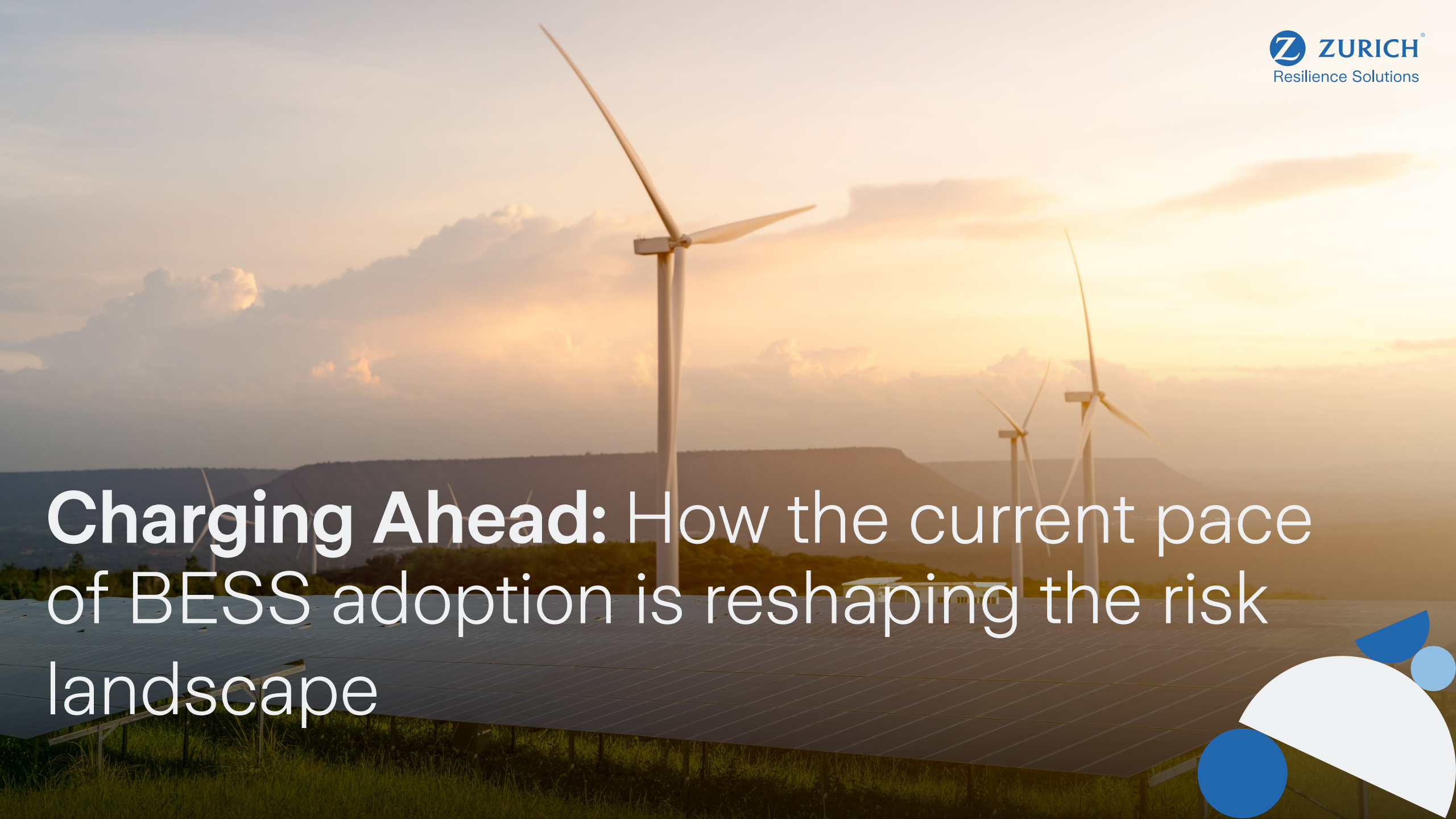


ZURICH
Resilience Solutions

Charging Ahead: How the current pace of BESS adoption is reshaping the risk landscape

ZURICH
Resilience Solutions

The path technology takes from early adoption to mainstream deployment is always a journey that embraces learning, development and of course, failure; the faster the deployment, the more intense the learning curve becomes. Here, our 'Charging Ahead', paper sets out how with Battery Energy Storage Systems (BESS), that journey has and is facing an evolving risk landscape, and goes on to demonstrate the evolving and interconnected profile of the risks. As with all complex risks, bespoke and risk resilient solutions are necessary to extract the optimum performance from the facility.

