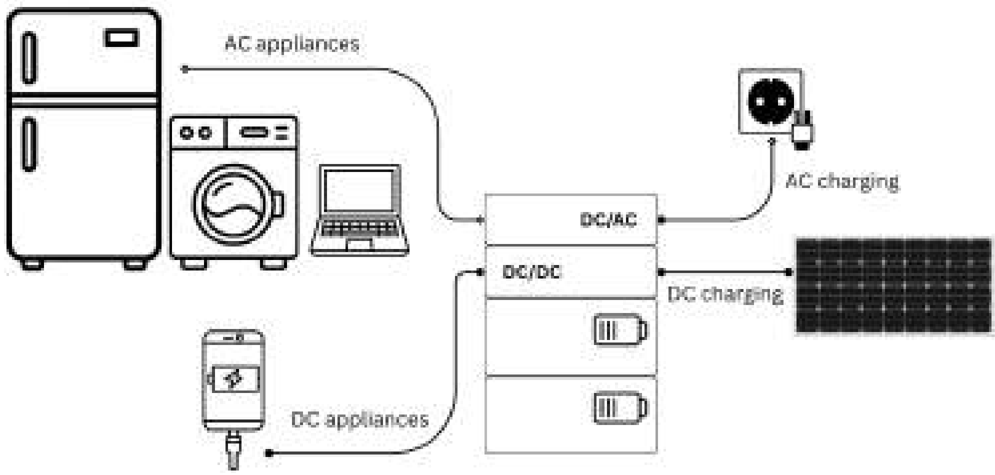
Product		
Brand	BigBlue	Zendure
Model	Powafree Balcony Solar H1 - C2500[14]	SolarFlow 800[15]
Chemistry	LFP	
Default export limit – grid tied (W)	800	
Maximum export limit – grid tied (W)		
Capacity per unit (kWh)	2.56	1.92
Maximum stacked capacity (kWh)	N/A	3.84
Round trip efficiency (%)	No data	
Lifetime (cycles)	No data	6000
Entry level cost (1 battery unit)	€ 1,005.00	€ 748.00

Source: Data and images sourced from [14,15]

Portable power stations

Portable power stations are designed to be mobile. They feature robust enclosures, handles or wheels for easy relocation, and are often marketed as suitable for off grid uses like camping or remote work sites. Portable power stations appeared in search results for plug-in residential batteries because they are also being marketed for residential home back up, for use during power outages. Portable power stations differ to plug-in BESS because they do not have the capability to back-feed electricity into the home circuit or grid. Instead, these batteries are designed to charge from the grid, or from solar panels, and supply power to appliances via AC power outlets on the front of the unit. Figure 6 shows the typical system configuration of the portable power station. The EcoFlow system in Table 4 can be connected in parallel with additional battery modules to expand the storage capacity. EcoFlow PowerStream microinverter enables the connection of a portable power station via AC coupling to the home [16], however, it is unclear whether this solution is still available. A similar unit is being marketed as an alternator charger for camper van systems in Australia. The solution that enables the connection of a portable power station to a home circuit via an AC coupled micro-inverter would likely have significant market uptake in countries with large portable power station markets, like Australia. However, for the remainder of the report, portable power stations are considered out of scope because an AC coupled solution is seemingly commercially unavailable.

Figure 6 Portable power station system configuration



Source: Created by author

Table 4 Portable Power Station example products

Product		
Brand	EcoFlow	Bluetti
Model	DELTA 2 Max[17]	Elite 300[18]
Chemistry	LFP	
Capacity per unit (kWh)	2.04	3.01
Round trip efficiency (%)	No data	
Lifetime (cycles)	3000 @ 80% original capacity	Unknown
Entry level cost (1 battery unit)	AUD 2,599.00	AUD 3,199.00

Source: Data and images sourced from [17,18]

3. Market adoption: Germany as a case study

The plug-in BESS market has grown rapidly since 2022, bolstered by growth in the plug-in solar PV market (also known as or 'balcony power plants'), where targeted legal changes for plug-in solar PV systems in Europe have enable streamlined adoption. Battery market innovations over the last decade have also reduced the cost per kWh, resulting in lower entry point to ownership. Plug-in BESS are popular for their flexible, modular, user friendly, and relocatable design, with several online communities of enthusiasts emerging around popular brands like EcoFlow [19,20]. A total of 113,703 plug-in BESS (BESS under 2kWh capacity) were estimated to be installed in Germany by the end of 2025 [1]. The legal installation of plug-in BESS currently sits in a grey area, systems are largely being designed to and installed under plug-in PV regulation and performance standards. Only Belgium has specifically legalised and certified plug-in BESS products, German standards relating plug-in BESS are still being developed, see Section 4 for more detail. Beyond Europe, several countries have recently legalised plug-in solar PV, including India in 2024, and the USA in 2025 (several states have introduced regulation or have indicated future developments), which may indicate further standards development and regulation to support plug-in BESS.

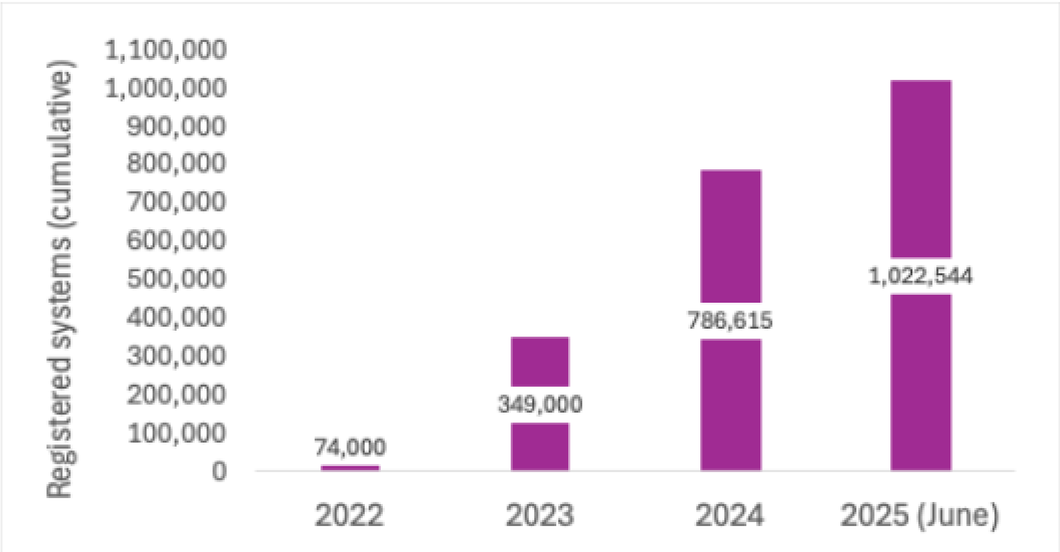
An overview of the drivers of plug-in BESS market growth in Germany is provided in the next section, as a case study that can help guide how future markets could emerge. Discussion of emerging regulatory developments in the USA and in the UK are also described to facilitate international efforts towards streamlined approaches to plug-in BESS regulation.

3.1. Adoption trends

Germany is a pioneer in the adoption of plug-in solar PV and consumers are increasingly adopting plug-in BESS, either in combination with their plug-in PV systems or as a stand-alone battery unit. Plug-in PV and BESS in Germany are referred to as balcony power plants ('Balkonkraftwerke'). Balcony power plant terminology is used in this section to discuss market trends relating to both plug-in PV and BESS.

