Guidelines to implement battery energy storage systems under public-private partnership structures

January 2023

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EXECUTIVE SUMMARY

Battery storage projects in developing countries

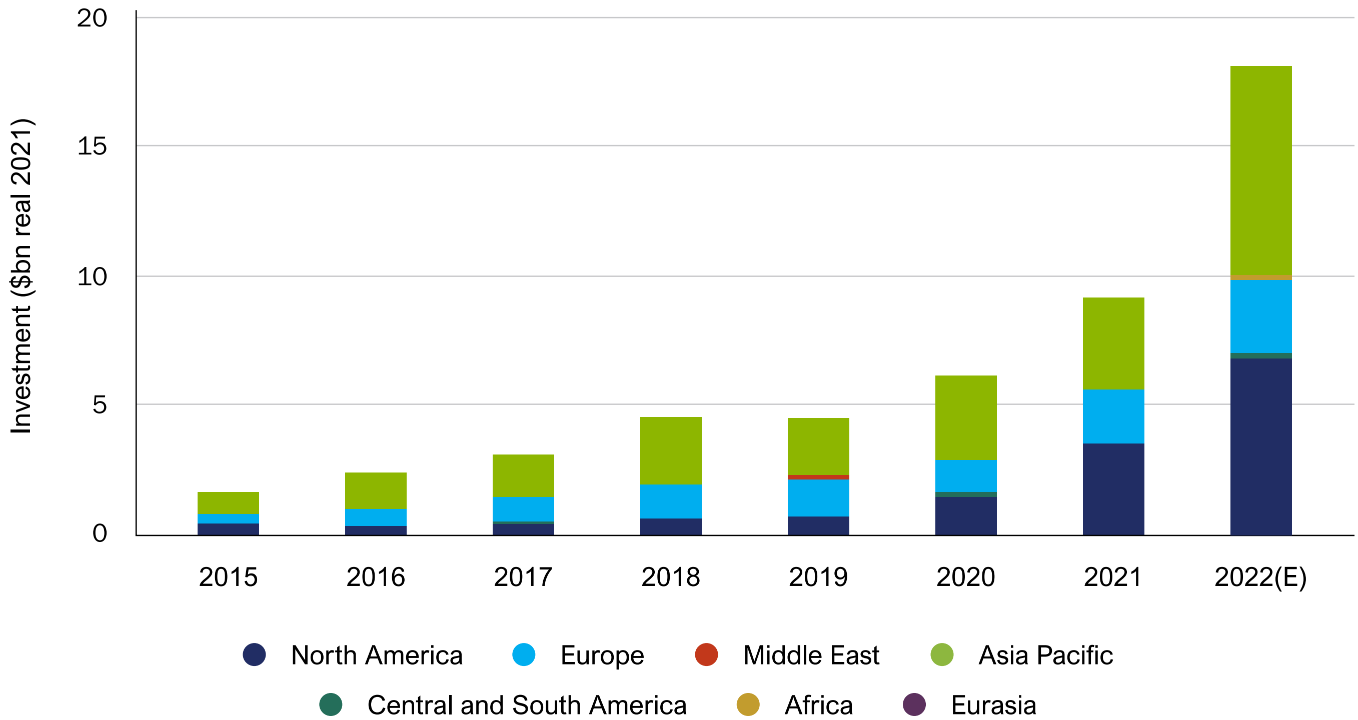
In recent years, the role of battery storage in the electricity sector globally has grown rapidly. Before the Covid-19 pandemic, more than 3 GW of battery storage capacity was being commissioned each year. About half of these additions were utility-scale 'front-of-meter' projects; the remaining half being 'behind-the-meter' projects addressing individual customer requirements. The growth in the role of the technology has been supported by rapid cost reductions: the cost of lithium-ion battery packs has fallen by 90% since 2010, reaching 150 $/kWh in 2019.

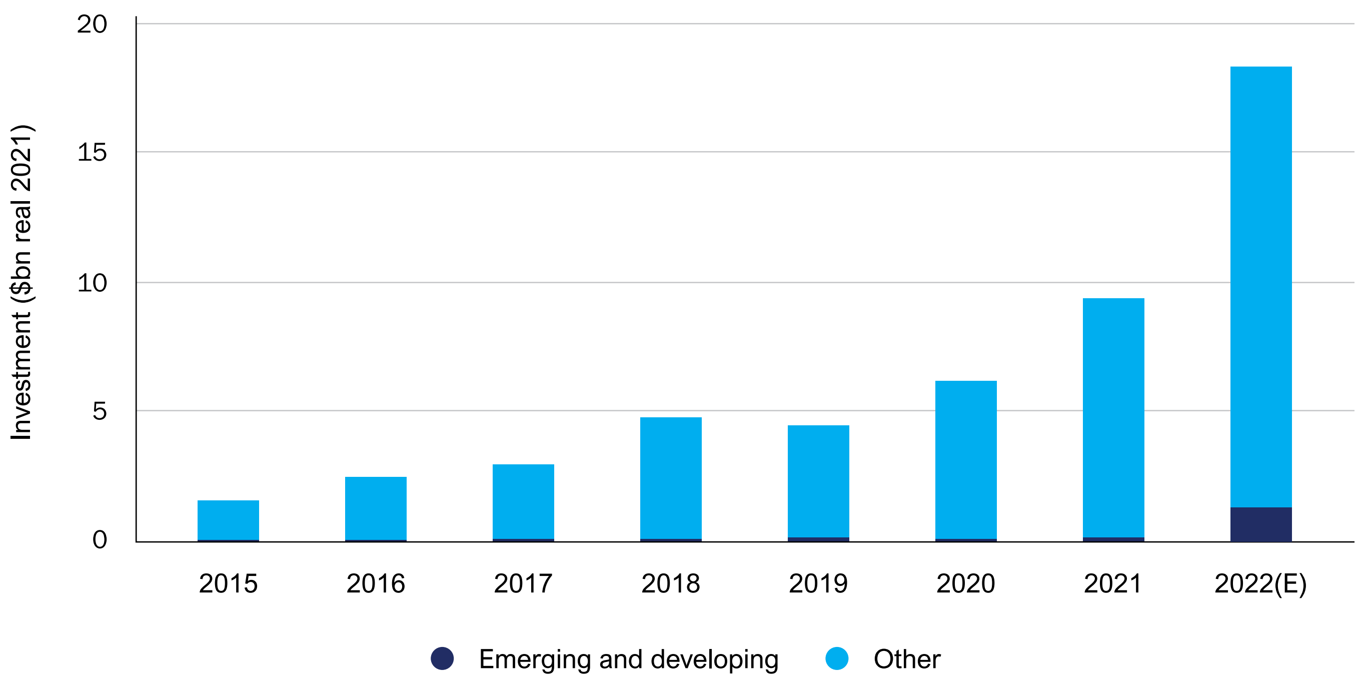
However, these projects have mostly been commissioned in developed countries, despite it being clear that batteries can deliver substantial benefits in less developed countries. As shown in the figure on the next page, almost all investment in battery energy storage systems (BESS) in recent years has been in high- and middle-income countries. This is even though there are multiple reasons why BESS might be especially beneficial in less developed countries:

- Reliance on expensive liquid fuels means that BESS could sometimes be an economically attractive alternative to expensive peaker capacity, a use case that is still rarely viable in more developed countries where less expensive peak generation capacity is often available.
- The smaller size of electricity systems in some less developed countries means that renewable penetration could reach high levels (in percentage terms) at an earlier stage in some cases. This can result in an increased demand for fast-responding technology to maintain grid stability as grid inertia falls.
- Less resilient grid infrastructure can also mean that there are more opportunities to use BESS to relieve existing network constraints or to defer investment in grid capacity upgrades.

This is at least partly because of the complexity of the asset class. Whereas the use case for a typical power generation project is clear (i.e., to generate electricity), batteries can be used to meet many different needs. This is part of the technology's appeal, but it also adds to complexity in project development. In developed countries, markets often already exist for many of the services that a battery can provide (e.g., frequency response and other ancillary services). In less developed markets, such markets do not normally exist. PPP structures to overcome these barriers have not yet been widely deployed. The objective of this report is to provide guidance on how such structures could be implemented to grow the role of BESS in developing countries.

INVESTMENT IN GRID-SCALE BATTERY STORAGE 2015–2022





Source: IEA World Energy Investment 2022

Implementing battery storage PPPs in developing countries

BESS projects can be categorized into 'types' that are commercially similar. When implementing a BESS PPP, it is useful to consider the factors that will be important in driving the commercial structure of the PPP agreement. The primary driver of this structure is likely to be the intended use case (i.e., how the BESS will be used, and to achieve what benefits), but it will also be important to consider whether a BESS is 'stand-alone', or whether a 'hybrid' project is being developed, where BESS is combined with a solar PV or wind generation project. When analyzing the options for implementation of PPP projects using BESS, three 'types' of project can be identified:

1. **Bulk energy shifting,** which includes the provision of peak power and arbitrage opportunities.

2. **Network and system services,** which includes both grid infrastructure services and ancillary services. These are grouped together as they are commercially similar in nature. Some of these services will be location-specific, others not.

   Note that these first two types of project are focused on stand-alone BESS projects. In some cases, BESS projects will involve multiple use cases that may overlap between the two project types.

3. **Hybrid projects,** which would cover projects paired with solar PV or wind generation. Note that this category is focused on projects where the BESS is explicitly used to ensure that the VRE generator meets certain requirements (such as a maximum ramping requirement, or limited dispatch ability). Projects where the BESS is co-located but is essentially providing services that are independent from the VRE, would normally be covered under one of the first two categories.

Note that 'behind-the-meter' projects are not covered by these categories as this type of project is likely to be agreed between two private sector parties, rather than being implemented as a PPP. It is important to note that the project 'types' are not intended to provide a complete or mutually exclusive list of use cases. Rather, the project types aim to categorize projects to reflect the different commercial characteristics likely to be reflected in PPP agreements. However, the use case categories do in most cases map well to these project types, as shown in the table on page 4.

This complexity means that it is important to be clear on the type of project being proposed from the outset. How the BESS is to be used will impact the technical design of the project, the benefits that it will deliver, and the commercial arrangements to be agreed between the parties, so it is important to be clear on the project's objectives, and the specification required to meet those objectives as soon as the project opportunity is identified.

OVERVIEW OF BATTERY USE CASES WITHIN EACH PROJECT TYPE

Bulk energy shifting	Network and system services	Hybrid projects
• Firm capacity • Balancing/shifting load over different timescales	• Voltage control and other locational services • Frequency control • Black start • T&D deferral or avoidance • Grid congestion relief	• Smoothing/VRE ramp control • VRE forecast error correction • VRE generation time shift

Technical analysis will be required both to validate the business case for the BESS and to ensure it is technically feasible. As with any other new energy resource being added to the grid, analysis will be required to ensure that project does not adversely affect the grid in any way, and that it complies with technical regulatory requirements, such as adherence to the Grid Code. Technical modelling might also be required to assemble an evidence base to validate the business case for the project. This analysis will need to be tailored to the type of project being proposed, focusing on validating the specific benefits being targeted by the project. Some of the key technical considerations when evaluating the business case for each type of project are summarized in the table on page 5.

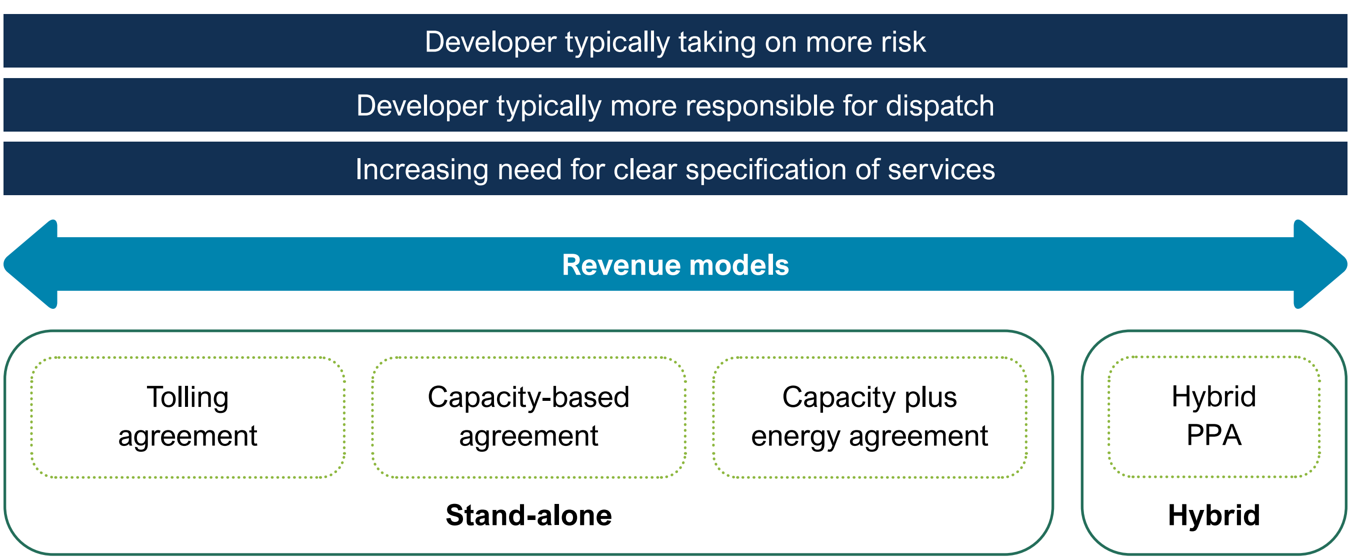
The commercial terms for a BESS PPP will also depend on the type of project being implemented. Each type of agreement will result in slightly different risk allocation between the parties. The four types of agreement that are explored in this guidance are:

- A **"tolling" agreement**, where the buyer pays a tolling fee to access the capacity provided by the BESS project and is also responsible for delivering and paying energy to the BESS asset for charging.
- A **capacity-based agreement**, where the buyer pays a capacity or availability fee. The agreement will set out what the purchase of capacity entitles the off-taker to, i.e., whether this is limited to the provision of certain services.
- A **capacity plus energy agreement**, where the buyer pays both a capacity and an energy fee. This might be appropriate if the project is responsible for paying for energy to charge the battery — in this case the round-trip energy losses essentially become a variable cost to be passed through to the offtaker via an energy fee.
- A **"hybrid" PPA**, which is an extended renewable energy PPA to accommodate a hybrid project combining a VRE generator with a BESS installation. Such a PPA might simply pay for metered energy output (as with a typical stand-alone VRE project), but impose conditions on the project, such as ramping limits or limited dispatchability during certain periods. The seller will typically reflect the additional cost of the BESS in the energy fee paid for metered output, either through the energy fee itself being higher or through a separate 'adder' to the energy fee. Alternatively, the hybrid PPA might include a time-of-use tariff structure; rather than imposing technical requirements on the project, the tariff structure provides an incentive to bidders to shift generation output to peak times.

FOCUS OF TECHNICAL ANALYSIS TO INPUT TO COST-BENEFIT ANALYSIS

	Data from the technical analysis that can be used in building the business case for BESS
Bulk energy shifting	Technical analysis needs to ensure that the proposed BESS design is fit-for-purpose in providing the required energy shifting. The modelling should help to validate that the proposed sizing of the battery is appropriate. For example, does the dispatch modelling show the battery always available to provide a peaking service, or would a longer duration battery be required. This analysis will also help with quantifying the extent to which the project displaces the need for other peaking capacity (if at all).
Network and system services	When evaluating the business case for system services, the technical analysis performed should evaluate the BESS's capabilities in providing the service. The analysis should consider whether the BESS provides the service as well (or, likely, better) than the existing provider of the service, if the service is being provided. If there are limitations in the BESS's ability to provide the service, can these be managed by locating the BESS somewhere else, or by refining the technical design of the installation?
Hybrid projects	Technical analysis of the project should be focused on validating whether the proposed BESS component of the project is successful in meeting whatever requirements have been imposed, resulting in the inclusion of BESS. This might include smoothing or load shifting. The analysis should also consider the size of battery required; could a smaller battery also provide the required service?

OVERVIEW OF BATTERY USE CASES WITHIN EACH PROJECT TYPE



The PPP agreement will need to carefully consider the technical limitations of the BESS, regardless of the type of project being implemented. The warranty secured from the battery manufacturer by a project developer will likely include limitations on how the system should be dispatched. For example, there might be limits on the number of cycles that can be incurred by the BESS, or limits on how much of the storage capacity is 'useable' (i.e., the depth of discharge). For projects where control of the asset is either directly or indirectly (via dispatch instructions) passed to the offtaker, these constraints need to be reflected in the PPP agreement so that BESS operations do not result in a breach of warranty. These constraints might necessitate iteration between finalizing the commercial terms of the agreement and refining technical design of the BESS, to ensure that both are supportive of the intended BESS use application.

Some types of BESS project will need to be implemented in a very specific location. If a project is intended to provide voltage support or to tackle an identified grid constraint, it will need to be in an appropriate location so that it can deliver the required service. However, other services that might be provided by the BESS might be less dependent on the location of the project. Site selection could either be determined up front by the procuring agency or could be left to individual project developers. This choice will often depend on how straight forward it is to secure land rights in a given country.

Design of the PPP procurement will need to carefully consider the role(s) to be assumed by the private sector. In particular, in many cases it will be appropriate to allocate responsibility for system design to the private sector. Rather than specifying a battery design during a PPP tender, the procuring agency would specify a service and/or a set of technical requirements that the BESS should be able to meet. This allows private sector developers to optimize a design to meet those requirements. Where responsibility for design is allocated to the private sector this will substantially reduce the amount of technical analysis and design work that needs to be completed by the procuring agency.

Testing requirements should also be covered in the agreement to ensure the BESS meets the requirements defined in the original brief. The procuring agency should be focused on clearly defining the technical requirements of the BESS and then ensuring the BESS meets those requirements at every stage of implementing the PPP. Typically, the agreement will allow for the buyer to perform tests on the BESS to check that it meets these requirements both prior to commissioning and throughout the life of a project.