BESS Adoption

BESS, based on Lithium-ion technology, has experienced explosive growth globally and in Europe over the past five years, and projections indicate this trend will accelerate further still. Between 2018 and 2024/25 around 140 GW of installed capacity was added to grid systems globally, with 18% in Europe, 4% in the UK, 21% in the US and 57 % in China. A dramatic increase in number of systems, up from just a few hundred projects seven years ago.

Figure 1 compares approximate deployed BESS capacity by region[1]. The projections are indicative, with actual outcomes dependant on policy and market conditions. Nonetheless, all regions are expected to see multi-fold increases. By 2030, large-scale batteries will be a mainstream component of power grids in many countries globally.

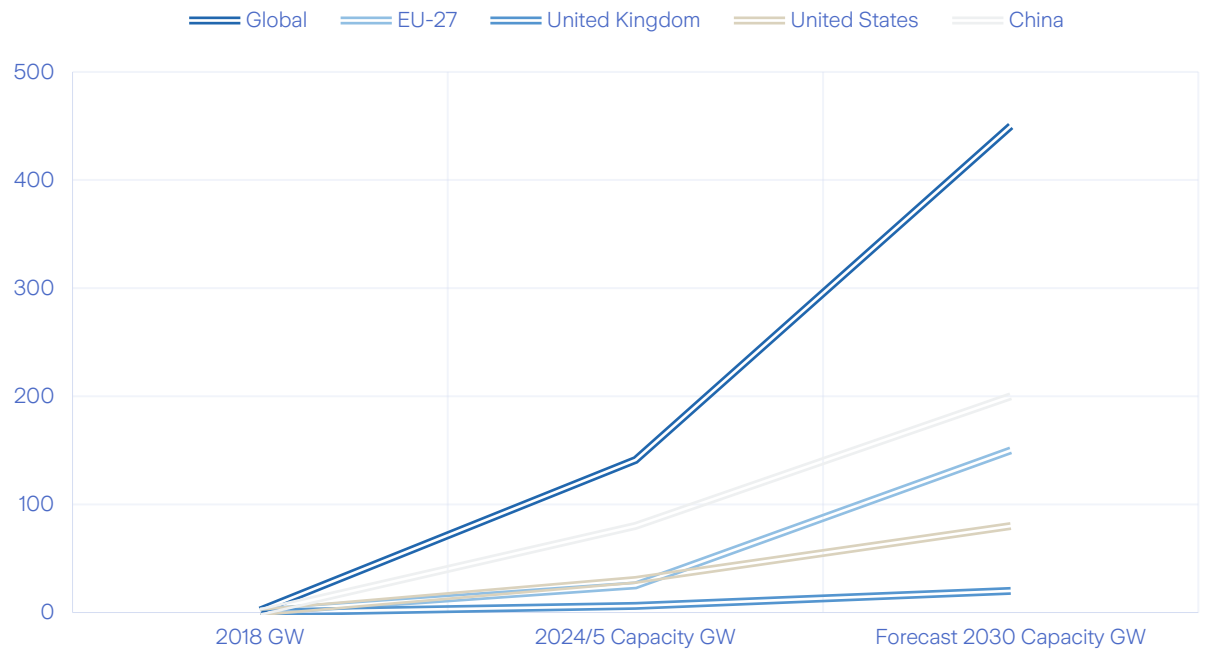


Figure 1: Illustration of estimated BESS deployment 2018 to 2030

[1] Global and China from CNESA/BNEF projections [1]; Europe from Solar Power Europe Medium Scenario [3]; UK extrapolated from pipeline data [4]; US based on EIA and industry roadmaps

As cost declines at a rate projected to be 50% lower by 2030 and the grid requirement for BESS increases in line with installed solar PV and wind, the sector is experiencing a demand that will be difficult to meet; that is without significant capital investment in, mining, manufacturing & integration facilities.

The pace of adoption is driving a learning curve within the ecosystem participants which in turn is generating a degree of standardisation in BESS manufacturing and integration. For example, in the megapack solutions where higher-volume outputs are being realised. Figure 2 illustrates the driving factors and their influence on the global rate of BESS deployment. What can be seen is how the cost point for MW installed capacity is on target to achieve a 50% reduction by 2030 since the early sales of 2018[1]. The grid requirement to support solar PV and wind technologies has increased and will continue to increase over the next 5 years as the global power sector aims to meet net zero commitments. There remains incentivisation in most countries to deploy BESS with capacity contracts being auctioned annually for 2, 4 and now 8 hr delivery periods. The coupling of increased demand for BESS and government lead incentivisation is contributing to a positive commercial environment, at the same time providing an opportunity for lower cost of capital with increased standardisation across the manufacturing and technology integration.