Between 2022 and 2025 balcony power plants, increased from less than 100,000 systems in 2022 to more than 1 million systems by mid 2025, a more than 10-fold increase within 3 years [21]. In just one year, between 2024 and 2025, over 430,000 systems had been installed and registered according to the Germany's national DER market register ('Marktstammdatenregister').

Figure 7 Number of registered balcony power plants in Germany, 2022-2025.

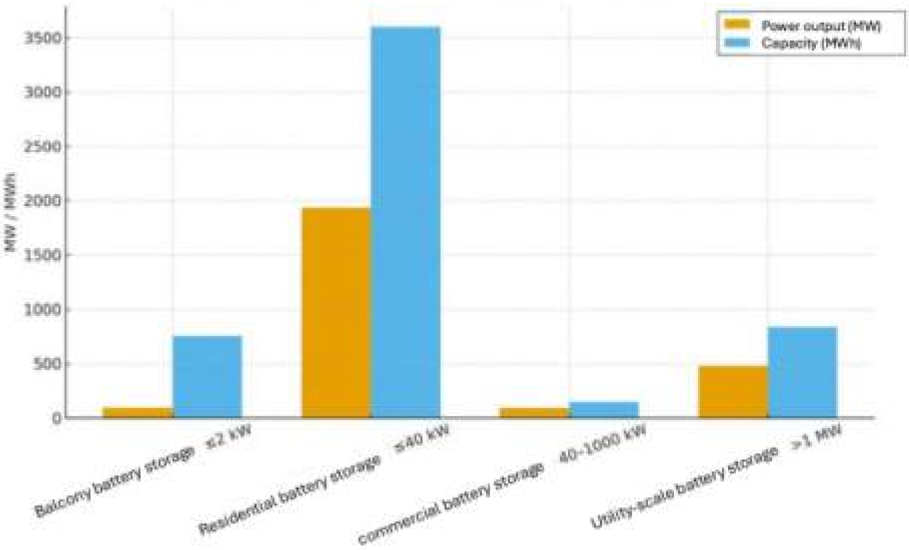


Source: Adapted from [21]

A survey of German households in 2024 suggests that strong demand for balcony power plants will continue, with a third of residents noting their interest in installing a plug-in solar PV system on their balcony, in the garden, or have already done so [23]. This trend may indicate a similar market growth potential for plug-in BESS.

According to Germany's national DER Market Register ('Marktstammdatenregister'), the total capacity of residential battery storage systems, which including plug-in BESS, is 23.16 GWh [1]. Plug-in BESS, considered here as systems under 2kWh storage capacity made up 30% of the total capacity of residential systems in 2025, see Figure 8.

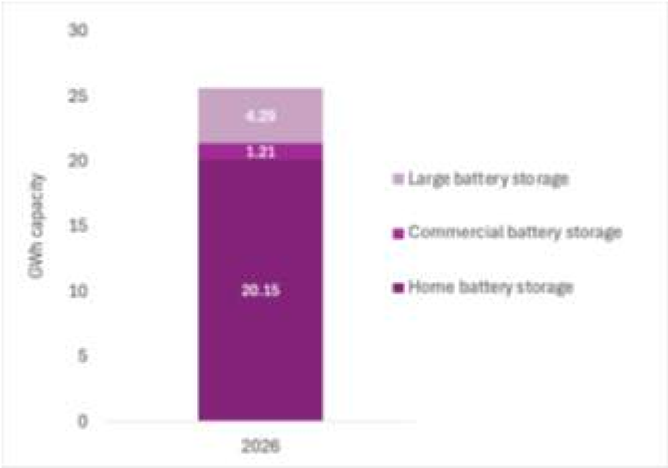
Figure 8 Battery storage capacity (MW) and power output (MWh) added in 2025.



Source: Adapted from [1]

In 2026, if the 30% share remained consistent, total installed capacity of plug-in BESS would approximate 6GWh, see Figure 9 [1].

Figure 9 Home battery storage market, Germany 2025



Source Data from [26,27] [2]

A growing share of countries are following Germany's lead, introducing regulation and standards to support the adoption of plug-in systems. However, not all regions are supportive. Sweden and Hungary have banned plug-in generation systems outright [24]. Other countries, like Australia, have seen little-to-no development towards supporting plug-in solar PV and BESS despite the excitement around opportunities highlighted in various media articles [24, 25]. Therefore, the next section outlines some of the drivers for adoption in Germany, to facilitate an understanding of how adoption may play out in emerging markets.

3.2. Drivers for adoption

In Germany, the key drivers behind balcony power plant adoption – range from geographic, demographic, technical, institutional and regulatory nature. This section presents an overview of these drivers to inform an understanding of how balcony power plant adoption may occur in emerging markets.

Geographic and demographic drivers for plug in solar PV and BESS include population density and ownership structures. Figure 10 shows the geographic distribution of installed balcony power plants across Germany, the darker blue shows a higher concentration of installed plants. There are two types of demographics preferencing plug-in solar PV in particular. First, geographic areas in west and north-west Germany that are characterised as densely populated, renter-dominated and show a preference for apartments versus free-standing homes. Plug-in solar PV are mostly adopted by medium size dwellings, as the largest metropolitan areas including Bremen, Hamburg and Berlin, show the lowest uptake due to challenges related to space restrictions and associated rental arrangements in multistorey apartment blocks [21].

Second, regional areas in southern Germany show the highest per capita adoption of balcony power plants, driven by strong home ownership, physical properties including a large number of sunshine days per year. These regions have also benefitted from a long history of favourable policy conditions, including financial incentives, enabling the uptake of balcony power plants, see Section 4 for more detail on the policy conditions.

---

[1] Note: this is an estimate and should not be relied on as an accurate representation of plug-in BESS installed capacity.

[2] Note: data entries into the national register can show inconsistencies as they are not administered by a governing body but instead rely on individuals to enter battery specifications to the national register. An example is the incorrect documentation of units, entries show the use of kilowatt (kW) instead of the correct Megawatt (MW) unit, which can skew databases.

Figure 10 Geographic distribution of installed balcony power plants across Germany.

Source: Energie Magazine, 2025 [21]

Technical drivers of balcony power plant adoption include the innovation, efficiency, technical advancements related to product accessibility, user friendliness and affordability [28]. Systems come equipped with smart energy management solutions, integrate with mobile apps and smart meters. The integration of electricity retailer data into the smart energy management apps of balcony powerplants enables sophisticated time of use controls that benefit the consumer. Balcony power plants are modular, and easy to set up, reducing the reliance on technical knowledge and certified trades for installation. Systems can be shipped directly to the customer and installed [29].

High energy prices are a key driver of uptake. A combination of events has affected the Germany electricity market and price developments in the last decade, particularly over the last 3 years, resulting in some of the highest electricity prices in Europe and the world, following the Russian invasion of Ukraine which forced the German federal government to substantially reduce its reliance on Russian gas [30,31]. The impact of these events on price developments and the shift towards electrification of home appliances, including water and floor heating (heat pumps), have further strengthened the Germany's DIY culture. The culmination of these factors has driven a sentiment among consumers towards energy independence or autonomy, sustainable and climate friendly solutions, and a desire to reduce household electricity prices. Due to the lower entry point for balcony power plants compared with hard-wired solutions, consumers have jumped at balcony power plants to meet a proportion of their energy needs.

