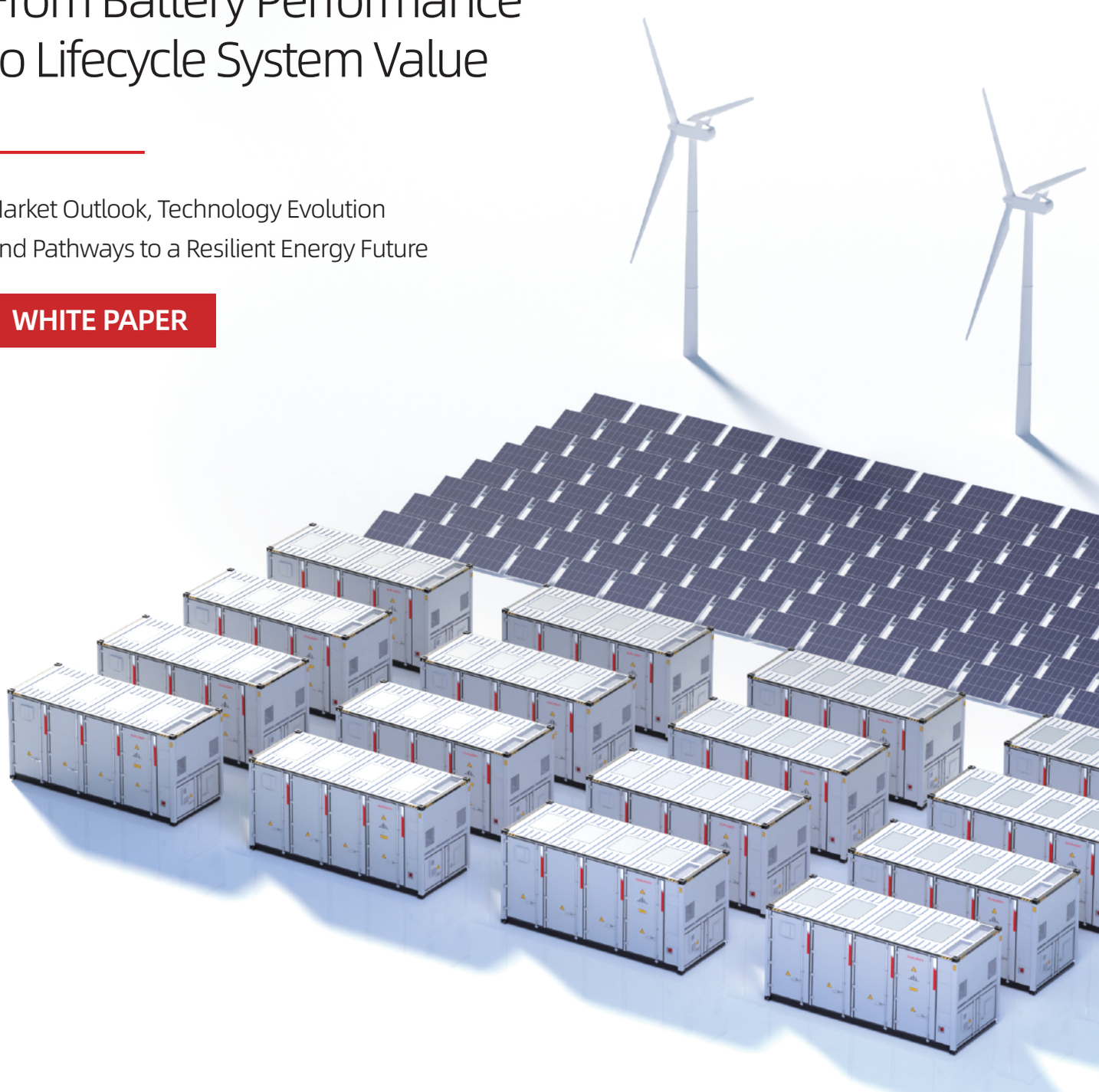
SUNWODA

THE NEXT GENERATION OF EUROPEAN BESS

From Battery Performance to Lifecycle System Value

Market Outlook, Technology Evolution
and Pathways to a Resilient Energy Future

WHITE PAPER



Executive Summary

Europe is entering a new phase of energy-system transformation.

The rapid expansion of renewable generation is fundamentally changing the structure of the European power system. BloombergNEF data indicates that European solar capacity is expected to increase from 575.3 GW in 2026 to 900.5 GW by 2030, while wind capacity is expected to grow from 325.3 GW to 454.1 GW over the same period.

At the same time, battery energy storage is scaling rapidly. European BESS cumulative capacity is projected to increase from 55.0 GW / 107.4 GWh in 2026 to 159.2 GW in 2030.

This growth is not simply a response to increasing electricity demand. It reflects a deeper transformation of the electricity system—from a system dominated by relatively predictable generation toward one characterized by increasing variability, price differentiation and flexibility requirements.

The changing market can also be observed in Germany's realized power prices. Since 2024, storage has increasingly captured a distinct and highly variable realized-price profile compared with wind and solar generation. This illustrates the growing economic value of time-shifting electricity and responding to market conditions, rather than simply generating electricity.

> **As a result, the competitive equation for BESS is changing:**
>
> `Past: BESS competitiveness = Battery Cost + PCS Efficiency + EPC Price`
>
> `Future: BESS competitiveness = Battery × System Integration × Market Optimization × Compliance × Service × Bankability`

Battery performance remains fundamental, but it is no longer sufficient.

The next generation of European BESS will compete increasingly on lifetime system value—how effectively a system converts battery capability into reliable project revenue over its entire operating life.

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CHAPTER 01

Europe Is Entering a New Era of Energy Storage

1.1 Europe's Power System Is Becoming More Renewable, Variable and Flexibility-Intensive

Europe's electricity system is undergoing a structural transformation driven by the rapid deployment of renewable energy.

According to BloombergNEF data, European solar capacity increased from 178.6 GW in 2020 to 575.3 GW in 2026, while wind capacity increased from 217.0 GW to 325.3 GW over the same period.

By 2030, solar capacity is projected to reach approximately 900.5 GW, while wind capacity is projected to reach 454.1 GW.

Figure 1. Growth of Solar, Wind and BESS Capacity in Europe

Technology	2020	2026	2030
Solar	178.6 GW	575.3 GW	900.5 GW
Wind	217.0 GW	325.3 GW	454.1 GW
BESS	**3.8 GW**	**55.0 GW**	**159.2 GW**

Source & Note: Source: BloombergNEF data provided by Sunwoda.

This expansion is changing not only the amount of electricity generated, but also when electricity is available and how its value varies over time.

1.2 From Renewable Penetration to Flexibility Demand

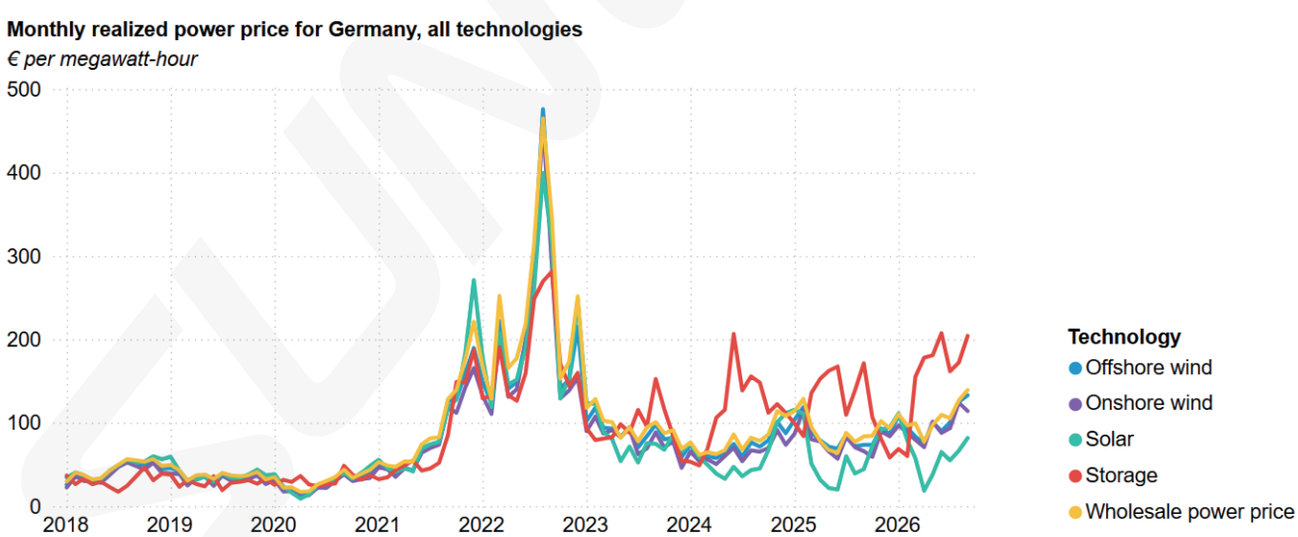
Solar and wind generation are inherently variable. As their share of the power system increases, the value of flexibility becomes increasingly important.

The system is moving through a chain of structural changes:



The economic significance of this transition is visible in Germany.

Figure 2. Realized Power Price in Germany by Technology, 2018–2026



The data shows that realized power prices for solar and wind have experienced substantial volatility, particularly during the extreme market conditions of 2022.