All these factors contribute to a virtuous cycle of greater adoption. In summary, the next five years should see BESS move from an opportunity technology to a mainstream power asset worldwide, with Europe and global totals growing several-fold. The 'rate of deployment challenge', has come at a cost, where loss events have occurred largely due to the learning and failure cycle in an unstandardised environment that lacks coherent regulation.

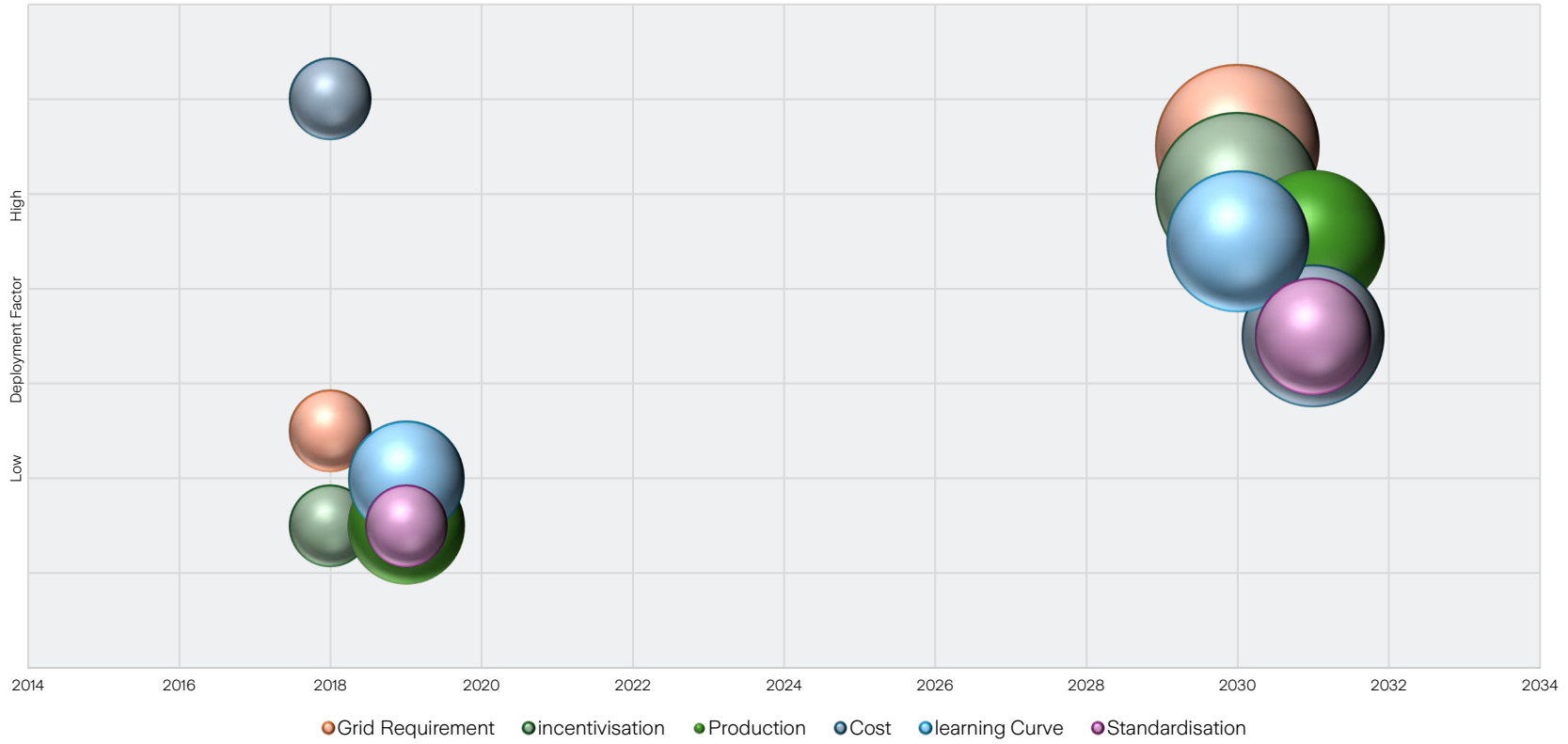


Figure 2: Deployment influence factors

Global and China from CNESA/BNEF projections [1]; Europe from Solar Power Europe Medium Scenario [3]; UK extrapolated from pipeline data [4]; US based on EIA and industry roadmaps

The Race for Regulation

Industrial bodies and regulators worldwide have been racing to establish rules and standards to keep pace with the adoption and deployment of BESS. It is fair to say that in the initial roll out legislation lagged behind technology, leading to several high-profile incidents that underscored the need for stronger safety and quality standards.