Previously, a barrier to the uptake of balcony power plants was the difficulty in getting approval from landlords and owners' corporations in multi-unit dwellings. Plug-in PV specifically has benefitted from legislative changes to the i) the Condominium Act (Home ownership in the context of strata groups, referred to as 'Wohnungseigentumsrecht - WEG'), and ii) The rental law and tenancy law (Mietrecht)[32,33]. As of October 2024, legislation gives apartment owners and tenants in Germany the right to install Plug-in PV, and prevents strata groups and landlords from blocking the installation.

Additionally, in 2025, legislative requirements at the electricity network level have been reduced to a simple registration of the balcony power plant via an online national register ‘Marktstammdatenregister (MaStR) consisting of only 4 key data inputs in the online registration process [33,34]. Prior to 2025, balcony power plants had to be registered with the network provider with 20 pieces of data required in the application.

Between 2013 to 2018, federal government incentives and low-interest loans for storage solutions were offered by the German Development Bank (KfW), although funding was limited to hard-wired batteries only. From 2018, state-run residential home storage funding programs have replaced the federal scheme. Incentives vary from state to state and range from 1000 to 15,000 Euros based on the size of the storage unit. Since 2025, a combination of federal and state financial programs and low-interest loans provided by the KfW will be incentivising the purchase of balcony power plants. Eligible systems include balcony power plants up to 800W [35].

According to the German Statistical Bureau, 4.2 million PV systems were installed by February 2025 which equivalent to every 10th household, and the share of electricity generated from residential solar was 14% [36]. With the increased uptake of solar, there is a growing need to stabilise the electricity network. Residential batteries in the form of plug-in BESS can support local networks, incentivise localised consumption and relieve pressure on the network [37].

4. Plug-in regulation and standards framework

This section provides a summary of current and emerging regulation and standards for the plug-in solar PV and BESS market. The first section provides an overview of regulatory changes that have permitted plug-in BESS adoption. The next section describes the relevant technical standards and safety requirements for plug-in BESS. Lastly, a discussion of challenges that remain can inform the further development of the plug-in BESS regulatory and standards framework.

4.1. The evolution of plug-in regulation

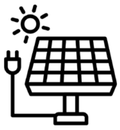
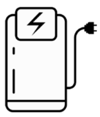
Europe is the leading market in terms of regulatory reform regarding plug-in solar PV and BESS. Article 15a 'Right to energy sharing' of the New Electricity Directive for Electricity Market Design (2024/11), specifies that *"Member States may promote the introduction of plug-in mini-solar systems of up to 800 W capacity in and on buildings*", however, plug-in BESS are not specifically addressed. In 2025, several countries in Europe have legalised plug-in solar PV, with Germany leading the charge in regulation and standardisation. However, only Belgium has developed specific regulations and standards that address plug-in BESS.

Developments towards plug-in legalisation have recently emerged across several states in the USA, starting with the introduction of House Bill 340 Solar Power Amendments in Utah in January 2025 [39]. United Laboratories (UL Solutions) released an accompanying testing standard for plug-in PV and BESS, 'UL 3700, the outline of investigation for interactive plug-in photovoltaic equipment and systems' [40]. However, the UL 3700 standard only applies to plug-in BESS under 1kWh capacity, no products were identified during this study that meet this capacity restriction. The legal export limits in the USA differ to Europe, default limits are between 1,200W and 1920W in the USA, most regions in Europe are limited to 800W.

The UK government announced the Future Homes Standard in March 2026, confirming that plug-in solar PV would be legalised, however, official legal frameworks and standards are still to be developed.

Table 5 provides an overview of countries and regions that have legalised plug-in PV and plug-in BESS around the world, this table is an adaptation of the work published by SolarPower Europe [37] and the Plug-in Solar Conference [38] - by expanding to cover plug-in BESS regulations.

Table 5 Countries and regions that have legalised plug-in PV and Plug-in BESS as of 2026.

 **Plug-in PV**	 **Plug-in BESS**
Country (date legalised if known)	Country (date legalised)
Germany (2024) Belgium (2025) Austria Spain France Lithuania (2024) Greece Slovenia Portugal Italy Switzerland India (2024)	Belgium (2025) USA – Utah, California, Maine, Connecticut, Virginia, Colorado, Maryland (2026) Germany (to be developed)

Source: Adapted from [38,41]

4.2. Plug-in BESS: technical standards and safety requirements

There are different approaches to managing plug-in energy systems across jurisdictions, which reflect regional grid operator requirements, allocation of responsibility for safety and risk, and speed of regulation and standard development. However, despite the significant regulatory reform that has enabled pathways for plug-in PV systems, standards for plug-in BESS specifically have only emerged in Belgium and the USA. German standards are under development. An overview of the technical requirements and standards is provided in Table 6 below, following this is a detailed discussion of the technical elements of the standards.

Table 6 Regulations and standards relevant to Plug-in BESS in Belgium, USA and Germany.

Country / region	**Belgium**	**USA**	**Germany**
Plug-in regulation	Synergrid - C10/11 Plug-in PV and BESS is legal with a smart meter installed - Amended edition 2.3 of 15 October 2025 - now use a P1 dongle to manage export (could be installed by the consumer)	Regulations vary by state. Utah (2025) – HB 340 Maine (2026) – LD1730 (SP 676) Connecticut (2026) – HB 5340 Virginia (Jul, 2026) – HB 395 / SB 250 Maryland (2026) – HB 1532 (Utility RELIEF Act) Colorado (2026) – HB26 -1007 California (2026) – SB 868 (Plug Into the Sun Act	Solar Package 1 regulation (smart meters not needed immediately, easy registration)
Plug-in standard	Synergrid C10/26 homologation	UL 3700 Outline of Investigation for Interactive Plug-in PV (PIPV) Equipment and Systems	DIN VDE V 0126-95 VDE V 0126-95:2025-12 Plug-in solar devices for grid-connected operation - Part 95: Safety requirements and tests.
Plug-in BESS addressed?	Yes. However, a smart metering device is needed.	Yes. But only batteries under 1kWh storage capacity, which eliminates most plug-in BESS.	No. To be developed.
DC and AC limit	AC: 800 W	AC: 1200W - 1920W (state dependant)	AC: 800 W AC: 2000W (professional installation)
Registration	Streamlined permitting via a notification to the network operator. For multi-owner building, a permission from the Owners Association. Potential need for landlord permission.	Unclear, the whitepaper suggests no registration.	Simple online registration with the federal network regulator’s core energy market data register
Installation by a professional	Unclear - metering requirements may dictate installation by professional unless using the P1 meter.	Home circuitry needs to be certified by a qualified electrician that it complies with the UL 3700 standard.	Not required for under 800W.

Country / region	Belgium	USA	Germany
Grid feed-in	Zero feed-in for battery only. If incorporated with solar PV - limited to total solar PV feed in.	Yes. Permitted with the mentioned export limits.	Yes. Permitted and also eligible for feed-in tariffs.
Do plug-in solar PV and BESS require certification?	Manufacturers need to be homologated under Synergrid requirements. Only types homologated by Synergrid included in the C10/21 list are legal.	Products need to be certified to UL 3700.	Not a legal requirement, products should be certified against VDE standards for insurance purposes.

Source: Adaptation from [40,42,43].

This section discusses in more detail, the technical standards for testing and certification of plug-in BESS.