A growing role for battery storage in the future

As more countries adopt ambitious emissions reduction targets, the role of BESS projects is only likely to increase. In most markets the drive towards net zero will involve a substantial increase in the role of variable renewable generation such as solar PV and wind. This will in turn increase the need for flexibility, to accommodate the rapid changes in output from these intermittent generators. Batteries can make an important contribution in providing this additional flexibility. However, the size of the role for batteries will depend on the other technologies available in a given market. For example, in some markets very flexible hydro resources might be available, whereas batteries might have a greater role in countries will a less flexible electricity system.

Further cost reduction and technological developments will also likely impact how BESS projects are deployed in future. Improvements and further reductions in the cost of technologies that are already well established will improve the business case for some projects and applications that are marginal, or that are not commercially feasible today. In addition, new technologies, such as flow battery technologies, could catalyze further potential for BESS, improving the technical feasibility of use applications not widely implemented today, such as longer-duration bulk energy shifting. Together, these factors are likely to result in growing potential for the application of BESS projects, and the implementation of PPP structures following the guidance in this report could help with implementing such projects in developing countries.

1 | INTRODUCTION

1.1 Purpose of this document

The role of battery storage has been growing in recent years and has the potential to play a major role in facilitating the transition to net zero. The deployment of Battery Energy Storage Systems (BESS) has ramped up in recent years as the cost of the technology has fallen. BESS installations are primarily being used in applications where they can help with the integration of Variable Renewable Energy (VRE), both in utility scale applications, and in smaller behind-the-meter applications for individual commercial and industrial energy users. Often, BESS projects are tapping into markets for ancillary services, such as frequency response. As the role of VRE continues to grow, the demand for many of the services that BESS projects can provide will also grow.

However, the role of BESS has been more muted in the less developed markets in which the World Bank operates. There are many reasons why this is the case, but the primary reason is that the revenue streams and complementary regulation that often facilitates such projects in more developed markets does not exist in less developed countries. For example, in many markets there is not transparent procurements of ancillary services, let alone a liquid market for these services. Regulation does not always encourage network utilities to consider alternatives to network infrastructure upgrades.

The objective of this document is to provide guidelines on how BESS projects can be implemented as PPPs. The guidelines cover the key considerations in identifying, assessing, structuring, preparing, and implementing PPPs using BESS technologies. The guidance is intended to be generally applicable, rather than being specific to any one country or region.

These guidelines aim to provide a framework that helps to unlock future BESS projects, leveraging private capital. BESS is a complex asset class; systems can incorporate different battery technologies and can be designed to meet different customer requirements. This complexity can act as a barrier to preparing successful projects. Improved understanding of the asset class, and the strategies that can be used to prepare successful projects, could help to catalyze investment in BESS projects in future.

We have engaged with a wide range of stakeholders in developing this guidance. As well as speaking to World Bank Group (WBG) teams around the world working on initiatives involving BESS, we have spoken with companies that are manufacturing batteries and developers of and investors in BESS projects. These discussions have helped to enrich our understanding of the barriers that are faced in developing BESS projects in developing countries, which this guidance aims to address.

1.2 How to use these guidelines

The BESS asset class is complex and can be used in many ways. The different 'use cases' for battery storage are often referred to. BESS can be used on many different scales to provide a range of different services. Within the asset class there are multiple technologies, each of which can be better suited to specific applications. As a result, there is a not a single 'cookie-cutter' approach that can be developed and applied when developing BESS projects.

The guidance on how to implement a PPP involving BESS varies, depending on the type of project being implemented. The different characteristics that define a specific BESS project are explored further in Section 3.2.1. At the end of this section, three 'types' of BESS project are identified, which encapsulate the categories of project that are most relevant to this guidance. The guidance then presented in subsequent sections refers to these project types, indicating where the guidance is specific to one project type, or where the approach taken might vary between different types of project.

1.3 Structure of this report

This report is structured as follows:

- Section 2 presents further context on the recent growth in the deployment of BESS, and reasons why this has not extended to less developed markets.
- Section 3 presents the detail of the guidance itself. Within this section, each step in the PPP implementation process is analyzed, from project identification through to the operational phase of a project.
- Section 4 explores some of the wider trends that might impact the guidance presented in this document in future. For example, this includes the impact of ambitious climate mitigation goals and the impact of new technologies.
- Appendix A contains high level Heads of Terms for BESS projects, which complement the guidance presented in Section 3.
- Appendix B contains sample Terms of Reference for some of the key advisory roles that might be required in developing a BESS project.

2 | CONTEXT

2.1 The growing role of battery storage

Battery technology has developed rapidly in recent years. This has largely been driven by ever-increasing demand for portable batteries with high energy density, for the electronics industry and now, for use in electric vehicles (EVs). The biggest gains have been in lithium-ion technology, but there are many other battery technologies with different characteristics (for example, flow battery technologies) where rapid improvements are also being made. While many of the technological advances are being driven by other sectors, the power sector stands to be profoundly impacted by the increased ability to store electricity.

Before the Covid-19 pandemic, global deployment of batteries in the electricity sector was running at over 3 GW per year. This includes both grid-scale (or utility-scale) deployments, and behind-the-meter applications, where BESS installations are used on an electricity consumer's own premises. Figure 1 presents a summary of recent grid-scale deployments by country. The graph shows how annual deployment stepped up substantially during the last few years of the 2010s. Behind-the-meter projects have been scaling up at a similar rate, although the more fragmented nature of this market means that data is less comprehensive.

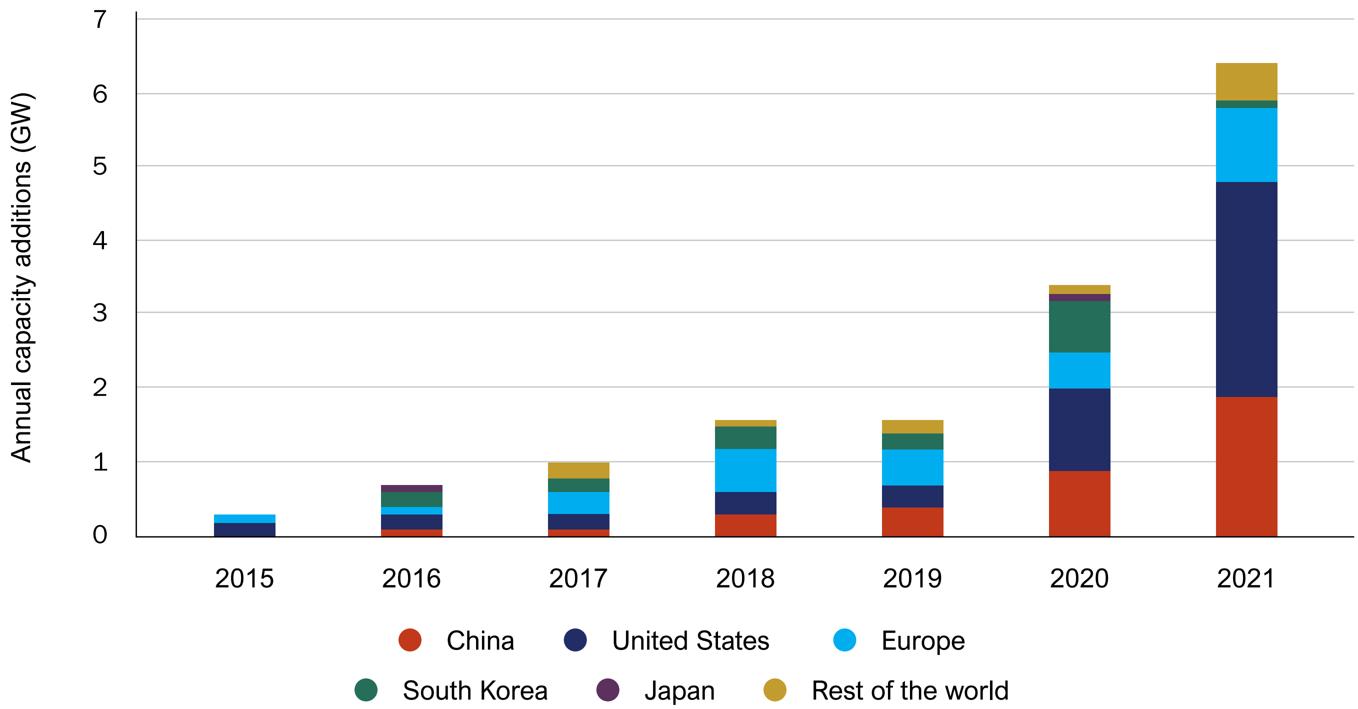
The cost of batteries has also fallen rapidly. Again, these gains have been focused on lithium-ion batteries. The cost of lithium-ion battery cells has declined by 86% over the past decade. In the IEA's Stated Policies scenario, this cost reduction trend is expected to continue, with costs declining by a further 40% to 2030, and 50% by 2040. These cost reduction projections are shown in Figure 2.

Sustained increases in metal prices could stall this trend. Despite recent increases in commodity prices, the cost of batteries continued to decline in 2021, with Bloomberg New Energy Finance (BNEF) reporting cost reduction of 6% compared to 2020. However, BNEF's 2022 survey, published[1] in December 2022, reports an increase in prices of 7%. The IEA's World Energy Outlook 2022[2] suggests that metal prices sustained at the levels seem during the first half of 2022 could results in costs increasing by as much as 35%.

1 BNEF (2022): Lithium-ion battery pack prices rise for first time to an average of 151 $/kWh. Link.

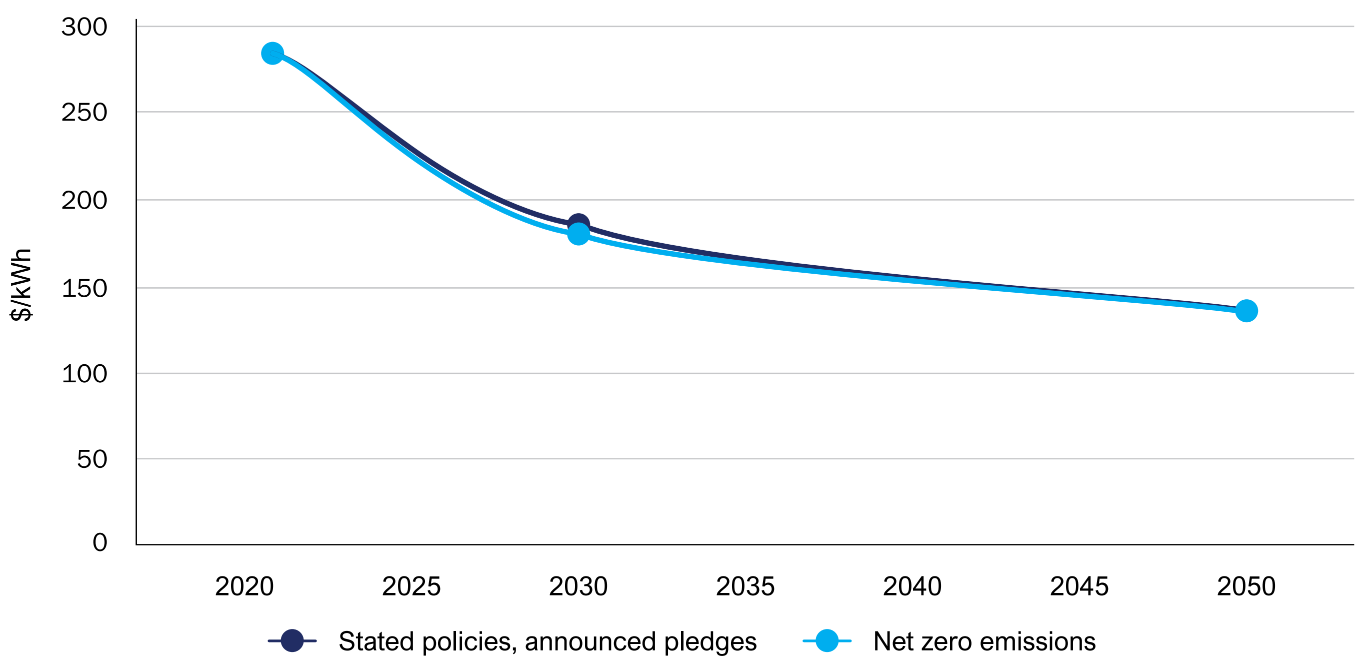
2 IEA (2022): World Energy Outlook 2022. Link.

FIGURE 1 | DEPLOYMENT OF GRID-SCALE BATTERY STORAGE BY COUNTRY, GW



Source: IEA World Energy Investment 2022

FIGURE 2 | COST OF UTILITY-SCALE BATTERY ENERGY STORAGE SYSTEMS[3] UNDER CORE IEA SCENARIOS



Source: IEA World Energy Outlook 2022

3 Numbers shown assume a 4-hour duration system.

The latest battery technologies could yield substantial benefits for the electricity sector. In particular, the rapid growth in the role of intermittent renewable energy technologies means that electricity systems are moving away from the 'traditional' use of baseload, mid-merit, and peaking power plants. There is a need for greater flexibility to complement the cheap, but non-dispatchable, energy that can now be generated using solar PV and wind. When combined, these technologies can provide some of the stable and dispatchable power supply that utilities require to operate the electricity system. The form of flexibility required varies from shifting bulk energy supply from off-peak to peak period, to providing ancillary services such as very fast frequency containment. Battery storage technology is well-suited to providing many of these forms of flexibility and can therefore have an important role in improving and maintaining grid stability.

In developed markets batteries are typically being used to provide system services or to meet individual load requirements. With system services, batteries are capturing a growing share of the market for frequency response in many markets. As shown in Figure 1, batteries are often being deployed by individual commercial or industrial energy consumers to optimize their energy costs (for example, reducing their exposure to peak-time energy charges, or optimizing their use of onsite solar PV generation).

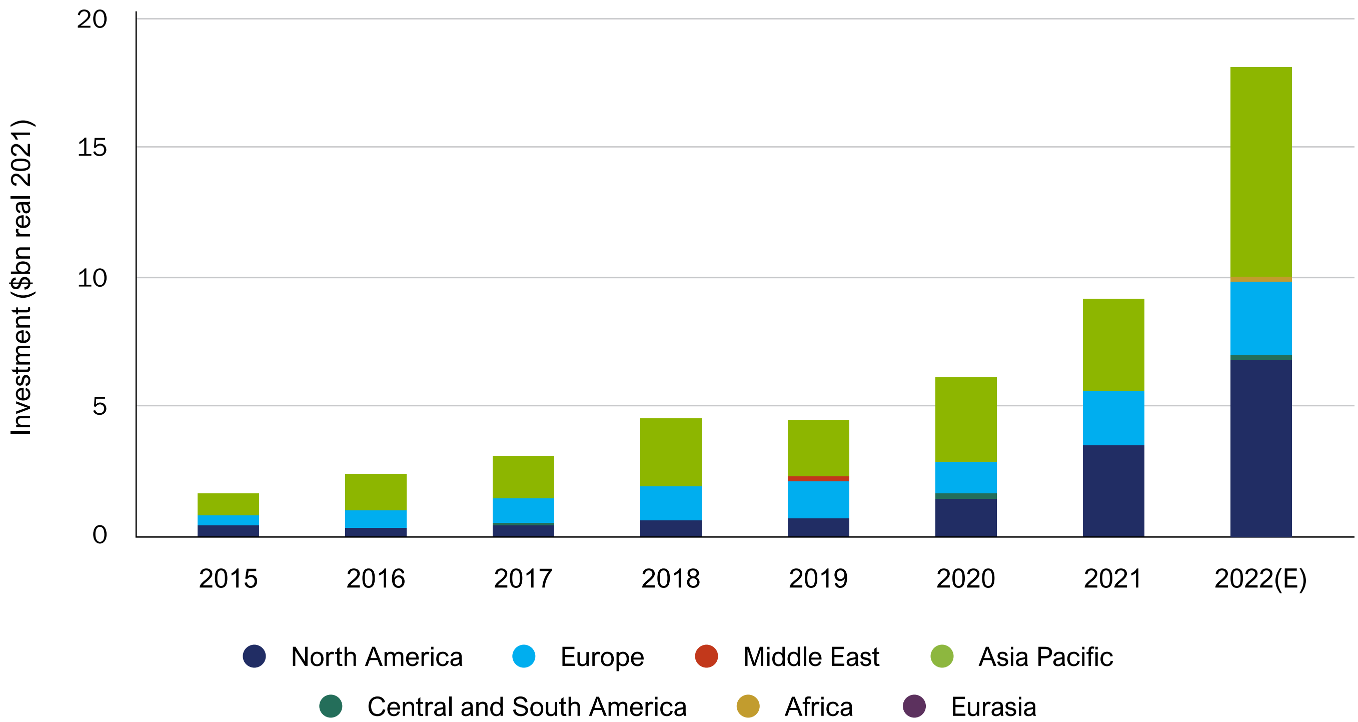
2.2 Battery storage in less developed markets

Most of the capital deployed into grid-scale battery storage to date has been deployed in developed markets. Figure 3 shows the breakdown by location of investment in the technology globally, since 2015. With the exception of China, almost all of the investment shown in Figure 3 took place in high-income countries.