When regulation lags technology, significant risks emerge. The inherent delay in the development of standards and regulation resulted in a risk profile that was heavily biased towards fire safety due to the thermal runaway condition of a battery cell.

Lithium-ion BESS concentrates large amounts of stored energy, and without the proper safeguards in the initial phase of the roll out, significant failures occurred. The lack of formal safety codes meant systems were sometimes installed with minimal fire protection. South Korea's experience in 2018 is a stark example

Rapid BESS deployment outpaced safety oversight, and at least 23 storage facilities experienced fire events and loss during 2018 [6].

The lack of standards and regulation also impact the reliability of the BESS facility and lead to high levels of forced outage in the early period of BESS deployment. The manufacturing of the initial storage systems lacked automation, utilizing recycled laptop cells without robust assurance programmes. Research shows that many failures stemmed from integration and control errors with 65% of incidents were due to system operations/integration vs. only 11% due to battery cell defects [2].

These and other examples demonstrated the risk of "learning the hard way", without clear standards, even well-intentioned projects can lack critical safety features, with catastrophic results.

2018	2020	2020	2023	2025
UL 9540 (and UL 9540A) – Underwriters Laboratories standards from the US, now used globally. UL 9540 (first issued 2016) is a safety certification for entire ESS units	NFPA 855: Issued by the U.S. National Fire Protection Association, NFPA 855 (2020) was the first comprehensive fire/safety code for BESS installations[5].	IEC & EN Standards: The International Electrotechnical Commission has developed the IEC 62933 series specifically for grid energy storage systems, covering terminology, parameters, safety, and environmental aspects.	EU 2023/1542. imposes obligations on economic operators for the safety and sustainability of industrial batteries that BESS facilities rely upon.	Energy Storage Europe and research bodies have issued reports on BESS fire prevention and risk management[2].

Figure 3: Regulation and standards roll out

South Korea's experience in 2018 is a stark example: Rapid BESS deployment (spurred by subsidies) outpaced safety oversight, and at least 23 storage facilities caught fire that year[6].

A government investigation found no inherent battery defect – instead the fires were blamed on poor system integration, faulty protection circuits, and subpar installation practices[6]

The changing Risk landscape

Zurich Resilience Solutions understands how the risk landscape is shifting from the binary position of safe or unsafe to one that brings together a more complex set of risk factors.

Fire Safety

Fire safety and reliability have been the primary focus of standards and regulations, resulting in greater levels of performance and fire safety. Thermal runaway has been the primary causation of BESS fires, which has seen the industry grabble with understanding the root causes of thermal runaway and how to prevent its occurrence. The learning curve has seen the development of a series of electrical and mechanical test aimed at the demonstration of robust construction and mechanical resilient cells.

The risk of fire is largely understood as are the most appropriate detection and protection systems, with the inclusion of off-gas detection and automatic fire detection systems installed as standard. That said, the industry is still learning about the layers of protection necessary and the cost benefit from those layers. It is fair to say that the learning around container spacing & stacking, fire barriers, the optimum number of heat, smoke, & fire detectors will continue as the scale of BESS develops.

As we see a greater energy density per container and a requirement for more capacity on sites that have reduced land area, the fire safety discussion at the project level is far from concluded. Zurich Resilience Solutions expects to see more development of the existing standards and more sector harmonisation within the safety design solutions. Figure 4 illustrates the obligations on battery manufacturers for testing cells to demonstrate safety and fit for purpose design and final product conformity.

Our Technical Perspectives paper, 'Battery Energy Storage Systems (BESS)', clearly sets out the latest position on fire detection and protection systems and the need for layers of protection[7].

APS McMicken BESS explosion (Arizona, 2019). A 2 MW lithium battery system exploded while firefighters were responding, severely injuring multiple first responders[6].

Investigations later determined that a single module overheated into thermal runaway, and the buildup of flammable gas in the container led to a deflagration when the door was opened.