Belgium

Synergrid, the regulator for Belgian electricity distribution system operators, amended grid connection rules in 2025 to enable a streamlined connection process for plug-in solar PV and BESS [42]. Plug-in BESS are required to be tested and certified to Synergrid's declaration of conformity procedure, the C10/26 homologation. Conforming products need to meet the technical requirements set out in Synergrid's amended version of C10/11 edition 2.3. A list of products that have been tested and conform to the requirements is provided on the Synergrid website.

The technical requirements specify that plug-in BESS must feature a power control system and smart meter that operates in a way that limits the power injected into the distribution network, the specific requirements are:

The power control system must be managed by a:

- P1 port meter
- A hard-wired zero export meter (referred to as an EnFluRi sensor),
- Or another equivalent and compliant smart sensor.

The power control system must be measure and transmit data at least once every 500 milliseconds

In the case of sensor malfunction, the plug-in solar PV or BESS must stop exporting electricity to the grid within one minute.

The total export limit in Belgium is 800W and registration has been streamlined. In Flanders for example, registration is not needed, while other regions still require the user to report installation to the grid operator.

USA

The Underwriters Laboratories Solutions (UL) announced the first US testing and certification program for plug-in PV systems in December 2025 – UL 3700, the Outline of Investigation for Interactive Plug-In Photovoltaic Equipment and Systems. Plug-in PV and BESS systems must be UL tested and certified to ensure compliance with the US National Electrical Code (NEC).

The UL standard was released in December 2025 and specifies several requirements for the connection of plug-in solar PV and BESS. The specifications are as follows:

1. The power outlet that a plug-in solar PV and BESS connects to, must:

    a. To be installed and confirmed to be designed and fit for purpose by a qualified person in accordance with the National Electrical Code (NEC),
    b. The circuit and associated components must be suitable for bi-directional power flow, including the ground fault circuit interrupter (GFCI) and overcurrent protection.

2. The plug-in solar PV and BESS should be the only device connected on a dedicated circuit. On a dedicated circuit no appliances can be connected to the same circuit. If connected to a non-dedicated circuit, the system can only be connected to the first power outlet on the branch and the outlet must include bi-directional circuit breaker protection.
3. The plug-in solar PV and BESS must be located so that the electrical cord is not in the path of foot or vehicle traffic or subject to physical damage.
4. The distribution panel needs to be labelled to warn service persons of the presence of the plug-in solar PV and BESS. Signage also needs to be placed on the power meter.
5. The electrical cord can be no longer than 3 feet.
6. AC and DC connectors need to latch or lock to avoid unintended disconnection and be labelled "Do Not Disconnect Under Load". Connectors need to meet touch safety requirements.
7. Installation instructions must include safety warnings and clear installation requirements including requirements around dedicated circuits and warnings that electrical circuits must be evaluated for and suitably rated for bi-directional flow.
8. Grid interactive inverters must feature no user accessible live parts and stop exporting electricity if disconnected from the grid within 0.5 seconds.

An overview of risks is described in the associated whitepaper 'Interactions of Plug-in PV with Protection of Existing Power Systems', the details of which are highlighted here:

- Overcurrent protection, should be managed via one of the following:
    - A dedicated circuit for the plug-in PV system.
    - A unique power outlet that can only connect the plug-in system, with overcurrent protection integrated at the power outlet.
    - The first power outlet in the circuit is replaced with oversized conductors.
    - A 'smart' power control system to monitor and control loads on the circuit.
- Electric shock protection, potential solutions:
    - Electrical connections that hide live parts so they cannot be touched by the user.
    - Grid interactive inverters that shut off generation if the grid is not detected.
- Ground fault/earth fault circuit protection, necessary when there are risks of wet area exposure such as when products are installed outdoors, solutions:
    - Ground fault circuit interrupter (GFCI) installed on the switch board.
    - GFCI installed on the first power outlet of the circuit.
    - GFCI must be bi-directional or the plug-in system must be installed on a stand-alone circuit with CFCI protection, where only the system can plug into that circuit.

- If the power outlet is outdoors, it requires a separate dedicated circuit.
- Installation and registration
  - DIY installation via standard wall plug if product meets standard requirements and limited to 1,200W AC generation output.
  - Plug-in systems below 1,200W that connect to a standard power outlet do not require registration.

The plug-in PV standard in Germany

The plug-in PV standard in Germany does not specifically address plug-in BESS, however, the structure of the standard is applicable for the rules governing plug-in BESS network connection. The German testing standard for plug-in PV systems – VDE V 0100-551-1 – was introduced in 2017 [44], developed by the Association for Electrical, Electronic & Information Technologies (VDE). The most recent version is VDE V 0126-95:2025-12 *"Plug-in solar devices for grid-connected operation - Part 95: Safety requirements and* tests", released in 2025. The standard differentiates the requirements across two types of plug-in PV systems:

1. *Systems under 800W AC*: considered an appliance, can be plugged into a standard power outlet by the consumer.
2. *Systems between 800W and 2,000W AC*: require specialised installation, a special power outlet and plug, and need to be registered with the grid operator.

The two typical system setups are described in more detail below.

<u>Systems under 800W</u>

Plug-in PV systems can be installed directly into a standard wall socked with a Schuko plug by the consumer, but they are limited to 800W AC maximum output and must meet electrical safety requirements to ensure consumer safety, outlined below.

Can be installed by the consumer if the following conditions are met:

- A regular power plug that connects to a standard socket outlet is acceptable but must incorporate shock protection. Shock protection includes a circuit switch in the plug or covers over pins to protect from touching live parts when connecting/disconnecting, (An example of the standard plug type is shown in Figure 11).
- The power cable must be at least 5 metres long to avoid using extension cords. The cable must be labelled to warn the consumer that only one device can be plugged in at any one time, extension cords or power boards cannot be used to connect the system.
- The system must be limited to a maximum inverter output of 800VA, and an injection current limit of 3.5A.
- The inverter must incorporate safety protections,such as rapid disconnection of power conversion, rapid isolation of any hazardous voltages from the plug contacts and anti-islanding protection to prevent back-feeding electricity to the grid if the grid goes down. Without these protections built into the inverter, shock protection must be built into the plug if it is the Schuko type (see image to the right in Figure 11)
- Mounting systems must be appropriate for the recommended mounting points, must have instructions and recommend the maximum height the system can be mounted.

Figure 11 Schuko plug connection type and (left) and shock protection required (right).

Source: Adapted from Balkon.Solar [45]

Systems between 800W and 2,000W

Specialised sockets and plugs enable a wider range of system options and a higher maximum output allowed to feed back into home circuits and the grid. This type of connector clips into place and requires mechanical means to disconnect, Figure 12. The specialised power outlet must be installed by a licenced electrician, and the associated circuit wiring and circuit protection must be checked to ensure that it can handle the plug-in system.

Figure 12 Wieland type connector and specialised socket.

Source: Wieland Electric [46]

In addition to product specific requirements, regulation has changed to ensure that owners and landlords cannot restrict reasonable applications to install plug-in PV systems. This important piece of regulatory reform gives power to occupants of in owners' corporations or strata buildings and renters to participate in the renewable energy market, by removing common and unreasonable barriers often raised by these groups.