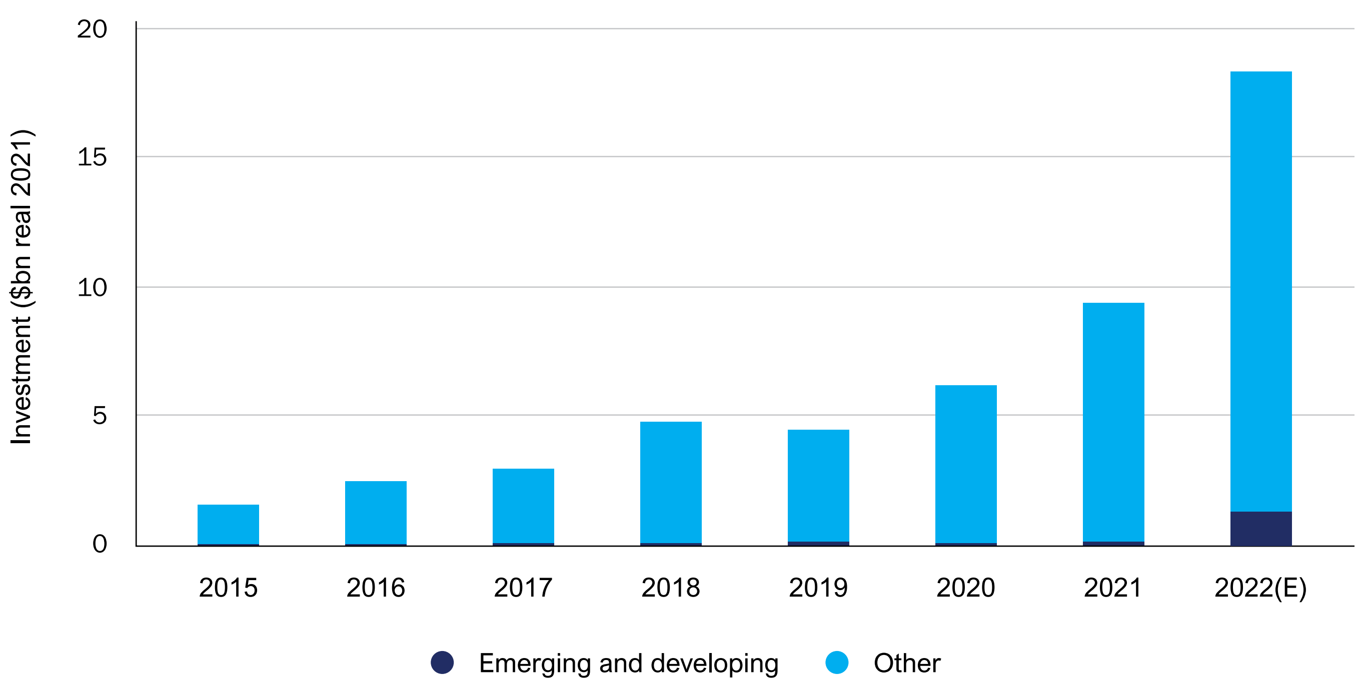
Where battery projects have been deployed in less developed markets, they have often been demonstration or experimental projects. For example, in some countries in Africa battery storage has been added to solar PV projects. The services to be provided by the battery are not always fully defined; rather the intention is to allow a utility offtaker to familiarize themselves with the technology and to understand where the system can provide most value. In some cases, these projects have benefitted from grant funding, rather than being on an entirely commercial basis.

In less developed markets, there is no route-to-market for many of the services provided by batteries in more developed markets. In particular, there are no ancillary services markets in most less developed markets. The complexity of the asset class and the lack of familiarity with many of the services that batteries can provide, act as a barrier to its wider deployment.

FIGURE 3 | INVESTMENT IN GRID-SCALE BATTERY STORAGE 2015-2022: BY REGION



IDENTIFYING PROJECTS IN EMERGING AND DEVELOPING COUNTRIES



Source: IEA World Energy Investment 2022

Technology risk can also be a barrier. While the most common lithium-ion battery technologies are now well understood by investors globally, the lack of projects in less developed markets means that there is a limited evidence base demonstrating the technology in more challenging operating conditions. For example, air conditioning for the BESS must be able to withstand extreme heat in some countries.

However, battery storage could also have an important role to play in less developed markets. Indeed, there are many reasons why battery storage could play an even more important role in some of these countries. For example:

- Reliance on expensive liquid fuels means that battery storage could sometimes be an economically attractive alternative to expensive peaker capacity, a use case that is still rarely viable in more developed countries where less expensive peak generation capacity is often available.
- The smaller size of electricity systems in some less developed countries means that renewable penetration could reach high levels (in percentage terms) at an earlier stage in some cases. This can result in an increased demand for fast-responding technology to maintain grid stability as grid inertia falls.
- Less resilient grid infrastructure can also mean that there are more opportunities to use battery storage to relieve existing network constraints or to defer investment in grid capacity upgrades.

3 | GUIDANCE ON PPPs FOR BATTERY STORAGE

3.1 Implementing PPP projects

PPPs have frequently been used to deliver infrastructure, in both developed and developing countries. A partnership between public and private sectors is often used when the delivery of an asset or service delivers a public benefit, but where additional skills, experience, or financial capacity can be delivered by the private sector. PPP structures are frequently used where the private sector can bring international expertise in financing, developing and managing/operating projects covering a specific class of infrastructure asset. Infrastructure projects often demand large capital outlays and leveraging private sector finance to help address this need can be another attraction of using PPPs.

A large body of literature exists that provides guidance on how to implement PPP projects. In particular, the PPP Reference Guide[4], which has been developed and maintained by the PPP Knowledge Lab[5], provides extensive guidance on what constitutes a PPP and how such projects should be developed and implemented. The guide also provides a useful definition of PPPs:

> *"A long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance."*

This definition of a PPP also helps to clarify which projects are not PPPs. For example, the delivery of infrastructure through an Engineering, Procurement, and Construction (EPC) contract would not typically be considered a PPP, as it is not long-term in nature and no management skills are contracted or future risk is accepted by the developer. PPP structures typically introduce longer-term performance incentives that are not contained in an EPC contract. Management contracts are also not included within this definition: such contracts do not involve the long-term commitments or the deployment of substantial private capital or acceptance of risks that would typically be required to be classified as a PPP.

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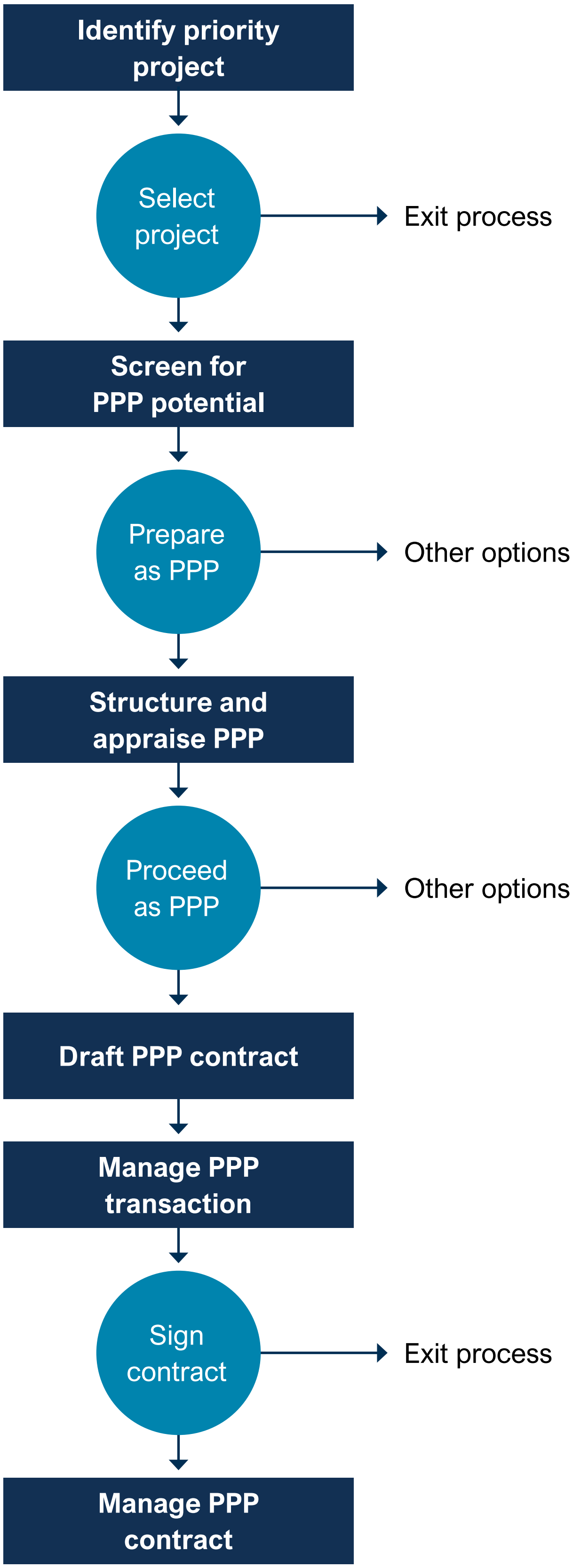
4 World Bank (2017): Public-Private Partnerships Reference Guide (Version 3). Link.

5 The PPP Knowledge Lab is an initiative that was launched in 2015 by a number of MDBs, including the World Bank Group, with the support of the Public-Private Infrastructure Advisory Facility (PPIAF), to develop and collate knowledge regarding PPP projects.

FIGURE 4 | KEY STEPS IN DEVELOPING A TYPICAL PPP PROJECT



For mature infrastructure asset classes, there are often well-established PPP models that can be used as templates when implementing new projects. This includes projects covering other asset classes in the electricity sector. Independent Power Producer (IPP) projects have been widely deployed to leverage private sector capital in the development of power generation capacity. IPPs are typically paid for the energy (and sometimes the capacity) provided by the power generation facility through a long-term Power Purchase Agreement (PPA). In recent years, IPP models have been widely used in scaling up renewable energy projects, in which incumbent state-owned utilities often have less experience. Concession models have also been used extensively in the power sector, especially in mobilizing private sector experience and capital in the electricity distribution sub-sector.

The process for developing a PPP is well-established. While the exact definition of the steps in developing a PPP project can be articulated in different ways, the key steps in the cycle are clear. The PPP Reference Guide[6] describes these steps as shown in Figure 4, and as described below:

- **Project identification and screening,** where potential projects are identified through planning processes and screened for their suitability as PPPs (World Bank, 2017).
- **Appraisal and feasibility analysis,** which includes both an assessment of the project's technical feasibility and an evaluation of the economic business case.
- **PPP option selection and structuring,** which is where the detailed commercial, legal, and financial structuring of the proposed transaction is developed and refined.

6 World Bank (2017): Public-Private Partnerships Reference Guide (Version 3). Link.

- **Transaction preparation and management,** which covers the process of originating and selecting a private sector partner to participate in the implementation of the PPP.
- **Contract management and operations,** which covers the long-term implementation of the contract after a winning bidder has been selected.

Implementing a PPP is an iterative process. While Figure 4 shows a single linear process there will be iteration between these steps as the PPP structure is refined and developed over time.

The guidance that follows covers each of these steps in turn, for the specific case of battery storage. Section 3.2 covers project identification, with subsequent sections covering each step of the PPP project cycle described above, until Section 3.6, which covers the operational phase of a PPP involving BESS. Additionally, Section 3.7 covers considerations regarding the handover and/or decommissioning of BESS projects. The guidance presented focuses on aspects of project implementation that are unique to BESS projects. As noted above, there is a wide body of literature that provides more general guidance on PPPs, which is not specific to this asset class.

3.2 Project identification

3.2.1 Types of battery storage project

A key challenge in developing BESS projects is the heterogeneous nature of the asset class and its application. BESS projects can cover a wide variety of technologies, deployed to deliver a range of different services. The service, or services, to be provided determines, and in turn impacts in different ways, the stakeholders and contract counterparties that might be involved in developing a PPP project. Importantly for this document, these characteristics can also have a fundamental impact on the structuring of the commercial terms for the transaction. Table 1 presents a summary of the 'dimensions' that define a BESS project.

One of the unique features of battery storage is that it can be used in many ways. Battery storage projects can be used in many different applications or use cases. These use cases can be categorized in different ways. One categorization of these use cases is described in a recent World Bank report[7] analyzing the policy and regulatory considerations for implementing BESS projects, as follows:

- **Generation-side services** — services traditionally associated with generation-wide resources:
  - » **Frequency and voltage control** — this covers a range of services, from very fast acting frequency containment services to slower acting reserve products. Some services, such as voltage control, are likely to be locational in nature.
  - » **Smoothing / VRE ramp control** — this limits the speed at which output from a VRE plant can increase or decrease. Sometimes this will be a requirement imposed through the Grid Code.

7 Energy Sector Management Assistance Program (ESMAP) (2020): Deploying Storage for Power Systems in Developing Countries: Policy and Regulatory Considerations (https://documents1.worldbank.org/curated/en/738961598380536870/pdf/ESP-Policy-Manual-Aug-2020.pdf)

TABLE 1 | SUMMARY OF THE DIMENSIONS FOR CHARACTERIZING A BESS PROJECT

Use cases	Batteries can be used in many different ways. For example: • Bulk energy shifting • Grid investment deferral • Ancillary services • Behind-the-meter • Etc.
Counterparty	Customers for a battery project might be a utility (in an unbundled sector there might be multiple candidates), or a private sector party (for example, in the case of behind-the-meter project).
Technology	While lithium-ion technology has been dominant in driving the growing role of batteries, there are many other technologies, which improve the viability of new use cases in the future.

  - » **VRE forecast error correction** — this is relevant for systems where generators are required to submit short-term generation forecasts. In this case, generators may face penalties if their forecast is inaccurate; a BESS can be used to manage this exposure.
  - » **Firm capacity** — this refers to the BESS being used as firm capacity to meet system peaks.
  - » **(VRE) generation time shift** — output from non-dispatchable power generation capacity is shifted to a later period; e.g., shifting output from off-peak to peak hours.
  - » **Black start** — the use of the BESS to restart the power system after a system-wide black-out.
  - » **Balancing seasonal and inter-annual** — although battery storage technologies are generally unlikely to be commercially viable in providing these services today.

- **Demand-side use cases:**
  - » **Uninterruptable power supply (UPS)** — the use of BESS to provide seamless power supply when switching to a back-up power supply during a system outage.
  - » **Backup power / micro-grid islanding** — similar to the UPS use case, but with the ability for onsite energy resources to operate autonomously from the grid, in 'island' mode, regardless of whether the grid is suffering an outage.
  - » **VRE self-consumption optimization** — customers with behind-the-meter VRE generation might use BESS to help optimize their use of this resource.
  - » **Time of use optimization** — this has some similarity to the previous use case in that it is focused on optimizing energy costs for an end consumer. However, in this case the focus is specifically on minimizing import energy costs in countries where end consumers are exposed to time of use energy charges.
  - » **Demand response (DR)** — BESS can be used to reduce onsite demand, either responding to a price signal (similar to the previous use case), or as part of a service agreement, e.g., signed with the system operator.

- » **Network/demand charge reduction, or demand charge reduction** — very similar to the time of use optimization use case, but focused specifically on reducing a customer's exposure to demand charges (where they exist) through reducing maximum consumption.

- **Grid-related use cases:**
  - » **Grid congestion relief** — this covers the use of a BESS to tackle a specific grid constraint, e.g., meeting peak demand at the end of an over-loaded line.
  - » **Transmission and distribution (T&D) deferral or avoidance** — similar to congestion relief, but the BESS is explicitly used in place of reinforcement of the grid.

However, this is just one way in which projects can be categorized. Other authors have categorized projects under different headers.

The purpose of the BESS deployment will be highly relevant when preparing a PPP. The revenues may be different, and structured in a different way (e.g., energy versus capacity), and the technical criteria that the operator is required to meet could be fundamentally different in each case. The type of battery required might also vary.

Location of the BESS project will be important for some of these applications; for others it will not be important. Arbitrage business cases, for example, are unlikely to require a project to be in a specific location, whereas a project that is designed to relieve a grid constraint will naturally need to be located in a certain place close to the constraint being addressed. The importance of location also varies for different ancillary services: providing voltage support will typically require response in a specific location, whereas for frequency response this might be less important.

BESS projects can also cover a range of different technologies. The rapid increase in the deployment of BESS projects in recent years has been dominated by lithium-ion batteries thanks to their round-trip efficiency (up to 95% or even higher, meaning that more of the energy stored in the battery is usable), higher energy density, and higher depth of discharge (DOD) compared to lead-acid batteries (85% versus 50%). This is mostly a result of the technological developments largely being driven by the electronics sector, as described earlier. The market share of key technologies to early 2020 is shown in Figure 5.[8]

However, there are many other battery technologies that might be important in the future. There are many different technologies, making use of different battery chemistries, that could also be used in electricity sector applications in future. Each technology has different characteristics: some have higher or lower round-trip efficiency (i.e., the process of charging and subsequently discharging the battery results in a higher or lower quantity of energy losses) compared to lithium-ion batteries; others are more suitable for shorter or longer duration applications. Some of the characteristics of different BESS technologies are described further in Table 5, in Section 3.3.2.

Technology is likely to be less important than use case in driving the structure of a PPP. Although the technology and use case may be closely related, the service characteristics that might be written

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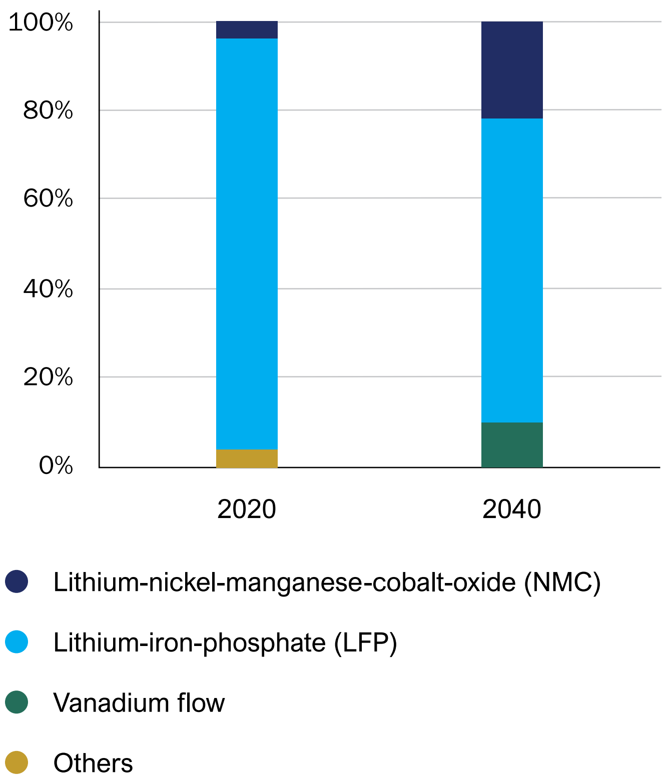
8 IEA (2021): The Role of Critical Minerals in Clean Energy Transitions. Link.