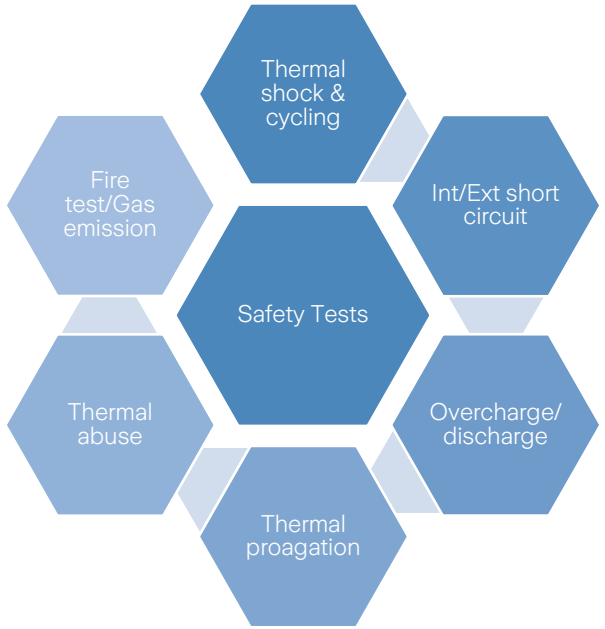


Figure 4: Safety testing as set out in EU 2023/1542

Regulation

Figure 3 above sets out the path to the current regulation, itself focused on battery safety, testing and grid integration, the collective then filling the risk-gaps that existing during the early adoption period. Low regulatory oversight can also result in environmental damage and health hazards, particularly if battery manufacturing and disposal aren't controlled. For instance, without legal recycling mandates, spent lithium batteries might be landfilled or processed unsafely, causing soil/water contamination.

Unclear legislation creates uncertainty that can slow down beneficial projects. Developers might face widely varying permitting requirements, or insurers might impose high premiums or refuse coverage if they perceive the risk as unmanaged.

The liability risks set out above is addressed by the creation of EU 2023/1542, setting out clear obligations for economic operators to ensure both safety and sustainability risks of batteries used within BESS projects are understood, documented and managed. The need to track batteries through their lifecycle, performing due-diligence activities, recording a carbon footprint and documenting any secondary life / re-use programmes is clearly obligated.

It is, however, unclear on how aware the Economic Operators are of their obligations and just how this far-reaching regulation is embedded into the BESS ecosystem. Whilst this regulation obligates for activities related to batteries landing within the EU, it is unclear how the global ecosystem is responding to this legislation either through modifying or aligning with the same obligations.

The risk to the BESS ecosystem is such that a position of non-compliance may exist due to the lack of awareness or the lack of a system that supports the delivery of all activities required of them. There is a need for each member of the ecosystem to manage a dataset that remains with the battery through each stage of its lifecycle and that required a joined-up approach to successful compliance.

Artificial Intelligence

As members of the ecosystem adopt artificial intelligence (AI) risks introducing increased risks of failure if the reliance on the solutions it provides is not supported by suitable and sufficient testing, validation and control. AI-driven automation must undergo thorough testing to ensure operational safety and prevent manufacturing defects. The use of AI is regulated to some degree through the EU AI Act, which attempts to ensure the use of AI remains ethical. It is fair to suggest that AI adoption increases cybersecurity risks, requiring strong defences against data breaches and intellectual property theft.

Of course, AI solutioning does not just apply to the battery cell manufacturing space. The integration of technologies to create a modular BESS container solution will also face the application of AI. Optimisation of sub-system designs for example water cooling, HVAC, cabling layout and battery management system designs (and operation) will all need to comply with regulation and best practice; which is still maturing and is not providing a standardisation approach.

So, the risk of early AI adoption in the value chain of BESS stands with the increased failures, potentially due to a disconnect within the quality control and assurance processes and the lack of maturity AI integration has. The drive for optimisation and increased production through AI will need to be heavily controlled within the ecosystem stakeholder businesses. The lack of industry standard AI-adoption controls effectively puts the BESS industry at risk of utilising non-standard products and methodologies; this presents a challenge for the procurement process that seeks to compare like for like and for the safety and sustainability through the BESS lifecycle.

Supply chain

The supply chain risk has the potential to significantly interrupt the intended and required deployment of BESS facilities.

Critical mineral shortages of lithium, cobalt and nickel is likely to restrict production as demand is expected to increase by up to 20 times by 2040.

In 2023, China's battery manufacturing capacity exceeded global demand, leading to oversupply and intense price competition. While this benefited developers with lower procurement costs, it created financial strain for manufacturers and raised concerns about market sustainability and geopolitical dependencies.

To mitigate supply chain risks U.S. developers are adopting augmentation and overbuild strategies to maintain performance. This involves adding new components periodically or initially oversizing systems. Whilst this approach can contribute to mitigation supply chain risks it requires accurate forecasting and flexible procurement models.

A 2024 report by the UK Manufacturing Technology Centre (MTC) revealed significant supply chain vulnerabilities, including heavy reliance on imported components and critical minerals.

The UK government responded by launching initiatives to build domestic manufacturing capacity and secure bilateral agreements for raw material sourcing.