4.3. Gaps in the regulation and standards framework

Policy measures for plug-in BESS are designed to address electrical safety, home circuit safety, and electricity network integration. However, a comprehensive set of policy measures needs to be developed to address broader risks and performance issues that may emerge with the uptake of plug-in BESS. For example, one of the key policy gaps is the specification of appropriate installation locations for plug-in BESS. A comprehensive regulatory and standards framework already exists for hard-wired residential BESS that stipulates installation requirements; however, it is unclear whether plug-in BESS should comply with installation requirements associated with hard-wired residential BESS in terms of installation location. Several other policy gaps emerged through conversations with battery value chain stakeholders during the stakeholder engagement stage of this research. These gaps are outlined below.

Table 7 Regulation and standards gap #1

Issue # 1	Plug-in BESS installation in habitable rooms
Description	Consumers may be installing plug-in BESS in habitable rooms which risks the safety of home occupants in case of emergency.
Driver	Product manufacturers are marketing the installation of plug-BESS in habitable rooms
Risk	Products are currently being marketed as safe to install in habitable rooms such as in home entertainment unit cabinets or in bedrooms next to the bed. While hard-wired BESS have clear and strict guidelines on legal installation locations, plug-in BESS lack clear guidelines. Portable power stations are also increasingly finding their way into consumer's homes as residential energy back-up. Several products in this category have IP ratings that limit the product to indoor use only, or the manufacturers specifically note that the product cannot be installed outdoors. Marketing on product websites also shows these products installed in habitable rooms [6,7,47]. The reason for BESS installation restrictions around habitable rooms in hard-wired BESS regulation relates to the risk of the battery going into thermal runaway – an exponential chemical reaction leading to catastrophic failure. If a battery enters thermal runaway the resulting impacts such as fire and the release of toxic gases can happen within a few seconds, risking the safety of those occupants in proximity. A comprehensive regulatory and standards framework already exists for hard-wired residential BESS that stipulates installation requirements, however, policy reform measures to date have focused on streamlining the adoption of plug-in solar PV and BESS by outlining separate and less prohibitive pathways to the legal installation of plug-in BESS. Hard-wired BESS installation locations are restricted to locations that do not restrict the passage of home occupants during a fire event, this includes habitable rooms and passageways to emergency exits. If a battery is installed in an outdoor area with good ventilation, or a fire protected and vented purpose-built room, the risk to occupants is significantly reduced. The risk of the battery entering thermal runaway is managed through the battery management systems (BMSs) and thermal management systems (TMS). These systems regulate individual cell characteristics such as temperature, voltage, and state of health. Plug-in BESS products are also increasingly integrating powder-based fire extinguishers within the battery case, however, the appropriateness of powder fire extinguishers for battery fires has been questioned by a battery expert during stakeholder engagement. It is important to note that although battery performance management reduces the risk of the battery entering thermal runaway, it does not remove the risk altogether. Therefore, installation location restrictions will continue to be necessary as a secondary fail safe, to ensure occupant safety in extreme circumstances. See Table 8 for an overview of the difference between hard-wired BESS and plug-in BESS installation practices.

Table 8 Installation requirements for hard-wired BESS compared to plug-in BESS

Installation requirements	Hard-wired BESS	Plug-in BESS
Installation locations **NOT** permitted	Habitable rooms Within certain distances (between 600mm and 900mm) vertically or horizontally of an opening to a habitable room. In access corridors, stairwells, entry ways or exits.	Not specified
Recommended installation locations	Garages Storage rooms with ventilation Dedicated BESS room with ventilation Verandas	Product manufacturers are advertising suitable locations for installation as: - Balconies - Habitable rooms such as bedrooms, kitchens, lounge rooms. - Open outdoor areas with access to a power outlet.

Table 9 Regulation and standards gap #2

Issue # 2	Installing multiple plug-in BESS into one home circuit
Description	Product manufacturers are promoting the installation of multiple plug-in BESS products on the same home electrical circuit/network. It is commonly recommended on product websites, to plug-in multiple batteries in different locations throughout the home. Without appropriate monitoring and control of export limits, circuits could become overloaded.
Driver	Marketing campaigns recommend installing multiple units. Consumers may lack the technical knowledge to install multiple units safely.
Risk	Increasing the installed capacity of plug-in BESS in the home, either through product stacking or by installing multiple individual units, needs to be managed very carefully to reduce the risk of overloading circuits. There is a possibility that two plug-in BESS units are installed in a home, by the consumer, without the oversight of a home energy management system (HEMS) to limit the total energy exported to the home circuit and grid. This scenario could play out if different branded systems are plugged into the same phased circuit without the use of a HEMS app. The potential for this risk to play out is higher than plug-in solar PV. Total installed capacity of plug-in solar PV is limited to the number of power outlets in close proximity to the solar installation. There are also space limitations for plug-in solar PV that limit the potential for installing multiple installations at a single premises. Additionally, in some countries, outdoor power outlets require a dedicated circuit.

	In contrast, given that plug-in BESS are being marketed as safe to install indoors, indoor power outlets are readily available, ultimately resulting in no apparent limit to plug-in BESS installation. Therefore, it would be possible to plug-in multiple plug-in BESS units throughout the house. To reduce the risk, future regulation will need to stipulate the total number of products that can be installed in a home without smart energy management to control total loads, or stipulate that plug-in BESS can only be installed with smart energy management enabled.

Table 10 Regulation and standards gap #3

Issue # 3	Smart integration and energy demand/supply response flexibility
Description	Energy storage technologies are a key enabler to managing energy demand on electricity networks. Demand can be managed both within households and remotely across broader electricity networks. Smart energy management is used to control loads, optimise energy use, and control grid export. Connectivity features like WIFI, LAN and/or Bluetooth enable the remote management and monitoring of plug-in BESS performance, energy use and state of health.
Driver	**Energy management, performance and efficiency**
Risk	Potential issues with smart connectivity and remote management of the plug-in BESS to be addressed are: Potential for cybersecurity issues associated with the cloud connectivity of devices. The severity or likelihood of this risk has not been explored; however, battery value chain stakeholders consulted during this research raised concerns about the potential unauthorised control of plug-in BESSs by bad actors. If companies supplying plug-in BESS products do not provide continued software and/or firmware support, updates and maintenance schedules may be missed. Appropriate management of battery state of health and performance is ensured through continued product support, without it premature battery cell deterioration can lead to performance issues, early end of life, and a higher risk of thermal runaway.

Table 11 Regulation and standards gap #4

Issue # 4	Plug-in systems do not require registration in all countries
Description	Not all countries require the registration of plug-in solar PV and BESS, however, there are reasons why mandatory registration for plug-in BESS might be beneficial: • Managing emergency fire response. Knowing the total size and quantity of plug-in BESS installed at a premises can help emergency response teams prepare appropriately. • Planning for end-of-life management. Waste management stakeholders need to actively plan collection and recycling capacity to match future end-of-life volumes. Data on the size and quantity of all products in use in a region aids future end-of-life planning efforts. • Energy demand response. Understanding the total capacity of plug-in BESS systems will enable grid operators to effectively manage energy demand across the network.
Driver	Policy makers prioritising streamlined adoption
Risk	In the absence of system registration, there is limited data on the size of the plug-in BESS market and total installed storage capacity. A lack of data on the quantity and capacity of systems plugged-in may negatively impact future electricity network planning and policy.