FIGURE 5 | CATHODE CHEMISTRIES FOR BATTERY STORAGE



Source: IEA (2021): The Role of Critical Minerals in Clean Energy Transitions

into a PPP contract will be driven by the use case. Technology per se is unlikely to drive the structure of the PPP. However, as some of these technologies become more widely used in future, this might help to unlock the economic case for some use cases that are not viable today.

The customer or contract counterparty will also depend on the type of BESS project being implemented. In most of the use cases mentioned above, the main customer for the services provided by a BESS project would likely be a utility. In countries with an unbundled or partially unbundled electricity sector, the customer may be the entity responsible for bulk electricity trading, the utility responsible for system operations, or a network utility, depending on which use case is being implemented.

Behind-the-meter or demand-side projects are, in most cases, likely to be agreed between private sector parties. The customer is likely to be either a private household or a business seeking to optimize the cost of (and/or 'green') its electricity supply. These projects are outside of the scope of this guidance, which covers PPP projects.

Use cases are therefore the primary driver of how a BESS transaction should be structured. Battery technology and counterparty are important mostly indirectly, through their interaction with use case. The configuration of the project (i.e., whether the BESS is part of a hybrid project, paired with VRE generation) is also an important determining factor when considering the options for how a BESS PPP might be structured. When analyzing the options for implementation of PPP projects using BESS, three 'types' of project can be identified:

1. **Bulk energy shifting,** which includes the provision of peak power and arbitrage opportunities.

2. **Network and system services,** which includes both grid infrastructure services and ancillary services. These are grouped together as they are commercially similar in nature. Some of these services will be location-specific, others not.

   Note that these first two types of project are focused on stand-alone BESS projects.

3. **Hybrid projects,** which would cover projects paired with solar PV or wind generation. Note that this category is focused on projects where the BESS is explicitly used to ensure that the VRE generator meets certain requirements (such as a maximum ramping requirement, or limited dispatch ability). Projects where the BESS is co-located but is essentially providing services that are independent from the VRE, would normally be covered under one of the first two categories.

It is important to note that the project 'types' are not intended to provide a complete or mutually exclusive list of use cases – such categorization is covered earlier in this section. Rather, the project types aim to categorize projects to reflect the different commercial characteristics likely to be reflected in PPP agreements (discussed further in Section 3.4). However, the use case categories do in most cases map well to these project types. A more detailed description of the project types, together with an indication of how the use cases map to the project types, is provided in Table 2.

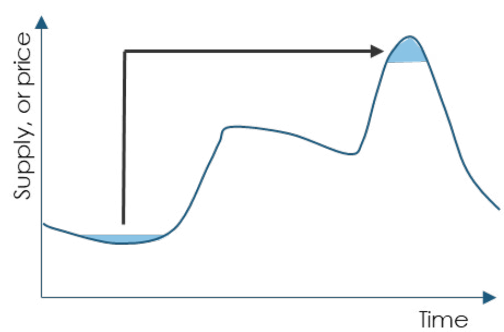
For the remainder of this guidance, we refer to these three project types. Where possible, the guidance is designed to be applicable to all types of BESS project, but where necessary we identify differences in how PPP projects should be implemented according to the type of BESS project being considered. These types aim to strike a balance between capturing the nuances of different types of BESS project, while resulting in guidance that is generally applicable and can be put into practice widely.

TABLE 2 | OVERVIEW OF BATTERY USE CASES WITHIN EACH PROJECT TYPE COVERED BY THIS GUIDANCE

Bulk energy shifting

Firm capacity

- The BESS is used to shift generated energy to times when it is most needed and/or can contribute most to minimizing system costs.
- The BESS is charged during off-peak periods and subsequently discharged during peak periods.
- The example shows this applied over a single diurnal cycle, but the same principle could be applied on different timescales.
- For example, as the penetration of Variable Renewable Energy (VRE) increases, there could be more volatile peak and off-peak periods as VRE output varies through the day.



Balancing seasonal and inter-annual

- As noted above, shifting of bulk energy could be applied over a range of different timescales.
- While in principle storage could be used to shift energy over longer timescales (e.g., seasonal), currently available technologies and duration limitations mean that BESS installations are unlikely to be used in this way.

TABLE 2, CONT. | OVERVIEW OF BATTERY USE CASES WITHIN EACH PROJECT TYPE COVERED BY THIS GUIDANCE

Network and system services
Voltage control and other locational services • BESS can be used to provide locational ancillary services. • For example, voltage may drop at the end of long power lines in a disperse network, which can lead to increased faults and outages. Voltage can fluctuate more as supply-side volatility increases with higher VRE penetrations. • This type of service requires the BESS to be located at a site where the voltage support will be effective. • Another example of a locational system service would be using the BESS to improve system reliability in a specific locality; for example, covering an economically important industrial park. This could provide a useful way of addressing the concerns of investors in industrial or manufacturing facilities, without having to address all the complex and interrelated challenges of the electricity system simultaneously.
Frequency control • The provision of other ancillary services is less dependent on location. • For example, reserve services or frequency response could potentially be provided anywhere on the system, subject to connection constraints. • BESS can respond much more quickly than many other flexibility providers, providing a response in less than 1 second. As VRE increases, this results in declining system inertia, which in turn results in a higher rate of change of frequency (ROCOF). Higher ROCOF increases the demand for very fast frequency response services. • The graph illustrates how BESS can be used to restore system stability. System frequency typically needs to be maintained within a fixed band (typically 50 Hz ± 0.5 Hz). If a large generation outage or a sudden drop in outputs from VRE results in a fall in system frequency, the BESS can respond very quickly to restore stability.
Black start • BESS can also be used to restart the system when there is no external power supply, i.e., when there is a total system outage.

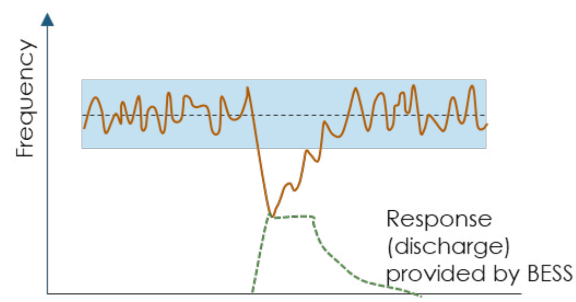
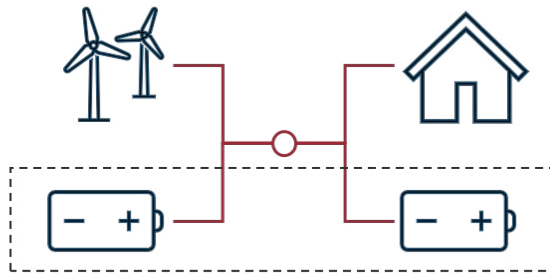


TABLE 2, CONT. | OVERVIEW OF BATTERY USE CASES WITHIN EACH PROJECT TYPE COVERED BY THIS GUIDANCE

Network and system services

T&D deferral or avoidance



Battery location will depend on the exact nature of the constraint

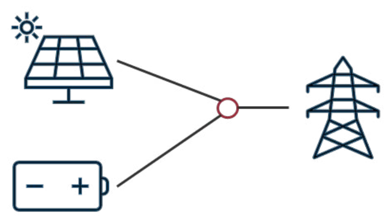
- BESS can also be used to defer or replace the need for investment in network infrastructure, for example if load growth means that more capacity is required on a line.
- Grid constraints can be avoided by using the BESS to shift load.
- This is a locational service: the location of the BESS will vary depending on the nature of the constraint being tackled.
- For example, if the BESS is addressing an export restriction on a VRE plant that is unable to export all the power it generates, the BESS needs to be on the same side of the network constraint as the VRE project. If a network constraint means that load cannot be met on a given feeder, a BESS located on that feeder (and charged during hours when the constraint is not binding) could be used to meet peak load on that feeder.

Grid congestion relief

- This is in effect the same use case as described above, where a BESS system is used to meet demand peaks at the end of an otherwise overloaded line or, conversely, to store generated energy from a supply-side resource that is located behind a grid constraint.

Hybrid projects

Smoothing / VRE ramp control



- BESS could be located alongside a VRE project to help it meet certain requirements imposed to maintain grid stability. For example, maximum ramp rate requirements might be imposed so that output from the VRE project does not change too suddenly.
- In this case, the BESS is in effect providing an ancillary service, but that ancillary service is being embedded in technical requirements set out in the PPA.

VRE forecast error correction

- In some cases, a VRE project might be required to provide a forecast of generation output to the offtaker or system operator. A penalty regime might be included within the PPA to incentivize good performance on the forecast.
- The developer of the VRE project might include a BESS in the design of their project to manage exposure to this penalty regime. The BESS size will need to be optimized to minimize the total cost of the project, including the exposure to penalties.

TABLE 2, CONT. | OVERVIEW OF BATTERY USE CASES WITHIN EACH PROJECT TYPE COVERED BY THIS GUIDANCE

Hybrid projects
VRE generation time shift • This use case has some similarity to the "firm capacity" use case described above; in effect the BESS is providing some dispatchability to a VRE project. • The PPA for a project might include a requirement for energy to be available during certain defined hours (for example, peak hours), when the VRE might not in the first instance be generating. • In each of the hybrid use cases, careful consideration should be given to whether it is economically advantageous to provide these services on the same site as the VRE generation capacity, or whether the same service could be provided more cost effectively if centralized. This will mostly depend on the extent to which the service being provided is itself locational.

Before designing and implementing the PPP, it is critical to be clear on what the BESS will be doing. Table 2 indicates the wide range of applications for the BESS asset class. However, the key considerations in designing the PPP will be different for each of the three project types identified (into which the applications have been grouped). Before proceeding with the identification, design, and implementation of a BESS PPP it is important to be as clear as possible on why the BESS project is being proposed, what it needs to achieve, and how it will be used.

3.2.2 Identifying battery storage projects with PPP potential

The first step in understanding whether there is potential for implementing PPP projects using BESS is to analyze a series of indicators that flag the potential for batteries in a market. These indicators are wide-ranging and provide an initial assessment as to whether BESS is a suitable technology for delivering a given service in the electricity market. The indicators are often specific to one of the three types of BESS project. For example, heavy reliance on expensive liquid fuels might indicate that BESS could be used for peak power provisions, displacing the need for some of the liquid fuel, but this indicator would provide no information on whether there is demand for BESS projects to tackle grid constraints. An overview of indicators of the potential for BESS in a given market is presented in Table 3. These indicators are not exhaustive but provide a signal that there might be opportunities to deploy battery storage, but they do not prove the business case for a project. In many cases, the indicators might identify an opportunity that could also be met by deploying other technologies that provide flexibility to the electricity system.

TABLE 3 | INDICATORS OF THE OPPORTUNITY FOR IMPLEMENTING BESS PROJECTS

Indicator	Explanation	Assessment approach	Relevance for each project type		
			1: Bulk energy shifting	2: Network and system services	3: Hybrid projects
System load factor	A low load factor indicates a peaky system load profile, and a need for more power generation capacity at peak times.	The load factor can be calculated as: $\frac{\textit{Total demand}}{8760 \times \textit{Peak demand}}$	✓		
Cost of peak power	A high cost of peak power, especially if accompanied by cheaper off-peak power, indicates that opportunities to arbitrage between peak and off-peak energy may be economically viable.	The energy price in PPAs will provide an indication of the Short Run Marginal Cost (SRMC) to the offtaker of energy from different generators. In the absence of this data, generator SRMCs can be estimated with reference to technology cost benchmarks.	✓		
VRE penetration	High penetration of VRE suggests that availability of supply-side resources will be volatile. This in turn will lead to volatility in the SRMC of electricity. In addition, high penetration of VRE may indicate an increasing demand for ancillary services, although this will also depend on other components of the existing supply mix, which may also be able to provide these services.	In most countries, publicly available data will provide information on the current supply mix. Power sector planning documents and renewable energy targets may also provide information on how this indicator can be expected to evolve over time.	✓	✓	✓

TABLE 3, CONT. | INDICATORS OF THE OPPORTUNITY FOR IMPLEMENTING BESS PROJECTS

Indicator	Explanation	Assessment approach	Relevance for each project type		
			1: Bulk energy shifting	2: Network and system services	3: Hybrid projects
System reliability	Poor system reliability suggests a need for grid infrastructure upgrades and/or procurement of ancillary services.	The utility may have detailed data available on system reliability. Publicly available WBG datasets (including Doing Business and Enterprise Surveys) also contain reliability metrics.		✓	✓
Ancillary services market	A market for ancillary services provides a route-to-market for BESS projects selling these services.	In most countries in which the WBG operates there is unlikely to be a mature and transparent market for ancillary services. The utility responsible for system operations is likely to be best placed to provide details on the arrangements for ancillary service procurement.		✓	
Demand growth	High growth in the demand for electricity is likely to indicate pressure on grid infrastructure, and it may not be possible to upgrade all the network infrastructure that is constrained.	Recent data on electricity demand may be available from the utility and/or regulator. For some countries, data will also be publicly available from the International Energy Agency (IEA).		✓	

Once the battery applications likely to be most relevant have been identified, other project requirements can be defined. The types of projects being brought to market will clearly have an impact on its technical characteristics. For example:

- If the project is to help meet peak power requirements, the duration of the BESS will need to reflect the characteristics of the load peak being targeted.
- If the service to be provided is a locational service, the BESS project will need to be on a suitable site, or in a suitable area.
- The size of the BESS system will need to be tailored to the specific application being proposed. For example, if the system is tackling a local grid constraint, it should be sized to that constraint.
- The parameters that the system needs to be aligned with will depend on the application being implemented. The number of times that a system will need to cycle (i.e., to charge and discharge) may impact the technical design of the BESS and may restrict the systems that can be used for the project.

After specific project opportunities have been identified, a pre-feasibility analysis could be prepared. As with similar documents for other types of PPP this would set out the main parameters defining the project: the BESS project's objective and scope, the services it is intended the BESS will provide, the specification of the BESS required, and the estimated cost. This document defines the project, albeit at a high level, with more detailed analysis to be completed during the feasibility analysis described in Section 3.3.

The project's suitability for a PPP structure should also be considered. The project types covered by this analysis have already been selected to reflect their potential suitability for a PPP. For example, behind-the-meter projects for commercial and industrial energy users have not been covered, because these BESS projects are likely to be defined by a transaction between two or more private sector parties. Conversely, BESS projects that fall into one of the three 'types' of project defined in Section 3.2.1 are likely to be suitable for development as a PPP. There could be some exceptions to this. In more liberalized electricity markets, a transparent ancillary services market might provide an alternative route-to-market for BESS project developers, although this is unlikely to be relevant in many markets in which the WBG is operating.

Sometimes, BESS projects can be catalyzed by procurement exercises that are not targeted specifically at batteries. To encourage BESS projects to be developed it may not be necessary (indeed, it may not be optimal) to design PPPs that are specific to the BESS asset class. There are many examples where BESS projects have been developed, or are being developed, in response to market signals that are technology neutral. In South Africa, the recent Risk Mitigation IPP (RMIPP) tender resulted in two hybrid solar PV and battery projects being awarded preferred bidder status. The tender was designed primarily with dispatchable power generation technologies in mind, but a combination of solar PV and batteries was able to meet the prescribed technical criteria. In China, the introduction of revenue streams intended to incentivize measures to improve the flexibility of coal fired power stations, to aid with VRE integration, has resulted in some plants adding battery storage to their sites. These examples illustrate the value that BESS projects can bring in addressing power system needs.

3.3 Feasibility analysis

3.3.1 Overview of feasibility analysis

A feasibility assessment of the identified BESS is conducted to evaluate the cost-benefit analysis for the project and to ensure that integration of the project doesn't adversely affect the grid. The feasibility analysis assesses the state of the grid and highlights all the system benefits associated with the proposed BESS to identify the revenue streams available to the project sponsor. It may not be straight forward to monetize some system benefits, which would require incentives or regulatory changes to unlock their value. This could include ancillary services that can be provided by the BESS for which a market may not be established yet.

The steps in completing the feasibility analysis can be described as follows:

- An **options analysis** is performed to identify the broad technology and design options for the project, based on the proposed application for the BESS. This will include, for example, options for sizing of the system.
- The **technical feasibility** of the BESS project is evaluated in a way that would be familiar to developers of power generation projects. The objective of this analysis, which includes load flow modelling, is to ensure that there is no detrimental impact to the grid.
- Building on the outputs from this analysis, **technical inputs to the business case** are analyzed. These are specific to the project type being implemented. The technical feasibility analysis should be designed to evaluate the beneficial impact(s) of the BESS, providing empirical evidence for the cost-benefit analysis.
- These inputs can then be used to complete the **economic cost benefit analysis** for the proposed project.
- For some projects, there may be **commercial considerations** related to the overall business case and allocation of project risks that impact the overall feasibility of the project.
- The final stage of the feasibility analysis involves preparing detailed **engineering designs** for the BESS taking into account the preceding feasibility analyses, with front-end engineering designs (FEED) for the construction and supervision of the BESS project being developed.

Completing these steps can be an iterative process, as illustrated by Figure 6. Outputs from the economic analysis might flag issues to be addressed in the technical design options being considered, or detailed design considerations might result in a change in system costs, requiring the cost-benefit analysis to be re-visited. Sample terms of reference for the completion of technical feasibility analysis and economic cost benefit analysis are attached to these guidelines in Appendix B.2 and Appendix B.1 respectively.