Climate Change

Physical climate risks, in the form of extreme weather events, are increasing in frequency and severity. These pose material risk to all forms of energy generation, but renewable generation and storage assets are particularly vulnerable to climate perils such as strong winds, flood, hail and drought. While recent extreme weather events, such as Storm Darragh in 2024, or the European Floods of 2021, have highlighted the risks posed to energy infrastructure, for the most part these physical climate risks remain under-assessed and under-addressed.

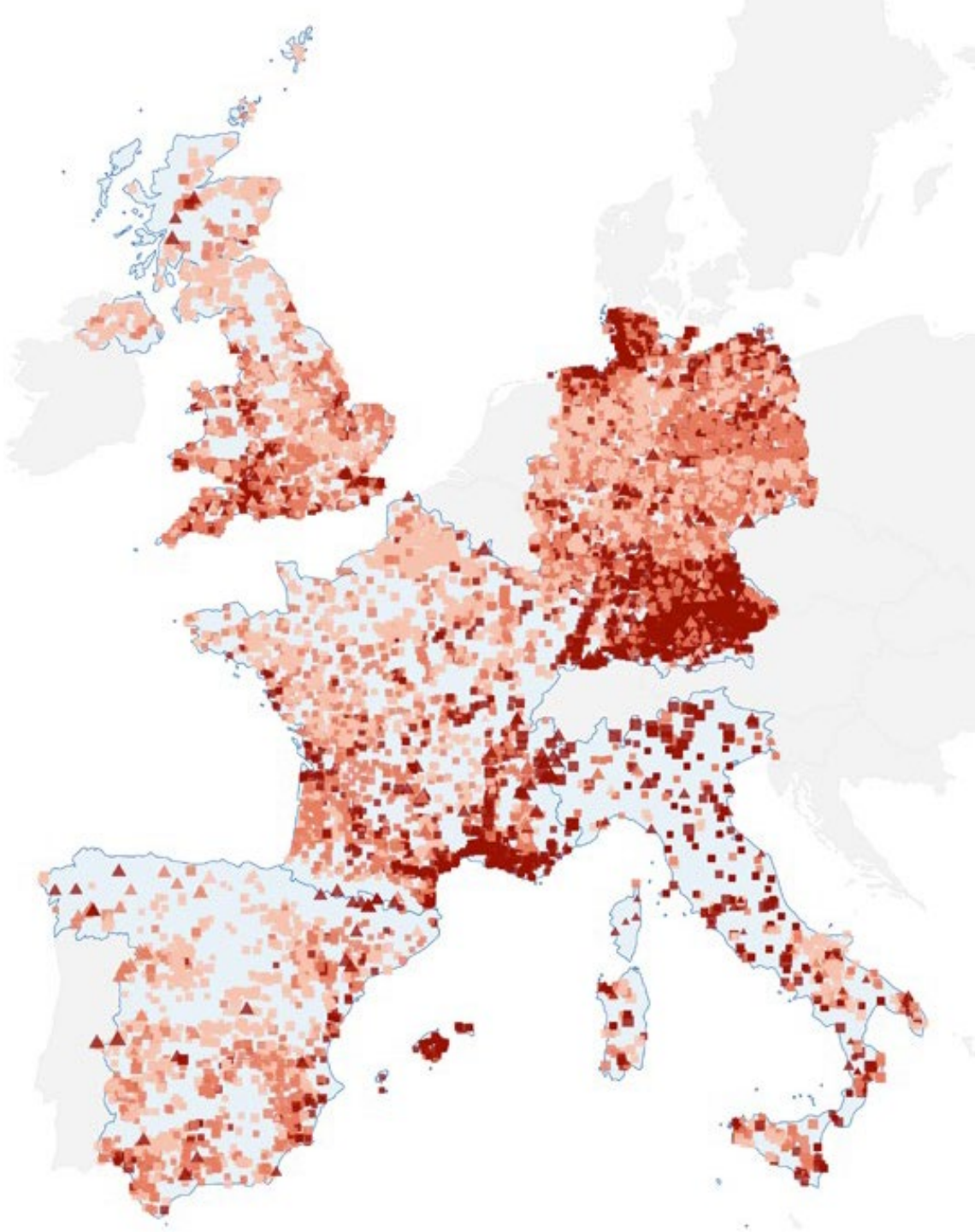
In Europe, average annual losses from weather and climate-related events have climbed from EUR 8.5 billion in the 1980s to EUR 16 billion in the 2000s, and approximately EUR 45 billion in the 2020s – a clear sign of rising financial exposure. These figures were calculated by the European Environment Agency, based on recorded estimates of economic losses from extreme weather events. [8]

Our analysis highlights that across Europe, physical climate risks are already posing a threat across all energy assets. However, it is clear from our analysis that renewable generation and storage assets are relatively more exposed to physical climate risks compared to conventional fossil-fuel assets. By 2030, nearly half (46 percent) of the total renewable generation capacity will fall into our critical-risk category, of which well over half (58 percent) are solar assets.

