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**Strategic sourcing in battery energy storage system
(BESS) supply chains under trade and regulatory
uncertainty**

A Case Study

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ABSTRACT:

The rising demand for electricity and the expansion of renewable energy integration has increased the need for flexibility in power systems. Utility-scale battery energy storage systems (BESS) are being deployed on an ever-larger scale and their continuous need in the future has intensified competition. To be able to stay competitive, BESS system integrators now need to focus on supply chain resilience which is a challenge to tackle due to several reasons. Battery supply chain options are being limited as battery cell production remains concentrated geographically. Tariff escalations and region-specific regulations have introduced uncertainty into global BESS supply chains. As projects are growing in size and capital intensity, sourcing decisions have become even more financially significant at the project level. This forms the core research question of this thesis: How do alternative sourcing configurations for battery suppliers and contract manufacturers affect total landed cost and sourcing feasibility in utility-scale BESS projects under trade and regulatory uncertainty?

This thesis builds on literature on the BESS industry and strategic sourcing under policy uncertainty. It reviews system architecture and battery technology in utility-scale applications and considers recent market development. It then examines supply chain structures in the sector, focusing on contract manufacturing models and the concentration of battery cell production. Research on supplier relationship management and supplier portfolios is used to analyze the linkage between supply chain types and how they tend to survive disruptive events. Regulatory and grid participation requirements in the United States, the European Union and Australia are also examined together with research on tariff effects on cost and sourcing risk. The thesis was conducted as a case study in collaboration with a company operating in the energy industry.

The empirical analysis was based on a U.S. utility-scale reference project and evaluated five alternative sourcing scenarios using a total landed cost (TLC) model developed with data provided by the case company. The findings shows that tariff escalation during 2025 significantly altered the cost ranking of sourcing alternatives within the U.S. policy environment. Import-oriented supply configurations were competitive under moderate tariffs but lost their position when duties intensified. U.S. domestic sourcing strategies gained relevance through eligibility for IRA incentives. Building on the U.S. cost comparison, four supply options were examined across the United States, the European Union and Australia to assess regulatory alignment and practical feasibility. The results are consistent with prior scientific literature and confirm the vital role of strategic sourcing and supplier portfolio management in sustaining business competitiveness even when faced with unstable trade policy circumstances.

KEYWORDS: battery energy storage systems (BESS), lithium-ion batteries, sourcing strategy, supply chain resilience, global supply disruptions, contract manufacturing

VAASAN YLIOPISTO**Tekniikan ja innovaatiojohtamisen akateeminen yksikkö**

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TIIVISTELMÄ:

Sähkön kysynnän kasvu sekä uusiutuvan energian osuuden lisääntyminen edellyttävät sähkön tuotanto- ja jakelujärjestelmien joustotarvetta. Akkuenergiavarastoja (BESS) otetaan käyttöön yhä laajemmassa mittakaavassa ja markkinan ennakoitu kasvu on kiristänyt kilpailua. Kilpailukyvyyn säilyttämiseksi energiavarastoja tarjoavien yritysten on panostettava toimitusketjujen tehokkuuteen ja resilienssiin. Akkutoimitusketjujen vaihtoehdot ovat rajallisia, koska akkukennojen tuotanto on maantieteellisesti keskittynyttä, minkä lisäksi tullien kiristyminen ja aluekohtaiset sääntelyvaatimukset ovat luoneet epävarmuutta BESS-toimitusketjuihin. Niin ikään kasvavat projekti koot ja alan korkea pääomaintensiteetti tekevät hankintapäätöksistä taloudellisesti entistä merkittävämpiä. Tähän perustuu diplomityön keskeisin tutkimuskysymys: Miten erilaiset akkutoimittajien ja sopimusvalmistajien hankintakokoonpanot vaikuttavat kokonaiskustannuksiin ja hankinnan toteutettavuuteen suurissa BESS-hankkeissa, kun kauppa- ja sääntelyolosuhteet vaihtelevat?

Diplomityö pohjautuu energiavarastosektoria ja strategista hankintaa käsittelevään kirjallisuuteen. Siinä tarkastellaan BESS-järjestelmien rakennetta ja akkuteknologioita sekä markkinan viimeaikaista kehitystä. Lisäksi työ rajautuu tarkastelemaan toimitusketjurakenteita erityisesti sopimusvalmistajien ja akkutoimittajien roolin näkökulmasta. Taustalla hyödynnetään tutkimusta toimittajasuhteiden hallinnasta ja toimittajaportfolioista sekä huomioidaan kauppapolitiikan ja kannustimien vaikutus projektien kannattavuuteen. Diplomityössä pureudutaan myös Yhdysvaltojen, Euroopan unionin ja Australian aluekohtaiseen sääntelyyn ja sähköverkkomarkkinoille osallistumisen vaatimukseen. Diplomityö toteutettiin tapaustutkimuksena yhteistyössä energiateollisuudessa toimivan yrityksen kanssa.

Empiirinen analyysi perustui tapaustutkimukseen referenssihankkeesta Yhdysvalloissa, johon kehitettiin skenaariopohjainen kokonaistoimituskustannusmalli (TLC) case-yrityksen dataa hyödyntäen. Vertailussa oli viisi vaihtoehtoista toimitusketjuskenaariota, joista kukin edusti realistista yhdistelmää komponenttitoimittajista ja tuotantomallista. Analyysin tulokset osoittivat, että tullien kiristyminen vuonna 2025 johti nopeasti eri hankintavaihtoehtojen kannattavuuden heilahteluun Yhdysvaltojen markkinalla. Tuontipainotteiset toimitusketjut olivat kilpailukykyisiä maltillisilla tulleilla, mutta kannattavuus laski merkittävästi tullien noustessa. Yhdysvaltojen kotimaisen hankintastrategian kannattavuus vahvistui valtion IRA-kannustinkelpoisuuden myötä. Lopuksi neljää hankintavaihtoehtoa tarkastellaan Yhdysvalloissa, Euroopassa ja Australiassa käytännön toteutettavuuden näkökulmasta. Tulokset tukevat aiempaa tutkimuskirjallisuutta ja korostavat strategisen hankinnan sekä toimittajaportfolion suunnittelun merkitystä kilpailukyvyyn säilyttämisessä epävakaisissa kauppapoliittisissa olosuhteissa.

AVAINSANAT: akkuenergiavarastot (BESS), litiumioniakut, hankintastrategia, toimitusketjun resilienssi, globaalit toimitusketjuhäiriöt, sopimusvalmistus

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Abbreviations

BESS	Battery energy storage system
CM	Contract manufacturer
PCS	Power conversion system
BMS	Battery management system
EMS	Energy management system
SCADA	Supervisory control and data acquisition
TLC	Total landed cost
IRA	Inflation reduction act
FEOC	Foreign entity of concern
LFP	Lithium iron phosphate
NMC	Nickel manganese cobalt
SoC	State of charge
SoH	State of health
MWh	Megawatt-hour
kWh	Kilowatt-hour
GWh	Gigawatt-hour
O&M	Operations and maintenance
OEM	Original equipment manufacturer
CAGR	Compound annual growth rate
COO	Country of origin
RES	Renewable energy sources

1 Introduction

Global electricity demand is about to grow with pace of around 3.5 percent per year for the rest of this decade as per (IEA, 2026) which is a notable acceleration compared to recent years. Battery Energy Storage Systems (BESS) now have a critical role as power systems incorporate larger volumes of variable renewable generation (EASE, 2022; Wood Mackenzie, 2025). BESS store excess electricity, support grid services such as frequency control and energy arbitrage, thus enable higher integration of intermittent renewable generation, including wind and solar (Zhao et al., 2023).

Earlier considered as niche and costly systems, BESS has now raised more interest due to broader electrification trends and continued public policy support, as well as ongoing improvements in battery chemistry and system control software (Sheth et al., 2025). BloombergNEF forecasts CAGR of 14.7 percent for global energy storage capacity through 2035, with annual additions reaching 220 GW and 972 GWh (Nsitem & Sekine, 2025). Wood Mackenzie (2025) estimates that cumulative BESS investment of approximately USD 1.2 trillion will be required by 2034 to enable large-scale renewable buildout.

Strategic sourcing of BESS components has proved challenging since the supply chains are geographically concentrated and competition among top-tier component suppliers keeps intensifying. China accounted for close to 85 percent of global battery cell manufacturing capacity in 2024 with a central role in cathode and anode material production and in the processing of several critical minerals (IEA, 2024). Greitemeier et al. (2025) raises concern about how this concentration is reflected in firm-level competition and whether individual regions succeed in securing their share of supply chain value through domestic companies. Especially the concentration of lithium-ion battery production narrows the range of technically and commercially viable supplier options and limits the options outside Asia.

Recent tariff uncertainty complicate sourcing decisions in the sector and forces BESS companies to strategically align their approach to it. Tariff crises act as macroeconomic shocks that disrupt supply chains which can lead to ripple and bullwhip effects, and have

widespread repercussions on the economy (Ivanov, 2025). Grossman et al. (2024) point out that the recent U.S. tariff increase has already triggered a need for broader reconfiguration of global supply networks, while some firms choose the “wait and see” tactic before making such decisions. These effects are relevant for BESS industry in which multi-tier supply steps require qualification processes and capital investments that limit short-term adjustment possibilities.

Local content rules with related incentive and compliance obligations vary between the regions which makes the multi-market offering challenging for BESS integrators. These differences complicate the ability to operate with a uniform supply network across markets. Sourcing strategy must therefore balance cost considerations with regulatory compatibility and the capacity to adapt when policy frameworks evolve.

1.1 Background and motivation

The motivation for this thesis arises from both practical and academic needs to better understand how sourcing strategies in the BESS sector can be designed under evolving trade and policy constraints. The research topic was defined in collaboration with the case company which operates globally in the energy technology industry.

BESS production relies on complex and globally distributed supply networks, and the business models and capabilities of BESS integrators (BESS providers) vary widely. Some companies manufacture part of the system internally while sourcing other components from suppliers. Others perform most production in-house. In contrast, some firms rely largely on external partners and outsource production to contract manufacturers. Weaver et al. (2024) gives an example that an U.S. integrator can rely on global supply chains for key components while reducing security and dependency risks by retaining control over critical system integration and software domestically. This kind of fragmentation creates stronger dependencies between different supply tiers and regions. As these networks grow more intricate, the ability to manage supplier portfolios becomes a key driver of operational performance.

Another noticeable topic is to understand what kind of impact trade disruptions have to global supply chains. Tariffs changes can force firms to restructure the supply chain by changing or by reassessing their target markets or production to less affected location (Ivanov, 2025). Zhang et al. (2025) point out that probability of being disrupted is higher for big companies that manage a large number and wide variety of suppliers. This is clearly a challenge in capital-intensive BESS sector where switching suppliers takes a lot of effort and time.

Regulatory environments also amplify sourcing complexity, like in the United States, where tariffs on imported batteries and China-origin components influence both project costs and access to federal incentives tied to domestic content and FEOC restrictions (Weaver et al., 2024). Battery supplier eligibility in the EU depends on meeting due diligence qualification for product conformity and sustainability reporting as well as demonstrating adequate supply-chain transparency according to the Batteries Regulation (EU) 2023/1542 (Cordingley, 2025). Digital battery passports will introduce an additional requirement that increases expectations for traceability and lifecycle documentation in European markets (Júnior et al., 2024; Tahir et al., 2025). Australian BESS market access is guided by technical performance and grid-integration rules alongside broader obligations for governance and infrastructure security that apply to large-scale storage projects (AEMO, 2019; Dentons, 2025). Among other things, the above-mentioned specifications determine which suppliers are eligible to participate.

The total cost of ownership (TCO) models used in many prior studies often assume a stable market environment, but in the BESS sector this assumption no longer holds. This creates a research gap, which this thesis addresses by developing a conceptual framework that links sourcing decisions to trade policy and cost impacts. The analysis first utilizes case company data in a scenario-based total landed cost (TLC) comparison to explore the viability of alternative supply options under changing tariff setting. Subsequently, possible supply strategies for BESS project deliveries are discussed.

1.2 Research objectives and questions

This thesis focuses on battery suppliers and contract manufacturers within the BESS supply chain, because they account for a large share of total system costs thus are exposed to trade related risks. The aim is to examine how sourcing configurations can be designed across different markets in the time of uncertainty and to provide options for supply strategies. Sourcing configuration in this thesis refers to the structural arrangement of battery suppliers and contract manufacturing partners selected to deliver a BESS project, considering the geographic distribution of production stages and their linkage to the end market.

The main research question guiding this thesis is:

How do alternative sourcing configurations for battery suppliers and contract manufacturers affect total landed cost and sourcing feasibility in utility-scale BESS projects under trade and regulatory uncertainty?

To answer this question, the study sets the following objectives:

Objective 1: Identify the main trade and regulatory factors that constrain BESS sourcing.

Objective 2: Examine how US, EU, and Australian regulations affect sourcing feasibility and project eligibility.

Objective 3: Develop a sourcing framework that supports decision-making under trade and regulatory uncertainty.

Objective 4: Compare how alternative sourcing configurations influence total landed cost and tariff exposure in the U.S. market under 2025 tariff conditions.

1.3 Definitions and scope of the study

This section defines the key concepts used in the thesis and specifies the scope within which they are applied. Clear definitions are required to ensure conceptual consistency, as terminology related to energy storage and supply chain management varies across disciplines and industry contexts. Each concept is first described and then contextualized to clarify how it is interpreted and bounded within this study.

Battery Energy Storage Systems (BESS)

Battery Energy Storage Systems are electrochemical systems that store electrical energy for later use and provide flexibility to power systems by balancing supply and demand (Chatzigeorgiou et al., 2024; Zhao et al., 2023). BESS are commonly used for grid services such as frequency regulation, voltage control, peak shaving, and energy arbitrage, especially in power systems with high shares of variable renewable energy (Guzman et al., 2022; Vučić, 2025).

Scope of this study.

This thesis focuses exclusively on grid-scale BESS applications. Residential and behind-the-meter storage systems are excluded. Other energy storage technologies, such as pumped hydro, thermal storage, or flywheels, are not analyzed.

Lithium-ion batteries

Lithium-ion batteries are rechargeable electrochemical energy storage devices characterized by high energy density, relatively long cycle life and enhanced safety (IEA, 2024). They currently dominate grid-scale energy storage markets due to their technological maturity and declining costs (Chatzigeorgiou et al., 2024).

Scope of this study.

The analysis is limited to lithium-ion battery technology used in grid-scale BESS. Emerging battery chemistries, such as sodium-ion or solid-state batteries, are outside the scope unless mentioned as part of broader industry trends. The study does not compare alternative battery chemistries in terms of performance or sustainability.

Sourcing strategy

Sourcing strategy refers to the carefully planned approach through which firms design and governs their supplier relationships to achieve both cost efficiency and strategic objectives (Monczka, 2009; Trent, 2007). It includes how companies choose suppliers, build those relationships, and decide where and in what proportions to source their materials (Kraljic, 1983; Ribas et al., 2021).

Scope of this study.

In this thesis, sourcing strategy is defined narrowly as the configuration of supplier networks for battery suppliers and contract manufacturers within the BESS supply. Broader procurement activities, such as logistics execution, supplier auditing, or transactional purchasing processes, are not examined.

Supply chain resilience

Supply chain resilience describes the ability of a firm to adapt to and recover their supply network from disruptions while maintaining core operational performance (Christopher & Peck, 2004). Resilience is linked to sourcing that balance efficiency with flexibility under uncertainty (Aguilar-Hernandez et al., 2023; Garcia, 2025).

Scope of this study.

Resilience is examined through a strategic sourcing lens, and the thesis investigates how the composition of a company's supplier base affects its vulnerability to disruptions caused by tariffs. Operational resilience measures like inventory buffers are outside the scope.

Global supply disruptions

Global supply disruptions are events that interrupt the normal flow of goods or services across international supply chains (Aguilar-Hernandez et al., 2023; Zhang et al., 2025). Such disruptions may arise from natural disasters, major strikes, trade litigation or geopolitical conflicts (Dumont & Varela-Irimia, 2024).