FIGURE 6 | SCHEMATIC REPRESENTATION OF THE STEPS INVOLVED IN COMPLETING THE FEASIBILITY ANALYSIS

Identified application(s)
Initial view on how the battery will be used and the requirements it should meet

Step	Feasibility task	Description
1	Options analysis	Design a battery system able to meet the requirements identified
2	Technical feasbility	Identify any system integration issues that might undermine feasibility of the project
3	Technical analysis	Dispatch and systems analysis to validate and quantify the technical benefits of the project
4	Cost-benefit analysis	Evaluate cost-benefit analysis, comparing the benefits delivered against the system's cost
5	Commercial analysis	Consider whether there are fiscal or commercial contraints that impact the project's viability
6	Refine or finalise design	If necessary, revisit the proposed use and/or technical design options

Technically feasible project design
BESS design meets set requirements and is ready to move to the next stage

The procurement strategy to be used while tendering for the services to be provided by the BESS will determine the scope of the technical feasibility. On one hand, the required services can be procured by defining the requirements of the BESS (or, indeed, any other asset class able to provide the service) to meet the use application(s), thereby passing on the risk of the detailed design to the project developer. On the other hand, a prescriptive approach can be taken where the detailed design of the BESS to meet the requirements of the use application(s) is developed during conduct of the feasibility studies and the project developer is procured to adopt the FEED. The former approach is more effective because it affords the project developer flexibility to come up with an optimal design to meet the project requirements. If the former approach is taken, most of the tasks described in this Section 3.3 will be undertaken by the project developer, although some initial high level analysis (such as that described in Section 3.3.2) is likely to be completed so that the likely value delivered by the system can be assessed before procurement commences.

3.3.2 Options analysis

Before a detailed feasibility assessment of the BESS project is conducted, technology, sizing, and configuration options are considered for optimally meeting the requirements of the proposed application. The technology selection involves a robust analysis of available options based on both technical and commercial grounds to inform further feasibility assessment. The BESS sizing derives the storage capacity to meet the requirements of the intended use application. Sizing of the BESS considers the power output required (i.e., the maximum MW output from the system) and the MWh capacity of the battery itself. Table 4 summarizes the technical considerations for system requirements and the configuration and design parameters for BESS that are likely to be important in implementing PPPs.

Technology selection will depend on the proposed application of the BESS and the operating characteristics required. Available battery storage technologies that can be considered include lithium-ion batteries, valve-regulated lead-acid batteries, sodium–sulfur (Na–S) batteries, reduction–oxidation (redox) flow batteries among others. While lithium-ion batteries have been extensively used in BESS projects world over, there are different lithium-ion technologies, each with different characteristics, including lithium nickel manganese cobalt (NMC), lithium nickel cobalt aluminum (NCA), lithium ferro-phosphate (LFP), and lithium titanate (LTO).

The suitability of the selected battery technology to the more challenging environments that sometimes exist in developing countries where large-scale BESS have not been widely deployed will be key. The prevailing ambient conditions, such as humidity, temperature, altitude, air quality, etc., will impact the technical characteristics of the BESS, although this will typically be managed with air conditioning systems. Whilst the site conditions and their impact on the BESS performance will be assessed in detail during the technical feasibility in Section 3.3.3, experience of the selected technology having performed in similar conditions will be important for many investors. In the absence of relevant evidence of the battery deployment, manufacturers' performance warranties will be relied upon for assurance that the battery will perform as expected.

The characteristics that vary across different battery technologies include cycle life, energy density, round-trip efficiency, charge/discharge rate, power density, discharge duration and thermal stability. Other factors relevant to the evaluation include the capital and operating costs of the project, years required for project development and construction, operating lifetime and the maturity of the technology. Table 5 lists some of the differentiating characteristics between battery technologies that should be considered when evaluating the suitability for the intended use application. The importance of each technical characteristic to each project type is indicated in Table 6.

BESS projects can be sized by power capacity in MW or storage capacity in MWh depending on the project type and intended use application. For bulk energy shifting, the MWh capacity is likely to be the primary consideration, determining the energy dispatched during each cycle (although the MW output from the BESS will also be important; for example, in determining the contribution that can be made to meeting peak demand). Conversely, for ancillary and grid infrastructure services, the MW capacity is likely to be the primary consideration, determining the peak power that can be dispatched from the battery to meet the required shortfall in system demand in the short-term, or to restore frequency or voltage stability. Again, the duration of the BESS will still be a relevant consideration, depending on the duration of response required to provide a given service. Basic tools exist to help with high-level analysis of battery storage projects, such as the World Bank's online tool[9] focused on two specific use cases (solar PV smoothing, and solar PV output shifting to meet a demand profile) for hybrid solar and battery projects. This tool analyses 12 representative days so it does not substitute a full pre-feasibility analysis, but it provides a useful starting for these specific use cases.

TABLE 4 | TECHNICAL CONSIDERATIONS FOR BESS SYSTEM REQUIREMENTS AND THE DESIGN PARAMETERS

Defining system requirements
Charging/Discharging time and depth of discharge
• Key consideration for grid support where localized generation and demand can be smoothed using a BESS with an appropriate charging cycle and MW capacity. • The charging/discharging rate (C-rate) impacts the duty cycle (charge/discharge profile), depth of discharge, and state of charge of the BESS throughout the project. • The depth of discharge required will impact the size of the system and thus its capital cost. • Technical assessment to derive average duty cycle with optimal charging rates is used as basis for optimized dispatch.
Number of cycles
• Depends on the use application (i.e., the dispatch schedule required duty cycle) and can determine the expected lifetime of a BESS project. • Depth of discharge during cycling impacts the degradation curve of the BESS. Depending on the battery technology, deep cycling (below a minimum state of charge and above a given depth of discharge) can hasten aging. • Could determine which battery chemistry is most appropriate.
Response time
• Key to frequency response applications that mitigate small disturbances caused by system-wide generation and demand mismatches. • BESS have faster response time than technologies that have traditionally provided frequency response services like large spinning generators.
Round-trip efficiency
• Depends on the losses incurred during charging/discharging the battery so dependent on the BESS duty cycle. • Degrades over time (often described by a degradation curve) so needs to be assessed in dispatch analysis. • Technical assessment of all BESS losses; thermal losses in battery, ohmic losses in inverters, and auxiliary power for HVAC. All the losses within the BESS should be standardized (in percentage terms) in relation to the rated power output of the BESS to evaluate overall system efficiency.

9 https://storagesizing.energydata.info

TABLE 4, CONT. | TECHNICAL CONSIDERATIONS FOR BESS SYSTEM REQUIREMENTS AND THE DESIGN PARAMETERS

System configuration and design
Capacity
• MW/MWh ratio of BESS depends on project type with bulk energy shifting and hybrid project types that require longer durations having higher ratios and tending towards 1:1 for network and system services. • The higher the MW/MWh ratio, the faster the charging rate and the greater need for optimized dispatch to lower/minimize aging. • Required rest state of charge for a BESS over its lifetime varies with use application and battery's aging rate.
Storage duration
• Applications determine the required duration of BESS at a given state of charge which is directly proportional to the rate of aging. • Dispatch strategy should be optimized to minimize the state of charge (and duration) required in the rest state to extend expected lifetime of the BESS.
System configuration
• Decentralized approach of battery inverters per string, though costlier (in terms of price per kW) should be considered for its technical advantages with increased flexibility, dispatch control, and increased efficiency. • Modular configuration increases operational flexibility and facilitates fault detection and clearing.
Supervision and protection systems
• Compatible SCADA should include a PLC to interface with the battery and inverter management systems to control the output from each battery string proportionally. • Battery dispatch should be optimized with respect to BESS efficiency (minimize losses) and aging via an EMS. • Protection systems with insulation monitoring and ground fault detection key to guarantee availability • BMS should extensively monitor all technical parameters for each battery state to maximize efficiency and ensure safety of the BESS from thermal runaway.

TABLE 5 | DIFFERENTIATING CHARACTERISTICS BETWEEN BATTERY STORAGE TECHNOLOGIES[10]

	Lithium-ion				Sodium-sulphur	Redox flow	Lead-acid
	NMC	NCA	LFP	LTO			
Technical characteristics							
Cycle life (cycles)	1,500–4,800	1,000–5,000	1,000–10,000	7,000–15,000	2,500–40,000	10,000–16,000	250–2,000
Round-trip efficiency (%)	75–97%	75–97%	75–97%	90–97%	75–90%	75–90%	63–90%
Charging rate (min – max)[11]	C/4–2C	C/4–1C	C/4–2C	C/4–10C	C/8–C/6	C/8–C/4	C/10–2C
Depth of discharge (%)	80–100%	80–100%	80–100%	90–100%	100%	100%	50–80%
Energy density (kWh/m^3)	200–250	250–350	95–200	50–80	150–350	10–33	25–90
Thermal stability	Medium	Low	High	High	Medium	High	High
Commercial characteristics							
Capital cost — DC ($/kWh)	170–210	250–300	150–190	400–1,000	300–600	240–390	210–240
Operating cost ($/kWh)	8	8	8	6	8	11	3
Development & construction time (years)	0.50	0.50	0.50	0.50	0.50	1.00	0.25
Maturity of technology	Mature	Commer-cialization	Commer-cialization	Early Commer-cialization	Commer-cialization	Demon-stration	Mature

Source: IRENA (2020), Electricity Storage Valuation Framework: Assessing system value and ensuring project viability; Šimić et al (2021): Battery energy storage technologies overview; PNNL Energy storage cost and performance database

10 It is expected that the performance of many of these technologies will improve while prices continue to fall. The parameters shown in the table were indicative of technology performance at the time of publication, in 2022. Note that the costs shown are indicative; where relevant cost ranges are indicative for utility-scale projects with 4h duration, but in practice, some BESS costs vary by kWh and others vary by kW, meaning that the overall system cost can depend on the duration and configuration of that system.

11 C-rate measures charging relative to maximum battery capacity; a 1C battery charges to full capacity in one hour, a 2C battery charges to full capacity in half an hour, a C/2 battery charges to full capacity in two hours.

TABLE 6 | IMPORTANCE OF BATTERY CHARACTERISTICS TO PROJECT TYPE

Technical characteristics	Bulk energy shifting	Network and system services	Hybrid/co-located projects
Cycle life (cycles)	High	Moderate	High
Round-trip efficiency (%)	High	High	High
Charging rate (min – max)	Moderate	High	High
Depth of discharge (%)	High	Moderate	High
Energy density (Wh/m^3)	High	Moderate	Moderate
Power density (W/m^3)	Moderate	High	Moderate
Response time	Moderate	High	Moderate
Storage duration	High	Moderate	Moderate
Capacity sizing	MWh	MW	MW/MWh

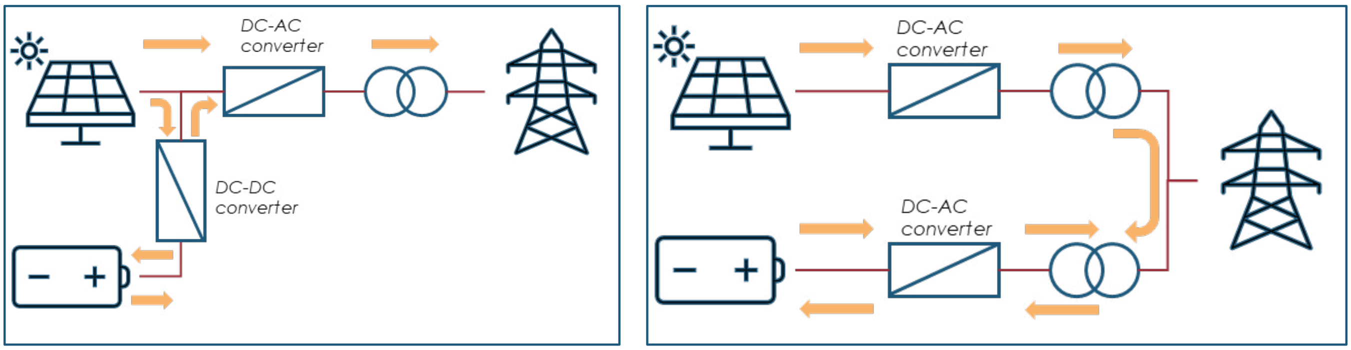
When providing system services, the exact service(s) to be provided by the BESS will impact the characteristics that need to be delivered by the technical design of the project. For example, the speed of response required will depend on the service being provided. Frequency containment may require a sub-second response (where batteries have a clear advantage over thermal assets), whereas secondary reserve might not need such a fast response. The length of time for which a response should be sustained will also vary. Typically, a fast response service might need to be sustained for a shorter period. This will impact the duration of the BESS system for the project to be able to meet the service requirements. This sizing of the battery will also need to consider the characteristics of the selected technology. For example, as indicated in Table 5, the maximum depth of discharge of lithium-ion technologies is typically only 90-95% of the battery capacity. This means that the 'usable' capacity is lower than the nameplate MWh capacity of the battery.

For hybrid solar PV and BESS projects, options for how the system is coupled also need to be considered. Traditionally, coupling a battery to a hybrid solar PV plant is done on the AC bus[12] through separate battery inverters and PV inverters. However, incorporation of DC-DC converters can enable the battery to be coupled directly to the DC bus of the PV plant. These options are shown schematically in Figure 7. The DC-coupled system has the advantage of higher round-trip efficiencies, lower system integration costs and maximizing the value of the solar resource by avoiding 'clipping' because excess energy generated when PV power output exceeds the inverter rating can be stored in the battery. However, this model can compromise flexibility and the extent to which dispatch of the BESS can be

12 A system bus s a transmission or distribution node to which various system components such as generators, transformers, feeders, interconnectors and loads are connected with specific voltage (and phase angle), active and reactive power.

optimized. It is likely to only be suitable for a more limited range of use cases, such as smoothing of the output from a solar installation. An AC-coupled system can result in a more flexible system as the battery can be charged from the grid independently of the PV plant, but this configuration leads to higher energy losses (lower efficiency) due to multiple power conversions, requires more consideration for grid interconnection requirements and does not mitigate 'clipping'.

FIGURE 7 | SCHEMATIC REPRESENTATION OF DC (LEFT) AND AC-COUPLED (RIGHT) HYBRID SYSTEMS



3.3.3 Technical feasibility

A comprehensive assessment of the grid (including power flow analyses) is performed to identify any challenges with integrating the proposed BESS. The objective of the technical feasibility is to determine the operational constraints within which the BESS can be integrated to the grid while ensuring the BESS (i) does not adversely affect system stability and/or security and (ii) beneficially impacts the grid by providing the proposed services.

While the tasks covered in this section are focused on the first of these objectives, the design of the analysis should also consider what evidence can be collected to support the business case for the specific project type being implemented, as is discussed further in Section 3.3.4. This will help to ensure that the analysis also meets the second objective. The distinction between these two objectives is key because while the former is of interest to the system operator and regulator for all new resources being connected to the system, the latter contributes to the business case and informs the development of the PPP structure. Both these aspects need to be addressed in detail during the feasibility analysis to ensure all the operational and performance risks are identified and allocated appropriately.

The tasks required to complete the feasibility assessment can be described as follows:

1. **A comprehensive system assessment to analyze the current state of the grid, and adherence to grid code requirements.** This assessment involves an in-depth review of the grid code (and related technical regulations), relevant national and international standards, and all available data from studies and reports in order to characterize the demand and supply across the power system to which the BESS is being connected.

This characterization involves analyzing the spatial distribution of loads, supply-side energy resources and the corresponding system nodes to which they are connected in order to ascertain the adequacy of supply resources to meet demand. The technical indicators (like demand growth, system reliability, VRE penetration, system load factor) relied upon when identifying the project opportunity as detailed in Section 3.2 and the considerations for developing the business case as detailed in Section 3.3.4 will be validated in this assessment.

This system assessment provides an overview of the system, the layout of the grid, and its demand-supply characterization laying the foundations for deeper and more focused analysis. This analysis may result in recommendations being made to the regulator for modifications to the grid code to increase commercial viability and facilitate implementation of similar BESS projects in the future. For example, the technical electricity rules in the host country may limit the provision of grid services by a BESS or any new technology.

2. **Power flow analyses to simulate the steady-state and dynamic behavior of the system with the BESS integrated under different operational scenarios.** The analyses are conducted on a simulation of the system with the BESS connected to ascertain whether system stability, security and reliability are maintained under all operational scenarios. Energy flows are also analyzed to quantify the beneficial impact of BESS relating to the proposed use case (discussed further in Section 3.3.4). These analyses will also impact the final design and sizing of the BESS installation (Section 3.3.7) by informing proposed equipment parameters and operational limits.

   The power flow analyses are conducted using internationally accepted simulation software (such as DigSilent and PSSE) based on actual system data provided by the system operator for grid studies. A load flow analysis, short-circuit analysis and dynamic stability analysis are simulated for different configurations of the BESS integrated to the grid under steady state, during short-term contingencies, and during prolonged disturbances.

   The simulations consider different operating modes of the BESS, establish the optimal BESS configuration to provide proposed services, and the BESS technical parameters to achieve optimized performance. Dispatch modelling is performed taking into account technical losses and supply security to simulate the technical behavior of the battery following the envisioned dispatch schedule. This informs the minimum performance parameters required of the battery during operation.

3. **Assessment of the proposed site and environmental impact of the BESS project during its lifetime.** The objective of the site assessment is to justify the suitability of the site and identify any significant risks to project success like land ownership, required interconnection infrastructure, access to the site, social and environmental risks etc. This assessment involves gathering site-specific information and details of the proximity to the grid interconnection point with consideration to social and environmental impacts. The site assessment report provides a recommendation on layout of the system at the proposed location and identifies any associated performance risks. The considerations in this work are mostly likely to be similar to those

encountered in an environmental impact assessment for other energy sector projects.[13] However, for BESS systems, safe disposal and/or recycling of all system components is also an important consideration. The contents of lithium-ion batteries are toxic if disposed of incorrectly. Recycling options should be assessed during the feasibility analysis, taking into account any specific local regulations concerning battery disposal (e.g., in the EU battery manufacturers are required to cover the costs of collection, treatment, and recycling, meaning this cost is in effect included in the up-front capital cost of a project). Any decommissioning costs associated with disposal/recycling need to be assessed so that these can be included in the cost-benefit analysis.