By 2030 7% of installed BESS systems in the UK will be located at locations in the top two risk categories indicating that they are exposed to greater than 45 % change of experiencing a climate event before 2030. [8]

BESS is particularly vulnerable to flooding, storm surge, tornado and heatwave. As climate patterns change, the information we use to develop BESS facilities needs to consider the potential and predicted exposures to and impacts from new normal events.

It is critical that organisations are ready to adapt to the impacts of climate change and have embedded sufficient capacity within the strategy and planning, management system and financial modelling. Harnessing appropriate levels of adaptive capacity within an organisation will directly support effective responses to events and will drive sound decision making during asset development, construction and O&M phases of the lifecycle.



ZURICH
Resilience Solutions

Cyber Risk

An emerging risk from minimal regulation is cybersecurity in BESS. Historically, industrial control systems, including those for batteries, have not been subject to the same cybersecurity requirements as IT systems. Most BESS control systems lack authentication and cyber protections[9]. This means a malicious actor (or even a virus) could potentially interfere with battery management settings. Table 1 sets out the Zurich Resilience Solutions' Principal cyber risks factors.

Focus	Risk
Operational Tech	BMS & ICS could lack strong authentication and encryption. It is possible effect thermal runaway through manipulation of the sub-systems, such as cooling sensor signals, charging limits
IT/OT	Remote monitoring necessitating the uncontrolled integration of OT and IT
Remote Access	Poor access criteria will allow unauthorised access Weak VPN security will provide access for an attacker
Firmware	Potential for access through alternative / non-traditional access ways, such as design alternative entry points not declared by the manufacturer.
Property Damage	Cyber attacks are likely to result in physical damage or event total loss of a BESS either through modification to charge and discharge rates leading to overheating and fire.

Controls adopted within industry and developed through industrial cyber events can prevent unwanted access by an attacker. Segmenting the network to isolate IT and OT and creating multifactor authentication for remote access are fundamental first steps. We know that as controls are introduced, attackers evaluate and test methods to break them or circumvent their protection. The industry will need to continue to employ and evolve cyber security controls.

ZURICH
Resilience Solutions

Mergers and Acquisitions (MA) risk

It is a given that BESS facilities are a technical solution to store and deliver energy, provide grid services, and to build grid resilience with the growth of deployed renewable assets. However, for some within the ecosystem they quite simply provide an opportunity to increase wealth through either energy transactions / trades or the buying and selling of the facilities at different phases of the asset's lifecycle. When a countries deployment of BESS is saturated, prices fall, capacity mechanism opportunity is no longer an option and balance sheets can be challenged. The buying and selling of BESS facilities is to be expected; it forms part of a typical lifecycle.

During periods of commercial pressure, O&M strategies and plans are often revised to suit resulting in modified OPEX and CAPEX decisions. Any reduction in staffing, predictive or planned maintenance will reduce the efficacy of those programs; Lower O&M effort results in a decreased awareness of asset health and is likely to have an impact of the risk profile. Similarly, decisions to work the assets harder, extending lifecycles, reducing the redundancy due to capex challenges will also place the facility at a greater risk of failure.

In some cases, the land is sold separate from the BES facility, introducing additional risk considerations such as liability, loss of risk information and increased charges for access to the BESS or for it to remain on the land. It is critical that all of these factors are monitored and re-assessed through the life of the asset.