Table 12 Regulation and standards gap #5

Issue # 5	Standardised requirements for product performance data and information
Description	Information **available** to consumers from plug-in BESS product websites, product datasheets, and instruction documentation is highly inconsistent. It is important that information provided to consumers by product manufacturers is of a minimum standard and consistent in the information provided. Issues identified with product information associated with some plug-in BESS products include: • Inconsistency in performance information provided on product datasheets. • Lack of clarity on product capability/functionality (e.g., for some products it was unclear whether they had the capability to be grid-tied or whether they were off grid only), • Information needs to be appropriate to facilitate safe installation by the consumer or a qualified electrician, • Lack of clarity on safe locations for installation of the plug-in BESS (e.g., products are promoted as being safe to install next to a bed while the occupant is sleeping), • Not all products featured IP ratings or what they mean in terms of the appropriate location for installation, • Incorrect information provided on websites related to emergency fire response (e.g., recommending an inappropriate fire extinguisher to be used in battery fires).
Driver	Policy makers prioritising streamlined adoption
Risk	A lack of standardised information and performance data across plug-in BESS creates a risk that consumers misinterpret information or purchase products that are less energy efficient. Consistent information is needed for the purpose of product comparison. Clear documentation is needed that guides consumers on safe installation locations. A consistent language is needed to differentiate product capability. Plug-in BESS that can export electricity to the grid should be referred to as grid tied. Portable power stations that can only be used to supply electricity to appliances that are plugged directly should be referred to as portable power stations.

Table 13 Regulation and standards gap #6

Issue # 6	Lack of regulation addressing portable power stations
Description	Portable power stations are becoming very popular with outdoor enthusiasts; however, these products are also being marketed for home energy storage and emergency backup. Products are sometimes designed to fit neatly atop the fridge or into a cabinet. They do not inject energy back into the home circuit or grid.
Driver	Increased uptake of portable batteries for energy security when the grid is down.
Risk	The absence of regulation around these products is resulting in consumers using portable power stations indoors, without the knowledge of risks to household occupants in the case a battery malfunctions resulting in fire/explosion.

5. Recommendations for future plug-in BESS policy development

The development of a comprehensive policy framework for plug-in BESS relies on efforts across three different policy ecosystems: products, property, and the electricity network. Regulations for hard-wired residential BESS are well established in these areas. This raises potential challenges for plug-in BESS policy development in emerging markets because it is unclear whether policy mechanisms plug-in products should be additional or incorporated into the existing BESS policy infrastructure.

Policy reform to date has focused on ensuring safe interaction of plug-in solar PV with electricity networks with very few reforms to address the specific requirements of plug-in BESS. There are now two countries that have introduced regulation and standards that address safety requirements for plug-in BESS - that is Belgium, where regulation for plug-in systems is worded openly to include plug-in BESS and certified products include plug-in BESS - and the USA, where the testing standard and regulation is inclusive of plug-in BESS. Germany has a standard for plug-in BESS in development, in the absence of this, regulation and standards specifically address plug-in solar PV only. However, policy development in all three of these countries continues to focus on safe interaction of plug-in BESS with home circuits and the wider electricity network. Standards related to product performance and installation requirements are yet to be developed.

To facilitate the further development of the plug-in BESS policy framework, this section provides a series of recommendations across the product, property and electricity network ecosystem.

Product ecosystem

Product standards ensure product minimum performance and safety expectations. They also stipulate the nature in which these performance specifications are communicated to consumers. Product datasheets are the primary tool for communicating performance information to consumers and this information should be standardised to enable effective performance comparison. Performance standards for energy storage systems already exist and outline key performance metrics that should be reported. These performance standards are appropriate for the testing and reporting of plug-in BESS performance. Gaps exist in the specification of requirements for how individual products should integrate with each other on the same home circuit. There is also a lack of clarity on how product performance information should be displayed on product datasheets to inform product comparison.

<u>Standards to leverage</u>

Existing performance testing standards that can be leveraged for plug-in BESS are listed below, information from [48].

- International Electrotechnical Commission 61427-2:2015+AMD1:2024 [49]
- Australian Battery Performance Standard [50]
- The Standard for Uniformly Measuring and Expressing the Performance of Electrical Energy Storage Systems [51]

<u>Recommendations</u>

Product integration: Require smart home energy management and control when installing a plug-in BESS to minimise risks to home circuits and ensure that products do not exceed the 800W export limit imposed in most countries.

Product information: Standardise the requirements related to product information provision on product datasheets and associated product documentation and guidance, to ensure that consumers are appropriately informed when purchasing and installing plug-in BESS.

Import of illegal or below standard products: Stakeholders interviewed during the stakeholder engagement phase noted challenges with consumers importing unregulated battery products directly from online retailers. Imported products through unofficial online websites can result in consumers effectively by-passing strict product regulations and standards. For example, in Australia, consumers are importing high performance electric bicycles that do not meet Australian regulations and standards that limit maximum power output to 250W and restrict throttle only operation [52]. Regulators will need to remain abreast of illegally imported products that do not meet minimum performance expectations.

Policy response for portable power stations: A policy response is needed to address the safety and performance expectations of portable power stations in inhabitable residential spaces. These products are currently unregulated for safe installation and performance.

Property ecosystem

Home occupier safety (including neighbouring homes and community) is the critical focus for policy reform in the property ecosystem section. Stakeholders relevant to the development of a policy framework include building, construction and property market regulators and standards organisations, owners' corporations and strata managers, landlords, home and contents insurance providers, fire services, home occupiers, electrical trades, and local governments managing batteries at end of life.

<u>Regulations / developments to leverage</u>

Property regulations and standards and the legal provisions for installing sustainability infrastructure such as solar panels and batteries are well developed but focus on hard-wired solutions. One of the key gaps related to policy reform to include plug-in BESS is clarity around installation location. Additionally, future markets could align with regulation in Germany for tenants that prohibits unnecessary restrictions on tenants installing plug-in solar PV. In Germany, plug-in PV has benefitted from legislative changes to the:

The Condominium Act (Home ownership in the context of owner's corporations or strata groups, referred to as 'Wohnungseigentumsrecht - WEG'), and

The rental law and tenancy law (Mietrecht) [32,33].

<u>Recommendations</u>

Installation location definition and standardisation. Clear guidance and regulation must be developed to ensure the safe installation of plug-in BESS. Without this guidance, plug-in BESS are being advertised as safe to install in habitable rooms putting home occupiers at risk. Several products identified during market research were unsuitable for outdoor use – limiting their use to indoor environments. In the absence of clear guidelines on how and where these products can be used, consumers may unknowingly be putting themselves and other home occupants at risk in the event of product failure resulting in fire/explosion.

Addressing landlords, owners' corporation's rights to refuse application to install. Best practice examples addressing the potential for arbitrary rejection of applications for plug-in systems by landlords or owners' corporations are found in Germany. Germany's regulatory reform extended to rental/tenancy regulations and strata regulation to ensure that home occupants have the right to install a plug-in system, albeit with application and notification requirements.

Insurance policy integration and support of plug-in BESS. Insurers need to develop policy on whether properties will be covered in the event a plug-in BESS damages the home, contents or neighbouring properties. The extent to which insurers would cover damage to homes and contents from issues arising by plug-in BESS is unclear. Recently insurance policy in Europe has expanded to include replacement of plug-in solar PV if the solar system is damaged and has provisions for public liability if the solar panels fall and/or damage other property or injure a person [53]. However, the extent to which insurance would cover property damage resulting from plug-in BESS failure (e.g., in the case of thermal runaway and fire) is uncertain.