A sample Terms of Reference for a consultant to carry out the tasks of the technical feasibility described above is included in Appendix B.2.

3.3.4 Technical inputs to the cost-benefit analysis

Detailed dispatch analysis should be completed to model how the BESS will operate. The detailed dispatch analysis is an important step in validating the technical feasibility of a proposed BESS application. The analysis should consider the operational constraints (e.g., number of cycles, rate of charging/discharging, depth of discharge, temperature, state of charge) in dispatching the battery and their impact on the degradation of the battery's available capacity and round-trip efficiency over time considering the battery's degradation curve[14]. For example, a proposed application might involve more rapid and/or frequent cycling of the battery than was originally expected, and this might in turn lead to more rapid degradation of the battery, meaning that it is unable to meet the requirements of the intended application for the entire project lifetime. The contract period for the PPP can be derived from this analysis as the time the battery takes to degrade to a defined state of health[15]. This dispatch analysis can be performed using off-the-shelf software packages such as Homer[16] or PLEXOS.[17] Analysis can also be performed using Excel and/or commercially available solvers. Whichever tools are used, it is important to consider the extent to which the modelling assumes perfect foresight, i.e., the model optimizes perfectly to a known set of inputs. Perfect foresight can lead to an overly optimistic set of outputs from the analysis, without considering sources of uncertainty (e.g., solar or wind resource levels) that might lead to a sub-optimal dispatch. One benefit of using a bespoke model is that changes can be made to the dispatch algorithm to reflect such uncertainty.

Information from the technical feasibility analysis described in Section 3.3.3 can also be used to validate the beneficial impact of the BESS when integrated to the grid. While much of the technical feasibility analysis described is focused on ensuring the BESS does not have any negative impacts on the system, the analysis should also be designed to validate the positive value that the proposed BESS

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13 Further guidance in the preparation of environmental impact assessments is available at https://ppp.worldbank.org/public-private-partnership/library/guidance-preparation-environmental-impact-assessment-report

14 Many factors that affect the degradation of the battery during its operation may not be easily modelled and simulated at the onset so the dispatch analysis should be based on the battery's warranted degradation curve that stipulates the guaranteed rate of degradation under different operational conditions and is incorporated in the contract.

15 The state of health is a degradation indicator measured by the ratio of rem aining capacity to initial rated capacity of a BESS over the lifetime.

16 https://www.homerenergy.com/products/pro/index.html

17 https://energyexemplar.com/solutions/plexos

can deliver to the system. Technical inputs to the cost benefit analysis will be specific to the project type proposed. These parameters should be investigated in detail during the technical feasibility assessment to inform the business case. The inputs and parameters most relevant for each type of project are highlighted in Table 7.

It is worth noting that during the feasibility assessment, other system benefits might be discovered from the BESS under different operational scenarios. These technical benefits can be investigated further, so that system benefits that may had not previously been evident can be better understood. The additional system benefits should be investigated further in the economic cost benefit analysis to quantify the unlocked revenue/value stream.

TABLE 7 | TECHNICAL INPUTS TO COST-BENEFIT ANALYSIS FOR SPECIFIC PROJECT TYPES

	Data from the technical analysis that can be used in building the business case for BESS
Bulk energy shifting	*Technical analysis needs to ensure that the proposed BESS design is fit-for-purpose in providing the required energy shifting. The modelling should help to validate that the proposed sizing of the battery is appropriate. For example, does the dispatch modelling show the battery always available to provide a peaking service, or would a longer duration battery be required. This analysis will also help with quantifying the extent to which the project displaces the need for other peaking capacity (if at all).*
Generation mix	• Impact of the BESS on the dispatch of other generation resources. This will often be from evaluated using a Production Cost Model (PCM), or dispatch model covering the whole electricity system. • Analysis of system dispatch to identify any generators or other resources that are no longer used or required after addition of the BESS. • Impact of BESS on the operating regime of other plants, e.g., more efficient dispatch of thermal plants, operating less at inefficient low load points. • Impact of the BESS on reducing curtailment of VRE across the system.
Supply-demand balance	• Identification of any issues with (or, indeed improvements in) supply meeting demand after addition of the BESS.

TABLE 7, CONT. | TECHNICAL INPUTS TO COST-BENEFIT ANALYSIS FOR SPECIFIC PROJECT TYPES

	Data from the technical analysis that can be used in building the business case for BESS
Network and system services	*When evaluating the business case for system services, the technical analysis performed should evaluate the BESS's capabilities in providing the service. The analysis should consider whether the BESS provides the service as well (or, likely, better) than the existing provider of the service, if the service is being provided. If there are limitations in the BESS's ability to provide the service, can these be managed by locating the BESS somewhere else, or by refining the technical design of the installation?*
T&D system load flows	• Voltages exceeding set limits at different buses (reactive power imbalances) during any operational scenario; BESS impact can be compared with voltage support alternatives like reactors and capacitors. • High levels of system congestion due to multiple VRE resources with correlated output, requiring T&D upgrade. • T&D infrastructure upgrade focused on mitigating the impact of peak flows that could be deferred by shifting load locally with a BESS.
Generation mix	• Significant level of VRE installed downstream in the distribution network requiring reactive power control and voltage regulation to increase the capacity of the feeders without significant infrastructure upgrade. • Significant share of VREs (and other non-synchronous generators) that lower system inertia (and increase the rate of change of frequency), resulting in addition reserve requirements to mitigate frequency fluctuations. • High ramp requirement of generators for supply to match the demand curve where storage could alleviate the slow start/stop times. • Extent of system redundancy (idle capacity) to provide frequency response services that could be displaced by BESS. • High levels of forecast errors arising from uncertainty of VREs that would require storage for more predictable dispatch schedule. Forecast error could also be managed by individual VRE plants through hybrid projects.
Operating reserves (spinning and non-spinning reserves) and black start capability	• High requirement for reserves to mitigate the uncertainty and variability of VRE forecasts. • Operational constraints of existing reserves that could be displaced or dispatched more efficiently with BESS. This could free up existing reserve providers to operate more efficiently, or it could allow services to be provided with lower emissions, or at lower cost. • High cost and inefficiency of generators providing reserve or black start services.
Level of flexibility of thermal plants (and other inflexible generators)	• Reliance on thermal plants in the provision of system services. There plants are typically less flexible that a BESS and often have inefficient low-load operation where the emissions are high and frequency control capability is reduced hence limiting their response to frequency deviations. Integration of BESS can increase the flexibility of these plants to respond to frequency and VREs[18]

18 More on the role of BESS in increasing the flexibility of thermal plants; Thermal Power Plant Flexibility, a publication under the Clean Energy Ministerial campaign (2018)

TABLE 7, CONT. | TECHNICAL INPUTS TO COST-BENEFIT ANALYSIS FOR SPECIFIC PROJECT TYPES

	Data from the technical analysis that can be used in building the business case for BESS
Hybrid projects	*Technical analysis of the project should be focused on validating whether the proposed BESS component of the project is successful in meeting whatever requirements have been imposed, resulting in the inclusion of BESS. This might include smoothing or load shifting. The analysis should also consider the size of battery required; could a smaller battery also provide the required service?*
Level of flexibility of the co-located VRE plant	• Evaluation of whether the proposed BESS provides the required smoothing, dispatchability, and/or predictability in dispatch schedule. • Quantification of any reduction in curtailment of output from the VRE component of the project
Impact of VRE project on the grid	• Validation that the BESS successfully reduces their impact to voltage regulation on lines by including BESS. This could also defer expenditure on network upgrades, covered in the "network and system services" category, above. • VREs that create system congestion and require a T&D upgrade before integration can be optimized by integrating a more cost-effective BESS

3.3.5 Economic cost-benefit analysis

The initial technical analysis and feasibility assessment provides a starting point for a detailed cost-benefit analysis. The analysis described above provides information on whether the project can technically provide the services required from the BESS, without adversely impacting the wider power system. The analysis described in this section is focused on whether the economics of the proposed project are attractive. Specifically, the analysis aims to quantify the benefits of the services being provided, so that these benefits can be compared to the cost of providing the BESS. This economic analysis provides the foundation for the commercial and financial analysis that is critical to understanding the viability of a specific PPP project. These additional considerations are discussed further in Sections 3.3.6 and 3.4).

The initial feasibility analysis should allow for the project costs to be estimated. While the detailed design of the project will not be finalized (see Section 3.3.7) until all components of the feasibility analysis have been completed, the main parameters of the project will have been determined through the options analysis (Section 3.3.2) and technical feasibility analysis (Section 3.3.3) described above. This outline specification can be used to obtain indicative quotes from suppliers of BESS equipment. Alternatively, depending on the level of detail to which the system has specified at this stage, it might be appropriate to use publicly available cost benchmarks, although these are unlikely to fully consider design detail that might be relevant to the specific application being considered. Example benchmarking documents include Lazard's annual "Levelised Cost of Storage Analysis" documents.[19] Note that

19 E.g., Lazard (2020): Levelised Cost of Storage Analysis – Version 6.0 (https://www.lazard.com/media/451566/lazards-levelized-cost-of-storage-version-60-vf2.pdf)

the Levelised Cost of Storage (LCOS) figures shown in these documents are very specific to the use case and dispatch schedule assumed in calculating the LCOS; the LCOS numbers should not be used without validating that the application proposed exactly matches the application assumed in calculating the LCOS. However, the documents do present assumption on the capital and operating costs used in calculating LCOS, which could be used in estimating project costs.

The cost and cost structure of a BESS project can vary materially depending on the project's design. Some costs will vary per kWh of storage capacity (such as the battery's storage capacity or "depth"), whereas other costs might vary by kW of output capacity (e.g., the cost of inverter systems or grid connection). This highlights the caution that should be taken in using published benchmarks for cost estimates, as these benchmarks will not always provide sufficient detail to allow for these effects to properly considered.

The cost assessment for the BESS should also consider any (operations and) maintenance requirements and decommissioning. Major maintenance events should be included in the analysis as should ongoing costs associated with operation and maintenance of the BESS. The costs associated with the safe disposal and/or recycling of the assets (as discussed earlier in Section 3.3.3), complying with any relevant local regulations, should also be analyzed.

The approach used to measure the benefits of the system will depend on the type of project being implemented. Because each of the three main categories of project type have a different purpose, the benefit of the BESS to the electricity system is evaluated differently in each case. Fundamentally, the objective is the same in each case: to compare system costs with the benefit of the BESS with system costs prior to the BESS being added (the 'baseline' or 'counterfactual'). However, because each type of project is targeting different components of system cost, the scope of the analysis will be different in each case. The considerations likely to be most important for each project type are summarized in Table 8. Further details on evaluating the cost-benefit analysis for each type of project are presented below.

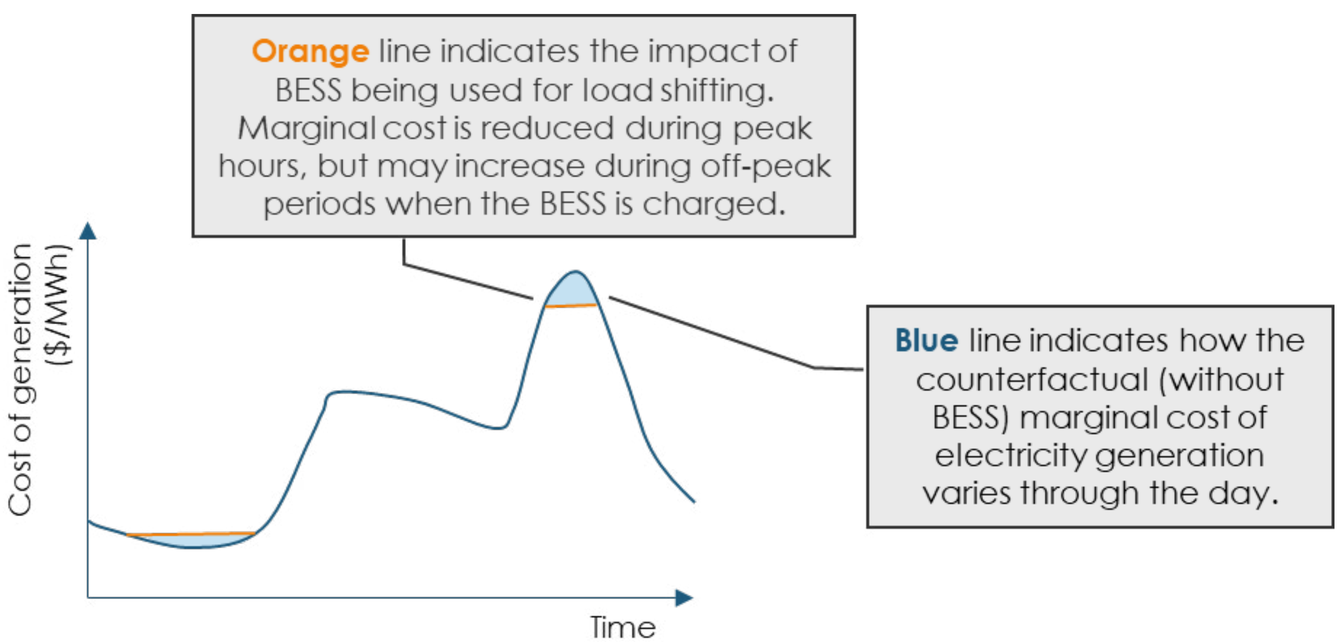
TABLE 8 | KEY ECONOMIC COST-BENEFIT ANALYSIS CONSIDERATIONS FOR EACH PROJECT TYPE

Bulk energy shifting	Network and system services	Hybrid and co-located projects
• Wholesale power generation costs • Consider which power generation costs are marginal • Cost of alternative peaker capacity	• Consider whether the service is new or is already being provided • Cost of alternative provider of the system service(s) • Cost of network infrastructure is this is being displaced or deferred • Improvements resulting from service: e.g., reduced load shedding, improved power quality	• Benefits of any VRE project (lower costs, lower emissions) being unlocked by the BESS • Benefits of additional services provided by the co-located BESS

For load shifting projects, the benefit is likely to be a function of the difference between peak and off-peak wholesale energy costs. As illustrated in Figure 8, the economic rationale for this type of project is essentially to reduce the total cost of wholesale power. By discharging the battery during peak periods, power generation costs are reduced; but this may partly be offset by the cost of charging the battery during off-peak hours. Understanding the characteristics of the supply curve can help with optimizing this type of project: trying to identify hours during which a reduction in system load could achieve substantial cost savings, while minimizing the cost of charging the battery. In some countries, there might be good data for wholesale electricity prices; for example, if there is an exchange on which wholesale electricity is traded. In other countries, it might be necessary to model the impact of the BESS on wholesale prices from first principles, using a simple stack model or a more sophisticated Production Cost Model (PCM) of the full electricity system. The modelling should also consider whether the benefit of load shifting is likely to evolve over time. For example, if diesel-fired generation is likely to be replaced over time, this might result in lower peak generation costs in the counterfactual, reducing the benefit of the BESS in future. Conversely, increased penetration of VRE might result in an increasing number of periods during which output from solar PV or wind generators is high, resulting in a zero or near-zero marginal cost of generation. This in effect means the battery can be charged for free.

Detailed modelling might identify additional benefits associated with adding the BESS. For example, dispatch analysis of the full system using a PCM may show a more optimal dispatch of thermal generators (with less part-load operations) with the BESS added. This would not only result in a cost reduction; it would also result in lower emissions of greenhouse gases, which are discussed further later.

FIGURE 8 | SCHEMATIC TO ILLUSTRATE THE IMPACT OF BULK SHIFTING ON WHOLESALE ELECTRICITY COSTS



Depending on how the load shifting project is designed, there might be a secondary benefit associated with reducing the amount of other power generation capacity contracted. This is referred to as a capacity credit. If less generation capacity from other sources (e.g., thermal plants) is needed, this will result in lower capital costs (or lower availability payments) for those projects in the future. However, it is important to carefully consider whether the need for other generation capacity is really removed. The BESS project will have a finite duration, so may not provide the same level of security of supply. In some cases, the need for other dispatchable capacity may not be reduced, although the utilization of some capacity may be reduced. Generally speaking, the longer the duration of the battery being considered, the more likely it is that it can reduce the need for other power generation capacity during peak hours while maintaining the same level of security (e.g., maintaining the same Loss of Load Probability, LOLP). In effect, the capacity credit is higher for longer duration projects. This is illustrated in the de-rating factors (which are analogous to a capacity credit) awarded to BESS projects with different durations in the capacity markets that are often present in more liberalized markets. Selected de-rating factors in recent capacity auctions in the UK and Ireland are shown in Table 9; this shows a much larger credit for longer duration systems. In cases where capacity can be removed, any changes in the resulting capacity mix should be reflected in system dispatch modelling mentioned earlier in the section.