More importantly, from approximately 2024 onward, storage exhibits a distinctly different realized-price profile, with several periods in which storage captures materially higher realized power prices than wind and solar.

This illustrates an important structural characteristic of BESS:

> Unlike generation assets, BESS can shift the timing of electricity delivery and respond to changing market conditions.
>
> The value of a BESS therefore depends not only on how much energy it stores, but also on when that energy is charged, when it is discharged, and how effectively the system responds to market signals.

This is one reason why BESS should increasingly be viewed as a flexibility asset, rather than simply an energy-storage device.

Source: Realized power price for Germany, all technologies; data provided by Sunwoda.

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1.3 BESS Is Scaling from an Emerging Technology to Grid Infrastructure

The rapid expansion of BESS provides another indication of this structural transition.

European cumulative BESS capacity increased from 5.8 GWh in 2020 to 107.4 GWh in 2026.

Annual additions increased from approximately 1.7 GWh in 2020 to 39.5 GWh in 2026.

In power terms, cumulative BESS capacity increased from 3.8 GW in 2020 to 55.0 GW in 2026.

Figure 3. European BESS Deployment

Year	Cumulative BESS	Annual Additions
2020	5.8 GWh	1.7 GWh
2021	8.8 GWh	2.9 GWh
2022	15.0 GWh	6.3 GWh
2023	28.3 GWh	13.2 GWh
2024	45.3 GWh	17.0 GWh
2025	68.0 GWh	22.7 GWh
2026	107.4 GWh	39.5 GWh

Source: BloombergNEF.

The scale of deployment suggests that BESS is increasingly becoming an integral component of the European electricity system.

1.4 The Economic Role of BESS Is Expanding

The economic role of BESS is fundamentally different from that of a conventional generation asset.

A wind or solar asset primarily converts available natural resources into electricity. A BESS can instead:

- store electricity;
- shift electricity across time;
- respond to price signals;
- provide balancing and ancillary services;
- support renewable integration;
- manage short-duration supply-demand imbalances;
- participate in multiple revenue streams.

The Germany realized-price data provides a useful illustration of this distinction. The relatively high and highly variable realized-price profile of storage in recent years indicates that the timing of electricity delivery can itself create economic value.

> Therefore, the question for BESS is increasingly not: **How much energy can the battery store?**
> but: **How effectively can the system convert stored energy into market value over its operating lifetime?**

This distinction is fundamental to the next generation of BESS economics.

1.5 Europe Is Not One BESS Market

The economic opportunity created by flexibility does not mean Europe represents a single homogeneous BESS market.

BloombergNEF forecasts substantial differences among major European markets.

Figure 4. Annual BESS Additions by Selected European Markets

Market	2025	2026	2027	2028
Germany	7.6 GWh	13.2 GWh	16.0 GWh	19.0 GWh
UK	5.1 GWh	10.8 GWh	13.4 GWh	15.6 GWh
Italy	6.5 GWh	7.8 GWh	8.8 GWh	10.2 GWh
Poland	1.5 GWh	3.2 GWh	7.7 GWh	8.7 GWh
Spain	0.8 GWh	2.3 GWh	3.5 GWh	3.9 GWh

Key Observations:

Different markets have different:

- **electricity-market structures;**
- **grid-connection requirements;**
- **revenue-stack opportunities;**
- **cybersecurity requirements;**
- **ancillary-service mechanisms;**
- **permitting regimes;**
- **safety requirements;**
- **customer expectations.**

Therefore:

A product optimized for one European market cannot automatically become a scalable solution across Europe.

1.6 Standardization and Localization Must Coexist

The European BESS market therefore requires a balance between platform standardization and market localization.

A scalable BESS platform should standardize:

- **battery architecture;**
- **BMS;**
- **thermal management;**
- **safety architecture;**
- **system controls;**
- **communication interfaces;**
- **testing methodology;**
- **manufacturing processes.**

At the same time, the solution must localize:

- **grid compliance;**
- **market participation;**
- **EMS strategy;**
- **protection settings;**
- **permitting;**
- **cybersecurity;**
- **fire-safety requirements;**
- **commissioning;**
- **service.**

This creates an important organizational and technical challenge:

The future European BESS supplier must be globally standardized in technology but locally adaptive in system application.

1.7 From Capacity Deployment to System-Value Optimization

The first phase of Europe's BESS market was largely focused on deploying capacity.

The next phase will increasingly focus on optimizing the value generated by that capacity.

The evolution can be summarized as:

```
Capacity Deployment → System Performance → Market Optimization → Lifecycle Performance → Lifetime System Value
```

This shift has important implications for BESS suppliers.

The winning system will not necessarily be the system with the lowest initial CAPEX or the highest battery energy density.

Instead, competitiveness will increasingly depend on how effectively the system performs throughout its lifetime.

CHAPTER 02

The New Competitive Landscape of European BESS

2.1 From CAPEX Competition to Lifetime Value Competition

Historically, BESS procurement was heavily influenced by:

battery price **PCS price** **EPC price** **initial system efficiency** **energy density**

As the market matures, this approach becomes increasingly incomplete.

The Germany market data illustrates why.

The value generated by a BESS depends heavily on when and how effectively it can operate. A system that is technically capable of storing 200 MWh does not necessarily create the same economic value as another 200 MWh system.

Differences in:

RTE **availability** **degradation** **auxiliary consumption** **response capability** **controls** **market optimization** **maintenance** **augmentation**

can accumulate over thousands of operating cycles.

> **Therefore:** The relevant comparison is no longer simply €/kWh of installed capacity, but lifetime value generated per unit of invested capital.

2.2 Lifetime BESS Value

A simplified conceptual framework is:

```
Lifetime BESS Value = Revenue × Availability × Efficiency − CAPEX − OPEX − Risk Cost
```

Where:

- **Revenue** = value created by energy arbitrage, ancillary services, capacity mechanisms and other market opportunities.
- **Availability** = proportion of time the system can perform its contracted or economically optimized function.
- **Efficiency** = how much usable energy is delivered relative to the energy required to charge the system.
- **CAPEX** = initial investment.
- **OPEX** = operating and maintenance costs.
- **Risk Cost** = costs associated with degradation, warranty, compliance, downtime, replacement, performance guarantees and other uncertainties.

This framework explains why small differences in technical performance can become economically significant over a 15–20 year asset life.

2.3 Illustrative Lifetime Value Model

To demonstrate the principle, consider a representative: **100 MW / 200 MWh utility-scale BESS**

Assumptions:

- 1 full cycle/day
- 365 days/year
- 97% availability
- illustrative energy value: €100/MWh
- no degradation for pure RTE sensitivity

The model is intentionally simplified. The €100/MWh figure represents an illustrative value of delivered energy, not an actual project revenue forecast.

2.4 Small Differences in System Efficiency Can Accumulate Over the Asset Lifetime

Consider two systems:

Parameter	System A	System B	Difference
RTE	85%	87%	**+2 percentage points**
Availability	97%	97%	—

Under the above assumptions:

Metric	10 Years	20 Years
System A delivered energy	601.9 GWh	1,203.8 GWh
System B delivered energy	616.0 GWh	1,232.1 GWh
Incremental energy	**14.2 GWh**	**28.3 GWh**
Illustrative value	**€1.42M**	**€2.83M**

The implication is straightforward:

A 2-percentage-point improvement in system RTE may appear small on a datasheet, but its economic impact can accumulate materially over the asset lifetime.

This is why system-level efficiency is increasingly an economic parameter rather than simply a technical specification.

2.5 Availability Is an Economic Parameter

The same principle applies to availability.

For the representative 100 MW / 200 MWh BESS:

Availability	Annual Delivered Energy	10-Year Value	20-Year Value
95%	58.95 GWh	€58.95M	€117.90M
97%	60.19 GWh	€60.19M	€120.38M
98%	60.81 GWh	€60.81M	€121.62M

Compared with 97% availability:

- 95% → 97% creates approximately €1.24M additional illustrative value over 10 years;
- 97% → 98% creates approximately €0.62M over 10 years;
- 95% → 98% creates approximately €1.86M over 10 years.

> **Therefore:**
> Availability is not simply an O&M metric. It directly affects the revenue-generating capability of the asset.

This also explains why availability guarantees, preventive maintenance, corrective maintenance, spare-parts strategy and remote diagnostics are becoming increasingly important in BESS contracts.

2.6 Degradation Changes Lifetime Economics

Battery degradation introduces another important dimension.

Using the same representative system, assuming:

- Availability: 97%
- RTE: 85%
- Cycling: 1 cycle/day
- Augmentation: None (unaugmented baseline)
- Degradation: Annual compounded capacity degradation

Annual Degradation	10-Year Delivered Energy	20-Year Delivered Energy
0%	601.9 GWh	1,203.8 GWh
1%	575.5 GWh	1,096.0 GWh
2%	550.5 GWh	1,000.3 GWh

At the illustrative €100/MWh value:

- 1% annual degradation reduces 20-year gross value by approximately €10.8M versus 0%;
- 2% annual degradation reduces it by approximately €20.4M.

The precise commercial impact will vary substantially by revenue stack, cycling profile and contractual structure.