Scope of this study.

This thesis concentrates on tariffs and localization concerns that affect sourcing. Short-term disruptions, such as natural disasters or pandemic-related logistics bottlenecks, are not considered.

Contract manufacturing

Contract manufacturing (CM) refers to an arrangement in which a firm outsources defined production activities to an external partner while retaining control over the product's design and performance specifications (Han et al., 2012; Wu et al., 2023).

Scope of this study.

Contract manufacturing is examined from the perspective of sourcing option in BESS supply chains. The study considers how the use and location of contract manufacturers influence supply network configuration and cost. Operational aspects of manufacturing execution, quality management, or logistics coordination between integrators and contract manufacturers are outside the scope.

1.4 Structure of the thesis

This thesis is structured into five chapters. Chapter 1 introduces the research topic and outlines the background and motivation. It presents the research question and objectives, defines key concepts, and sets the scope.

Chapter 2 provides the literature review. It introduces utility-scale BESS and summarizes the technical foundations relevant for sourcing, encompassing system architecture and key subsystems. The chapter then examines sourcing and supply chain dynamics in the BESS industry, focusing on battery suppliers and contract manufacturing. It reviews strategic sourcing theory and supplier portfolio design and discusses how trade policy and regulatory conditions influence sourcing feasibility in the United States, the European Union and Australia. The chapter concludes by synthesizing these insights into the conceptual framework guiding the empirical analysis.

Chapter 3 describes the research methodology. It explains the embedded single-case design and case context, outlines the data sources and confidentiality approach, and presents the analytical methods applied. These cover the formation of feasible sourcing configurations and a scenario-based total landed cost model for a U.S. reference project. The chapter also addresses validity and ethical considerations of the analysis.

Chapter 4 presents the empirical results and analysis. It examines the temporal evolution of trade measures in 2025, compares alternative sourcing configurations using the total landed cost model for the U.S. case project, and extends the analysis through a cross-market comparison across the United States, the European Union and Australia. The chapter concludes with a synthesis of the findings.

Chapter 5 concludes the thesis by summarizing the main findings and contributions, discussing managerial implications and research limitations, and outlining directions for future research.

2 Literature review

This chapter reviews academic and industry literature relevant to sourcing strategy development in the energy storage sector. Its purpose is to build a theoretical and contextual foundation for understanding sourcing decisions amid technological complexity and global supply chain disruption.

2.1 Overview of battery energy storage systems

Battery energy storage systems (BESS) store electrical energy for later use and are capable of various power system applications, covering frequency regulation, black start, voltage support and renewable energy integration (Njema et al., 2024; Zhao et al., 2023). Frequency regulation (FR) is a critical ancillary service that maintains balance between electricity supply and demand by keeping the grid frequency stable, typically at 50 Hz in Europe (Chatzigeorgiou et al., 2024). Their sub-second response capability allows rapid correction of generation-load deviations, which makes them highly effective for grid stabilization (Guzman et al., 2022).

In addition to fast-response applications, BESS contribute to broader energy-management needs. Revenue streams can be made by energy arbitrage, which involves charging during low-price periods and discharging when prices rise (Garttan et al., 2025). In energy shifting applications, storage systems reduce peak demand by reallocating energy use to periods of lower system load (Zhao et al., 2023). They can also provide backup services such as black-start capability, enabling grid restoration after major outages (Zhao et al., 2023). The before mentioned BESS applications are needed as wind and solar among other RES are being installed, not to mention the huge data center investments that are announced.

The deployment of BESS has accelerated in recent years due to decreasing costs and supportive policy frameworks (Guzman et al., 2022). A typical system charges when electricity supply exceeds demand and discharges during peak consumption periods or grid disturbances (Zhang et al., 2025). System performance is commonly evaluated using

round-trip efficiency, which measures the proportion of stored energy that can be recovered during discharge (Dong et al., 2025). This efficiency depends on the operational purpose of BESS, battery chemistry and component quality (Dong et al., 2025).

BESS installations vary widely in scale, from small behind-the-meter (BTM) systems to large utility-scale front-the-meter (FTM) projects connected directly to utility grid (Sheth et al., 2025). The equipment can therefore be connected to many purposes either for residential use or for larger scale.

2.1.1 Components and functional architecture

Manufacturers work to deliver higher energy density, faster charging performance and longer operational lifetimes to meet rising demands (Dong et al., 2025). Several interconnected subsystems that together store and manage electrical energy demand specialized suppliers which makes effective sourcing so critical.

Figure 1 provides a conceptual overview of a standard BESS, showing the functional links between the battery, the Power Conversion System (PCS), the Battery Management System (BMS), the Energy Management System (EMS) and system-level monitoring.

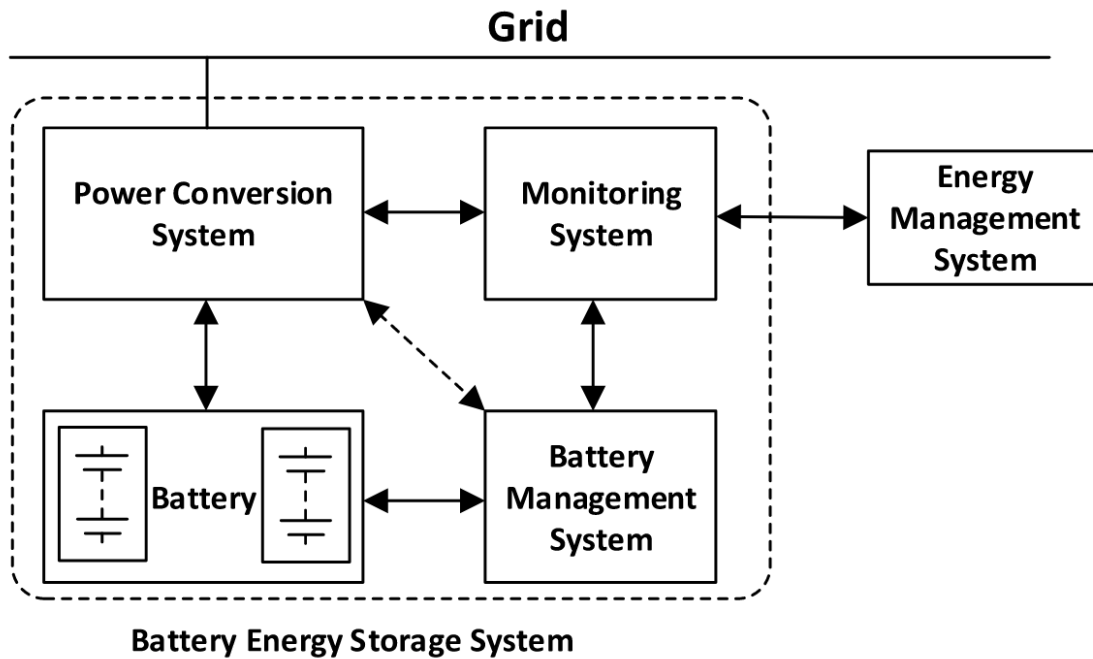


Figure 1. Functional architecture of a typical BESS (Liu et al., 2022).

At the center of the system is the battery enclosure, which houses the battery modules in racks responsible for storing energy (Sheth et al., 2025). Electrical energy is stored in chemical form and released through electrochemical reactions during discharge (Chatzigeorgiou et al., 2024). Batteries represent the largest share of capital cost in utility-scale projects (Cole et al., 2025) and are subject to strict safety and certification requirements (Jaradat & Khatib, 2025). These qualifications can limit short-term substitutability between suppliers, tying battery sourcing decisions to pre-qualified manufacturers and specific production locations.

The PCS acts as the interface between the battery and the grid. It converts direct current (DC) from the battery into alternating current (AC) suitable for grid operation and enables bidirectional energy flow during charging and discharging (Liu et al., 2022). PCS design plays a key role in services such as reactive-power control and frequency regulation and ensure energy exchange in accordance with grid codes and operational targets (Villa-Ávila et al., 2025).

The BMS provide average, minimum and maximum cell voltages and temperatures ensures safe and reliable battery operation (Ledro et al., 2025). Using this information it

performs protection functions and estimate of State of Charge (SoC) and State of Health (SoH), both of which are essential for managing battery lifespan (Dong et al., 2025). The BMS communicates continuously with the PCS and system-level monitoring through coordinated data exchange (Liu et al., 2022). Because these interactions are closely tied to specific battery designs, switching suppliers needs system-level revalidation which can limit sourcing flexibility.

EMS supervises system operation by controlling power dispatch across integrated sources and managing charging/discharging behavior in response to demand and operating constraints (Khoury et al., 2025). Monitoring systems collect operational data across storage and power-system components to ensure safety (Albarakati et al., 2022). In storage applications, for example SCADA systems can collect data from sensors to provide automated control actions (Zhang et al., 2025).

Thermal management is another essential subsystem in BESS as batteries generate heat during operation (Mdachi & Choong-koo, 2024). Air and liquid among others cooling approaches are used to maintain appropriate cell temperatures during charge and discharge cycles (Mdachi & Choong-koo, 2024). Proper temperature control reduces the likelihood of overheating and thermal runaway to ensure long-term reliability (Mdachi & Choong-koo, 2024). Fire detection and suppression systems are also integrated in accordance with safety standards such as NFPA 855 and UL 9540 (Close et al., 2024).

2.1.2 Battery technology choices

Rechargeable batteries used in stationary energy storage draw on several chemistries, including lead–acid, nickel–cadmium and lithium-ion systems, together with new variants (Chatzigeorgiou et al., 2024). Studies consistently point to lithium-ion as the prevailing technology for BESS because it's efficiency, cycle life and scalability position it as the strongest option. Greitemeier et al. (2025) and the IEA (2024) links this dominance to supply chains that depend on lithium availability and geographically concentrated production. Within this technology family, LFP and NMC remain the most common choices in current grid-scale deployment (IEA, 2024).

Battery operation is governed by reversible electrochemical reactions inside cells that contain electrodes, an electrolyte and a separator (Dong et al., 2025). Rahman et al. (2021) outline how lithium ions move to the negative electrode (the anode) during charging and to the positive electrode (the cathode) during discharging, and Lingappan et al. (2023) highlight the separator's role in preventing direct electrode contact and safe operation. Figure 2 illustrates this process. These findings overall define the battery assumptions used in this thesis, notably the application of lithium-ion chemistry and modular configurations.

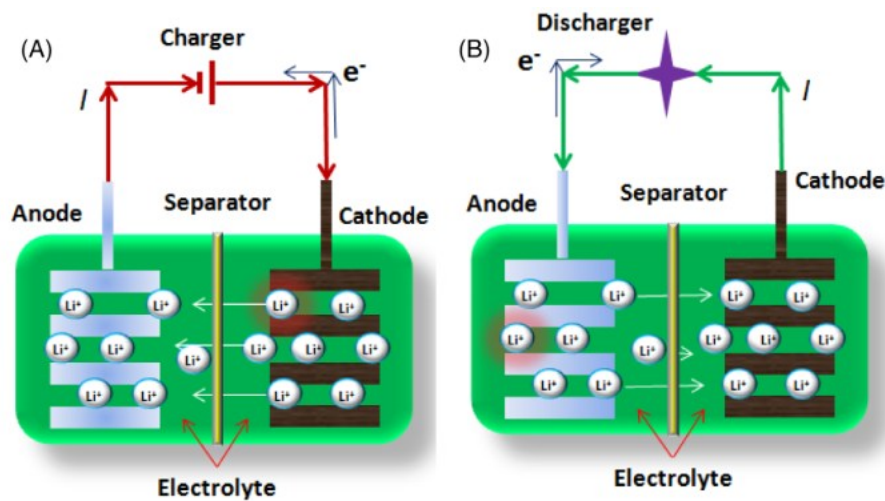


Figure 2. Schematic of lithium-ion battery charging process (Rahman et al., 2022).

2.1.3 BESS market overview

Global electricity demand is forecasted to grow by a CAGR of about 3.5 percent as electricity consumption intensifies in manufacturing, transport, air conditioning, and data centers (IEA, 2026). For the response, according to IRENA (2025) total installed renewable generation increased from 2 813 GW in 2020 to 4 448 GW in 2024, while annual additions rose from 270 GW to 585 GW. This growth reflects the decarbonization goals through supportive policy measures and also steady improvements in grid integration as solar PV and wind now represent majority of all new renewable capacity installed worldwide. Table 1 combines historical data from IRENA (2025) with scenario projections from

the IEA (2023) to illustrate this development and the additional expansion required under the Net Zero pathway.

Table 1. Global renewable power capacity development and Net Zero Outlook (IEA, 2023; IRENA, 2025).

Year	Total Installed Renewable Capacity (GW)	Annual Capacity Additions (GW)
2020	2 813	270
2021	3 076	263
2022	3 379	303
2023	3 863	484
2024	4 448	585
<i>2030 (forecast)</i>	11 000	1 250
<i>2050 (forecast)</i>	30 000	1 268

The data in Table 1 shows that renewable capacity grew by almost 60 percent from 2020 to 2024. The IEA (2023) expects capacity to reach 11 000 GW by 2030 and 30 000 GW by 2050. However, the IEA also notes that current installation rates remain below what is needed for the 1.5 °C pathway. Achieving this target requires annual additions above 1 250 GW and continued growth of about 1 268 GW per year through mid-century. In that case renewables would supply close to 90 percent of global electricity (IEA, 2023).

Growing RES penetration are needed to meet decarbonization targets but they bring variability to the grid. BESS is a solution because of their ability to store excess energy and covering shortfalls and providing ancillary services (Garttan et al., 2025). Figure 3 represents the global BESS market across utility-scale, commercial and industrial, and residential applications, based on forecasts from McKinsey & Company (Jarbratt et al., 2023).

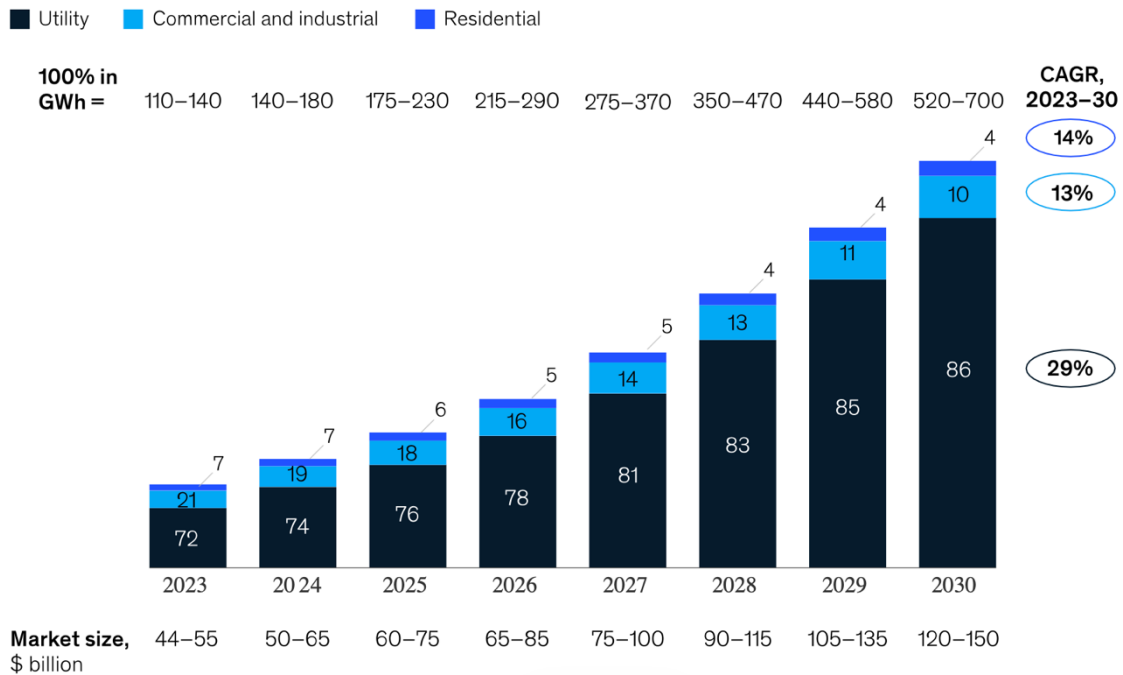


Figure 3. Global battery energy storage system market outlook by application segment, 2023–2030 (McKinsey & Company, 2023).