TABLE 9 | DE-RATING FACTORS FOR BATTERY STORAGE FROM RECENT CAPACITY AUCTIONS IN THE UNITED KINGDOM AND IN THE REPUBLIC OF IRELAND

Duration	United Kingdom T-4 auction for delivery 2024/25	Republic of Ireland[20] T-4 auction for delivery 2024/25
0.5h	12.4%	12.5%
1.0h	24.7%	22.6%
2.0h	48.6%	37.6%
4.0h	73.8%	58.5%

Source: EMR Delivery Body (UK), SEM-O (Ireland)

When providing system services, the benefit can be estimated by understanding the cost of alternative technologies that might have provided the service, in the absence of the BESS. If the BESS is providing an ancillary service, such as a reserve service, or frequency response, there are two key questions to consider in quantifying the benefit of the project: (i) would the service be provided in the absence of the BESS, and (ii) if so, what would provide the service in place of the BESS. If the service would not be provided without the BESS, the analysis should consider what the consequences are of the service not being available. For example, this might include higher LOLP. While in theory the value of such an increase can be valued with reference to the Value of Lost Load (VOLL), in practice

20 Note that the de-rating factors used in Ireland also vary by installation size, with larger units suffering more de-rating, reflecting the greater impact that their loss would have on system security. The de-rating factors shown in the table are for a 50 MW installation.

this can be challenging. In some markets, analyses have been completed to evaluate VOLL; in other markets it might be necessary to refer to benchmarks from similar or neighboring countries. Where an alternative technology would be used to provide the service in the absence of the BESS, the saving generated by using the BESS should be calculated by also considering the cost of providing the service using the alternative technology. For example, if a thermal power plant would be used to provide a reserve or response service, this imposes an operating constraint as the plant is required to maintain headroom[21], so that it can respond when required. This will often lead to a deviation in system dispatch from a theoretical least-cost dispatch without such a constraint imposed. The cost-benefit analysis should evaluate the cost saving associated with such effects by evaluating system dispatch costs with and without the BESS providing the service. This analysis can be used to evaluate whether the BESS technology is delivering value-for-money when compared against other technical options.

For projects tackling grid constraints, the project cost should be compared to the cost of grid upgrades. If the BESS is being used to tackle a constraint in the transmission or distribution system, the economic benefit is related to the avoidance or the deferral of the investment in the related grid infrastructure. That might include uprating lines or expanding substations. The costs of this counterfactual investment are likely to be unique to the specific constraint being addressed but understanding these costs will be key to evaluating the business case. The technical feasibility analysis might also have identified other benefits that can be quantified; for example, reduced technical losses, reduced voltage exceedances, or improved power factor. It is possible that the battery might also result in some wholesale cost savings, although this benefit will be secondary to the business case. For example, if the battery is charged during off-peak periods so than it can be discharged when a network constraint is active during peak hours, this might reduce the total costs of power generation over a full day.

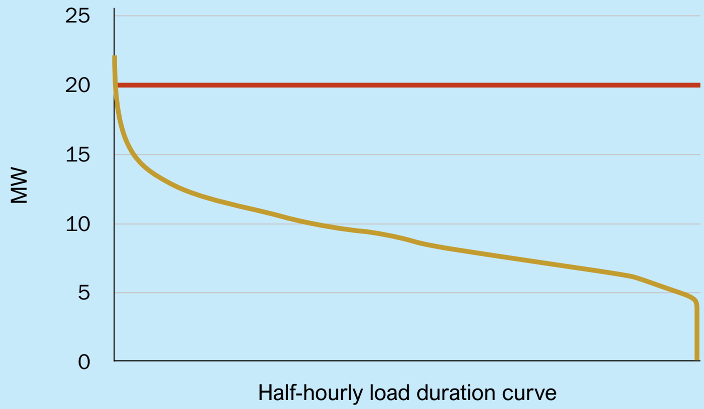
Hybrid projects can be more complex. As with the project types covered above, evaluation of the cost-benefit analysis should be focused on the problem that the project has been set up to solve. In some cases, where BESS technologies are combined with VRE, it might be the case that the VRE project would not be possible without the BESS; for example, if the stand-alone VRE installation would have violated Grid Code requirements. In such cases, the BESS can be considered to have unlocked all the benefits associated with the VRE itself, including wholesale electricity cost reductions and emissions reductions. In other cases, the co-location of energy resources might be incidental, and the BESS might in fact be providing unrelated services, such as ancillary services, in which case the business case should consider the same factors described above.

In any of these cases, it might also be important to consider economic externalities, such as greenhouse gas emissions. In addition to some of the pure economic considerations outlined above, one of the advantages of battery storage is that it can help achieve emissions reductions. In some cases, as mentioned above, these reductions might result from a previously infeasible VRE project being unlocked by a BESS installation. Where the BESS is being used to provide a service that would otherwise be provided by a carbon intensive thermal power generation (e.g., a diesel generator, or a coal-fired power plant), the BESS may reduce emissions. It is important to be careful here: because a battery stores energy, rather than generating carbon-free energy, the energy stored might have

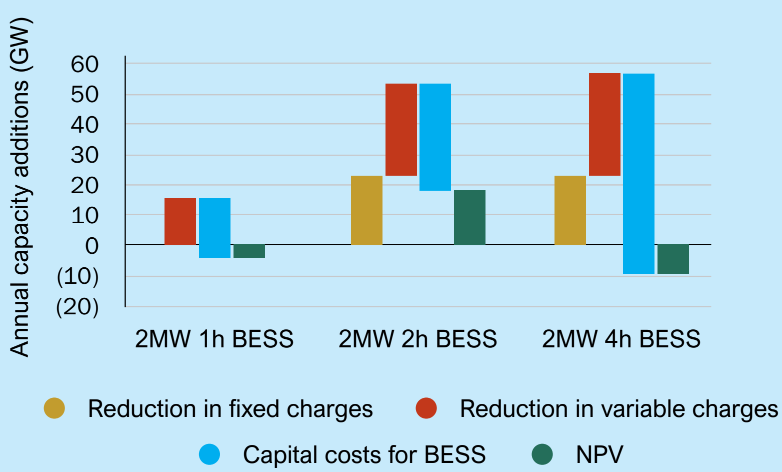
21 i.e., the thermal plant operated below its full generation capacity, meaning that it can increase output in the event that the reserve service is called upon.

Illustrative example economic cost-benefit analysis for constraint management

Kuungana recently evaluated the business case for multiple battery storage opportunities for a municipal utility in a middle-income country. This included cases where storage could be used to reduce peak load, mitigating the risk of incurring penalty charges that might apply if energy imports were to exceed a contractual peak demand for certain connection points with the transmission system. The graph shows how half-hourly load at one connection point exceeds a contractual peak demand of 20 MW.



In this case, a high-level economic assessment of the potential use of BESS involved comparing the capital cost of the BESS with the wholesale tariff savings that could be realized by the municipality. The graph below presents summary results. The business case was analyzed for a 2 MW system of 1h, 2h, and 4h duration.



The 1h BESS does not have sufficient duration to mitigate the fixed penalty charges for exceeding the contracted capacity. The additional duration of the 4h BESS is not sufficiently well utilized to justify the higher capital costs. Conversely, the 2h duration BESS achieves the optimal balance between capital expenditure and wholesale tariff savings.

resulted in carbon emissions. However, because the battery will typically be charged during off-peak periods of the day when energy is cheaper, this will often result in using electricity with a lower carbon intensity. The emissions saving evaluated through the analysis could be valued using an agreed carbon price – even in markets where there is no traded carbon price. Including this economic externality in the economic evaluation for such a project is now standard practice in many companies and to inform government decision-making in many developed countries, although it remains less common in developing markets.

Depending on the design of the project being implemented it might be appropriate to combine, or to 'stack,' benefits that can be delivered by the BESS. Sometimes the project might be used to address multiple use cases, and this might mean that more than one of the business case frameworks outlined above are relevant. This is often referred to as 'stacking'. In developed markets, where these different use cases often translate to distinct revenue streams, revenues are often stacked for a project to be able to meet its required return. In a less developed country, the same principle can still be applied: it might be necessary to consider multiple use cases for the cost-benefit analysis to have a positive outcome. This is another area to exercise care: it might not be possible to be available to provide two service simultaneously, and the provision of a secondary service might restrict the extent to which value can be extracted from the primary use case. For example, being available to provide a frequency regulation service might require the load point of the battery to be maintained in a certain range so that the contracted response can be provided. However, this may restrict the extent to which the battery can engage in load shifting activities.

The net benefit of the project can be estimated by calculating a net present value (NPV) of the costs and benefits. The costs and benefits outlined above can be compared in an NPV, which evaluates the net benefit (or net cost) of the proposed project. Utilities and/or government counterparties should typically have an agreed discount rate, or hurdle rate, that is used in such analyses.

Key uncertainties in the analysis should be considered and evaluated through sensitivity analysis. Many of the factors mentioned in this section are highly uncertain. For example, commodity prices might have a material impact on the cost of power generation at certain times of the day, which might in turn impact the viability of a business case focused on load shifting. There might be uncertainty over how much of a particular system service will be required in future, which could impact the business case for using a BESS installation to provide that service. A key part of the cost-benefit analysis work should be to identify the main uncertainties in the analysis, and to test the resilience of the business case to different sets of assumptions. This analysis might also flag risks that require further attention when considering the risk allocation in the PPP structure (risk allocation is discussed further in Section 3.4.1).

Uncertainty in the cost-benefit analysis is likely to be particularly high in developing countries. Electricity systems in many developing markets are changing rapidly as they remain under development. This increases the level of uncertainty when quantifying the benefits of a proposed BESS project. For example, the benefit of a BESS project providing system services such as frequency response might be reduced suddenly if a new gas-fired power station is commissioned that is able to provide the same services, displacing the need for the BESS.

Many of the concepts outlined above are explored further in a World Bank report[22] dedicated to the economic analysis of battery projects.

3.3.6 Commercial considerations

The commercial feasibility of the project will depend on whether it can be structured in a way that generates sufficient returns for the private sector, while still delivering value-for-money. This is critical to the success of any PPP. It requires the business case to be robust, as evaluated through the economic cost-benefit analysis outlined above, and it requires an appropriate risk allocation and commercial structure for the project to be agreed. This is discussed in more detail in Section 3.4.

As with other PPPs, the fiscal space for the public sector counterparty to perform its role needs to be evaluated. The utility or government counterparty that contracts with the BESS project will be required to may payments to the project under the PPP contract – the options for structuring these payments are discussed further in Section 3.4. Regardless of the structure chosen, the counterparty will need to be sufficiently credit-worthy for the private sector to be interested in bidding for the PPP contract. This is again common to all PPP projects. As with other PPPs, in some countries a government guarantee and/or political risk insurance products might be required for the project to be bankable. These instruments could all impose additional costs on the project, which will need to be considered in evaluating the business case for the project and its commercial viability. Beyond the immediate credit-worthiness concerns, consideration should also be given to whether the project results in government fiscal constraint being breached. This might be the case, for example, if guarantees are required and these add to the state's contingent liabilities. These factors are explored in more detail in the literature on infrastructure PPPs, such as the World Bank's PPP Reference Guide[23].

In performing this analysis, it should be remembered that BESS technologies, especially when implemented as a PPP, can help to reduce the capital expenditure burden on utilities. By implementing the project as a PPP, the government or utility is in effect replacing a capital expenditure requirement that it would need to finance with an operating expense, i.e., the payment stream defined under the PPP contract. This reduction in the requirement for finance should on balance reduce the fiscal risk resulting from the project.

3.3.7 Finalizing the technical design

Front End Engineering Designs define the technical parameters of the BESS to meet the requirements of the proposed application. The detailed engineering designs consist of a single line diagram for all the equipment, functional technical specifications of the battery modules and power conversion system, supervision systems (SCADA[24], protection and safety systems), and detail all

22 World Bank (2020): Economic Analysis of Battery Energy Storage Systems (https://openknowledge.worldbank.org/bitstream/handle/10986/33971/Economic-Analysis-of-Battery-Energy-Storage-Systems.pdf?sequence=1&isAllowed=y)

23 World Bank (2017): Public-Private Partnerships Reference Guide (Version 3). Link.

24 Supervisory Control and Data Acquisition (SCADA) comprises a set of hardware and software systems used to remotely monitor and control power systems equipment and plays a fundamental role in power systems operation.

works required for the full integration to the grid. For hybrid projects, the FEED should identify the optimal AC/DC coupling configuration. Depending on the procurement strategy to be adopted, this detailed design may be left to the project developer so long as the project requirements are met. This approach would afford the developer flexibility to come up with a more optimal design than prescribing the FEED during feasibility.

The single line diagram and equipment layout provide an overview of all the BESS components. Together with their functional technical specifications, they provide a basis for contract monitoring during construction. The FEED should define the specifications of the battery modules (including sizing and their configuration and mounting), DC/AC power conversion units (including the coupling configuration for hybrid projects), and balance of system components like air conditioning, cabling, earthing details, switchgear, etc. The design should also specify the T&D infrastructure required to connect the BESS to the grid and the connection topology (which should conform to the requirements of the network operator for smooth interconnection) and envisioned civil, structural and mechanical works during construction.

The BESS supervision systems (including protection and dispatch control) and their integration into any existing SCADA are designed to ensure reliability and security of the BESS. The key BESS supervision systems whose design and configuration are to be specified in the FEED include the energy management system, battery management system, and protection system as summarized in Table 10. The supervision systems (combined into the overall SCADA system) are designed to guarantee that the BESS will meet its performance requirements reliably assuring safety and security.

TABLE 10 | OVERVIEW OF BESS SUPERVISION SYSTEMS

	BESS Supervision system	Objective	Key aspects
1	Energy Management System	Ensure reliability, availability, and optimal dispatch of the BESS	• Dispatch control; Implementation of dispatch instructions • System power flow control • System thermal management i.e., ventilation, air conditioning
2	Battery management system	Ensure battery charges/discharges safely and reliably	• Monitoring voltage, current and temperature of battery cells • Balancing varying states-of-charge (SOCs) of batteries within the same serial connection • Prevention of thermal runaway of battery cells
3	Protection system	Detect faults within the BESS and isolate faulted parts timely	• Fault analysis • Protection schemes; overcurrent, earth fault, etc. • Protection devices; relays and circuit breakers

Depending on the procurement strategy to be adopted, the FEED shall be part and parcel of the tender documents. They should be comprehensive enough to sufficiently guide the OEM manufacturer and the installer during construction prescribing to the grid code and applicable international and national standards. As mentioned earlier, the more effective procurement approach where the utility tenders requirements of the services to be provided and leaves the detailed design to the project developer.

3.4 PPP options and selection

3.4.1 Risk identification and allocation

For a PPP to be undertaken in any country, regardless of the sector, the project must also be commercially viable. That is, a PPP must be workable in the sense that the structure and project contracts are designed to ensure that each party is confident (i) that it is able to perform its obligations, and (ii) that it will receive the benefits it expects, and contracts to obtain. The allocation of risks amongst the parties, and the parties' acceptance of them, mainly through contracts, is thus critical. A successful PPP normally requires that the risks that are inherent in the project are accepted by the party that is in the best position to manage them.

A PPP model in a developing country must have risk allocations that match the capabilities and expectations of the relevant participants. This will sometimes lead to different contractual solutions than would be found in more liberalized or developed markets. The key risks inherent in any PPP in a developing country are, broadly, those described below:

- **Sovereign risk**, which is the risk perceived by lenders of a country being unable to meet its debt obligations;
- **Offtaker credit-worthiness** — it is often the case that government-owned utilities or purchasing agencies do not have sufficient revenues or certainty of revenue to obtain or maintain an investment-grade credit rating. The electricity sector may be characterized by subsidized prices and widespread theft. Such utilities struggle to assuage lender fears of inability to pay for power and services, and so lenders seek credit support from the host government;
- **State of regulatory reform** and the existing policy, market, and regulatory framework within the sector in which the PPP is being implemented (in our case, the electricity sector). "Regulation by contract" may be necessary in countries with less developed legal and regulatory frameworks (this is discussed in Section 3.4.2);
- **Restrictions on the convertibility of the currency** in which project revenues are based exist in countries where the capital markets are weak;
- **Political risks** — apart from the risks associated with the provision of government support (change of government and thus policy, unpopularity and/or perceived impact on electricity prices, cost and complexity of enforcement), political risks take the shape of nationalization, confiscation or expropriation, adverse changes to exchange rate controls, import restrictions or quotas, changes in taxes, duties or withholdings, legal/regulatory changes that have an adverse

effect on the costs or profitability of the project, currency devaluation, political instability and civil disturbances or civil war, disputes between states or governmental organizations, blockades and embargoes, and corruption;

- **The legal system may not be sophisticated enough** to secure contractual rights and obligations of the type created in a project financing, a key example being the ability to take and enforce security of the project assets; and
- **Experience in the country of private sector investment** and the overall policy framework to support that investment.

Country risks will often be more significant than project risks and will have a substantial impact on project viability and therefore the extent to which finance can be secured.

The World Bank Guarantee Program, often combined with other World Bank Group instruments, including from IFC and MIGA, is a powerful tool to overcome or mitigate political risks and to enhance the credit quality of sovereign and sub-sovereign counterparties to achieve acceptable or affordable levels, reduce costs and improve financing terms for projects and governments to attract private-sector investment and commercial financing in projects in developing countries.[25]

Some risks are either specific to, or particularly important, in the case of a BESS project. Additional challenges applicable to, and risks inherent in a BESS project include:

- Defining and quantifying accurately the services to be provided by the BESS;
- Valuing these services and the benefits provided accurately, to enable assessment of project value;
- Structuring the pricing of the services provided (the remuneration model) in an appropriate way, following the principle that risks are allocated to the party best able to manage them;
- Ensuring the technology works; that is, that the built project provides the services contracted for, including securing appropriate warranties in respect of expected performance and ensuring operation and maintenance is conducted in accordance with manufacturer's recommendations;
- Considering who will operate or dispatch the project on a day-to-day basis, and what protocols and constraints apply to ensure the BESS both delivers the required services and is operated in such a way that it does not suffer excessive degradation; and
- Where the services provided by the BESS are locational, ensuring that the siting of the project is appropriate and allows the required services to be delivered.

Each of these points will need to be addressed for the project to meet lender requirements and to be bankable. Additionally, disposal or recycling of the battery at the end of its useful life poses risks for developers as well as for host countries and is a key aspect to be agreed under a PPP transaction (see Section 3.4.2).