Nevertheless, the strategic message is clear: **Battery degradation is ultimately a system-value issue, not merely a battery specification issue.**

2.7 Augmentation Becomes Part of Lifecycle Optimization

Degradation does not necessarily mean that a BESS should simply accept declining performance. Augmentation can be used to restore system capacity during the asset lifecycle.

For example, with:

- 200 MWh initial capacity;
- 1% annual compounded degradation;
- augmentation at the end of Year 10;

capacity retention after 10 years is approximately 90.4%.

The degraded capacity is therefore approximately:

$$200 \times (1 - 0.99^{10}) \approx 19.1 \text{ MWh}$$

If illustrative augmentation cost is €100/kWh:

$$\text{Augmentation cost} \approx €1.91\text{M}$$

This creates an important optimization question: **When should the system be augmented, how much capacity should be added, and what is the resulting incremental lifetime value?**

This is fundamentally different from designing a battery only around its initial nameplate capacity.

2.8 The Four Layers of BESS Competitiveness

The competitive landscape can therefore be structured into four layers:

- **Layer 1 — Battery:** energy density; cycle life; degradation; safety; temperature performance; manufacturing consistency.
- **Layer 2 — System:** PCS; EMS; BMS; thermal management; fire safety; controls; grid compliance; system efficiency.
- **Layer 3 — Project:** grid connection; permitting; revenue optimization; EPC integration; commissioning; bankability.
- **Layer 4 — Lifecycle:** availability; LTSA; spare parts; remote monitoring; predictive maintenance; warranty; augmentation; end-of-life strategy.

The competitive evolution can therefore be expressed as:

```
Battery → System → Project → Lifecycle
```

2.9 Battery Performance → System Performance

A battery does not create project value independently. Its performance must be translated through the entire system:

```
Cell → Battery Pack / Container → BMS → PCS → EMS → Grid → Market → Project Revenue
```

A high-performance cell can therefore fail to generate corresponding project value if:

- PCS efficiency is poor;
- thermal management is inefficient;
- auxiliary consumption is high;
- controls are poorly optimized;
- system availability is low;
- grid integration is inadequate;
- EMS cannot effectively capture market opportunities.

> **This is why:** The performance of a BESS is ultimately determined by how effectively its components operate as one system.

2.10 Lifecycle Economics and TCO

Initial CAPEX represents only one part of the economic equation.

A more complete lifecycle cost model includes:

Cost Side:

- Initial CAPEX
- Installation & Commissioning
- OPEX
- Auxiliary Consumption
- Efficiency Losses
- Downtime
- Warranty Risk
- Augmentation
- Replacement
- End-of-Life Costs

Value Side:

- Energy Arbitrage
- Ancillary Services
- Capacity Value
- Grid Services
- Other Market Revenues

The resulting economic objective is therefore not simply: **Minimize CAPEX**

but: **Maximize risk-adjusted lifetime value.**

2.11 From Component Competition to Lifecycle Competition

The European BESS market is therefore moving through a fundamental competitive transition.

Previous Competition: Cell price → System price → EPC price

Emerging Competition: Battery performance → System integration → Project execution → Lifecycle optimization

Future Competition: Risk-adjusted Lifetime System Value

This transition has important implications for BESS suppliers.

The most competitive supplier will need to combine:

Deep Technology Capability WITH **Broad European Application Capability** AND **Long-Term Lifecycle Capability.**

2.12 Lifetime Value Sensitivity Matrix

The different performance parameters should ultimately be viewed together.

Parameter	Technical Impact	Revenue Impact	Lifecycle Impact
RTE	Energy losses	High	High
Availability	Usable operating hours	Very High	Very High
Degradation	Capacity decline	High	Very High
Auxiliary consumption	Energy losses	Medium	High
Response capability	Market participation	Medium–High	Medium
Thermal performance	Efficiency / degradation	Medium	High
Safety	Operational continuity	High	Very High
Maintenance	Downtime	High	High
Augmentation	Capacity restoration	High	Very High
Compliance	Market eligibility	Very High	Very High

This creates a fundamental shift in how BESS should be evaluated. The best BESS is not necessarily the one with the best individual component specifications, but the one that delivers the highest reliable, bankable and risk-adjusted value throughout its lifecycle.

2.13 Strategic Implication

The evolution of the European electricity system and the development of BESS point toward the same conclusion.

Europe is moving: From renewable generation → to renewable integration → to flexibility optimization → to system-value optimization.

At the same time, BESS competition is moving: From battery → to system → to project → to lifecycle.

This creates a new definition of BESS competitiveness:

```
Battery Performance × System Integration × Market Optimization × Compliance × Lifecycle
                                Service × Bankability
```

The competitive advantage of the next generation of BESS suppliers will therefore come from their ability to connect these dimensions into a single lifecycle value proposition.

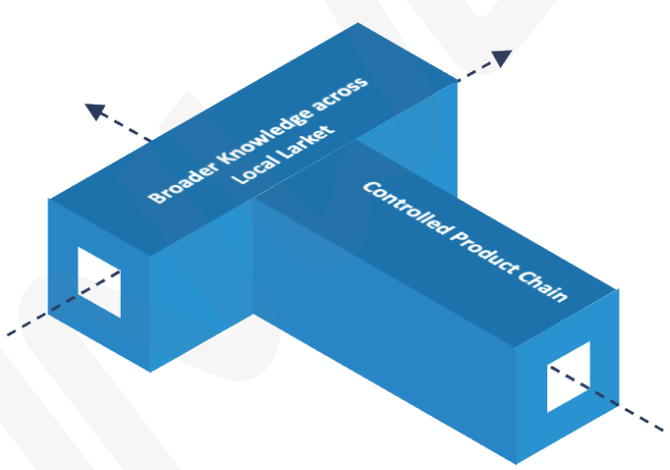
CHAPTER 03

Sunwoda's T-Shaped Strategy in Europe

3.1 A T-Shaped Strategy: Vertical Depth and Horizontal Breadth

Sunwoda's European strategy brings together two sets of capabilities. The vertical dimension covers cell technology, manufacturing and the DC container, drawing on the company's battery-manufacturing base. The horizontal dimension covers the work needed to deliver and support projects in Europe: sales, product and application engineering, compliance, cybersecurity and long-term service. Both are needed to turn manufacturing capability into projects that customers and lenders can assess with confidence.

Vertical depth - controlled product chain	Horizontal breadth - local market capability
Battery chemistry and cell manufacturing	Sales and customer interface
Pack, BMS, thermal and safety design	Application and product engineering
DC container architecture and manufacturing	PCS/EMS integration ecosystem
Performance model, quality and warranty evidence	Compliance, ESG and cybersecurity
Product-roadmap control and continuous improvement	Delivery, service and lifecycle support



3.2 Vertical Integration: A Controlled Chain from Cell to System

Vertical integration gives Sunwoda control over quality, safety, performance and product changes across the DC system. Its practical value lies in how the engineering and manufacturing teams work together:

- Translate application requirements into cell, pack and DC-system specifications through a shared product roadmap.
- Design the electrical architecture, thermal paths, mechanical structure, BMS logic and safety functions together.
- Maintain manufacturing consistency, supplier change control and traceability from cells to packs and containers.

- Use cell tests, system validation and field data as a common basis for degradation models, performance claims and warranties.
- Feed market requirements and manufacturing experience back into product engineering and the next platform generation.

> **Value created by vertical depth:**
> Lower interface, quality, supply-chain and warranty risk; faster product iteration; clearer ownership of DC-system performance.

3.3 Horizontal Integration: From Customer Interface to Compliance by Design

European projects also need commercial, engineering, compliance and service teams that understand local conditions. Sunwoda does not need to build every capability in-house, but it does need clear responsibility for the full customer interface. This includes:

- **Customer engagement:** key-account work, use-case definition, tender clarification and agreement on the project's value case.
- **Local engineering:** translating country-specific grid, environmental, acoustic, fire-safety and site requirements into product and solution design inputs.
- **Integration partners:** qualifying PCS, EMS, MV-equipment, EPC and service partners, and controlling the technical interfaces between them.
- **Compliance by design:** addressing the EU Battery Regulation, Battery Passport, CE and product requirements, grid compliance, cybersecurity, carbon footprint, responsible sourcing and recycling.
- **Lifecycle support:** application engineering, commissioning support, remote diagnostics, spare-parts planning, warranty coordination and augmentation planning.

> **Value created by horizontal breadth:**
> Faster requirement translation, lower compliance and execution risk, stronger customer confidence and deeper local market knowledge.

3.4 Sunwoda ESS Platform: The Strategy in Practice

Sunwoda puts this strategy into practice through a controlled DC product core and qualified integration and service partners in Europe. Cell characteristics inform pack layout, thermal behaviour, BMS models, safety architecture and warranty assumptions. A standard core provides the basis for market and project variants, with defined limits on customization.

PCS, EMS, MV equipment and plant controls are integrated through agreed protocols, interface documents and verification plans. Traceability, cybersecurity, diagnostic access, component replacement and lifecycle data are considered at the architecture stage.

At AC-system level, this approach is intended to improve partner integration, preserve architectural flexibility, manage total system cost and performance, and reduce delivery and commissioning risk. Its value depends on how reliably these capabilities carry through from the DC container to the completed project.