According to Figure 3, installed BESS capacity is expected to rise from about 110–140 GWh in 2023 to 520–700 GWh by 2030. The utility segment makes up roughly 85 percent of this growth. McKinsey estimate a compound annual growth rate of about 29 percent and a global market value of USD 120–150 billion by 2030. Moreover, BloombergNEF expects cumulative energy storage capacity to reach about 2 terawatts, equal to roughly 7.3 terawatt-hours by 2035 (Kikuma, 2025). When read together with McKinsey’s projections toward 2030, these outlooks indicate a long-term and large-scale acceleration of new BESS installations.

2.1.4 Global market outlook for utility-scale BESS

Utility-scale BESS represents the fastest-growing segment of the global energy-storage industry and now accounts for the majority of new capacity additions worldwide. BESS providers in utility-scale segment are typically either vertically integrated battery manufacturers or large system integrators (Jarbratt et al., 2023). Figure 4 illustrates the annual utility-scale capacity additions by country between 2020 and 2034 (Wood Mackenzie,

2025). Global annual additions are projected to rise from roughly 6 GWh in 2020 to around 500 GWh by 2034 which is equivalent to an average annual growth rate in installed energy capacity exceeding 36 percent. This rapid rise may impact sourcing strategies because concentration of demand increases competition for qualified suppliers and tightens available manufacturing capacity.

According to Figure 4, annual additions grew from about 6 GWh in 2020 to more than 77 GWh in 2023 reflecting a clear acceleration in large-scale deployment (Wood Mackenzie, 2025). Forecasts indicate continued growth with annual additions expected to reach close to 500 GWh by 2034. Utility-scale storage would act a core component of future power-system planning if the scenario presented below actually materializes.

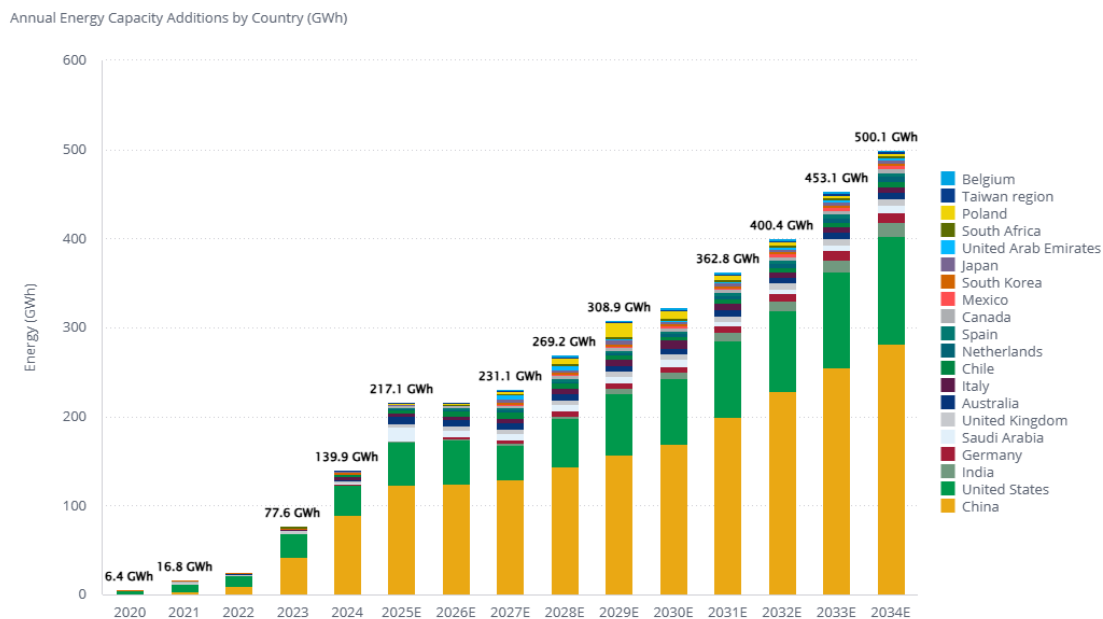


Figure 4. Regional utility-scale battery energy storage capacity additions by country, 2020–2034 (Wood Mackenzie, 2025).

When analyzing the chart regionally, China and the United States seems together account for more than two-thirds of global utility-scale capacity growth through 2034 (Figure 4). Since 2024, gigawatt-hour-scale projects have also been commissioned or begun construction in Saudi Arabia, South Africa, Australia, the Netherlands, Chile, Canada and the United Kingdom, reflecting the wider international spread of large-scale deployments (Nsitem & Sekine, 2025).

2.2 Sourcing and supply chain dynamics in the BESS industry

BESS projects are built through supply chains that stretch across countries and production stages. A single project may depend on battery cells produced in one region, power electronics sourced from another, and final assembly completed elsewhere. It is also about securing qualified supply for all other components and managing risks. This section reviews how sourcing and supply chain dynamics play out in the BESS industry.

2.2.1 Structure of the BESS value chain

Porter (1985) defines the value chain as a sequence of activities through which firms create value and incur cost. Value chains extend beyond the internal activities of a single firm and include the broader network of suppliers, producers, processors, distributors and service providers that contribute to bringing a product from its initial concept to the final market (Kumar, 2016). Figure 5 presents a high-level representation of these primary stages in BESS but does not aim to depict the full lifecycle.

BESS supply value creation begins with raw material extraction and chemical refining, meaning that lithium, nickel, cobalt and graphite are processed into battery-grade materials used in cell manufacturing (LaRocca, 2020). Cell production includes electrode fabrication, assembly and formation (Mauler et al., 2021).

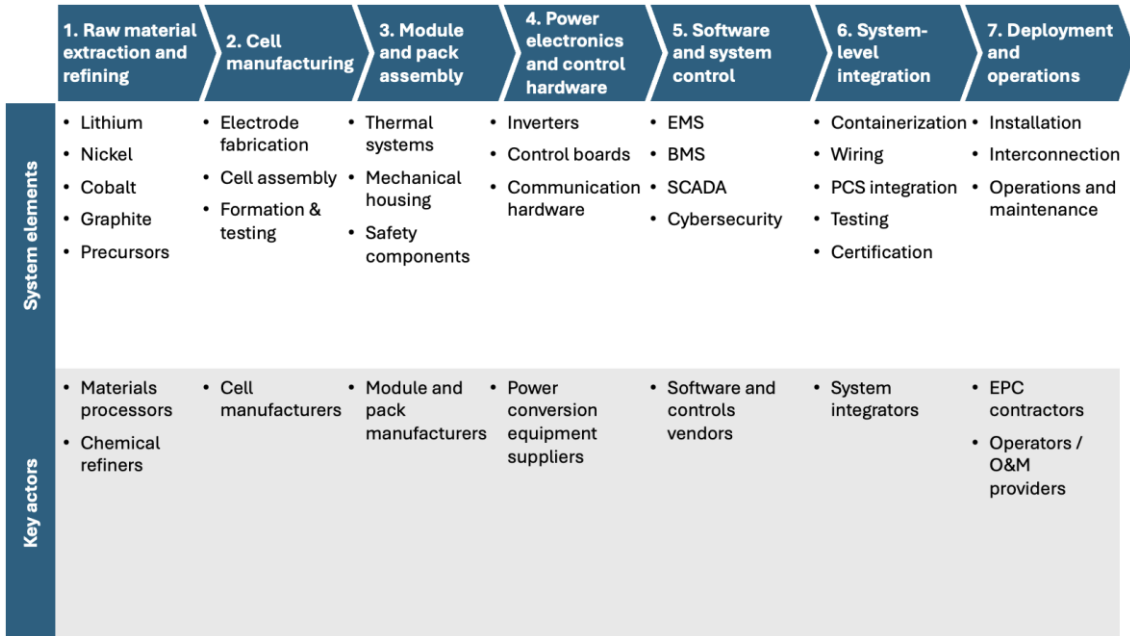


Figure 5. Seven stages of the BESS value chain.

In parallel or series connected battery cells form a module, and when combined with cooling systems and BMS they make up a battery pack (IEA, 2024). PCS is critical value-adding stage because it realizes the power exchange between BESS and the grid (Liu et al., 2022), so battery characteristics such as voltage range and chemistry must be matched to the PCS (Sheth et al., 2025). EMS software form another activity layer as it enable monitoring and operational optimization of the BESS unit (Khoury et al., 2025).

The sixth step in the Figure 5 is system integration which represents a critical value-adding stage. It combines battery packs, power electronics and control systems into a grid-ready solution. Additional complementary functions at integration are for example engineering design, wiring, testing and certification. Article from McKinsey & Company shows that a substantial share of profit pools is captured at this stage, their estimation being approximately 25–30% of BESS hardware-only value chain (Jarbratt et al., 2023).

The final stage includes deployment and commissioning of BESS units at site, including interconnection and other operations. Although operations are outside the cost boundary of the later TLC analysis, they hold a big part of the broader value adding share of BESS projects.

2.2.2 Contract manufacturers in the BESS supply chain

Contract manufacturing (CM) refers to an arrangement in which a firm outsources defined production activities to an external partner while retaining control over the essential elements of the product's design and its required performance standards (Han et al., 2012; Wu et al., 2023). Third-party contract manufacturers can provide cost-efficient solutions by pooling production capacity for multiple clients in large manufacturing facilities (BCG, 2025). Sanders et al. (2007) classify outsourcing arrangements based on the scope of supplier responsibility and the criticality of the outsourced task. These range from limited out-tasking to full outsourcing.

System integrators are the companies that deliver complete BESS solutions and hold responsibility for the overall system concept (Jansen, 2020). Their operating model determines whether manufacturing remains in-house or if selected manufacturing stages are delegated to contract manufacturers. This decision reflects the classic make-or-buy choice, where firms decide whether components and services are produced internally or sourced from external suppliers (Maltz & Ellram, 1997). These choices are linked to the degree of vertical integration, which defines how much of the value chain is controlled internally. Maltz & Ellram (1997), propose the Total Cost of Relationship (TCR) concept to be utilized when evaluating such options, emphasizing that outsourcing means additional supplier management costs. Contract manufacturers in BESS manufacturing may take responsibility for example on assembly and testing which are critical for system performance. In some cases, they assemble battery modules or packs from customer-selected cells. In others, they perform full system assembly. Some contract manufacturers also manage logistics and intermediate warehousing related tasks. The relationship between with CM's require closer coordination and higher managerial involvement than transactional procurement (Wu et al., 2023). Figure 6 illustrates a generic contract manufacturing flow in which production, warehousing, and distribution activities are divided among entities.

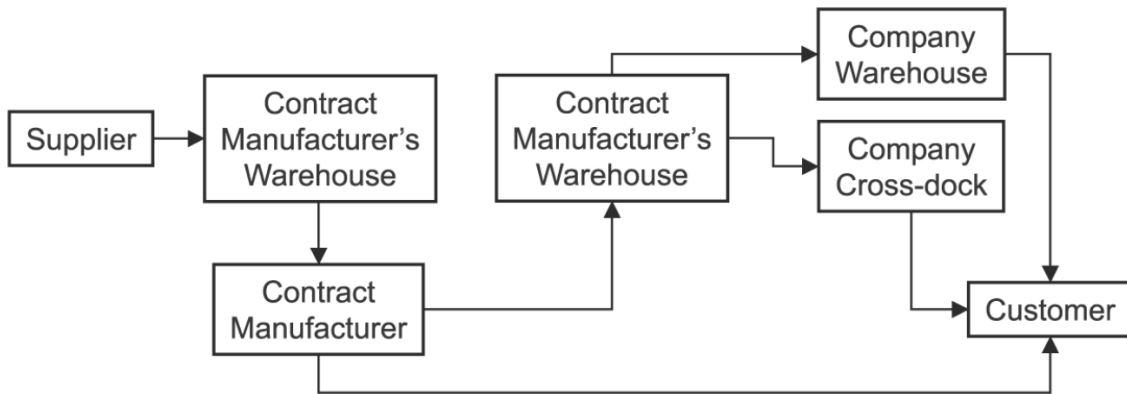


Figure 6. Conceptual contract manufacturing logistics process (Mason et al., 2002).

Manufacturing quality at the CM level influences the final system, which means the integrator must ensure that outsourced stages meet technical and documentation needs. Mason et al. (2002) emphasize that outsourcing represents a significant commitment because it changes how firms manage product development work and oversight of production. CM location is an additional strategic factor. Mason et al. (2002) explain that the position of facilities and suppliers optimizes the logistics network. Selecting CM with sites in low-cost regions can lower manufacturing expenses but should still be located nearby strong transport hubs (Mason et al., 2002).

CMs may act as an important link between upstream component supply and final system delivery in the BESS supply chain. Han et al. (2012) argues that outsourcing tends to be more advantageous when supplier markets are competitive because competition reduces input prices and limits supplier bargaining power. Wu et al. (2023) provides a more nuanced view by noting that the best productivity benefits of contract manufacturing emerge mainly in moderately competitive supplier environments.

2.2.3 Battery pricing and scale-driven supply concentration

Battery cell production is inherently capital-heavy and scale-driven, with cost efficiency improving as plants operate at larger volumes and higher utilization rates (Mauler et al., 2021). These factors have affected to a global supplier landscape in which production capacity is concentrated in a limited number of regions. According to the JRC, EV and ESS batteries rely on the same upstream and mid-stream supply chains and diverge only at

the point of end-use (JRC, 2025). This link is relevant as global EV deployment grows fast and adds demand for battery materials.

According to Wood Mackenzie, Figure 7, China accounts for the majority of cumulative global battery cell manufacturing capacity measured in annual gigawatt-hours, far exceeding that of other regions (Wood Mackenzie, 2025). Consistent with this distribution, the IEA estimates that China accounted for nearly 85% of global battery cell production capacity in 2024 and held a dominant position in cathode and anode material manufacturing (IEA, 2024). By comparison, capacity in the United States and Europe remains substantially smaller, despite recent investment announcements as reflected in the cumulative capacity distribution (Figure 7).

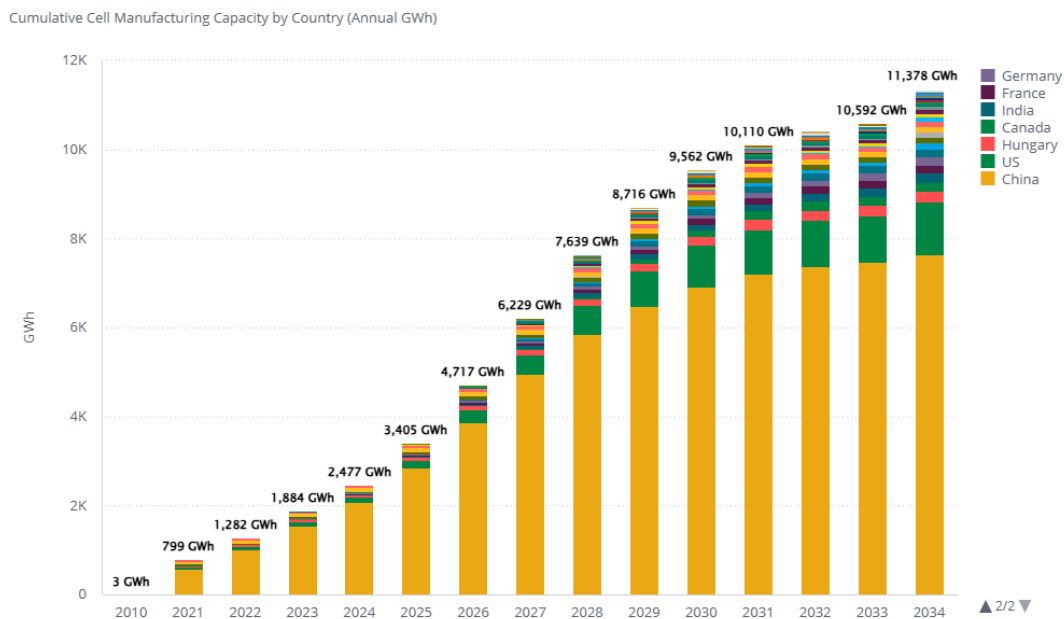


Figure 7. Cumulative cell manufacturing capacity by country (annual GWh) (Wood Mackenzie, 2025).