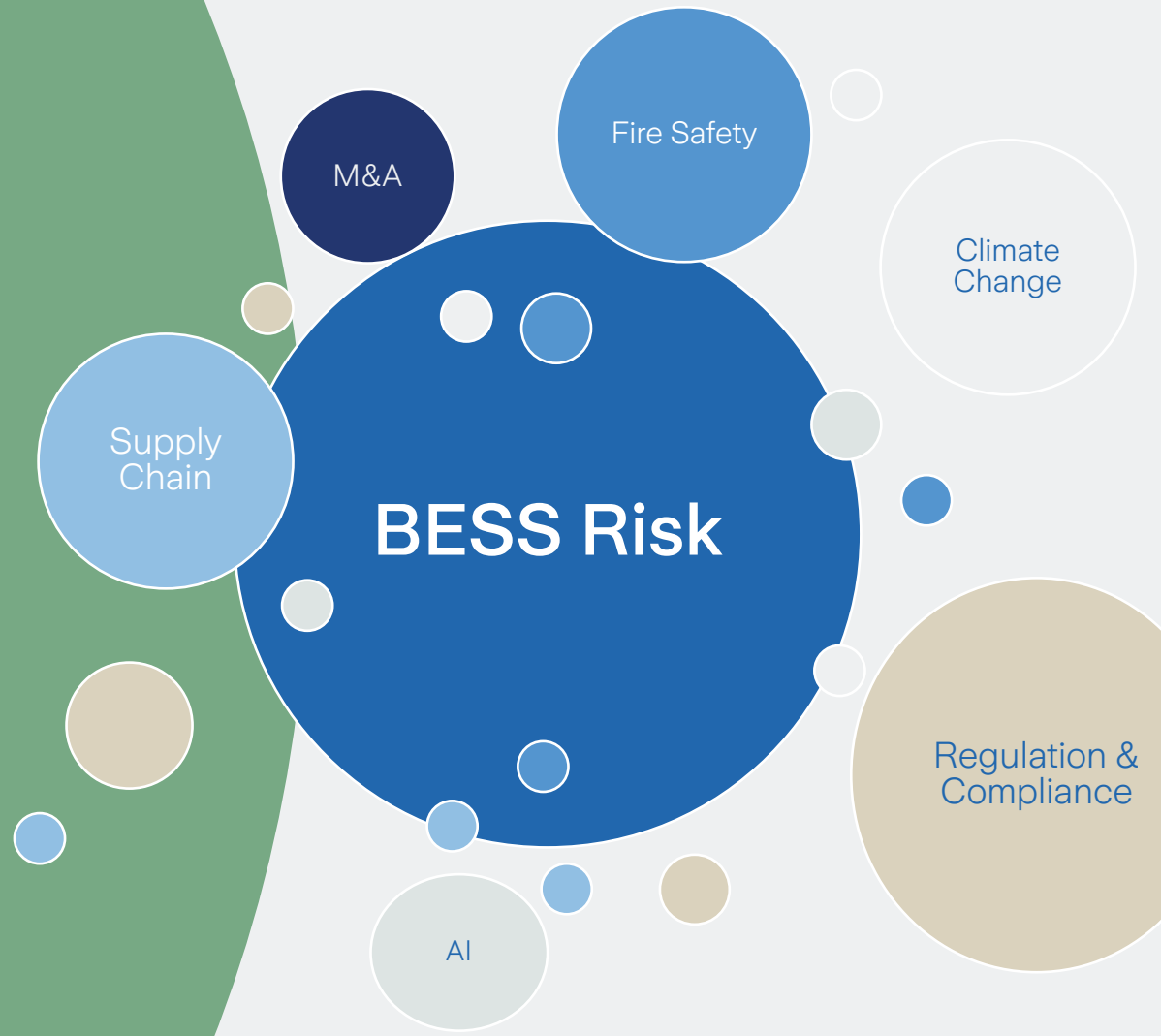
Risk integration

As the requirements from fire safety, climate change, supply chain, artificial intelligence and regulatory risks emerge so does the evolving complex and interconnected risk landscape. There is a need to fully understand, for example, just how climate risks can impact on the safety of the BESS and likewise how the unregulated adoption of AI through the ecosystem can impact on the safety or sustainability performance of BESS components.

Fire safety has for some time now related to the impact on the environment and how contaminated run-off water can, if uncontrolled, result in an environment impact event, itself requiring significant mitigation and cleanup.

Identifying hazards, exposures and risks is essential to be capable of managing the risks but it is essential to map out the relationship between those factors and how the behaviour of a single element can carry through to a related risk. The mitigation and controls are likely to be more sophisticated and with clear line-of-sight between hazards and risks.

Zurich Resilience Solutions understands the breath of interconnectivity and are supporting the ecosystem with guidance of how to develop risk and compliance strategies, not only capable of meeting obligations but also supporting the communication and competency requirements.



ZURICH
Resilience Solutions

Recommendations

[1] Global Installed Energy Storage Capacity Exploded in 2022, and is ...
[2] Energy Storage Evaluation Tool (ESET) - PNNL
[3] European Market Outlook for Battery Storage 2025-2029
[4] UK reaches 6GW/8GWh of operational grid-scale BESS
[5] Tesla's Shanghai Megapack Gigafactory Hits Over 95% Local Content
[6] Safeguarding Our Energy Future: Protecting Europe's Energy Infrastructure Against Climate Risk
[7] Zurich Resilience Solution BESS Technical Paper 2025
[8] Zurich Resilience Solution Safeguarding our energy future 2025
[9] Cyber-vulnerable battery systems are catching fire and communicate

© Zurich