CHAPTER 04

Battery Performance — From Specification to Track Record

4.1 Research Scope and Roadmap Boundaries

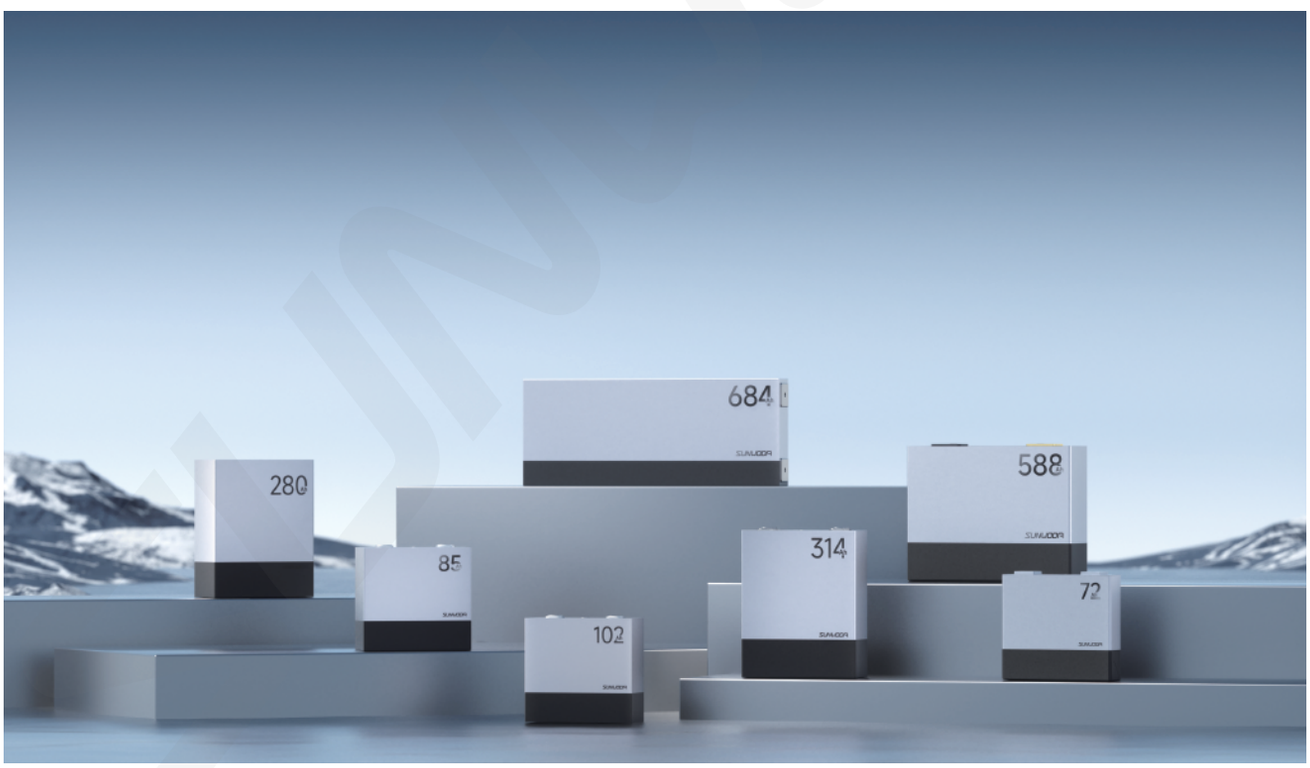
Selecting a cell for a European utility-scale BESS involves several trade-offs. Rated capacity, C-rate, cycle and calendar life, temperature range, efficiency, safety, manufacturing consistency, delivery capacity and warranty terms all need to be assessed together.

The choices are closely connected. A larger cell changes the energy associated with a single-cell failure, thermal propagation paths, mechanical loading and maintenance needs. C-rate and temperature affect cooling demand and auxiliary consumption. Cycle life depends on depth of discharge, average SOC, ambient temperature, rest periods and the criteria used to end a test. The cell roadmap must establish what the market will accept, what the system platform needs and what the available evidence can support.

Sunwoda's LFP energy-storage portfolio includes 102Ah, 280Ah, 314Ah, 588Ah and 684Ah formats, serving different applications and platform generations. Established 280Ah and 314Ah formats fit existing pack, DC-system and procurement arrangements. The 588Ah and 684Ah formats support platforms with greater integration: 588Ah cells are used in the 20-foot 6.26MWh and 10-foot 3.13MWh platforms, while the stacked 684Ah cell has progressed into mass production.

Each format should be assessed by its intended application, assigned platform, validation status and manufacturing maturity. Capacity alone says little about readiness for a particular project.

Figure 4-1 — Sunwoda Energy Storage Cell Portfolio



Note: The figure illustrates the product family. Applicable specifications, production status, and project suitability shall be governed by effective technical documentation.

4.2 Mainstream European Requirements and Their Constraints on Cell Specifications

European BESS projects impose different demands on cells. Two-hour systems commonly serve frequency response, arbitrage and combined ancillary services, making current response, heat generation, dynamic power limits and efficiency particularly relevant. Four-hour and longer-duration systems more often serve energy shifting, renewable-energy smoothing and capacity support. These applications place more weight on sustained discharge, low-rate efficiency, calendar ageing and long-term usable energy.

An asset's duty cycle may change as it moves between market services. Annual cycle count, average SOC, charge/discharge depth and power profile can all shift with the revenue strategy. Location also matters. Northern European cold, Southern European heat, coastal salt mist, noise limits near populated areas and altitude affect cooling, materials, protection and auxiliaries.

Capacity and cycle life cover only part of the cell specification needed for system design. The specification should also include:

- Nominal and operating voltage ranges.
- Continuous and peak charge/discharge rates.
- DC internal resistance across SOC and temperature.
- Heat-generation characteristics and self-discharge.
- Dimensional tolerance, swelling force and venting direction.
- Short-circuit and overcharge response.
- Capacity and resistance distributions.
- Degradation curves under defined operating conditions.

For a long-life infrastructure asset, the supporting evidence should state sample sizes, instrument accuracy, rest and calibration procedures, the SOH determination method and extrapolation assumptions. Procurement teams need this information to assess substitutability and supply continuity. Engineers use it in electrical, thermal, mechanical and control design; lenders and insurers need traceable results with clear limits on their applicability.

Keeping established cell formats on existing platforms allows larger cells to be developed for distinct two-hour and four-hour architectures. Joint tests with PCS and control-system partners can verify communication, start-up and shutdown, operating behaviour, fault handling and compatibility. These checks help establish whether a larger cell delivers value in its intended application.

> For Sunwoda, this supports retaining established specifications for customer compatibility while developing 588Ah and 684Ah technologies for future system platforms.

4.3 Dual-Track Cell Planning and Product Mapping

Cell planning follows two routes. The first serves existing customer architectures and mainstream specifications, keeping adoption costs down through comparable, verifiable dimensions, rate capability, technical data, qualification records and manufacturing quality.

The 280Ah and 314Ah formats draw on mature equipment, pack and testing ecosystems. They suit customer-specified applications, joint development, extensions of established platforms and projects sensitive to replacement risk. The 102Ah format can continue to serve applications with particular power, modularity or form-factor requirements. For these formats, competitiveness rests on consistent manufacturing, type-test evidence, controlled changes and reliable delivery. Development should focus on chemistry, reducing lithium inventory loss, improving process windows and statistical quality control.

The second route starts with system-platform requirements. The established 314Ah platform uses a liquid-cooled CTP 2.0 architecture for 20-foot 4.17MWh/5MWh products. The subsequent 588Ah platform supports 20-foot 6.26MWh and 10-foot 3.13MWh DC products and is designed for centralized and string PCS architectures and two-hour and four-hour applications. The stacked 684Ah cell supports the development of system concepts with higher volumetric energy density and longer life.

For this route, cell definition should account for pack boundaries, series/parallel arrangements, cooling interfaces, BMS sampling and balancing, pressure-relief paths, assembly, transport limits and field maintenance. Further cell development should depend on demonstrating value at platform level.

Both routes share chemistry development, pilot production, quality planning and data systems. Their qualification priorities differ: the first emphasizes customer approval, continuity of supply and compatibility across platforms; the second also requires validation at pack, cluster, container, PCS-interface and field-operation levels.

A five-stage qualification sequence is recommended:

```
Engineering sample validation → Design validation → Process validation → System-platform validation → Field-operation validation
```

Each stage should define the version tested, sample size, failure criteria, treatment of deviations and data-retention requirements. Commercial commitments and production release can then be assessed against the same evidence used to judge engineering maturity.

Table 4-1 — Dual-Track Cell Planning and Qualification Logic

Route	Representative Specifications / Platforms	Primary Objective	Qualification Evidence
Market-led route	102Ah, 280Ah, 314Ah; customer pack or existing DC platforms	Improve adoption efficiency and cover mainstream procurement and replacement requirements	Manufacturing consistency, customer qualification, type testing, supply continuity, change control
System-led route	314Ah platform; 588Ah 6.26MWh/3.13MWh; 684Ah future high-density platform	Co-design energy density, thermal management, safety, lifetime, and maintainability	Layered cell, pack, cluster, container, PCS-integration, and field validation
Common foundation	LFP chemistry, manufacturing processes, quality control, and data platform	Reuse data and continuously improve both external cell products and proprietary system platforms	Unified serial-number traceability, quality gates, failure analysis, and warranty evidence

4.4 Propagation of Cell Parameters into DC-System Definition

Cell parameters shape the electrical, thermal, mechanical, control and safety design of the DC system.