Wood Mackenzie (2025) forecasts according to Figure 7 that China would retain the largest share of global battery cell production capacity throughout the decade, and the ranking does not seem to have dramatic changes. Related to this, JRC (2025) notes that the EU faces elevated supply risk throughout nearly all phases of the battery supply chain due to the bottlenecks of battery materials from Asia. Keeping up with China's battery production factories elsewhere is complex due to weaker economies of scale and higher

input prices but countries are seeking to expand their domestic battery production to reduce strategic dependencies. Sheth et al. (2025) note that U.S. cell manufacturing is expected to grow almost tenfold by the end of this decade, mainly due to new tax credits and subsidies, surpassing the planned capacity additions in Europe.

When speaking about price volatility, battery prices are also vulnerable to fluctuations in raw material index, and it can lead to sudden changes in costs. The IEA reports that average lithium-ion battery pack prices declined to around USD 140/kWh in 2023 following a temporary spike in 2022, followed by easing critical mineral prices and expanding manufacturing capacity (IEA, 2024). Even with the global decrease, there are clear regional cost differences. Prices are lowest in China and about 10–20 percent higher in the United States and Europe (IEA, 2024). These differences stem from variations in manufacturing scale, supply-chain integration and production efficiency (IEA, 2024) thus contributing to sourcing of batteries for BESS projects as well.

2.2.4 Strategic sourcing in global supply chains

Sollish & Semanik (2011) defines strategic sourcing as a procurement process through which firms identify, develop and engage suppliers that reinforce long-term business objectives and create maximum value for the organization. Sourcing has continuously moved from a transactional role into a central part of supply management across industries especially with complex and expensive products. Research by Trent (2007) shows that sourcing decisions influence cost efficiency and technical capability, and they also validate long-term competitiveness. Supplier selections guide how supply networks develop and how fragmented component markets become usable for system-level delivery.

Monczka (2009) notes that effective sourcing relies on clearly defined processes that link demand planning with market analysis and supplier evaluation. Strategic supply management aims in the end to achieve the lowest total cost while improving factors such as delivery performance, technology capability, responsiveness and overall competitiveness, instead of concentrating only on purchase price (Trent, 2007). Firms need to take

multiple other aspects into account as well such as sustainability targets and meeting engineering needs across several regions.

Kraljic (1983) introduced one of the most influential frameworks in strategic sourcing. His portfolio model evaluates purchases along two dimensions, supply risk and profit impact, and guides firms toward differentiated sourcing strategies. High-risk and high-impact items require partnership development and risk-mitigation strategies, whereas leverage and routine items can be sourced through competitive tendering. This logic fits the BESS value chain. Battery cells represent the most critical category, while some other components may fall into lower-risk groups. The model also reinforces supplier segmentation and the planning of long-term partnerships.

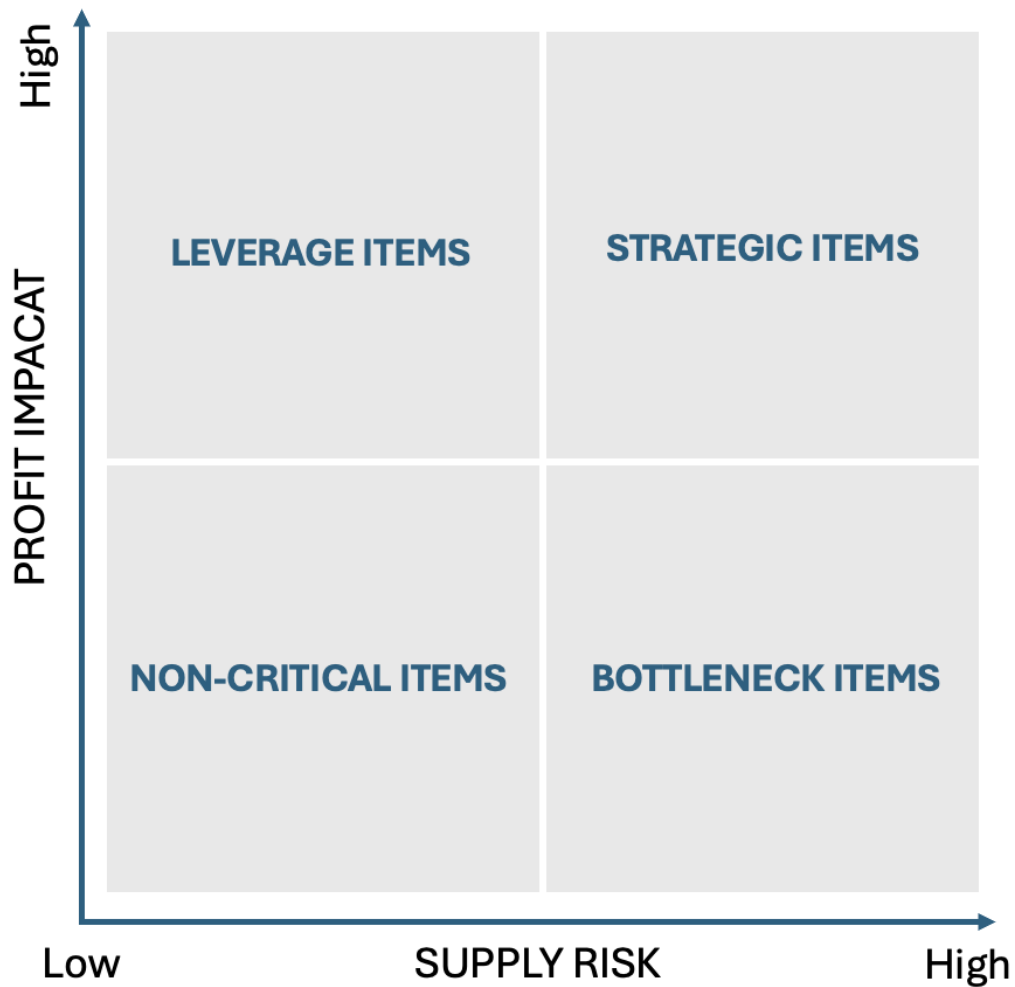


Figure 8. The Kraljic purchasing portfolio matrix (adapted from Kraljic, 1983).

As per Kraljic (1983), items positioned as strategic items (high profit impact, high supply risk) require long-term supplier collaboration and accurate demand forecasting. Leverage items (high profit impact, low supply risk) emphasize cost efficiency through targeted pricing negotiations and volume-based agreements. Non-Critical items (low profit impact, low supply risk) focus on process simplification and transactional efficiency, while Bottleneck items (low profit impact, high supply risk) prioritize continuity of supply and risk mitigation despite limited spend significance (Monczka, 2009). Battery cells and system-level assembly activities typically combine high supply risk with high impact on system cost and performance, placing them in the strategic quadrant.

Supply chain resilience has been discussed in academia as an additional dimension to strategic sourcing. Jain et al. (2022) find that long-term supplier relationships often allows faster recovery from interruptions while supplier diversification would be associated with slower recovery. Trent (2007) specifies that still most relationships are not win-win situations, meaning that not all of them are created equally. Possibilities to achieve strong long-term relationships with key suppliers depends on resources and of course scale and market footprint as well. Close relationships could be easier to handle if dealing with small number of suppliers, but more challenging with wide portfolio. BCG notes based on the recent disruptive events affecting international supply that some companies have now started to improve their supply chain resilience by diversifying manufacturing and sourcing across geographically distributed locations, particularly in low-cost and geopolitically neutral countries that enable broader market access (BCG, 2025). This can be considered as a proactive risk management initiative that firms are ready to take to build resilience for the future.

2.2.5 Supplier portfolios and disruption risk mitigation

Wagner & Johnson (2004) define a strategic supplier portfolio as a deliberately assembled set of supplier relationships that is managed as a whole to balance risk and returns and to confirm competitive advantage. In this thesis, supplier portfolio thinking is especially relevant for battery suppliers and CMs, as these actors dominate cost and performance in BESS projects.

Portfolio-based sourcing builds on Kraljic's purchasing portfolio model, which links supply risk and profit impact to differentiated sourcing strategies (Kraljic, 1983). Portfolio design must jointly consider both the number of suppliers and the nature of buyer-supplier relationships. Sourcing arrangements range from short-term, arm's-length transactions to long-term strategic partnerships, depending on dependency, task criticality, and coordination needs (Monczka, 2009; Ribas et al., 2021). Christopher & Peck (2004) says that many organizations operate with forecast-driven supply chains instead of demand-driven ones, meaning that decisions are often made in isolation. The possible lack of information sharing between buyer and supplier in that kind of business environment

can result in both supply chain costs and overall vulnerability. These factors collectively will determine how companies want to balance coordination performance and build supplier portfolios in their respective industries.

Chen et al. (2022) show that portfolios differ in the extent to which sourcing is concentrated among a few suppliers or distributed across many. Highly concentrated portfolios with only few suppliers allows firms to invest in trust-building to which leads to deep knowledge and innovation (Chen et al., 2022). On the otherside, more dispersed portfolios create access to multiple knowledge sources, which can similarly foster innovation. While dispersed portfolios reduce dependency risk, it increases coordination effort and managerial complexity. The more dispersed the portfolio is, the more buying companies must strive to ensure that quality, safety, and labor standards are met (Monczka, 2009).

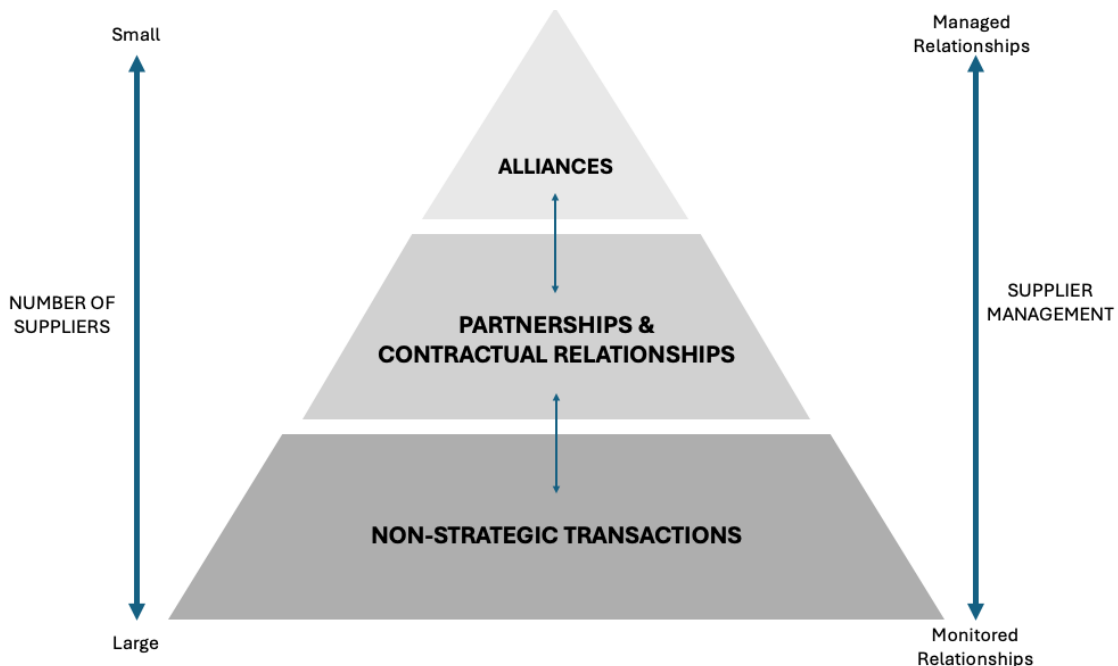


Figure 9. Supplier relationship intensity and number of suppliers (adapted from Sanders et al., 2007).

Figure 9 illustrates how supplier relationships form a layered portfolio structure. The pyramid adapted from Sanders et al. (2007) classifies sourcing arrangements based on task scope and criticality. The lower level represents non-strategic transactions, where many suppliers exist and relationships are mainly monitored through standard purchasing

practices. The middle level captures partnerships and contractual relationships, which involve fewer suppliers and require ongoing coordination. The upper level reflects alliance-type relationships that demand intensive management and long-term commitment. Battery suppliers and CMs are typically both positioned at this “Alliance” level due to high limited supplier availability and strong influence on system performance.

Supplier portfolio design involves explicit choices regarding the number of suppliers per sourcing category. Supply management literature distinguishes between single sourcing, dual sourcing, and multi-sourcing as alternative portfolio configurations (Cui et al., 2025). Single sourcing refers to relying on one supplier for a specific component or service, which can improve cost efficiency and quality control but increases supply chain vulnerability if disruptions occur (Christopher & Peck, 2004). Single sourcing in other words give chance for deeper coordination and relationship-specific investments but increases dependency. Monczka (2009) finds that buyer can control the dependency risk caused by a disruptive event through selecting single source that have multiple production facilities in various regions. Additionally, a concept of cross-sourcing can be beneficial in which the selected suppliers are capable of contributing to more than one part of production process and each can act as a backup for one another (Monczka, 2009). Linking this to manufacturing a BESS unit can mean for instance that the integrator uses single supplier for contract manufacturing but has PCS supplier with this same capability if a disruption occurs. Even the PCS supplier has not originally planned to perform the CM activities, they would be prepared and able to do it.

Dual and multi-sourcing can promote supplier competition and reduce risk of supply disruptions, yet maintaining multiple suppliers may also trigger coordination costs, product variability and limit economies of scale compared to sourcing larger volumes from fewer suppliers (Monczka, 2009). Moreover, Elmaghraby (2000) notes that multi-sourcing strategy may drive to price competition among suppliers as allocating production to multiple suppliers reduces information rents and encourages suppliers to submit more competitive bids. Aguilar-Hernandez et al. (2023) give an example from chip industry where lack of supplier options limits the diversification chance but encourages high-tech producers to do so to enhance resilience. Chen et al. (2022) find that firms tend to perform

better with either clearly concentrated or clearly diversified portfolios, while intermediate ones may often underperform. It can refer that firms do better when strategy is clear and volumes and roles are clearly allocated.

Geographic dispersion is another important feature of supplier portfolios thus sourcing can be local, regional, or global, and each choice implies different pros and cons. Nearshoring and reshoring represent selective forms of geographic diversification. Zhang et al. (2025) explains that reshoring refers to relocating production activities back to a firm's home country, often in response to trade policies or supply chain risks that encourage greater resilience and stability. Nearshoring refers to sourcing from nearby country as locating suppliers closer can improve delivery times and reduce trade-related friction (Garcia, 2025).

Negotiating flexible contracts with volume reallocation clauses can ease adjustments under changing conditions (Garcia, 2025). Tariff pass-through clauses or price adjustment mechanisms in BESS projects can be critical to be able to allocate part of the tariff risk between suppliers, contractors and developers when unexpected tariffs raise production costs (Alice & Weaver, 2025). These clauses typically define the triggering events, such as new tariffs or tariff increases, and specify how additional costs are shared between the parties. Strategic inventory practices, such as safety stocks and risk pooling are other options to enhance short-term resilience (Garcia, 2025). To summarize all this, supplier portfolios are defined by a few core characteristics: supplier count, concentration level, relationship intensity, geographic spread, and the contractual mechanisms that govern reallocation and cost exposure under uncertainty.

2.3 Trade and regulatory conditions in BESS sourcing

BESS markets operate under different policy frameworks and tariff regimes. These differences affect how supply networks can be organized in practice. The following sections outline the key conditions in the United States, the European Union and Australia.