Registration of plug-in BESS. A database accessible by authorised entities such as fire services and local government that notes the size and location of plug-in BESS systems would be valuable both for managing risk in cases of fire, and for preparing municipal waste management and recycling capacity at end of life.

Electrical network ecosystem

Registration of systems and network level coordination, reliability and safety are the key focus for this policy ecosystem. Stakeholders involved in policy reform include electricity network policy makers, electrical standards organisations, product installers including consumers and qualified electricians, and electricity network providers including both retailers and wholesalers.

<u>Regulations / developments to leverage</u>

Regulations are well developed for plug-in solar PV in some countries but not for plug-in BESS. Electrical network policy addresses the requirements for system registration, anti-islanding protection, and grid feed-in restrictions. Policy in Belgium and the USA specify requirements that include plug-in BESS in the policy language, relevant policy instruments include:

Belgium [42]

Amendment C10/11 edition 2.3 of 15 October 2025

Synergrid C10/26 homologation

USA [41]

Utah (2025) – HB 340

Maine (2026) – LD1730 (SP 676)

Connecticut (2026) – HB 5340

Virginia (Jul, 2026) – HB 395 / SB 250

Maryland (2026) – HB 1532 (Utility RELIEF Act)

Colorado (2026) – HB26 -1007

California (2026) – SB 868 (Plug Into the Sun Act)

UL 3700 the Outline of Investigation for Interactive Plug-in Photovoltaic Equipment and Systems

<u>Recommendations</u>

In some countries, registration of plug-in solar PV and BESS is not required. The benefit of removing this requirement is that it streamlines uptake of plug-in systems and removes delays associated with system registration and approval, however, such policies result in a significant data gap. In the absence of system registration, there is no data showing the size of the plug-in market which may negatively impact future network planning and policy.

Grid feed-in for plug-in systems is largely limited to between 800W and 1,200W where systems are legalised, with one exception in the USA. While these restrictions ensure safety across a broad spectrum of home circuits, they create a large disparity between the users of plug-in versus hard-wired solutions. Hard-wired systems can feed-in between 1,500W and 5,000W per phase depending on the jurisdiction. There are technical reasons, such as circuit breaker capacity, as to why plug-in systems may never reach this feed-in potential. However, in the case where a home circuit has been added or upgraded specifically to incorporate a plug-in system, regulations around export limits should reflect system carrying capacity.

6. Summary and outlook

Plug-in BESS are an innovative technology solution to residential energy storage, particularly for apartment dwellers or renters who have traditionally been locked out of the renewable energy market. Considerable uptake of plug-in BESS has occurred in Germany, aided by policy reform that streamlines installation processes. Many other countries in Europe as well as the USA and the UK are following Germany's lead by working through the required policy frameworks needed to support adoption.

Policy reform to date has focused on ensuring safe interaction of plug-in solar PV with electricity networks and home electrical circuits, with limited developments that specifically apply to plug-in BESS. Belgium and the USA feature inclusive policies and standards that apply to both plug-in solar PV and plug-in BESS. The details of these policies and standards are outlined in this report to aid in international adoption of best practices. In Germany, policy and standards for plug-in BESS are in development.

Plug-in BESS feature innovative energy management technology that enables energy load shifting, reduced energy costs, and aids sophisticated whole of home energy management with a few in app settings. However, several risks have been identified by this study that warrant further policy development. Key to the safe adoption of plug-in BESS is the specification of appropriate installation locations, there is currently no clarity on where plug-in BESS can or should be installed (e.g., habitable v non-habitable spaces). Performance testing and information provision is also highly variable between products available on the market and consumers would benefit from clear performance information for the purpose of product comparison. This issue is not unique to the plug-in BESS market.

A policy gap exists for the portable power station market. Consumers are increasingly using portable power stations in the home for energy back up in case of a power outage and to reduce the total cost of energy use in the home. According to market analysis performed in this research, portable power stations featured lower IP ratings than other plug-in BESS, making them only suitable for indoor use and so they are more likely to be used in habitable spaces. Further research is required to understand appropriate regulatory responses to the portable power station market due to the use of these products in residential homes.

Future policy reform should concentrate on filling gaps across the product, property and electricity network ecosystem to ensure that a holistic approach is being applied to regulation and standards development, reducing the burden of risk for consumers that may be unaware of the impacts of product or installation choices. The introduction of minimum performance standards for plug-in BESS would ensure that consumers are purchasing products that perform to expectations and continue to perform to expectations well beyond warranty periods.

7. References

1. Enkhardt, S. (2025, September 5). *Addition of almost 4.59 gigawatt hours of battery storage capacity in Germany so far this year.* PV Magazine. https://www.pv-magazine.de/2025/09/05/zubau-von-fast-459-gigawattstunden-an-batteriespeicherkapazitaet-in-deutschland-bislang-in-diesem-jahr/

2. International Energy Agency. (2025). *World energy employment 2025.* https://iea.blob.core.windows.net/assets/e5b9e908-26fe-4228-8978-e4ee36c555ed/WorldEnergyEmployment2025.pdf

3. Lo Franco, F., Morandi, A., Raboni, P., & Grandi, G. (2021). *Efficiency comparison of DC and AC coupling solutions for large-scale PV+BESS power plants.* Energies, 14(16), 4823. https://doi.org/10.3390/en14164823

4. Zendure. (2025). *SolarFlow 1600 AC.* Retrieved 20th May, 2026, from https://zendure.com/products/zendure-solarflow-1600-ac

5. Zendure. (2025). *SolarFlow 2400 AC.* Retrieved 20th May, 2026, from https://zendure.com/products/zendure-solarflow-2400-ac

6. Marstek Energy. (2025). *Venus E Gen 3.* Retrieved 20th May, 2026, from https://eu.marstekenergy.com/products/marstek-venus-e-gen-3

7. EcoFlow. (2025). *STREAM AC Pro.* Retrieved 20th May, 2026, from https://eu.ecoflow.com/products/stream-ac-pro-ac

8. Anker SOLIX. (2025). *Anker SOLIX Solarbank 3 E2700 Pro.* Retrieved 20th May, 2026, from https://support.ankersolix.com/s/product/a08J1000000YgCNIA0/anker-solix-solarbank-3-e2700-pro

9. EcoFlow. (2025). *STREAM Ultra X.* Retrieved 20th May, 2026, from https://eu.ecoflow.com/products/stream-ultra-x

10. Anker SOLIX. (2025). *Anker SOLIX Solarbank product page.* Retrieved 20th May, 2026, from https://www.ankersolix.com/eu/products/a17c13z1

11. Zendure. (2025). *SolarFlow 2400 Pro.* Retrieved 20th May, 2026, from https://zendure.com/products/zendure-solarflow-2400-pro

12. Growatt. (2025). *NOAH 2000 balcony solar storage datasheet.* Retrieved 20th May, 2026, from https://en.growatt.com/upload/file/NOAH_2000_Datasheet_EN_202509.pdf

13. Marstek Energy. (2025). *Marstek Saturn-C balcony solar battery system datasheet.* Retrieved 20th May, 2026, from https://d.otto.de/files/4151d72e-4b2d-43fe-941e-3f517ba3810e.pdf

14. BigBlue. (2025). *PowaFree balcony solar system.* Retrieved 20th May, 2026, from https://bigblue-tech.com/products/powafree-balcony-solar-de