Nominal DC energy can be approximated from cell voltage, capacity and the number of cells in series and parallel. Usable energy also depends on the SOC protection window, temperature correction, cell dispersion, degradation margin and DC losses. The series count sets cluster start-of-charge and end-of-discharge voltages, which must be considered alongside the PCS DC window, insulation coordination and component voltage ratings. Parallel count and C-rate set continuous and transient current requirements for busbars, fuses, contactors, connectors and cables. Changes may require revised protection settings, pre-charge logic, DC distribution or PCS selection.

Thermal design needs resistance and heat-generation data across SOC, temperature and ageing state. Ohmic heating becomes more significant at high current; low-temperature charging adds lithium-plating constraints. The worst operating conditions should determine cooling-plate design, coolant flow, pump power, heat-exchanger size, refrigeration capacity and control strategy.

Larger cells reduce connections and part count and can improve integration efficiency. Each cell also carries more thermal mass, localized fault energy and potential gas release. Cooling contact, propagation barriers, directional pressure relief and fault isolation need to be strengthened accordingly.

Dimensional tolerance, cyclic swelling and end-plate preload affect the long-term stability of modules and packs. Terminal location and joining methods influence automation, resistance and repairability; vent orientation informs gas routing, detector placement and pressure relief. For high-density 20-foot containers, transport mass, lifting points, centre of gravity, road limits and replacement access need to be assessed during product definition. Fewer cells can mean fewer sampling points and connections, but also different replacement costs, isolation granularity and spare-parts needs.

The BMS translates these physical limits into operating limits. It should calculate SOC, SOH and available charge/discharge power from measured voltage, current, temperature and model states, then continuously communicate dynamic limits to the PCS or EMS. In series-connected cells, capacity and resistance differences cause the weakest cell to reach its limit first, reducing usable energy. Active balancing, cluster management and controlled cell matching can mitigate this effect.

The 588Ah platform uses cluster-level active balancing, layered electrical protection and coordinated liquid- and air-flow management to improve electrical and thermal consistency. Project verification should still check these functions against the delivered software version, measurement accuracy, communication cycle and PCS control logic.

> Platform data for the 588Ah 6.26MWh system indicate improvements in volumetric energy density, footprint and part count over the preceding generation. The economic assessment needs a consistent comparison boundary, including container quantity, PCS and MV configuration, cabling, civil works, auxiliaries, usable energy, maintenance windows and augmentation. Nominal cell capacity alone cannot establish levelized storage cost or project return.

4.5 Adaptation Criteria for the Sunwoda ESS Platform

Adapting the Sunwoda ESS Platform to a project starts with defining which elements are fixed and which can be configured. The fixed core includes cell chemistry, pack structure, cluster topology, the main thermal-management circuit, BMS safety logic and fundamental fire-safety interfaces. Configurable elements may include cluster quantity, external DC branches, communication mappings, environmental packages, auxiliary power architecture and project-specific identification.

A fixed core supports repeatable validation and consistent manufacturing. Configurable elements accommodate different PCS technologies, plant layouts and national requirements. Every configuration should have an approved drawing set, BOM, software version and validation record, carried consistently through sales, technical agreements, manufacturing and delivery.

Two-hour and four-hour applications can share much of their mechanical and control design, but C-rate, continuous current, thermal equilibrium and life models require separate verification. For the same 6.26MWh container, a two-hour configuration demands more PCS power, DC-branch current and peak cooling capacity. A four-hour configuration places more emphasis on low-rate efficiency, calendar life, temperature stability over sustained operation and energy retention.

Centralized and string PCS architectures also differ in DC-branch granularity, fault isolation, power allocation between clusters and control topology. Compatibility claims should be backed by an approved integration list, operating envelope and validation report that identify the PCS firmware and controller versions.

Maintenance and capacity management should inform roadmap decisions. High-density containers can reduce initial footprint and infrastructure cost, while spare-part granularity, batch compatibility, cluster isolation and replacement time affect availability. Augmentation plans should reserve adequate DC-voltage, communication, mechanical and control interfaces and account for capacity, resistance and degradation differences between new and aged cells. These arrangements need to remain under platform configuration control as cells evolve.

4.6 Manufacturing Consistency and Engineering Maturity

A utility-scale BESS can contain thousands or tens of thousands of cells. At this scale, outliers and abnormal units matter, so manufacturing assessment needs to examine distributions, process drift and defect rates as well as averages.

Critical characteristics include coating mass loading, compaction density, moisture, electrode burrs, stacking or winding alignment, electrolyte fill, formation temperature, rest time, capacity, DC resistance, self-discharge and open-circuit voltage. Statistical process control and process-capability measures should track shifts in process averages and variation between batches.

Line efficiency, process capability and repeatability determine whether a large-format design can be manufactured consistently. For customer, insurer and lender review, Sunwoda needs evidence from its own lines, defined batches, inspection criteria and traceability records. The 684Ah cell's entry into mass production represents industrialization of stacked large-format manufacturing and its inspection processes. For a European project, that status must still be tied to the specific version being delivered.

Traceability should connect raw-material batches, manufacturing orders, cell serial numbers, pack assembly, BMS software, liquid-cooling configuration and container factory records. Changes to critical materials or suppliers should trigger technical assessment, representative validation and customer notification where applicable.

Cell screening, pack-matching windows and factory inspection should remain consistent with degradation and warranty models. Early abnormalities, capacity dispersion and abnormal resistance growth need to be detected before system assembly.

4.7 Performance Validation, Degradation Modelling, and Warranty Evidence

Cell-performance information falls into six levels: design targets, engineering tests, third-party type tests, production sampling, DC-system validation and field-operation data. Each has a different role. Engineering tests establish physical mechanisms and design windows; type tests demonstrate conformity of specified samples under stated conditions; production sampling monitors process stability. System validation captures the effects of pack architecture, cooling, BMS and safety design, while field data help calibrate models under actual operating conditions.

Whitepapers, technical agreements and warranties should identify the evidence level, sample version, operating conditions and measurement boundary behind each claim.

A cycle count alone does not describe degradation. Models should separate calendar ageing from cycling ageing and account for temperature, average SOC, SOC swing, C-rate, rest time and cut-off voltage. High temperature and high average SOC generally accelerate parasitic reactions. High-rate charging at low temperature increases lithium-plating risk.

Combining equivalent full cycles, energy throughput and elapsed time allows project teams to model annual SOH under a representative duty cycle. This model should inform usable-energy guarantees, efficiency assumptions, augmentation and maintenance. High-frequency two-hour dispatch, four-hour energy shifting and operation at low or high temperatures need distinct validation profiles. Where appropriate, accelerated ageing should be used alongside long-duration physical tests.

For the established 314Ah platform, cell qualification data support its positioning for long cycle life and service life. The 588Ah platform has been validated under defined cycle-life and energy-efficiency conditions. Applying these results to a project requires retaining the original test conditions and limits.

Efficiency figures also need clear boundaries. Cell energy efficiency, pack DC efficiency, container DC efficiency and AC round-trip efficiency include different losses. AC performance additionally depends on the PCS, transformer, cabling, reactive-power operation, standby loads and plant auxiliaries. Until the AC configuration is frozen, validated DC data and a transparent loss model provide the appropriate basis for assessment. A final system-level commitment should follow joint validation of the defined AC configuration.

Table 4-2 — Layered Evidence Chain from Cell to Project Operation

Evidence Level	Main Outputs	Applicable Boundary
Engineering and type testing	Cycle life, degradation, efficiency, rate capability, temperature and safety	Defined sample, operating condition and test methodology
Production and process evidence	Parameter distributions, process capability, batch consistency and outgoing inspection	Manufacturing stability of the delivered version
DC-system validation	Usable energy, DC efficiency, temperature spread, auxiliary power, protection and safety functions	Defined BOM, BMS and thermal configuration
AC-integration validation	PCS compatibility, power response, AC efficiency, interlocks and fault management	Defined PCS/EMS/PPC hardware and software versions
Field-operation evidence	Availability, degradation, alarms, root-cause analysis and corrective-action closure	Model calibration and long-term project commitments

4.8 Roadmap Governance and Interim Conclusions

Market, product, R&D, manufacturing, quality, certification and service teams should jointly manage the cell roadmap. A shared requirements register should bring together European customer RFPs, grid and fire requirements, PCS-integration results, manufacturing deviations, field alarms and warranty data. Priorities should reflect market coverage, commercial value, technical risk and delivery timing.

The external product portfolio should remain relatively stable. Internal development can move through quarterly reviews and annual rolling plans. Changes to chemistry, structure, critical materials, software models or safety strategy need defined impact assessments and revalidation requirements. Projects with frozen configurations should use configuration control and formal deviation approval to preserve delivery consistency.

Roadmap changes should also reach quotation and financing documents. When cells are substituted, systems upgraded or specifications introduced, commercial teams need approved performance limits, supply status and warranty terms. Project teams need confirmation of certification coverage, evidence for financing and the long-term supply strategy.