2.3.1 United States: Industrial policy and technical approval standards

BESS projects growth in the United States are influenced by governmental tax incentive initiatives, with The Inflation Reduction Act (IRA) passed in 2022 being the key driver (Sheth et al., 2025). According to IEA (2024), the U.S. IRA can provide up to a 50% federal tax credit for battery energy storage projects, but also offering a 30% tax credit for residential installations of clean energy equipment. Weaver et al. (2024) observes that the Infrastructure Investment and Jobs Act (IIJA) support BESS projects by incentivizing domestic content and restricting reliance on foreign suppliers. In parallel, Weaver et al. (2024) describes the introduction of Foreign Entities of Concern (FEOC) restrictions, which limit the use of components or suppliers owned by, controlled by, or subject to the jurisdiction of governments of covered nations such as China, Russia, Iran, and North Korea. Based on these facts, sourcing decisions for battery cells and system assembly directly affect customers eligibility for federal incentives.

UL 9540 functions as a recognized safety standard for BESS and is referenced by fire codes such as NFPA 855 and the International Fire Code (El Ouaragli & Conzen, 2025). NFPA 855 established steps are the development of an emergency response plan coordinated with local fire departments and measures for hazard mitigation, fire detection, and safe response to thermal runaway and explosion risks (Sheth et al., 2025).

2.3.2 European Union: Sustainability regulation and supply chain governance

The REPowerEU initiative aims to accelerate deployment of renewable generation and broader electrification of the energy system, which increases the need for large-scale energy storage (EASE, 2022). Aligning energy storage targets with existing climate objectives is therefore considered essential at the EU level. Many EU member states have already established energy storage targets, and upcoming electricity market reforms will require all member states to incorporate such targets into their National Energy and Climate Plans (IEA, 2024).

Importers established in the EU who place batteries from third countries on the market assume direct regulatory responsibility, which has implications for sourcing strategies

relying on non-EU production. CE marking is a mandatory EU label showing that a BESS meets safety and environmental preconditions and can be legally sold on the EU market (El Ouaragli & Conzen, 2025). Then, Batteries Regulation (EU) 2023/1542 applies to operators placing batteries on the EU market, like manufacturers, importers and other entities introducing products from third countries (Cordingley, 2025). It assigns direct compliance responsibility also to actors other than the original producer (Cordingley, 2025). Within this framework, the digital battery passport emerges as a key regulatory threshold. OEM's are required to document full lifecycle traceability data for all large rechargeable batteries placed on the EU market (Júnior et al., 2024). Tahir et al. (2025) specifies that these machine-readable records for batteries will become a mandatory step starting from 2027. By gathering performance data, the act aims to enhance battery recycling and the use of second-life batteries in secondary applications (Júnior et al., 2024). According to JRC (2025) the BASE scenario for repurposing rate may rise from about 10% of collected batteries in 2023 to as much as 35–50% by 2050.

2.3.3 Australia: Grid participation and infrastructure regulation

Australia supports the deployment of utility-scale battery energy storage through its Capacity Investment Scheme, which aims to enable higher shares of variable renewable energy and compensate for the planned phase-out of coal-fired generation (IEA, 2024). To participate in the National Electricity Market (NEM), BESS assets must satisfy registration and performance obligations (AEMO, 2019). Those are specified through grid codes, which define technical performance and response benchmarks (Garttan et al., 2025).

Security of Critical Infrastructure Act (SOCIA Act) adds a governance layer toward stricter control of sourcing and supplier governance in the Australian market. Storage facilities with a capacity of 30 MW or more are classified as critical electricity assets thus they require registration in the Critical Infrastructure Asset Register and compliance with mandatory risk management programs (Dentons, 2025). Operators must identify and mitigate operational, cyber and supply chain risks as well as report significant incidents (Dentons, 2025). Dentons (2025) adds that SOCIA compliance rules expect formalized contractual controls and verification across supplier relationships.

2.3.4 Trade and tariff pressures

BESS supply chains rely on cross-border manufacturing and upstream material flows and that makes them exposed to changes in tariffs. These tariffs are paid by importing firms at the point of entry and often raise costs for buyers (Contractor, 2025). Ivanov (2025) describes that tariff crises fundamentally represent external macroeconomic shocks to supply chains, whose responses propagate back to the broader economy. Adjustments to these shocks in the supply chain design are rarely fast because supplier qualification and long-standing relationships slow relocation.

US–China tariff tensions in 2018–2020 remained a bilateral conflict, compared to the 2025 crisis that reached a global scale (Ivanov, 2025). Tariff pressure in BESS sector is amplified by China’s dominant position in battery manufacturing. Consequently, the exposure to tariffs in China–US sourcing often reflects tariff stacking, where multiple measures apply at the same time to the same product classification (Angeles & Harput, 2025). This can include Section 301 that refers to U.S. tariffs introduced after a 2018 investigation concluded that China used unfair practices in technology transfer and intellectual property (ST&R, 2025). These Section 301 tariffs have largely remained in force following the USTR’s four-year review (USTR, 2024). More imposed tariffs like reciprocal tariffs and emergency-based measures such as fentanyl-related tariffs, may apply alongside Section 301 (Reed Smith, 2025) thus compound total tariff effect.

To illustrate cumulative tariff exposure for BESS components imported into the United States in 2025, landed cost can be expressed in simplified form as:

$$C_{\text{landed}} = C_{\text{FOB}} \times (1 + t_{\text{base}} + t_{301} + t_{\text{reciprocal}} + t_{\text{policy}}), \quad (1)$$

where:

- C_{FOB} = customs value at origin
- t_{base} = base duty rate
- t_{301} = Section 301 tariff (China-origin)

- $t_{\text{reciprocal}}$ = reciprocal tariff
- t_{policy} = other policy-based tariffs

Customs treatment in the EU is determined by Customs Tariff (TARIC), where duty rates depend on product classification and declared country of origin (European Commission, 2025). As a result, BESS components may face different tariff and not unified tariff for the system. However, batteries are recognized as a strategic industrial value chain, with policy objectives aimed at reducing reliance on non-EU supply (European Commission, 2019). The tariff framework also allows trade defence measures to be introduced when policy situation justify such action. A recent example is the imposition of countervailing duties on battery electric vehicles imported from China following an anti-subsidy investigation (European Commission, 2024). While these measures do not apply directly to stationary storage, they highlight potential exposure for battery-related imports linked to China.

Australia's trade policy framework works differently for imported battery energy storage systems. A free trade agreement (FTA) is an international treaty that reduces or eliminates trade barriers between participating economies (DFAT, 2025). Under the China–Australia Free Trade Agreement (ChAFTA), most BESS and solar products imported from China can enter Australia tariff-free when they meet the agreement's rules of origin and certification requirements (DFAT, 2025). In addition, tariff outcomes in Australia depend on customs classification and concession mechanisms administered by the Australian Border Force. Through the Tariff Concession Order system, certain imported goods may be granted duty-free status if no substitutable products are manufactured in Australia (Australian Border Force, 2025), which can reduce tariffs for specific components used in BESS.

2.3.5 Tariff effects on cost and sourcing risk

The same tariff regime can lead to different cost outcomes depending on where value creation activities are located and how sourcing and assembly are organized across

regions. That is to be taken into account for globally sourced goods where the sudden tariff changes can ruthlessly harm margins.

Figure 10 by Boston Consulting Group illustrates estimated margin impacts across alternative supply chain configurations under selected U.S. tariff scenarios for automotive industry based on Feb 1st 2025 tariff levels (BCG, 2025). The figure distinguishes between impacts at the auto OEM level and across the full supply chain and shows that tariff exposure can be limited at the OEM level while remaining substantial upstream. For example, configurations with strong concentration in tariff-exposed regions show modest margin impacts for OEMs but significantly larger impacts across the full supply chain, whereas more diversified configurations reduce risk at both levels.

	OEM (Normal EBIT: 8–12%) EBIT at risk (pp)	Full supply chain (Normal EBIT: 5–9%) EBIT at risk (pp)
China-centric supply chain China-based OEM with 100% of assembly in China; 80%+ of supply chain in China	0 to -1	-11 to -12
EU-centric supply chain OEM with 90%+ of assembly in Europe; ~50% of supply chain in the EU, ~20% in China, and ~10% in EU neighbors (e.g., Turkey, Morocco, the Balkans)	-1 to -2	-5 to -6
China-exposed EU supply chain EU OEM with 50%+ of assembly in the EU, ~30% in China, and ~10% in the US; ~40% of supply chain in China and ~40% in the EU	-1 to -3	-7 to -8
China-exposed US supply chain US OEM with ~70% of assembly in the US and ~30% in China; ~40% of supply chain in the US and 25% in China	-5 to -7	-9 to -10
Global supply chain mainly in advanced economies OEM with ~40% of assembly in Japan and South Korea, ~30% in China, and ~15% in the US and the EU; ~20% of supply chain in Japan and South Korea, ~20% in China	-1 to -3	-6 to -7
Truly global supply chain OEM with ~50% of assembly and supply chain in advanced economies (e.g., the US, the EU, Japan, South Korea), ~40% in developing economies (e.g., Mexico, Turkey), and ~10% in China	-2 to -4	-6 to -7

Figure 10. Illustrative impact of U.S. tariffs on margins across different supply chain configurations (BCG, 2025).

Tariff shocks do not necessarily lead to identical adjustments in sourcing practices across all industries, because the components being sourced and the materials used in them differ from one another. Zhang et al. (2025) used cluster-based analysis based on manufacturers' monthly global sourcing activities and revealed that observed firms followed

diverse strategies across different tariff stages. Some firms might relocate production, while others increase dual or multi-sourcing to distribute risk (Zhang et al., 2025).

Dong & Kouvelis (2019) argues that tariff-related price increases are already integrated into raw material prices, such as lithium or aluminum in the case of BESS. The possibility to substitute away from tariff impacted material depends on product complexity and bill of material rigidity thus defining how susceptible a multiproduct firm is to trade policy changes (Dong & Kouvelis, 2019). Battery suppliers and contract manufacturers play a major role in this supply network as their location choices determine where a large share of value is created and where tariffs materialize.

2.4 Summary of theoretical and empirical insights

The literature reviewed in this chapter identified that strategic sourcing is a combination of firm-level configuration choices and a complex external environment. Academia has discussed how the supply concentration and trade rules may cause obstacles to supply chains. It directs the analysis toward sourcing configuration as the central decision variable in project-based businesses. Figure 11 simplifies how a supplier selection process might proceed.

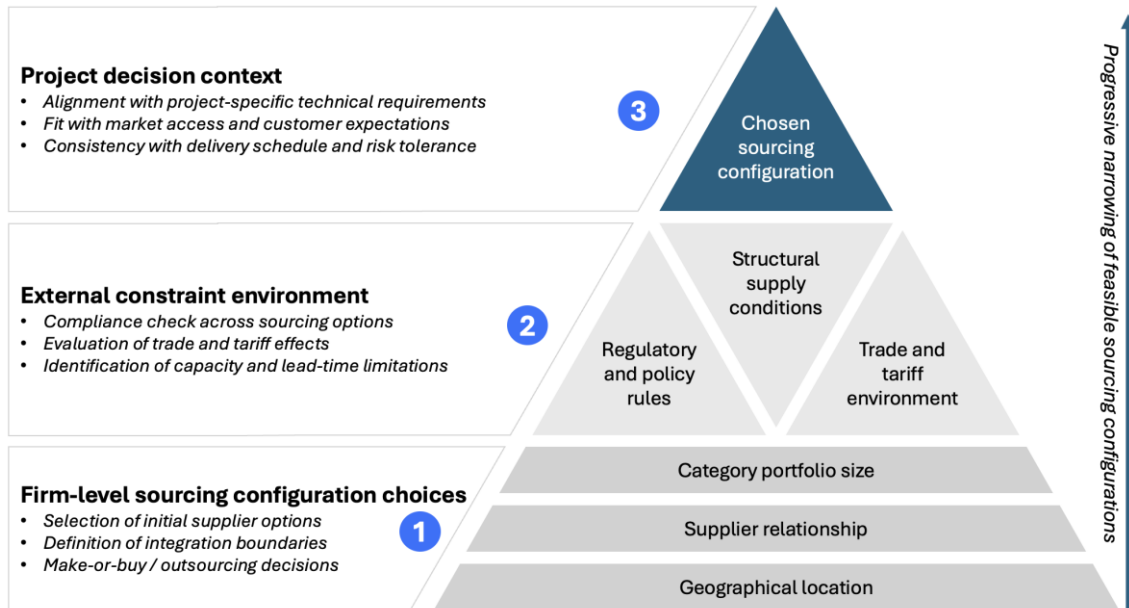


Figure 11. Levels of decision-making in BESS supplier selection

The figure explains progressive narrowing which can help to approach supplier selection in practice. The starting point in level **(1)** is when firms build their category strategy and establish the supplier portfolio base. At the second level **(2)**, suppliers are screened based on external factors. For example, tariffs and the target market may, at this stage, disqualify some suppliers for the project in question. From the remaining supplier options at the third level **(3)** the most suitable one is selected for each project individually. Various criteria may influence the final choice, namely project-specific technical requirements, the project's location, the customer's special specifications, the supplier's ability to deliver on time, and its capacity at the time of delivery.

Figure 12 presents the conceptual framework of the thesis and identifies sourcing configuration choices as the central decisions in the supply chain taken under trade and regulatory uncertainty. The figure aims to express the high-level business decisions around supply chain and how each may affect supply chain resilience, risk and cost.

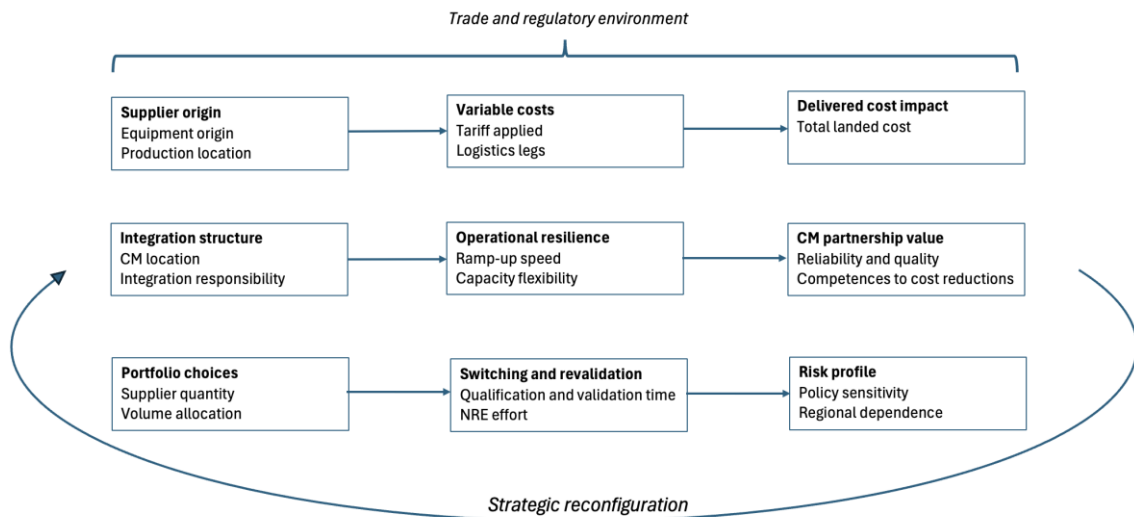


Figure 12. Conceptual framework linking sourcing configuration to total landed cost and supply risk.

Supplier origin defines where the initial point at which cost factors such as tariffs and logistics are introduced into the supply chain. Equipment origin and production location determine how tariffs and logistics routes enter the cost structure. These factors translate directly into variable costs, such as applied tariffs and transport complexity, which together form the delivered cost impact measured as total landed cost.

Integration structure choice set how the company can respond to changes in supply conditions. The location of contract manufacturing and the allocation of integration responsibility affect ramp-up speed and capacity flexibility. These factors define operational resilience, which is reflected in the value of CM partnerships through reliability, quality and their ability to contribute to cost reduction.