15. Zendure. (2025). *SolarFlow 800.* Retrieved 20th May, 2026, from https://zendure.com/products/solarflow-800

16. EcoFlow. (2025). *PowerStream user manual.* Retrieved 20th May, 2026, from https://manuals.ecoflow.com/us/product/powerstream

17. EcoFlow. (2025). *DELTA 2 portable power station user manual.* Retrieved 20th May, 2026, from https://manuals.ecoflow.com/eu/product/delta-2-portable-power-station

18. BLUETTI. (2025). *AC240 portable power station.* Retrieved 20th May, 2026, from https://www.bluettipower.com.au/products/ac240-portable-power-station

19. EcoFlow UK Community. (2025). *EcoFlow UK Facebook group.* Retrieved 20th May, 2026, from https://www.facebook.com/groups/ecoflowuk/

20. Facebook Group. (2025). *Facebook group.* Retrieved 20th May, 2026, from https://www.facebook.com/groups/1187495626375501/

21. Energie Magazine. (2025, July 4). *Balkonkraftwerk Markt 2025: Zahlen, Daten & Fakten.*

22. Neubauer, L. (2024). *Balcony power plant boom: A third of Germans want mini solar plant.* Verivox. https://www.verivox.de/strom/nachrichten/balkonkraftwerk-boom-ein-dr

23. SolarPower Europe. (2025). *Plug-in solar PV: Solar for all—A deep-dive on a fast-emerging PV segment.* https://www.solarpowereurope.org

24. Ryan, D. (2025, July 24). *Plug-in solar panels are the latest green energy trend – here's what you need to know.* The Conversation. https://theconversation.com/plug-in-solar-panels-are-the-latest-green-energy-trend-heres-what-you-need-to-know-260467

25. Hill, J. S. (2025, July 1). *"Interest has been record-breaking:" IKEA launches its own balcony solar kit.* One Step Off The Grid. https://onestepoffthegrid.com.au/interest-has-been-record-breaking-ikea-launches-its-own-balcony-solar-kit/

26. Figgener, J., Hecht, C., Haberschusz, D., Bors, J., Spreuer, K. G., Kairies, K.-P., Stenzel, P., & Sauer, D. U. (2026, January). *Battery energy capacity.* Battery-Charts. https://battery-charts.de/battery-charts/#batteryenergy

27. Figgener, J., Hecht, C., Haberschusz, D., Bors, J., Spreuer, K. G., Kairies, K.-P., Stenzel, P., & Sauer, D. U. (2023). *The development of battery storage systems in Germany: A market review (status 2023).* arXiv. https://doi.org/10.48550/arXiv.2203.06762

28. Plug in Energy. (2025). *Entdecke unsere batteriespeicher für Balkonkraftwerke.* https://pluginenergy.de/pages/speicher

29. Home & Smart. (2025). *Balkonkraftwerk Anbieter Test: Das sind die besten 2025.* https://www.homeandsmart.de/balkonkraftwerk-anbieter-test

30. European Commission. (2025). *Household electricity prices in 1st half of 2025: −0.5%.* Eurostat. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20251029-2

31. Verivox. (2025). *Strompreisentwicklung 2015–2025.* https://www.verivox.de/strom/strompreisentwicklung/

32. Haufe. (2025). *Balkonkraftwerke: Das gilt für WEG & Vermieter.* https://www.haufe.de/immobilien/verwaltung/balkonkraftwerk-das-gilt-fuer-weg-vermieter_258_626800.html

33. Liebert & Röth. (2025). *Balkonkraftwerke und Wohnungseigentumsrecht.* https://www.liebert-roeth.de/de/rechtsgebiete/wohnungseigentumsrecht/balkonkraftwerke-und-steckersolaranlagen

34. EcoFlow. (2025). *Balkonkraftwerk Förderung 2025.* https://www.ecoflow.com/de/blog/balkonkraftwerk-forderung

35. SolarEnergie. (2021). *Stromspeicher-Förderung: Programme, Zuschüsse, Konditionen.* https://www.solarenergie.de/stromspeicher/foerderung

36. Statistisches Bundesamt (Destatis). (2025). *4,2 Millionen Photovoltaikanlagen in Deutschland installiert.* https://www.destatis.de/DE/Presse/Pressemitteilungen/2025/07/PD25_N034_43.html

37. European Sustainable Technology Group. (2025). *Warum eine Batterie auch ohne Solarpanels eine kluge Wahl ist.* https://www.estg.eu/de-de/informationen-ressourcen/blog/why-a-solar-battery-is-a-smart-choice-even-without-solar-panels

38. Plug-in Solar Conference. (2025). *New plug-in solar regulations around the globe.* https://pluginsolarconference.com/regulation/new-plug-in-solar-regulations-around-the-globe/

39. Utah State Legislature. (2025). *House Bill 340: Solar power amendments.* https://le.utah.gov/~2025/bills/static/HB0340.html

40. UL Solutions. (2026). *UL Solutions debuts testing and certification framework for safer plug-in solar across the United States.* https://www.ul.com/news/ul-solutions-debuts-testing-and-certification-framework-safer-plug-solar-across-united-states

41. Plug-in Solar USA. (n.d.). *The race to legalize plug-in solar across America.* Retrieved 20th May, 2026, from https://pluginsolarusa.com/

42. Synergrid. (2025). *Amended C10/11 edition 2.3 of 15 October 2025.* https://www.synergrid.be/images/downloads/C10-11_amend2.3_plug_and_play_EN_20251015.pdf

43. DKE. (2025). *DKE publishes world's first product standard for plug-in solar devices.* https://www.vde.com/en/press/press-releases/first-product-standard-for-plug-in-solar-devices

44. Gerber, D. L., Ginsberg-Klemmt, A., Stoler, L., Shackelford, J., & Meier, A. (2025). Barriers to Balcony Solar and Plug-In Distributed Energy Resources in the United States. Energies, 18(8). https://doi.org/10.3390/en18082132

45. Balkon.Solar. (2025, November 22). *What does the new German plug-in PV norm say?* https://balkon.solar/news/2025/11/22/what-does-the-new-german-plug-in-pv-norm-say/

46. Wieland Electric. (2025). *Balcony power plant.* Retrieved 20th March, 2026, from https://www.wieland-electric.com/en/building-technology/solutions/balcony-power-plant/

47. MyGrid Energy. (2025). *Module One.* Retrieved 20th May, 2026, from https://www.mygrid.energy/module-one

48. Langdon, R., Briggs, C., and Allen, S. (2025) Advancing the energy efficiency of home energy storage systems.

49. International Electrotechnical Commission. (2024). *IEC 61427-2:2015+AMD1:2024 secondary cells and batteries for renewable energy storage—General requirements and methods of test.*

50. Liebrich F, Mendis N, Bhatt AI, Munnings C, Hollenkamp AF, Smith W. PV Connected Battery Performance Evaluation Best Practice Guide. 2020.

51. National Electrical Manufacturers Association. (2019). *ESS 1-2019 standard for uniformly measuring and expressing the performance of electrical energy storage systems.*

52. England, D. (2026). *That e-bike you bought your teen might be an illegal electric motorbike – and the risks are real.* The Conversation. https://theconversation.com/that-e-bike-you-bought-your-teen-might-be-an-illegal-electric-motorbike-and-the-risks-are-real-275427

53. Anker. (2025). *Balcony power plant insurance.* Retrieved 20th March, 2026, from https://www.anker.com/eu-en/blogs/balcony-power-plant-with-storage/balcony-power-plant-insurance