For technologies still under qualification, three labels are recommended:

```
Target Value → Validated Value → Project Commitment Value
```

These labels distinguish a development objective from a tested result and a contractual commitment. Across the portfolio, common manufacturing, quality, traceability and data systems connect established formats for mainstream customer integration, the 588Ah 6.26MWh platform and 684Ah development for subsequent high-density, long-life systems. Roadmap decisions can then connect cell and system development to manufacturing maturity, validation results and project economics.

CHAPTER 05

System-Level Integration — Where Battery Value Becomes Project Value

5.1 System Boundary and Engineering Methodology

A utility-scale European BESS typically includes the DC battery system, PCS, step-up transformer and MV switchgear, plant controller or PPC, EMS/SCADA, auxiliaries, fire-safety systems, and communication networks. Each component may meet its own product requirements. Project performance still depends on how their interfaces, controls, protection logic, and fault responses work together.

Sunwoda controls the product core: cells, packs, BMS, thermal management, safety architecture, and the DC container. PCS, EMS/PPC, MV equipment, and site engineering are incorporated through qualified partners, with interfaces governed at project level.

Engineering starts with an agreed requirements and interface baseline. The duty cycle, grid requirements, environment, availability, efficiency, noise, fire safety, cybersecurity, and data requirements inform the single-line diagram, control architecture, equipment selection, responsibility matrix, ICD, signal list, protection settings, state machine, and interlock matrix. Validation proceeds through component testing, FAT, FIT, SAT, and performance testing, with a traceable link at each stage:

```
Requirement → Design → Verification → Evidence
```

AC integration is demonstrated by testing actual combinations of hardware, software versions, operating states, and responses to abnormal conditions. Nominal compatibility alone does not establish that these combinations will work.

5.2 Battery–PCS Operating Envelope and Protection Coordination

The DC operating envelope is the main technical interface between the battery and PCS. It should specify permissible voltage, continuous and short-duration current, charge and discharge power, and recovery conditions as functions of SOC, temperature, and SOH.

The PCS DC window must accommodate the battery voltage range over its full life, allowing for measurement error, cell dispersion, and control response. An inadequate window can cause premature derating near SOC limits. The PCS must also correctly interpret and apply dynamic current limits at low or high temperatures and as the battery ages.

At equivalent energy, a two-hour configuration places substantially higher demands on current capability and thermal management than a four-hour configuration. Centralized PCS architectures connect larger DC groups to common buses, making protection selectivity and fault-impact assessment particularly important. String architectures offer finer fault isolation and power granularity but add communication and coordination complexity. Both need defined DC-branch designs, protection settings, and communication topologies.

Protection coordination should cover pre-charge, normal switching, DC short circuit, insulation faults, overcurrent, overvoltage, undervoltage, reverse polarity, and emergency shutdown. BMS, DC distribution, and PCS settings must account for fault energy, equipment withstand capability, and selectivity. Time-synchronized event records should be retained for fault attribution, warranty analysis, and root-cause investigation.

5.3 Hierarchical Control Across BMS, EMS, and PPC

Large-scale BESS normally manage batteries at cell/pack, cluster, and system levels. The BMS supervises battery safety and calculates available charge/discharge limits. The EMS sets operating schedules and energy-management strategy; the PPC translates grid or dispatch requirements into active-power, reactive-power, voltage, or power-factor commands.

The control hierarchy needs a unique command source, explicit priorities, and consistent feedback logic. If BMS, PCS, EMS, and PPC make simultaneous power corrections, the result can be oscillation, repeated derating, or unstable recovery.

Interfaces should define signal meaning, units, accuracy, refresh rate, quality flags, heartbeat, timeout behaviour, and default states. Calculation boundaries also need to be clear for SOC, SOH, maximum charge power, and maximum discharge power.

Alarm levels should distinguish notification, derating, shutdown, and emergency shutdown. Signal lists, register mappings, time synchronization, and software versions should be frozen before FIT. Records of remote commands, critical events, and software upgrades should retain timestamps and version information, with rollback capability maintained for software upgrades.

In plants with multiple containers and PCS units, station-level control should coordinate asset availability, ramp rate, SOC targets, fault derating, and restart sequences. It must also maintain a defined safe state under single-point failures.

5.4 Thermal Management, Safety Functions, and Emergency Interfaces

Thermal management must control cell temperature, temperature spread, auxiliary energy use, environmental derating, and acoustic performance. Cooling design should account for worst-case heat generation, ambient temperature, solar radiation, altitude, salt mist, cooling-system degradation, pump redundancy, leak detection, and low-temperature protection.

Safety design should follow how an abnormal event develops, connecting detection, limitation, isolation, pressure relief, suppression, and emergency response. At cell level, the focus is internal short circuit, overcharge, external short circuit, and thermal stability. Pack and cluster layers add temperature and gas detection, propagation control, electrical isolation, and fault localization. Container-level provisions cover combustible-gas management, ventilation, pressure relief, fire interfaces, structural resistance, and personnel safety.

The applicable Sunwoda ESS architectures incorporate multiple layers of electrical and thermal safety functions. Each project must define the hardware, software versions, activation thresholds, interlocks, and acceptance criteria that implement these functions.

Fire-safety and electrical-control sequences should be settled during design. Depending on the alarm state, actions may include derating, stopping charge/discharge, opening contactors, changing ventilation, blocking the PCS, activating the extinguishing system, and issuing station-level alarms. Spacing, water supply, ventilation, emergency access, and firefighter information remain subject to national and local authority requirements.

5.5 Grid, Plant-Level Interfaces, and Validation

European grid compliance combines EU network frameworks, national technical rules, and TSO/DSO connection requirements. Project requirements may include active- and reactive-power control, voltage regulation, frequency response, ramp-rate control, voltage and frequency ride-through, harmonics, and fault-current contribution.

The PCS, PPC, transformer, and plant controller primarily determine grid behaviour. Battery SOC, temperature, and available-power limits constrain how that response can be sustained. Grid models and control parameters should represent the hardware and software versions actually deployed on site.

System optimization should be assessed at the point of interconnection. Energy and power models should include P-Q capability, derating, transformer losses, auxiliaries, part-load operation, environmental conditions, equipment unavailability, and N-1 states.

Validation should move from digital models to physical equipment in the following sequence:

```
Power Flow / Short Circuit / Harmonics / Dynamic Simulation → SIL/HIL → FAT → FIT → SAT →
                          Grid Compliance and Performance Testing
```

FIT should cover normal start-up and shutdown, charge/discharge, power tracking, SOC limits, communication loss, auxiliary-power loss, safety alarms, cluster outage, and recovery sequences. Test records should retain equipment serial numbers, software versions, settings, instrumentation, and raw data. These records allow validated configurations to be reused across projects.

Table 5-1 — System Interface Baseline and Verification Outputs

Interface Domain	Design Baseline	Key Verification Outputs
Battery–PCS	DC voltage/current/power envelope, pre-charge, insulation and protection coordination	Start/stop, power tracking, dynamic derating, fault isolation, efficiency boundary
BMS–EMS/PPC	Command priority, signal list, state machine, alarms, time synchronization, data permissions	Communication, SOC boundary, derating, timeout, loss-of-communication and recovery
Thermal–Fire Safety	Heat generation, cooling capacity, gas/smoke detection, pressure relief and interlocks	Worst-case temperature, fault triggers, equipment coordination and emergency response
PCS–MV–Grid	P-Q capability, transformer, protection, grid model and plant-level control	FAT/FIT/SAT, grid-compliance testing and site performance
Network–Remote Service	Segmentation, access permissions, encryption, logging, patching and rollback	Configuration/security testing, remote-access audit and incident-response validation

CHAPTER 06

European Compliance — From Certification to “Compliance by Design”

6.1 European Compliance Architecture: Regulation, Standards, and Project Permitting

For a European BESS project, the team needs to establish which requirements apply to the product, which apply to the site, and who is responsible for meeting each. Certificates form part of this work, but the compliance assessment has to cover four levels:

- Applicable legislation, including EU requirements for projects within their scope and the relevant national laws governing market access and lifecycle obligations.
- Harmonized standards, EN/IEC standards, and conformity-assessment schemes.
- National grid codes, building and fire requirements, environmental permitting, and local-authority requirements.
- Customer, EPC, insurer, and financing requirements.

A compliance applicability matrix should record the requirements and assign a responsible party to each.

Battery Regulation

Regulation (EU) 2023/1542 covers industrial-battery obligations for carbon footprint, performance and durability, labelling and information, supply-chain due diligence, recycling, and producer responsibility. These obligations have different scopes and implementation schedules. They include a battery passport for industrial batteries with a capacity greater than 2 kWh placed on the EU market or put into service, once the relevant provision applies.

The product and data architecture should support this information throughout manufacturing and project operation. It needs to preserve battery identity and link materials and supply-chain records with carbon-footprint, conformity, performance, repair, and end-of-life data.

Demonstrating early strategic foresight, Sunwoda initiated the planning and architectural design of its battery passport platform at the early stages of the new EU Battery Regulation's introduction, simultaneously advancing battery passport pilot projects. Notably, two of Sunwoda's battery passport projects were recognized by the Global Battery Alliance (GBA) as "Top 10 Battery Passport Pilot Projects 2024". In parallel, Sunwoda is deepening its collaboration with Siemens to launch an Eco-Co-Creation Solution for Green Overseas Expansion, specifically exploring carbon footprint traceability solutions. This partnership aims to better address and structure the various compliance requirements under the battery passport framework, ensuring that the underlying data architecture fully supports carbon-footprint calculations, supply-chain due diligence, and lifecycle traceability.