Portfolio choices determine how easily the configuration can be adjusted over time. Supplier quantity and volume allocation shape the effort needed for switching and revalidation. Switching a supplier means engineering adjustments, qualification and validation processes, and often non-recurring engineering (NRE) efforts like production line setup or investment in required tools. It also involves quality assurance and commercial validation, which together require time and additional resources. These factors define the

overall risk profile through policy sensitivity and regional dependence, which may lead firms to reconfigure their sourcing decisions under changing conditions.

3 Research methodology

This chapter describes the research design and methodological approach used to examine sourcing configurations in BESS supply chains. The research process and analytical workflow are summarized in Figure 13.

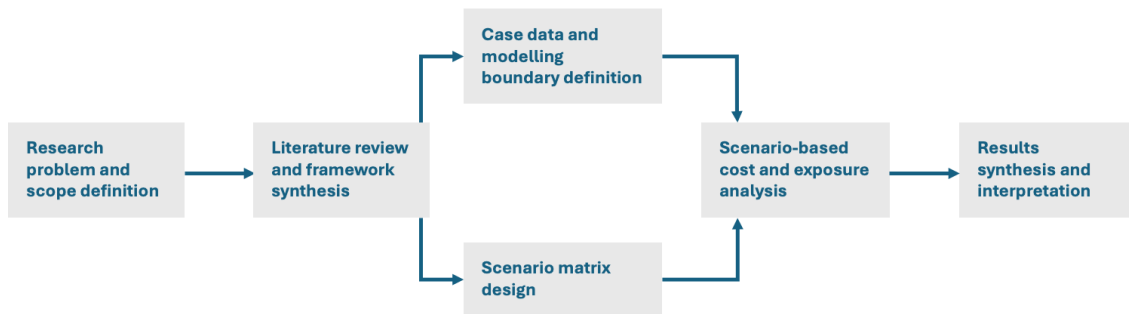


Figure 13. Research process and analytical workflow of the thesis.

The process begins with defining the research problem and scope. The literature review then informs the analytical framework that guides both the modelling boundary and the scenario design. In parallel, case data and modelling assumptions are specified and used to construct a scenario matrix that captures alternative sourcing configurations and policy conditions. These inputs are then combined in a scenario-based cost analysis. The results are synthesized and interpreted in relation to sourcing configuration choices and tariff-driven cost outcomes.

3.1 Research design and case study approach

This thesis adopts an embedded case study research design to examine how optional sourcing configurations scenarios influence total landed cost under conditions of trade uncertainty. The empirical setting is anchored in a single case company operating as a system integrator and BESS provider across multiple geographic markets. The purpose of the case study is not to describe the company itself, but to use its real-world decision context to analyze sourcing configuration choices that reflect challenges faced by firms engaged in global BESS delivery.

To transparently position the methodological choices of the study, the research design is built using the layered framework proposed by (Saunders et al., 2009). The framework clarifies how philosophical stance, research logic, strategy, time horizon and analytical techniques align with the research question.

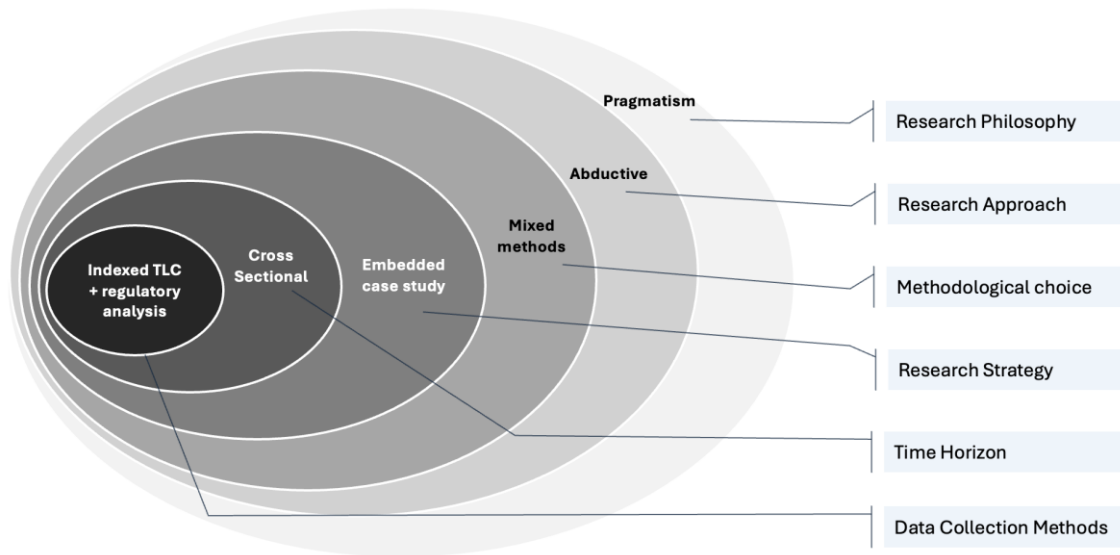


Figure 14. Methodological positioning of the study (adapted from Saunders et al., 2009).

At the level of research philosophy, the study adopts a pragmatic stance. The objective is not to develop abstract theory in isolation, but to evaluate how alternative sourcing configurations perform under real trade measures and incentive schemes. Knowledge is therefore assessed through its explanatory value in understanding cost formation within a case project context.

The research approach is abductive. Deductive reasoning is applied in constructing the TLC model based on established cost components, tariffs and supply chain configuration logic as explained in Chapter 2. Inductive elements are present in interpreting how scenarios interact with different institutional environments.

Methodologically the study combines quantitative and qualitative elements. Quantitative analysis is applied through indexed total landed cost modelling. Qualitative reasoning validates the definition of feasible configurations and the interpretation of results in

relation to managerial decision-making. Numerical modelling is used for explanatory purposes and does not aim at statistical inference.

The research strategy follows a single embedded case study design. Sourcing decisions in BESS projects are highly context-dependent and are made based on project-specific technical prerequisites and multi-tier supply chain. These limit the applicability of large-sample, statistically driven research designs and instead call for an in-depth explanatory approach. The selected case provides a bounded but realistic decision environment in which alternative sourcing configurations can be systematically compared. The configurations represent embedded units of analysis within the case and do not constitute abstract theoretical constructs.

The time horizon of the study is cross-sectional. The analysis focuses on tariff conditions observed in 2025. Temporal sensitivity is incorporated through scenario modelling of tariff escalation and policy shifts rather than through longitudinal data collection.

While prior studies have examined trade policy impacts or supply chain resilience at aggregate levels, fewer studies analyze how firms operationalize sourcing decisions at the project level with simultaneous cost and tariff pressure. By modelling concrete configuration alternatives within a defined project setting, the study contributes to bridging this gap.

3.2 Data sources

The primary empirical input consists of confidential cost data provided by the case company. The dataset reflects the cost structure of a BESS unit used in the reference case in this study. It includes itemized cost components at system level, covering battery modules, power conversion systems and other balance-of-plant equipment, system integration and engineering, logistics costs, and applicable tariff bases. The data represent commercial conditions relevant to 2025 and reflect the cost data available to the case company at the time of analysis.

Cost inputs were reviewed for internal consistency prior to modelling, including verification of component and logistics costs and that tariff bases correspond to declared import values. Values were converted into indexed form for analysis to protect commercially sensitive information while preserving relative differences between scenarios.

Public benchmark data are used solely for plausibility checks and are not integrated into the core calculations. Regional capital expenditure benchmarks from Wood Mackenzie serve as external reference points to validate the proportional weight of equipment cost within the overall system structure. These benchmarks function as comparative indicators and do not replace internal data.

Policy parameters and regulatory information are derived from public sources. The Investment Tax Credit applied in U.S. scenarios is based on publicly available summaries of the Inflation Reduction Act (US EPA, 2025). Tariff rates are treated as scenario inputs reflecting the selected 2025 policy snapshot.

Data triangulation is applied by combining three input categories: confidential internal cost data, publicly available industry benchmarks, and official policy and regulatory sources. Internal data provide project-level realism, benchmark data reinforce plausibility assessment, and policy sources ensure consistency in the application of tariff and incentive assumptions. Together these sources enhance the robustness of the analytical framework while maintaining transparency regarding data boundaries.

3.3 Analytical framework and TLC model

In supplier selection literature, total cost approaches are commonly distinguished between Total Cost of Ownership (TCO) and Total Landed Cost (TLC) frameworks (Pumpe & Vallée, 2017). TCO seeks to capture all quantifiable costs incurred over the full life cycle of a purchased asset, including pre-transaction, transaction and post-transaction costs. While comprehensive, TCO can be complex to operationalize when lifecycle elements extend over the direct scope of supplier configuration decisions. TLC represents a more

focused subset of TCO, concentrating on the costs associated with bringing a product through the supply chain to its point of delivery (Pumpe & Vallée, 2017).

In this study, TLC is defined as the delivered-to-site cost of a BESS project. It does not represent a lifecycle cost assessment. Operations and maintenance, degradation effects and end-of-life treatment are outside the defined boundary. TLC determines the CAPEX basis for project owner used in financial modelling and return assessment. From BESS integrator's point of view, it influences bid competitiveness of alternative sourcing sets.

Key fixed parameters are summarized in Table 2. These parameters define the reference project, system architecture, battery specification, cost boundary and reporting method. They remain constant across all scenarios to ensure comparability.

Category	Parameter	Assumption / Definition
Reference project	Project size	100 MW / 200 MWh
System architecture	BESS architecture	AC-block configuration
System architecture	BESS unit size	5 MWh unit
System duration	Energy-to-power ratio	2-hour system
Battery cell specification	Cell capacity	314 Ah
Cost boundary	Cost scope	Delivered system cost to site
Battery definition	Battery modules	Modules incl. module-level BMS
Non-battery equipment	Scope	PCS, enclosure, EMS, auxiliaries
Integration	Assembly responsibility	Integrator or contract manufacturer
Logistics stages	Transport steps	1) Supplier → integration 2) Integration → site
Tariff base	Tariff-sensitive components	Battery + non-battery equipment
Country of origin	COO assumption	COO follows cell manufacturing location
Policy incentives	Treatment	Included where applicable (e.g., IRA)
Output metrics	Reported results	TLC index; tariff deltas
Reporting method	Disclosure	Indexed results (baseline = 100)

Table 2. Key model parameters and assumptions.

Table 3 below distinguishes between fixed parameters and scenario variables.

Table 3. Scenario variables and fixed parameters in the TLC model.

Fixed parameters	Scenario variables
Project size and duration	Supplier locations
System architecture and unit size	Component prices
Battery cell specification	Tariff rates applied
Cost boundary (delivered-to-site)	Policy incentive eligibility
Reporting method (indexed results)	Logistics legs activated

For each scenario s , total landed cost is calculated using a consistent cost structure:

$$TLC^s = C_{BM}^s + C_{NBE+INT}^s + C_{LOG}^s + T^s - I^s \quad (2)$$

where:

- TLC^s = total landed cost for scenario s (delivered-to-site cost)
- C_{BM}^s = battery module cost in scenario s
- $C_{NBE+INT}^s$ = non-battery equipment and integration cost in scenario s
- C_{LOG}^s = total logistics cost in scenario s (stage 1 + stage 2)
- T^s = total tariff cost applied to tariff-sensitive components in scenario s
- I^s = total policy incentive value in scenario s (treated as a cost reduction)

The TLC model applies a consistent system scope and cost structure across all scenarios. Component and integration prices may vary by scenario to reflect realistic supplier and supply network alternatives for the US reference project.

Logistics costs are modelled in two stages to reflect the structural separation between battery sourcing and system integration. The same modelling logic is applied across scenarios to preserve internal consistency.

The tariff base includes battery modules and non-battery equipment. For example, if battery modules are manufactured in Country A and integrated in Country B before delivery to Country C, tariffs are applied when the tariff-sensitive components enter the importing jurisdiction according to the applicable scenario assumptions.

The country-of-origin rule follows the cell manufacturing location. If cells are manufactured in Country X, battery modules are treated as originating from Country X for tariff purposes, irrespective of subsequent module assembly location.

Policy incentives are modelled as explicit scenario parameters. In US scenarios, the IRA investment tax credit is applied as a reduction in eligible delivered cost components, following the public policy definition referenced in this study (US EPA, 2025). Incentives

are not embedded in equipment cost but represented separately to maintain transparency.

Cost outcomes are reported in indexed form to protect confidential data. A baseline scenario b is defined for the analysis and set equal to 100. All scenario results are expressed relative to that baseline:

$$Index_{TLC}^s = 100 \times \frac{TLC^s}{TLC^b} \quad (3)$$

where:

- $Index_{TLC}^s$ = total landed cost index for scenario s (baseline = 100)
- TLC^s = total landed cost for scenario s
- TLC^b = total landed cost for the baseline scenario b
- s = scenario identifier
- b = baseline scenario identifier

Indexing is analytically sufficient as the study evaluates relative differences between sourcing configurations and avoids reporting absolute price levels to preserve commercial confidentiality.

3.4 Reliability and validity of the study

Reliability is validated through a fixed and version-controlled model, and the total landed cost equation and cost boundary remain unchanged across scenarios. Scenario inputs are recorded systematically creating an audit trail that enables recalculation under identical assumptions.

Construct validity is addressed by linking each cost component to the supplier selection figure developed in Chapter 2. Battery module cost represents sourcing configuration at cell level. Non battery equipment and integration cost reflect system assembly flow. Tariff terms operationalize origin-based trade exposure. Incentive adjustments represent

institutional eligibility conditions. Logistics cost corresponds to spatial configuration and transport network.

Robustness is achieved through systematic checks of key assumptions. Internal battery cost shares were compared against published benchmark ranges to confirm plausibility. Key parameters such as tariff base definition and country of origin rule were reviewed to assess the stability of relative scenario outcomes.

The study relies on a single case company and one reference project, which limits statistical generalizability. The findings are therefore analytically generalizable to similar sourcing contexts but cannot be considered universally representative of all BESS markets or firms.

The results are bounded by the chosen supplier scope and trade conditions modelled in the scenarios. Changes in regulatory regimes, supplier configurations, or cost assumptions may alter quantitative outcomes. The analysis thereby limits its claims to the defined scenario parameters and offers a framework for evaluating sourcing decisions in comparable institutional and price circumstances.

4 Results and analysis

This chapter presents the empirical results of the scenario-based total landed cost (TLC) analysis. The chapter first defines the reference project and tariff environment before comparing alternative sourcing configurations. The analysis proceeds from empirical within-market evaluation to qualitative cross-market interpretation.

4.1 Overview of scenarios and baseline definition

All scenarios are assessed using the same TLC framework and system assumptions. Component and integration prices vary across scenarios to reflect realistic supplier and supply network choices for the U.S. reference project. The analysis assesses how tariffs and incentives, when included in the costs of local and import-based supply chain options, change which option is the most cost-effective way to deliver the system.

A baseline scenario is defined for consistent comparison. It represents a domestic U.S. supply configuration with applicable IRA incentives in 2025 and is normalized to an index value of 100. All other outcomes are reported relative to this reference.

The scenarios relate to a single U.S. project and compare domestic and import-based sourcing under tariff and incentive conditions observed in mid-2025 (Table 4). Tariff assumptions are applied consistently to tariff-sensitive cost components across cases.

Scenario	Tariff level	IRA treatment	Analytical role
US domestic with IRA	No import tariff	30% ITC	Baseline (100)
US domestic without IRA	No import tariff	No ITC	Incentive sensitivity
China (30.9%)	30.9%	Not eligible	Moderate tariff case
China (155.9%)	155.9%	Not eligible	Tariff stress case
Southeast Asia	22.0%	Not eligible	Diversified alternative

Table 4. Scenario settings for the U.S. TLC analysis.

4.2 Tariff sensitivity and temporal effects in 2025

The sourcing scenarios evaluated in this study are defined against a specific tariff environment. Because U.S. trade policy toward China evolved rapidly during 2025, it is necessary to clarify the effective tariff stack used in the model before presenting the configuration results. This section outlines the policy measures and their cumulative impact on China-origin battery imports.