Recognition and Collaboration

GBA awarded two of the Sunwoda battery passports project as “Top 10 Battery Passport Pilot Project 2024”

Sunwoda and Siemens Collaborate to Launch an Eco-Co-Creation Solution for Green Overseas Expansion



Beyond strategic planning and platform development, Sunwoda is actively advancing battery passport implementation across its energy storage battery (ESS) product portfolio. The first successfully implemented battery passport pilot project is the Sunwoda 261kWh ESS Cabinet, which was officially completed in September 2026. This milestone marks a significant transition from architectural design to practical, product-level deployment. By integrating digital battery identity, material composition, carbon footprint data, and lifecycle traceability into the 261kWh ESS Cabinet, Sunwoda has established a replicable blueprint for scaling battery passports across its broader ESS product lines. This practical implementation not only ensures readiness for the EU Battery Regulation's upcoming obligations but also provides real-world operational data to further strengthen supply-chain transparency and project bankability.



CE and Product Compliance

By affixing the CE marking, the manufacturer declares that the product meets the applicable EU product legislation requiring that marking. This follows the required conformity assessment; CE marking is not a standalone third-party certificate.

For each configuration, the product team should establish the applicable legislation and essential requirements, select the conformity-assessment route and standards, and define the technical documentation and declarations required. The assessment also needs to address how later hardware or software changes could affect conformity.

IEC 62619, IEC 63056, and IEC 62933-5-2 provide important safety-evidence foundations for industrial cells, ESS batteries, and grid-integrated electrochemical storage systems. At project level, the assessment must also cover applicable power-electronics, EMC, transport, fire, installation, and national EN requirements.

Grid Compliance

Grid compliance and CE conformity are related but separate assessments. The PCS and PPC provide the primary grid-control functions; the battery system defines the available DC power and the duration for which it can be sustained.

At tender stage, the project team should establish the point of connection, voltage level, network characteristics, grid-code requirements, and model format. It should also allocate responsibility for model submission, certification, field testing, and final connection approval. Sunwoda should supply the necessary DC voltage, dynamic power, SOC, and fault-state inputs and participate in joint model and field validation.

Cybersecurity

Cybersecurity responsibilities need to be allocated between the operating entity and the product supplier. NIS2 sets requirements for covered entities, including those in the energy sector. The Cyber Resilience Act addresses the cybersecurity of products with digital elements over their lifecycle. Its applicability should be assessed for the BMS, gateways, remote-service platforms, and other connected components, taking account of the Act's scope.

The product architecture should include network segmentation, account and access control, certificates and keys, event logs, software-component inventories, vulnerability management, secure updates, backup, recovery, and rollback capability.

Remote service should use controlled access paths, encrypted communication, strong authentication, and traceable operations. Security updates must remain compatible with plant availability requirements and the validated system configuration.

ESG and Supply Chain

ESG and supply-chain evidence increasingly affect whether a project can secure financing. Carbon-footprint calculations depend on consistent data for materials, energy use, production sites, and methodology. Responsible sourcing requires traceability and supplier due diligence. Producer responsibility and recycling arrangements require clear ownership of obligations across market placement, cross-border logistics, operation, and end of life.

Manufacturing and regional supply options can improve resilience. The evidence submitted for a project must nevertheless match the actual delivery plant, trade route, importer, and contractual structure.

Sunwoda translates these compliance and resilience requirements into verifiable business practices through a robust ESG governance framework. The company holds an MSCI ESG Rating of AA, a Wind ESG Rating of AA, and a CDP Climate Rating of B, demonstrating strong environmental management and data transparency. In terms of strategic commitments, Sunwoda joined the United Nations Global Compact (UNGC) in 2021, submitted its Communication on Progress (COP) in 2022, and aims to be a UNGC LEAD corporate by 2030. In October 2023, Sunwoda signed the Science Based Targets initiative (SBTi) commitment, establishing science-based emission reduction targets.

Furthermore, as an Affiliate Member of the Responsible Business Alliance (RBA), Sunwoda has established a comprehensive internal CSR management system in accordance with the RBA Code of Conduct. These ESG achievements provide audit-ready data support for carbon-footprint calculations, responsible sourcing, and manufacturing traceability. This not only satisfies EU localization requirements for supply-chain due diligence but also ensures that the evidence submitted to project financiers precisely matches the actual delivery plant, trade route, and contractual structure—ultimately reducing non-technical project risks and enhancing bankability and lifecycle system value.

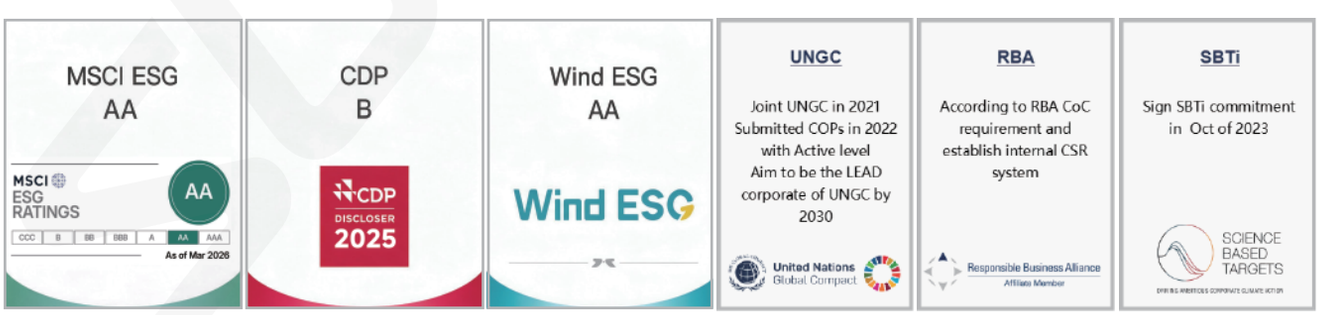


Table 6-1 — Platform-Level and Project-Level Allocation of European Compliance

Compliance Domain	Platform-Level Responsibility	Project-Level Delivery
EU Battery Regulation	Product identity, material and supply-chain data, carbon footprint, performance and battery-passport architecture	Import/market-placement entity, producer responsibility, recycling and lifecycle-data handover
CE and Product Regulation	Applicability assessment, risk assessment, testing, technical file, declaration and labelling	Confirmation of final configuration, installation conditions and national market requirements
Safety and Fire	Cell, pack and DC-system safety design and standard validation	Site spacing, fire system, permitting, emergency plan and authority coordination
Grid Compliance	DC operating boundaries, PCS integration, modelling inputs and joint validation	Network application, model submission, field testing and final connection
Cybersecurity	Security architecture, access control, vulnerability management, updates, logging and product documentation	Operator-level security measures, station network, user administration and incident coordination
ESG and Supply Chain	Carbon data, supplier due diligence, traceability and manufacturing/logistics evidence	Trade route, importer, financing review and end-of-life responsibility

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6.2 Compliance-by-Design Execution and Evidence Package

Compliance work should begin with product development and continue through each release. At platform initiation, the team should establish a process for tracking regulatory changes and make an initial applicability assessment. The subsequent development stages should address the following:

- **Requirements:** Convert applicable compliance requirements into design inputs.
- **Architecture:** Incorporate safety, EMC, cybersecurity, traceability, and lifecycle-data requirements.
- **Prototype development:** Complete pre-compliance testing and close the identified gaps.
- **Design release:** Freeze the official test samples and software versions before release.
- **Mass production:** Complete technical files, declarations, labels, and supplier evidence before production begins.

Project delivery adds the country-specific evidence for grid connection, fire safety, installation, permitting, and site acceptance.

A standard European evidence package should contain six categories:

- Product identity and configuration baseline.
- Regulatory applicability and conformity declarations.
- Cell, pack, and system safety and performance evidence.
- Battery Regulation, carbon-footprint, supply-chain, and recycling evidence.
- Cybersecurity architecture, access control, vulnerability management, and update mechanisms.
- System-interface, FAT/FIT, commissioning, and site-acceptance records.

Every document should identify the applicable model, hardware and software versions, production location, validity period, and its relationship to any document it supersedes.

Evidence also needs to be reviewed when the design or delivery configuration changes. This includes changes to cell materials, critical components, extinguishing media, cooling configuration, BMS algorithms, communication modules, remote platforms, production sites, PCS firmware, or EMS software. Each change should be assessed for its effects on performance, safety, CE conformity, grid compliance, cybersecurity, Battery Regulation obligations, and contractual guarantees.

During project execution, a frozen configuration list and formal deviation process should keep the installed system consistent with the configuration covered by the test and approval records.

CHAPTER 07

Project Value and Interim Conclusions

The project is where the choices discussed in Chapters 4–6 have to work together. Cell performance sets the energy and lifetime potential. Battery–PCS matching determines how much of that energy and power is accessible, while control coordination determines whether the plant can follow dispatch instructions and meet dynamic-response requirements. Thermal and safety design affect degradation and availability; AC architecture affects losses, equipment count, footprint and balance-of-plant cost. Compliance establishes the conditions for delivery, connection and operation, and provides evidence needed for financing.

These relationships are reflected in the conceptual value framework below. It brings the main influences together; it is not a project cash-flow calculation.

```
Lifecycle Project Value = Revenue × Availability × Dispatchability × Efficiency − CAPEX
                                  − OPEX − Risk Cost
```

For procurement, the practical test is whether the complete system can sustain the required performance over the project life at an acceptable level of technical and commercial risk. Integration testing helps resolve interface problems before commissioning. Early compliance work helps avoid redesign, approval delays and gaps in the evidence needed for acceptance.

7.1 From DC Product to Repeatable System Platform

Sunwoda ESS products provide the DC foundation for this approach, integrating cells, packs, BMS, thermal management and safety architecture within defined manufacturing configurations and DC performance limits. Qualified integration packages connect these products to PCS, EMS/PPC, MV equipment and plant communication systems, with regional requirements addressed in the project configuration.

The engineering work continues from the controlled DC platform through AC integration, project configuration and verified delivery. Delivery and operating records then provide the evidence needed to assess performance over time.

Projects will still differ in duration, grid requirements, PCS architecture, environmental conditions, layout, fire requirements, cybersecurity and commercial structure. A repeatable platform needs a clear way to accommodate those differences. Defining the fixed core, permitted configurations and verified interfaces allows teams to adapt a project without reopening the underlying cell, pack, BMS, thermal and safety design each time.

7.2 Four Dimensions of AC-System Value

The customer should be able to see the value of integration in four areas.

Integration Ecosystem

PCS, EMS/PPC, MV equipment and plant controls must work together under normal operation and during faults. Defined interfaces, communication tests, control-sequence checks, protection coordination and progressively more representative FAT/FIT testing establish whether they do.

Approved interface control documents (ICDs), signal lists, control logic, test procedures and configuration baselines can then be reused. A completed integration is most useful when its records make the next project easier to engineer and verify.

Beyond technical compatibility, the integration ecosystem also supports supply chain resilience. Sunwoda is advancing collaboration with local PCS and EMS providers in Europe, combining its battery technology with regional integration capabilities. As additional system configurations and partner interfaces are validated, this approach can broaden qualified supplier options, improve sourcing flexibility and help customers respond to potential geopolitical and regulatory changes affecting European supply chains.



Figure: Sunwoda battery system undergoing integration testing at a well-known European PCS manufacturer's facility.

Architecture Flexibility

The platform needs to accommodate different durations, power ratings, PCS topologies, environmental packages and plant layouts within defined configuration limits. This includes centralized and string PCS designs, two-hour and four-hour applications, and regional requirements.

Keeping the product and safety core stable makes that flexibility manageable. It allows broader application coverage while preserving the basis for repeatable engineering and validation.

System-Level Cost and Performance

System comparisons need a common boundary. Usable energy, AC efficiency and auxiliary consumption should be assessed alongside PCS and transformer configuration, cabling, civil works, footprint, maintenance access, augmentation and expected availability.

Higher DC energy density illustrates the trade-off. It can reduce container count, foundations, communication nodes and installation interfaces. The saving must still be checked against PCS configuration, current limits, thermal performance, transport constraints and the service strategy. The preferred architecture is the validated configuration that meets the required energy and power at the lowest lifecycle cost within the project's acceptable risk limits.

Delivery and Commissioning Risk

Communication mismatches, conflicting protection settings, software-version changes, incorrect settings and unclear control ownership can remain hidden until equipment is brought together. Incomplete fault-handling logic can be equally difficult to resolve on site.

The validation sequence provides opportunities to identify and resolve these issues at successive engineering and delivery stages: ICD → Design Review → FAT → FIT → SAT → Performance Verification. FIT is particularly useful for testing representative hardware and software under both normal and abnormal conditions before delivery. Reusable test procedures and commissioning sequences can reduce site troubleshooting, schedule uncertainty and disputes over interfaces on later projects.

7.3 From Technical Evidence to Bankability

Technical evidence supports bankability when it can be traced from the original performance claim to the equipment installed and operated. Cell tests, DC-system validation, AC-integration tests, project acceptance and field data each cover a different part of that record.

A cycle-life figure needs representative operating conditions. An availability commitment based on PCS compatibility needs a controlled equipment configuration and software baseline. An efficiency value used in a financial model needs a stated measurement boundary. Without those details, it is difficult to judge what the project can reasonably be expected to deliver.

Commercial commitments should follow the same discipline: identify the performance being guaranteed, the conditions under which it applies and the configuration that supports it. Configuration control and compliance records help keep that commitment consistent as equipment and software change.

Sunwoda retains control of the cell-to-container product core and its defined performance limits. Interfaces with PCS, EMS/PPC, MV equipment and other partners are managed through approved integration packages and joint validation. Project responsibilities should sit with the parties able to control and verify the relevant work, so that ownership remains clear without extending any party's commitments beyond its technical scope.

7.4 Closing Perspective

The Sunwoda ESS Platform brings cell technology, manufacturing, BMS, thermal management and safety design together within a common DC platform. Combined with qualified system integration, applicable compliance evidence and lifecycle support, this provides a repeatable foundation for European BESS projects.

> **For customers, the result should be easier to assess: a defined operating envelope, clear responsibilities, traceable performance evidence and a practical basis for long-term service. Those are the conditions under which a high-density DC product can become a repeatable European system platform and support lower project risk and stronger bankability.**

CHAPTER 08

Case Studies

From Technology to Value: European Project Case Studies

This chapter illustrates how the battery performance, system integration, compliance and lifecycle capabilities described above translate into customer value in real European and overseas projects. The three cases below are drawn from the Sunwoda case book (EN Case Book, slides 7, 13 and 14) and respectively address a large-scale utility BESS, a complex grid environment with local compliance, and long-term lifecycle operation.

Case 1 — Large-Scale Utility BESS: Sweden 152 MW / 152 MWh Grid Frequency Regulation Project

Item	Detail
Project size	152 MW / 152 MWh
Country	Sweden
Configuration	344 kWh liquid-cooled ESS
Grid requirement	Fast-response frequency regulation
System architecture	Multi-site deployment across Birsta, Stockholm and Starvo
Performance	Designed for fast frequency response; enhances grid stability
Availability / operation	Supports reliable operation of the local power network

This is one of Sunwoda's largest European utility-scale BESS deployments. With a total rating of 152 MW / 152 MWh built from standard 344 kWh liquid-cooled units across multiple Swedish sites (Birsta, Stockholm and Starvo), the system is designed for fast-response frequency regulation to strengthen grid stability and the reliable operation of the local network. It exemplifies the large-scale dimension discussed in Chapter 2: at gigawatt-scale deployment, standardised liquid-cooled units, system availability and fast response directly determine the revenue capability and grid value of the service.



Case 2 — Complex Grid Environment: Hungary 10 MW / 20 MWh Frequency Regulation Project

Item	Detail
Project size	10 MW / 20 MWh
Country / sites	Hungary (Soroksár / Győr)
Configuration	344 kWh liquid-cooled ESS
Grid requirement	Fast-response frequency regulation, aligned with Hungarian national grid code
System integration	Joint integration and validation of the DC battery system with local PCS / grid interfaces
Local compliance	Country-specific grid connection, fire-safety and permitting delivered at project level
Operation	Enhances grid stability and supports reliable local-network operation

Located in Soroksár and Győr, Hungary, this 10 MW / 20 MWh project again uses the 344 kWh liquid-cooled unit for fast-response frequency regulation. Hungary has its own national grid code, connection process and permitting regime; the case therefore realises the point made in Sections 1.5 and Chapter 6 — while the DC product core remains standardised, the platform is localised around the point of connection, voltage level, grid model and national fire/permitting requirements, and validated through joint model and field testing.

The same case book lists the related 2.5 MW / 5 MWh wind-farm + BESS project at Hepburn, Australia (5.015 MWh liquid-cooled unit), which stabilises wind-power integration and raises renewable utilisation. Its container exterior was turned into a vibrant mural by the artist Ghostpatrol, reflecting local nature, culture and community spirit — a reminder that BESS delivery also carries community and local-engagement dimensions.



Case 3 — Lifecycle Operation: Kanowna 5 MW / 11 MWh Solar-Storage Project, Australia

Item	Detail
Project size	5 MW / 11 MWh
Location	Kanowna, Australia
Application	Solar-farm (PV) storage
Configuration	2.752 MWh liquid-cooled ESS
Significance	Sunwoda's first overseas project using the 2.752 MWh liquid-cooled unit
Performance	Stabilises solar integration and improves overall renewable-energy utilisation

The Kanowna project pairs a solar farm with a 5 MW / 11 MWh battery using Sunwoda's 2.752 MWh liquid-cooled unit — the company's first overseas deployment of this unit — to stabilise PV integration and improve renewable utilisation. As one of the earlier overseas deployments, its long-term operating data can calibrate degradation, availability and auxiliary-consumption assumptions, and in turn validate the platform's long-term performance and warranty commitments — an illustration of the move from initial CAPEX competition to lifecycle operating value discussed in Chapters 2 and 7.



Conclusion:

Through real-world deployments across Europe and global key markets, Sunwoda demonstrates how vertical engineering depth coupled with localized horizontal execution unlocks dependable, bankable, and verifiable lifecycle system value.

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