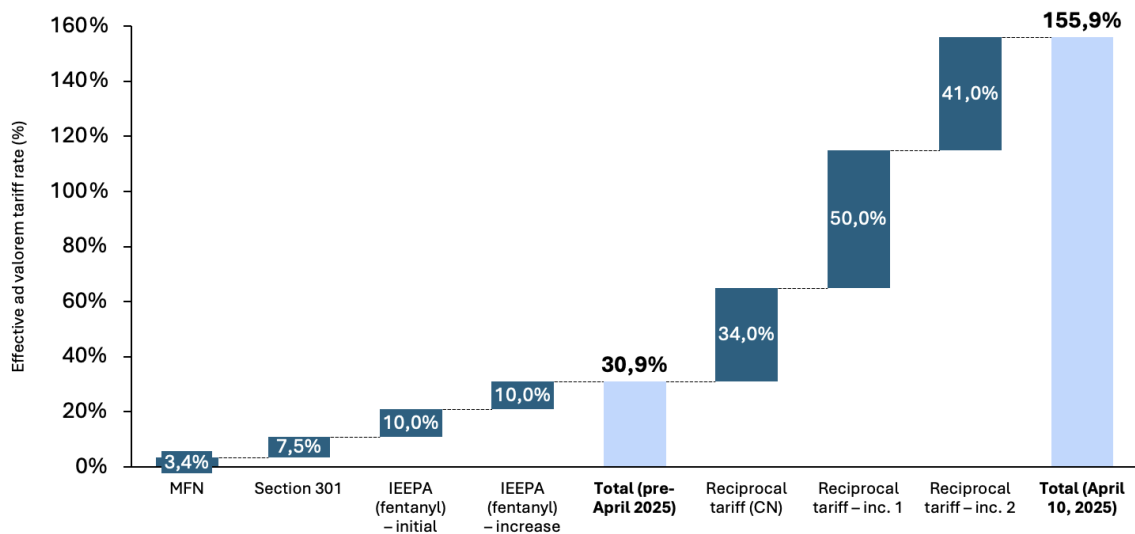


Figure 15. Evolution of stacked effective tariff layers applied to China-origin battery imports to the United States in 2025.

Figure 16 illustrates the stepwise escalation of tariff layers applied to China-origin BESS imports to the United States during 2025. The figure reconstructs the cumulative tariff stack used in the scenario model, combining most-favoured-nation (MFN) duties, Section 301 tariffs, fentanyl-related measures imposed under the International Emergency Economic Powers Act (IEEPA), and the reciprocal tariffs introduced under the “Liberation Day” trade actions. All increments shown are based on publicly documented policy actions by Congressional Research Service and their effective dates.

At the beginning of 2025, China-origin battery imports classified under HTSUS subheading 8507.60.0020 were subject to a 3.4 percent MFN duty together with an additional 7.5 percent Section 301 tariff (U.S. Customs and Border Protection, 2020). This combined

level formed the baseline that had already been internalized in sourcing decisions prior to the 2025 escalation.

On February 1, 2025, Executive Order 14195 introduced an additional 10 percent tariff on goods from China, effective February 4. This measure was explicitly linked to fentanyl-related policy objectives and applied broadly across product categories (CRS, 2025). On March 3, the same tariff was increased from 10 percent to 20 percent (CRS, 2025), raising the cumulative tariff burden within a short time frame.

The escalation continued in April 2025 with the introduction of reciprocal tariffs under the “Liberation Day” trade actions. Effective April 9, a 34 percent reciprocal tariff was imposed on goods from China. Within days, this rate was increased in two additional steps, first to 84 percent and then to 125 percent, with the final rate effective April 10 (CRS, 2025). In the scenario model these reciprocal measures are treated as incremental layers, allowing cumulative effect to be represented transparently.

When combined with MFN duties, Section 301 tariffs and fentanyl-related measures, the stacked effective tariff rate applied to China-origin battery imports reached approximately 155.9 percent by April 10, 2025. The lower 30.9 percent tariff scenario used in the model reflects the pre-reciprocal escalation snapshot, whereas the 155.9 percent scenario represents the peak tariff environment observed in April 2025.

Although the reciprocal tariff was later temporarily reduced, these adjustments occurred after the mid-2025 policy snapshot applied in the core analysis. The April escalation is therefore retained in the model as a representation of the upper bound of tariff exposure observed during the year. The logic for calculating stacked tariff effect follows the equation (1) presented earlier in the thesis.

4.3 Comparison of sourcing configurations

This section compares indexed total landed cost outcomes across alternative sourcing configurations for the US reference project under a mid-2025 policy snapshot. Results

are indexed to the baseline scenario, where US supply with IRA incentives is set to 100. The figure shows how cost competitiveness shifts when policy-driven cost components change.

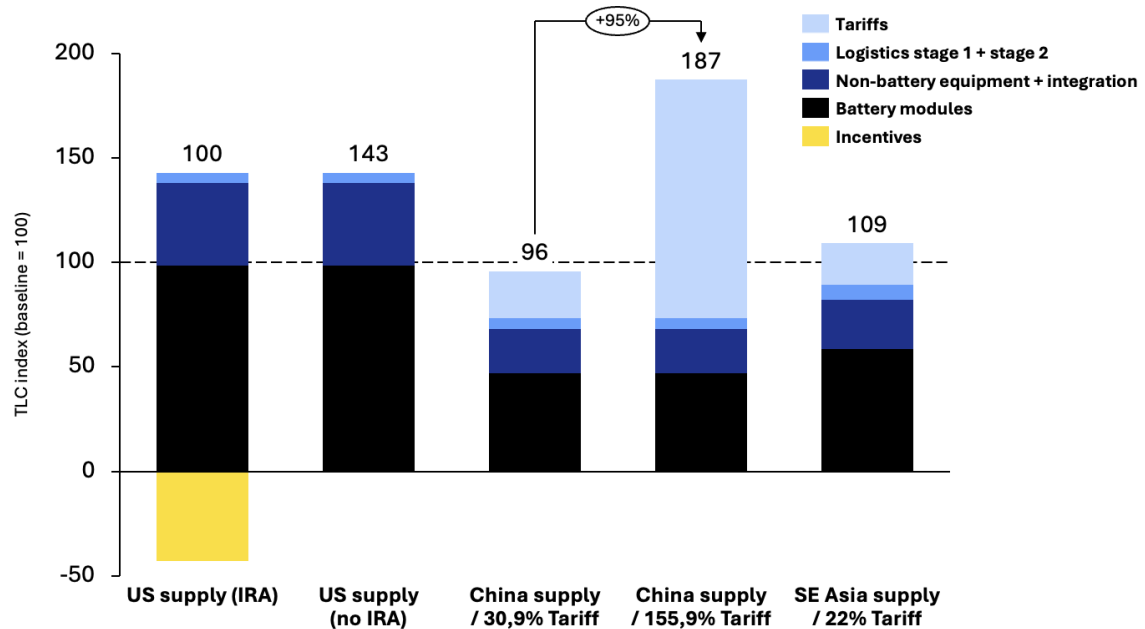


Figure 16. Indexed total landed cost across sourcing configurations for a U.S. based BESS project (baseline = 100).

At first glance the results reveal that identical system assumptions produce markedly different cost outcomes once sourcing configuration and policy regime vary. Under the lower tariff condition, China supply achieves the lowest total landed cost outcome (index 96). This indicates that when tariff pressure is moderate, import-based sourcing can remain cost-competitive relative to domestic supply even after accounting for logistics and integration. In this state, the cost advantage appears to be driven mainly by the underlying equipment and manufacturing cost structures.

The same China-oriented supply logic becomes highly exposed when tariff conditions change. Under the high-tariff scenario, China supply rises to an index of 187. This represents a 95% increase relative to the China (30.9% tariff) scenario within the same modelling boundary. The magnitude of this change is analytically important because it tells that tariff policy does not operate as a marginal adjustment. Tariff escalation clearly

dominates the cost structure and overwhelms other cost components. The cost outcome depends on political stability to a greater extent than it does on the implementation of the supply chain itself.

Domestic US supply performs very differently depending on whether IRA incentives apply. With IRA the US configuration is the baseline at 100. Without IRA the index rises to 143. This confirms that federal incentives are a central driver of project economics in the analyzed period. At the same time domestic manufacturing costs including component pricing and workforce expenses are overall higher than in Asian sourcing options. The IRA is modelled as a 30 percent investment tax credit based on the baseline level specified for qualifying energy storage projects (US EPA, 2025). Although the credit is realized by the project owner it also motivates sourcing strategy at integrator level. Developers may want to prioritize projects that can secure both baseline and bonus credits. Integrators that can demonstrate compliant domestic or allied supply chains aligned with domestic content and FEOC provisions are therefore better positioned in competitive tenders. The 30 percent credit represents a baseline assumption rather than the upper bound. Additional bonus credits may apply for domestic content energy community location and labour requirements under the IRA framework (US EPA, 2025). In qualifying cases the effective incentive can exceed 30 percent which would strengthen even more the relative competitiveness of domestic US supply.

The incentive dependency also links to supplier selection logic in Figure 11 developed earlier in the thesis. The domestic scenario with IRA implies that the whole supply network must satisfy eligibility policies that determine whether the incentive can be realized in practice, also compliance related to FEOC. A policy-aligned domestic configuration can be cost-competitive under incentives, but it may require a capability to form and evidence compliant sourcing options in a credible manner. Whether this is worth pursuing depends on how firms value exposure reduction versus implementation complexity.

The Southeast Asia scenario provides an intermediate outcome (index 109). This result suggests that Southeast Asia sourcing may reduce risk to extreme tariff escalation compared with China under the high-tariff condition, even it does not fully reach the cost

level of China under low-tariff conditions. From a sourcing strategy perspective this can be interpreted as a partial hedge. It potentially offers a “middle path” where tariff is lower than in the high-tariff China case, while the cost base remains closer to import economics than to domestic US supply without incentives. Whether Southeast Asia functions as a safe zone depends on how stable its tariff treatment remains.

All in all, the simulation shows that the choice of supply configuration indeed is a policy-dependent business case. Import-based strategies may be cheaper than domestic supply under reasonable tariff circumstances, but their advantage can vanish quickly if trade measures get tougher. Domestic arrangements gain competitiveness mainly through incentive alignment, which requires proven compliance and continued political support. The case of Southeast Asia shows that partial geographical restructuring can reduce extreme tariff vulnerability without fully replicating the benefits of domestic alignment. A key insight for BESS integrators is that total costs are inseparable from the regulatory and trading environment in which sourcing decisions are made as visualized in conceptual framework of the thesis (Figure 12). BESS manufacturing option that appears cost-efficient under one policy regime may lose its advantage if tariffs escalate or incentives change. Strategic procurement in this regard calls for balancing the base level costs of equipment, tariff vulnerabilities, and incentive eligibility in a coherent delivery configuration, while avoiding over-optimizing individual cost components in isolation.

4.4 Cross-market comparison

The TLC results identifies that sourcing network configuration determines cost outcomes under a given policy regime, but performance in a single U.S. reference case does not alone resolve the strategic question facing BESS integrators. Sourcing strategies must also function across markets that differ in tariff treatment and institutional predictability.

This section extends the TLC analysis by evaluating strategic sourcing configurations across the United States the European Union and Australia. The structural logic presented in Figure 17 separates battery sourcing, CM assembly and end market to clarify where tariffs, logistics and compliance requirements arise. The representation builds on

generalized configuration settings for stress testing and adapting supply chain designs proposed by Ivanov (2025), but is adapted to reflect simplified BESS supply chains.

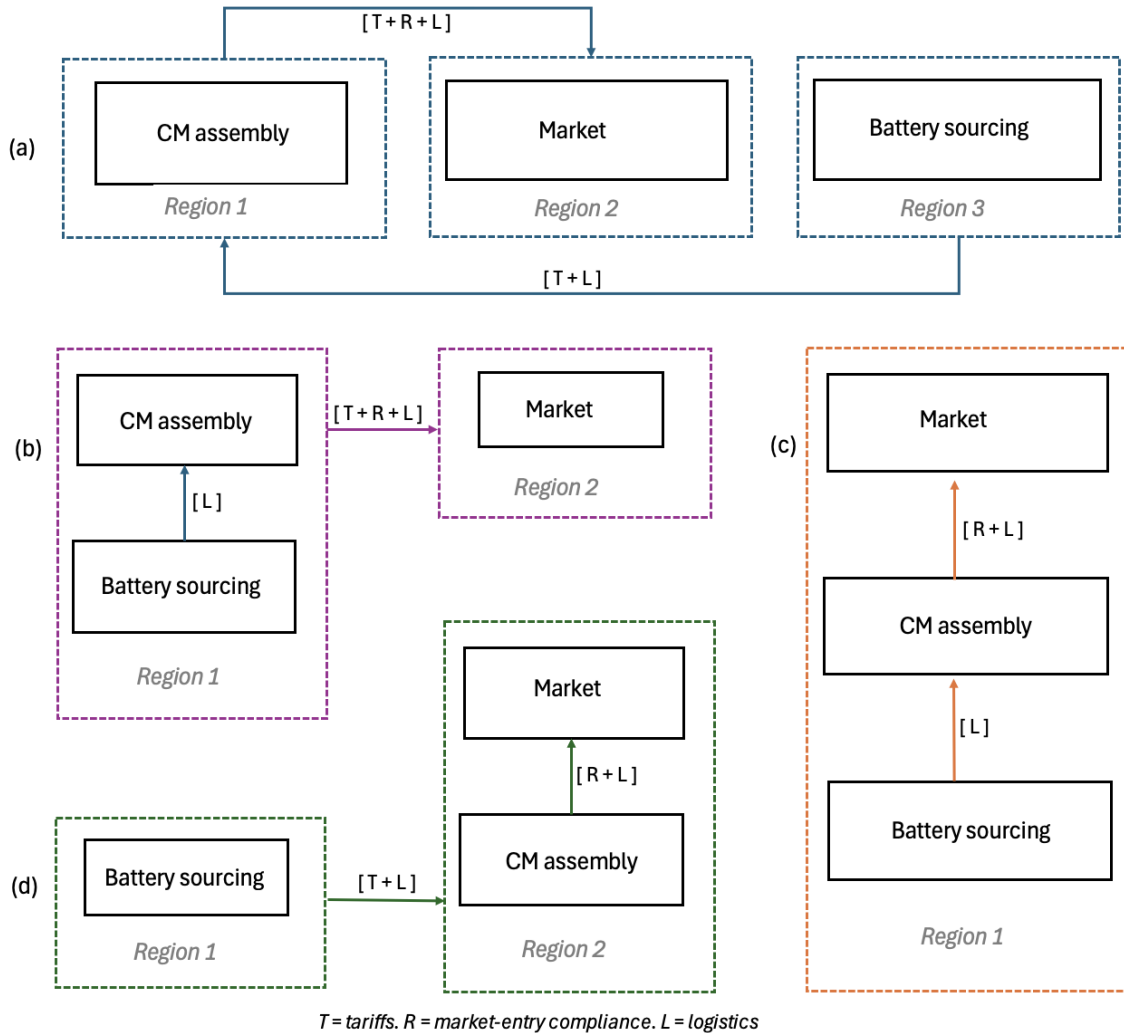


Figure 17. Structural sourcing configurations for BESS supply chains.

Figure 17 defines four structural configurations. Configuration (a) separates battery sourcing, CM assembly and market delivery across three jurisdictions. Configuration (b) co-locates battery sourcing and integration and exports the finished system. Configuration (c) represents full localization within one jurisdiction. Configuration (d) imports batteries while integration and delivery remain domestic. Each configuration allocates dependency differently between battery origin, integration location and deployment market.

Table 5 summarizes how each configuration could possibly interact with the regulatory and trade regimes of the United States, the European Union and Australia.

Market	Global (a)	Mixed (b/d)	Full Localization (c)
USA	Highly sensitive to tariff escalation Risk of losing IRA eligibility Cost advantage if tariffs remain stable	Battery origin determines incentive access Partial insulation from single-policy shock Flexibility in integration location	Supports IRA compliance positioning Reduces trade-related cost volatility Constrained by high battery pricing
EU	Increased documentation and traceability effort Flexibility to access global cell supply	Compliance managed at single entry stage Balances import access and EU integration	Simplifies CE and battery passport management Limited by EU cell production scale
AUS	Tariff-free imports possible under ChAFTA rules Competitive with efficient logistics and favorable tariff classification	Allows domestic integration capability building Distributes logistics and sourcing risk	Simplifies customs treatment and compliance Limited by absence of domestic cell base

Table 5. Strategic implications of sourcing configurations across markets.

Across all three markets the central strategic issue concerns how dependency between battery suppliers and contract manufacturers is distributed and how readily that arrangement can be adjusted. Theory on portfolio design in the literature review raised that concentrated portfolios would enable deeper coordination and relationship-specific investment but increase sensitivity to regional or policy shifts. Diversified portfolios instead distribute origin risk but require additional onboarding effort.

Switching battery suppliers or CMs is not a straight-forward step, because it requires careful transfer of design files, training of assembly personnel and alignment of quality management systems. In some cases, non-recurring investment is needed to launch or

adapt production. Contractual arrangements and capacity commitments also play a role in how quickly reconfiguration can be implemented.

The comparison reveals the fact that the supply strategy for BESS integrators goes beyond finding the lowest equipment bid price. Battery origin, integration process and regulatory alignment must be considered jointly. Companies shall also account for the practical limits of flexibility when trade or policy conditions change. The configurations in Figure 17 therefore represent alternative allocations of dependency and adaptability within project-based BESS supply chains.

4.5 Synthesis of empirical findings

In the scenario analysis it is identified that the origin of the battery, the location of contract manufacturing, and the market supply structure collectively influence total cost. The tariff escalation in 2025 underscores that these relationships are dynamic. Relative cost positions can shift within a short period when policy conditions change as seen especially in the tariff changes between United States and China. Similar changes may occur in any other end market as well which encourages BESS integrators to be proactively prepared to adjust the supply flows. TLC analysis therefore captures more than component pricing and transport in the project profitability evaluation as it reflects institutional impacts like renewable energy related incentive availability which are embedded in the sourcing architecture itself. The observations align with the theoretical framework (Figure 12) by showing how procurement choices can trigger cost-shifting mechanisms.

The cross-market perspective adds that identical configurations carry different strategic consequences in the United States, the European Union and Australia. IRA eligibility and FEOC provisions connect battery origin directly to project qualification and commercial attractiveness in the U.S. For components delivered to European market, CE marking and battery passport requirements elevate traceability and compliance capability to central considerations. NEM participation rules and SOCI obligations define the regulatory boundary within an import-reliant BESS for Australian market.

5 Conclusions

Overall electricity demand growth projections make BESS a critical equipment to maintain grid stability due to continuous RES additions. Traditionally used to support the integration and ancillary services of energy supply assets, the technology has recently been recognized as a necessary element also in hyperscale data centers that control artificial intelligence and machine learning workloads.

This thesis adds to existing sourcing literature by examining BESS supply chains through total landed cost modelling during a rare period of tariff escalation. It was conducted as a case study and analyzed how different BESS sourcing configurations for battery suppliers and contract manufacturing partners can affect total landed cost (TLC) and feasibility in uncertain market conditions. For these two categories of suppliers, possible supply chain options in the US, EU, and AUS energy storage markets was proposed and evaluated, and the potential outcomes of import-based and partially or fully locally sourced strategies are assessed as one of the thesis objectives.

Lowered trade barriers in recent decades have generally encouraged firms to distribute their production across the globe. International supply flows for global BESS projects are normal, but the combination of tightened policies and concentrated lithium-ion battery production in China has brought headwinds to industry. Despite growing interest in supply chain resilience, limited research examines sourcing strategies for BESS supply chains or evaluates their costs using real-world TLC modelling under rare tariff escalation events such as those observed in 2025. This study contributes to both academia and industry by connecting sourcing theory with empirical TLC modelling in a policy-driven BESS supply chain context.

The literature review covered both industry developments and academic research relevant to sourcing decisions in BESS supply chains. Industry, legal and consultancy reports were used to describe market dynamics and recent developments in the energy storage sector. Academic studies provided the theoretical foundation, especially research on strategic sourcing, supplier portfolio strategy and differences in supplier relationship

intensity. The additional literature discussed the use contract manufacturers and common outsourcing and supply chain concentration strategies. The conceptual framework of the thesis then integrates supplier portfolio and strategic sourcing theory from the literature and connects these ideas to cost and resilience consequences and guides the empirical part of the study.

Supplier portfolio and strategic sourcing theories brought up important points when evaluating firms supply chain readiness. First of all, it has been identified that long-term supplier relationships enable faster recovery from sudden disruptions such as tariff escalations. A comparison of supply chain strategies for single and multiple suppliers revealed that both have their advantages in specific situations. Single sourcing can reduce costs of maintaining many supplier accounts while it holds high dependency risk. To stay prepared for supply chain disruptions, one possible risk mitigation strategy proposed by Monczka (2009) would be selecting a single source with various globally distributed production facilities. For most critical BESS components with high spend, single sourcing can offer chance for deep coordination on operations and quality as well as trust building. However, more dispersed supplier portfolios, in turn, can open up access to multiple sources of information that can promote innovation and reduce the dependency risk aspect. Keeping in mind the fact that management of larger portfolio of “alliance” level suppliers requires more firm-specific resource capabilities compared to non-strategic transactions, as presented in Figure 9 earlier in the thesis. Building deeper partnerships can bring significant benefits, especially via using contract manufacturers, who can bring their engineering expertise to product development. Christopher & Peck (2004, p. 16) puts it:

“Choose supply chain strategies that keep several options open. This may not be the lowest cost course of action in the short term but may provide an opportunity to reduce the impact of a disruption if and when it occurs.”

The effects of a well-functioning supply chain can have an impact outside of operational performance, for better or for worse. Poor planning in equipment deliveries can weaken a company's attractiveness from an investor's perspective if they see it as a risk to

performance reliability. For example Hendricks & Singhal (2003) analyzed 519 supply chain disruption announcements which reported an average abnormal stock market decline of around 11 percent for affected firms. The negative reaction in their analysis was consistent across time and largely independent of the specific cause of disruption, with smaller firms experienced stronger adverse effects. These findings suggest that capital markets interpret supply chain instability as a signal of more serious vulnerability and encourages firms overall to adjust their supply networks proactively. In energy storage projects specifically, tariff pass-through and risk-sharing clauses are emerging as practical ways to allocate unexpected trade-related cost increases between suppliers, contractors and developers to allow projects to proceed even when tariff conditions change (Alice & Weaver, 2025).

Sourcing strategy defines where dependency resides and how flexibility is preserved under uncertainty. In the times of active industrial policy and shifting trade regimes, this design choice sits at the intersection of operations, finance and corporate strategy. The ability to align sourcing with long-term positioning may therefore prove as important as technological performance or cost efficiency in keeping up sustained competitiveness.

5.1 Findings

The TLC analysis results for a reference project in the United States practically show how strongly the BESS sourcing choices can be linked to external trade policy and incentive conditions and lead to corresponding delivered-to-site cost. The focus parameters of the analysis were tariff and incentive effect but also the value of equipment and assembly for each scenario. The comparison answers to main research question by showing how alternative delivery scenarios affect cost outcomes and by presenting four sourcing configuration options.

Configuration	Cost	Risk	Feasibility
Global (China)	Low → very high (tariffs)	High	High, policy-dependent
Mixed (SE Asia)	Medium	Medium	Flexible
Domestic (U.S.)	High → competitive (IRA)	Low	Incentive-dependent
Localized	High	Very low	Capacity-limited

Table 6. Sourcing strategy comparison.

Import-based supply was competitive when tariff levels remained moderate but strong tariff volatility in U.S. almost doubled the TLC value from China. The tariff hike thus neutralized the otherwise cost competitive supply chain. This example showed how international trade obligations may impose a massive expense on enterprises that do business across several geographic regions. It also reflect the argument presented by Christopher & Peck (2004), that firms who rely on single source strategy, in this case for any of key BESS components, would be more vulnerable to being affected by disruptions due to lack of resilience capability. Dual- or multi-sourcing strategies allow firms to maintain alternative battery or contract manufacturing suppliers and enable adjustments to supply chain configurations according to project location and prevailing policy conditions. In other words, this flexibility would allow firms to shift volumes between supplier locations or contract manufacturers if tariff or regulatory requirements change. This kind of phenomenon has recently been observed as industrial companies across sectors have reacted to disruptions through diversifying to low-cost and geopolitically neutral countries in hope for more stable price levels (BCG, 2025). Therefore, the SE Asian supply chain presented in the TLC model could be considered such strategy. Managing multiple suppliers increases the coordination workload and costs, but Elmaghraby (2000) explains that allocating production to more than one supplier can reduce information rents and encourage suppliers to quote more competitive bids. This would suggest that a broader supplier portfolio could offer chance for lower pricing while maintaining alternative supplier options.

Domestic supply in this particular case project gained a clear advantage when policy incentives applied, and eligibility requirements were satisfied. However, the TLC results

showed that domestic supply in the U.S. still faced relatively high manufacturing and component costs thus included major price premium without IRA applied. When evaluating this from BESS integrators point of view, it is worth to understand that U.S. based customers may value whether systems comply with IRA and FEOC requirements, as eligibility for these incentives enables them access to domestic tax benefits. So, pursuing a U.S. domestic supply network therefore represents a strategic choice that can provide a competitive advantage while the incentives remain active, but its value may diminish if the incentives are removed or reduced.

To clarify these dynamics, the study proposes four sourcing options that represent different combinations of global and local supply arrangements between battery source and integration partner location, before transporting BESS containers to customer. The synthesis summarized key conditions for each arrangement for the United States, the European Union and Australia. In the U.S., tariff risk and IRA eligibility dominate. In the EU, traceability and regulatory compliance influence feasibility. In Australia, sourcing conditions are driven by logistics efficiency and by trade frameworks that enable low-tariff imports through FTAs and tariff concessions. A sourcing structure optimized for one market may underperform in another. A common bottleneck is that battery production in these three regions remains limited compared to the global market dominated by China. Even though the regions might have new “gigafactories” in plans, there is a risk that these countries would suffer from battery material shortages also in the future.

Any changes made to the battery, PCS, CM or other critical suppliers in the BESS supply chain require planning and preparation to succeed in ramp-up. Supplier qualification, technical validation, and contract changes must be completed before production can be transferred between partners. BESS supply networks have the flexibility to do this, but it requires careful supplier portfolio management as shown in conceptual framework. A concept of cross-sourcing can be beneficial in which the selected suppliers are capable of contributing to more than one part of production process and each can act as a backup for one another (Monczka, 2009). For example, an integrator may rely on multiple suppliers with similar manufacturing capabilities, enabling one supplier to take over production tasks if another faces disruptions. A concentrated supplier base can lead to deeper

technical coordination and reliable supplier relationships. More diverse portfolios spread risks across different regions and suppliers, but they require more resources and coordination.

5.2 Managerial implications

The results point to three managerial recommendations that could be useful to stakeholders in the field.

Companies operating in tariff-exposed markets should regularly test how alternative sourcing configurations affect project-level CAPEX under different policy scenarios. Both McKinsey and the European Commission have emphasized the value of stress testing as a tool for identifying supply chain vulnerabilities under geopolitical and regulatory uncertainty (Dumont & Varela-Irímia, 2024; McKinsey & Company, 2020). The TLC results show that tariff escalation can rapidly change cost competitiveness, which means sourcing strategies should be evaluated through scenario-based stress tests before major supplier commitments or project bids. These stress tests should specifically evaluate tariff escalation, incentive withdrawal and alternative supplier locations to better understand how sourcing configurations perform.

The findings highlight the strategic role of contract manufacturers in BESS supply chains and that switching them is rarely immediate because new partners must complete qualification, engineering validation and other critical steps before mass production ramp-up could start. Monczka (2009) explains that formally designating suppliers as strategic partners allows deeper information sharing and continuous improvement. As cited by Monczka (2009), supply management expert Dave Nelson described this effect by noting that strong supplier relationships can mobilize “10,000 additional brains” working on product improvement and cost savings. BESS integrators who rely at least partially on CMs in their business operations should therefore establish long-term partnerships with selected ones while either working with a CM that has production facilities across multiple countries or maintaining at least one validated alternative CM in another region.

When multiple CMs are used, this also enables continuous benchmarking of cost levels and performance between suppliers.

Supply management decisions should be integrated into broader market strategy. Monczka (2009) explains that effective supply strategies emerge when corporate objectives cascade into aligned supply management and commodity-level decisions through cross-functional planning. As analyzed in the thesis, the principles underlying each supply chain design differs across the United States, the European Union and Australia. For this reason, sourcing decisions should not be handled only within supply management teams. BESS integrators entering new markets should evaluate battery origin and contract manufacturing location jointly between supply management, engineering, legal and strategy teams. This type of coordination allows firms to align supplier selection together with most optimal manufacturing location to comply with wide range of requirements and to match long term goals.

5.3 Limitations of the study

This study should be interpreted considering few limitations that arise from its methodological choices and empirical scope. These limitations do not invalidate the findings but define the context in which they should be understood.

First, the analysis is based on a single case study. The modelling framework and the total landed cost scenarios were developed using confidential data from case company. While this provides realistic cost structures and practical insights, it also limits the ability to generalize the findings across the entire industry. This may influence the results because the cost structure and sourcing practices reflect the specific conditions of the case company.

Second, the total landed cost model focuses on delivered-to-site cost rather than full lifecycle economics. For example, battery degradation, financing costs and O&M were intentionally excluded in order to break down the cost risks only related to supply chain. This may influence the results because some technologies or suppliers that appear cost

competitive at delivery stage could differ when long-term operational costs are considered.

Third, the policy scenarios represent simplified snapshots of observed regulatory environment. Tariffs or incentives such as IRA are subject to political change and administrative interpretation. The modelling approach assumes defined tariff levels and a baseline investment tax credit of 30 percent. These factors must be taken into account, as changes in tariffs or incentive programs will change the relative cost competitiveness.

Lastly, the thesis focuses primarily on batteries and contract manufacturing categories. Other BESS balance-of-plant equipment were not analyzed with the same level of detail. These elements may also influence sourcing feasibility and project cost, particularly if supply chains for these components face similar trade and regulatory challenges.

5.4 Suggestions for future research

1. Extending sourcing analysis to lifecycle cost metrics

Future research could extend sourcing analysis from delivered project cost to broader economic metrics such as total cost of ownership (TCO) or the levelized cost of storage (LCOS). A comparative modelling approach could evaluate how different sourcing configurations affect long-term costs by incorporating degradation behavior and O&M costs. This would allow assessing whether sourcing options that are cost competitive at delivery stage remain optimal over the full project lifecycle, addressing the limitation of this study focusing only on delivered-to-site cost.

2. Sourcing strategies in data center-integrated BESS projects

Future research could investigate how the emergence of BESS projects connected to data centers will change sourcing strategies compared to more traditional applications. A multi-case study design in selected regions could analyze how integrators focusing on data center connected BESS market possibly adjust their supplier portfolios. Focus could be placed on how strict reliability and uptime expectations influence system configuration choices, and consequently supplier strategies and costs.

3. Sensitivity analysis of battery costs under policy and raw material volatility

In January 2026, China's State Council Information Office announced the removal of certain export tax rebates related to battery products, which is likely to increase the cost base of Chinese battery suppliers and lead to higher battery prices that feed directly into project CAPEX for BESS developers (China's State Council Information Office, 2026). At the same time, battery prices are influenced by volatility in lithium and other critical materials captured in the Raw Material Index (RMI). Future studies could quantify how these factors affect battery costs and evaluate how different sourcing strategies could respond.

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