The rest of this section is focused on the risk allocation challenges that are specific to BESS projects. In addition to these specific risks, most of the challenges that would apply to other infrastructure PPPs, and especially to IPP projects, will also apply here. There already exists an

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25 See, for instance, https://ppp.worldbank.org/public-private-partnership/library/world-bank-guarantees-program.

extensive literature providing a comprehensive overview of these risks and advising on how they should typically be managed. Recommended references covering these areas include:

- The World Bank's own PPP Reference Guide[26] which provides a comprehensive guide to managing PPPs and to designing PPP contracts to allocate the key risks that are common across many transactions to the appropriate party.
- Two reference guides prepared under US AID's Power Africa program: one covering project finance in the power sector;[27] the other specifically focused on Power Purchase Agreements (PPAs).[28]
- An IRENA report[29] analyzing the role of risk mitigation and structured finance in unlocking investment in the renewable energy sector.

Many of the risks covered in these documents would be equally relevant in structuring a BESS PPP, but the material below focuses on risks that are specific to BESS projects.

Where a BESS PPP is intended to be project financed, additional scrutiny will be focused on revenue streams and contracts. Determining an appropriate allocation of risks will require a careful analysis of delivery requirements and periods and performance obligations and penalties. In countries where BESS projects have been financed on a non-recourse basis, such as the UK and US, mitigating the risks inherent in these different revenue streams has presented challenges and required innovative debt structures. Challenges to ensuring a secure revenue stream from a BESS project in a developing country – where these revenue streams simply do not yet exist – will likely result in PPP model being adopted that utilizes a contract that is at least very similar to a long-term PPA.

As a country's electricity sector becomes more liberalized, the nature of the revenue risks for a BESS project will evolve. Regulators in advanced economies such as the US, UK and Australia are experiencing pressure for changes to the design of rates to facilitate the drive towards 'net zero', but some of these changes can and have resulted in increased revenue risk for investors in BESS projects. The lessons learned will, in time, need to be relevant in designing the electricity market of those countries that have less advanced energy markets. However, in the short- to medium-term, BESS projects in less developed countries are likely to capture revenues associated with the services that they provide through mechanisms that differ from projects in countries with liberalized energy markets.

Remuneration structure, demand risk, dispatch, and performance of the BESS are some of the key risks to be considered in structuring a PPP involving BESS. The remainder of this section considers three main categories of risk that are specific to BESS projects:

- Demand and commercial risk, which covers both revenue structure and the allocation of responsibilities relating to dispatch of the BESS,

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26 World Bank (2017): Public-Private Partnerships Reference Guide (Version 3). Link.

27 Power Africa (2018): Understanding Power Project Financing (https://cldp.doc.gov/sites/default/files/UnderstandingPowerProjectFinancing.pdf)

28 Power Africa (2017): Understanding Power Purchase Agreements (https://www.usaid.gov/powerafrica/ppahandbook)

29 IRENA (2016): Unlocking renewable energy investment: the role of risk mitigation and structured finance (https://www.irena.org/publications/2016/Jun/Unlocking-Renewable-Energy-Investment-The-role-of-risk-mitigation-and-structured-finance)

- Operations and performance, which covers the considerations when ensuring the BESS can provide the services that have been procured from it, and
- Location, which considers how responsibility for selecting an appropriate location might be allocated for different types of BESS project.

In many developing countries, these risk allocation challenges have not to date been successfully navigated, especially for stand-alone BESS projects. Most projects in developing countries so far have been developed either as hybrid projects or have been fully or part-funded by grants.

Demand and commercial risk

There are many ways in which the revenue streams for a BESS project can be structured. As discussed above, the absence of markets for the services provided by BESS projects in most developing countries, means that offtake revenues will usually be secured under long term agreements. These agreements are likely to take one of the following forms:

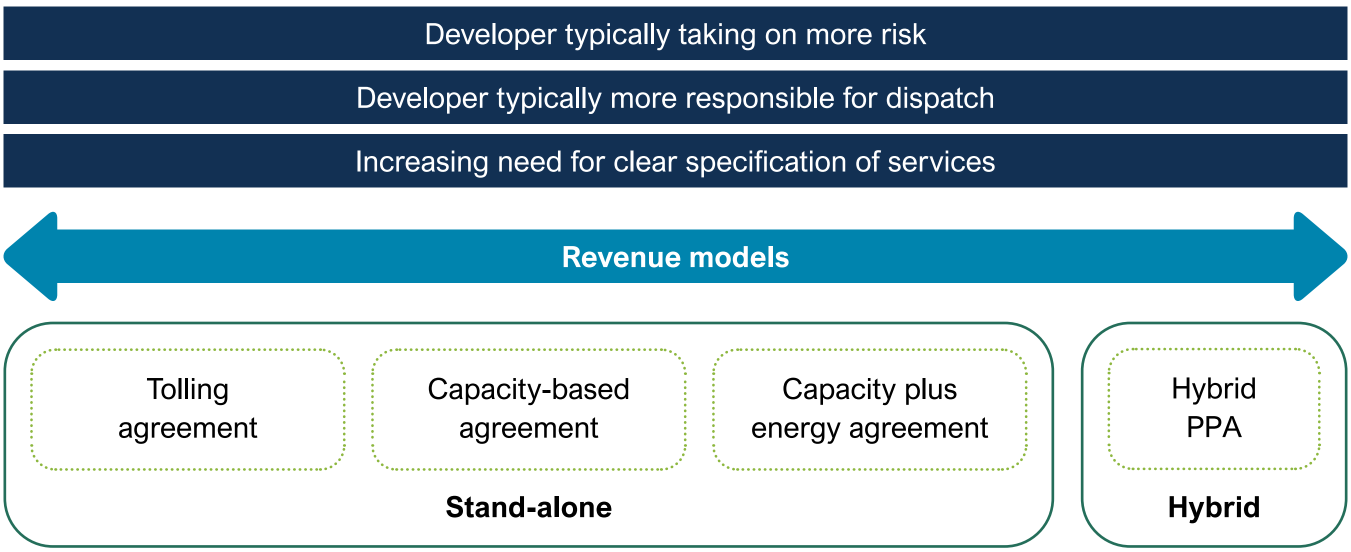
- A **"tolling" agreement**, where the buyer pays a tolling fee to access the capacity provided by the BESS project and is also responsible for delivering and paying energy to the BESS asset for charging.
- A **capacity-based agreement**, where the buyer pays a capacity or availability fee. The agreement will set out what the purchase of capacity entitles the off-taker to, i.e., whether this is limited to the provision of certain services. Ancillary service agreements in more developed markets typically pay for capacity.
- A **capacity plus energy agreement**, where the buyer pays both a capacity and an energy fee. This might be appropriate if the project is responsible for paying for energy to charge the battery – in this case the round-trip energy losses essentially become a variable cost to be passed through to the offtaker via an energy fee.
- A **"hybrid" PPA**, which is an extended renewable energy PPA to accommodate a hybrid project combining a VRE generator with a BESS installation. Such a PPA might simply pay for metered energy output (as with a typical stand-alone VRE project), but impose conditions on the project, such as ramping limits or limited dispatchability during certain periods. The seller will typically reflect the additional cost of the BESS in the energy fee paid for metered output, either through the energy fee itself being higher or through a separate 'adder' to the energy fee. Alternatively, the hybrid PPA might include a time-of-use tariff structure;[30] rather than imposing technical requirements on the project, the tariff structure provides an incentive to bidders to shift generation output to peak times. Kuungana has recently provided input to a project adopting a hybrid PPA structure in West Africa.

The revenue model which is most appropriate for a given project will depend on the type of BESS project being implemented. Clearly the hybrid PPA structure is specific to hybrid projects where BESS is being combined with VRE generation located on the same site. Most other applications could be covered by a tolling agreement structure or a capacity-based agreement. A structure that includes energy payments is likely to only be appropriate in an energy-focused application, for example

30 For example, the PPA might include multipliers (a fraction of 1) for each hour in the day, which are multiplied by a 'base price' to determine the amount paid to the seller for energy volumes delivered to the export meter. These multipliers would be lower during off-peak hours and higher during peak hours.

dispatching the battery to cover peak period energy requirements. The revenue model adopted will also typically be closely related to the allocation of other key risks. For example, in the case of the tolling agreement, the buyer will typically largely take control of the dispatch of the BESS and will have some flexibility in what services the BESS is used for. Figure 9 presents a schematic representation of the various revenue models described above.

FIGURE 9 | SCHEMATIC SHOWING A RANGE OF REVENUE MODELS FOR BESS PROJECTS



Many developing countries have recently seen push-back against the use of capacity-based payment structures. IPPs with 'take-or-pay' clauses have increasingly been resisted by some utility and government off-takers. While a clear case for these revenue models can be made, these challenges emphasize the importance of preparing a robust and clearly articulated cost-benefit analysis that demonstrates the value delivered by the proposed project, as described in Section 3.3.5.

BESS projects often rely on more complex "stacked" revenue streams than traditional energy generation projects. In developed markets this often results in BESS projects relying on a range of different revenues, with each revenue stream having different characteristics (e.g., some revenues might be capacity-based; others energy-based). In less developed markets, it is more likely that multiple services will be provided under a single revenue model. However, there are some cases where additional complexity might be required. For example, in a hybrid project where the BESS will be used to provide other services (e.g., ancillary services) and/or where the dispatch of the BESS will be controlled by the buyer, the parties will need to consider the volumes on which energy revenues are to be accrued. If revenues are paid on energy exported from the site, this could vary as a function of dispatch as well as gross energy generation, because of the round-trip losses suffered as the BESS is charged and discharged. This risk could be mitigated using a separate meter, measuring energy generated by the VRE generator so that revenues are not impacted by the dispatch decisions made by the buyer.

Dispatch of the BESS will impact the quantity of round-trip losses suffered by the project. This can be mitigated simply by allocating to the buyer responsibility for procuring and delivering input energy to the BESS. A tolling agreement structure mitigates this risk, and this will often also be the case with a capacity-based agreement. If the project is instead required to pay for energy used to charge the battery, the risk can be mitigated through inclusion of an energy payment in the contract. This revenue structure reflects the fact that the losses suffered are in effect a variable cost. If round-trip losses are not explicitly covered by the revenue model deployed in the contract, the seller will instead need to estimate the losses that they expect to suffer over the lifetime of the contract so that this cost can be reflected in pricing for the project. However, this requires a clear definition of how the BESS is likely to be used so the dispatch (and hence the losses suffered) can be estimated. One situation in which the seller might be best placed to manage this risk is where the BESS is part of a hybrid project and is being used to ensure a VRE generator meets certain technical criteria. In this case, the seller is best placed to analyze the VRE facility and hence to estimate the likely operating regime of the BESS.

The operating regime for the BESS will also impact wear and tear. This can be managed in the PPP contract using mechanisms similar to those deployed in the PPA or tolling agreement for a thermal power plant. Such agreements will often include, for example, limits on the number of starts that a power plant can incur, or incremental costs if these thresholds are exceeded. Typically, the constraints and/or costs will be a direct pass-through of terms included in the warranty for the equipment being used. The same approach can be used for BESS projects. The parameters to be considered will depend on the warranty agreed with the equipment provider, and on the technology being used, but might typically include:

- Restrictions on the number of charge/discharge cycles that a BESS system can complete.
- Constraints on the extent to which the battery's full name plate storage capacity is used (i.e., the depth of discharge). Exceeding this 'usable' capacity can cause damage to some battery technologies.
- Costs for major maintenance events, e.g., after the BESS has been operating for a certain period of time or number of cycles.

Operations and performance

The warranty terms offered by the battery manufacturer should be interrogated to ensure they are appropriate to the context. Many battery manufacturers may not have delivered many projects outside of their core developed markets. Assurances will need to be sought (and included in the warranty) that the BESS will perform as required in the location in which it is deployed. Additional considerations might include extreme climatic conditions, a lack of suitable skills for operating and maintaining the system in the local market, and a less resilient grid than might be the case in more developed markets.

The PPP contract will need to be tailored to ensure that performance requirements for providing the specific services to be delivered are met by the BESS. These requirements will vary substantially depending on the services being delivered. Some of the system requirements that might need to be met by a BESS project were summarized in Table 4, in Section 3.3.2. The service requirements, which should be specified in the agreement, include:

- Speed of response, which will be particularly important for services such as frequency response.
- How long a given response can be sustained for.
- The quantity of MW response provided by the project.
- Hours during which the system is expected to be available to provide a response.

Other factors might include ramp rates, or the number of times that the system might be required to provide a given service during a day. For a hybrid project, the technical requirements to be met will typically be different in nature. Rather than specifying requirements for the BESS system per se, the contract will likely define technical requirements for output from the VRE generation installation, which the BESS component of the project is the used to manage.

Risks associated with how the BESS's performance evolves over time also need to be managed. In particular, the usable MWh capacity or duration of the battery is likely to degrade over time. This will often be expressed as a degradation curve, which describes how the usable capacity declines as the number of cycles completed by the battery increases. Such a degradation curve will normally be included in the warranty from the battery manufacturer. The interaction between this degradation of the battery and the requirement for the project to meet certain technical criteria can be managed in different ways. In theory, the PPP contract could include a degradation curve that the project is expected to match.

However, in most cases it is likely to be more efficient to allow the project flexibility in how this risk is managed. If clear service requirements, such as a minimum duration of response, are clearly defined in the contract, this should be sufficient. Defining the requirement in this way ensures that the buyer still receives the services that it expects, but also allows the seller some flexibility in how it meets the buyer's requirement. For example, the seller could oversize a battery and allow it to degrade, or alternatively the seller might swap out individual battery cells during the project lifetime to augment the BESS and/or to maintain the required performance standards. Allocating this risk to the project developer ensures that the seller must find the most cost-effective solution.

Dispatch protocols and responsibility for meeting the technical requirements need to be clearly defined and allocated. It should be clear who is responsible for dispatch of the BESS. For some services – especially for very fast response system services – dispatch might be controlled automatically by equipment owned by a utility offtaker. Alternatively, the BESS project might receive dispatch instructions from the buyer, but with the project controlling the actual operation of the asset. In the latter case, the agreement should define the timescales over which dispatch instructions are issued. Penalties or liquidated damages might apply if the dispatch instruction is not accurately followed, to compensate for lost revenue or increased system dispatch costs.

Hybrid projects, or projects in more liberalized markets with self-dispatch arrangements, are likely to have more control in dispatching the asset. For hybrid projects, the seller will be best placed to decide how the BESS should be dispatched to meet the operating constraints imposed on the project. Where self-dispatch of the BESS applies, the buyer is likely to require the seller to provide a forecast or to nominate the volumes likely to be exported or imported from the site. A utility will require this information so that it can optimize dispatch and operation of the rest of the system. Penalties or liquidated damages might again apply if the seller deviates from these nominated volumes, to compensate the buyer for excess costs incurred.

A specific challenge in managing dispatch of the BESS is ensuring that it maintains a state of 'readiness' to provide the required services. The BESS by definition can only provide a response for a limited duration, so the parties will need to consider how the state of charge of the BESS will be maintained such that it is able to provide the services procured under the agreement. This risk will need to be addressed in cases where the BESS is dispatched by the seller. The simplest way to address the challenge would be through definition of the performance requirements described above. For example, the performance requirements could limit the numbers of times that a service can be delivered, or it could prescribe a minimum gap between dispatch instructions.

Location

For many BESS projects in developing countries, the project location is likely to be prescribed. Because of the complexity often associated with securing land rights, the procuring party may secure a site in advance of procurement or accept in the agreement obligations to secure and provide a site, as is often the case for other infrastructure PPPs. The developer/seller must assure itself that any site provided is in fact secure and not subject to challenge or exposed to risk of additional costs for the period of the PPP.

However, in cases where developers are left to select and secure appropriate locations, the buyer needs to be sure that the site is appropriate for provision of the required services. For example, the site might need to have access to certain parts of the electricity network if the intention is for the project to provide voltage support services, or it the project is intended to tackle a specific grid constraint. Where relevant, these requirements will need to be clearly stated in the tender documentation.

3.4.2 Further considerations when structuring the PPP

The risk allocation decisions described in the previous section then need to be translated into a contract structure that will govern the PPP. Appendix A contains two high-level heads of terms for contracts for BESS projects. One example covers stand-alone BESS projects; the second example covers hybrid projects. The heads of terms indicate areas where the terms will need to vary depending on the type of project being implemented. The heads of terms focus on the areas of a PPP contract where there are considerations specific to the use of BESS, mirroring the risk allocation issues covered in Section 3.4.1.

Determining the most appropriate public sector counterparty for the PPP will depend on the service procured and the state of the power sector. In most countries with a state-owned vertically integrated utility, that utility is likely to be the counterparty. However, if the sector has undergone unbundling, the counterparty will depend on the nature of that unbundling and the service being provided. For example, a bulk energy shifting project that is intended to reduce wholesale energy costs might be managed by the utility responsible for wholesale power purchase; projects focused on ancillary service provision are likely to be managed by the system operator (which may be the same entity in many countries); projects focused on addressing specific grid constraints are likely to be contracted by the utility that owns the affected network.

Other public sector entities are likely to need to be involved in structuring the PPP. For example, the ministry responsible for energy could be instrumental in initiating the PPP, especially to the extent that it has a role in energy sector planning. Ministry of Finance could also be involved, especially if guarantee or payment security (for example, letters of credit) structures are required for the project to be bankable. If required, such instruments could be used to tackle creditworthiness risks, similar to those used in many IPP projects.

The energy regulator will also very likely be involved in the project. The regulator may need to approve the agreement, which often requires an assessment of the impact on consumer electricity tariffs of the prices negotiated under the PPP. Regulations will need, at least, to be updated, and possibly to be introduced, to facilitate the introduction of a new technology to the system.

"Regulation by contract," may be necessary in countries that have still to develop their legal and regulatory frameworks to accommodate projects that utilize BESS technology (quite apart from other legal concerns about contractual rights and enforcement). This term is used to describe the situation where the regulatory framework does not contain all the necessary rules to ensure clarity of rights and obligations and how disagreements will be resolved, or otherwise adequately cover the legal concerns a developer may have, and so these concerns are covered in the PPP agreements themselves. Additionally, the legal system may not be sophisticated enough to secure contractual rights and obligations of the type created in a project financing.

The scope of the PPP agreement will depend on exactly which responsibilities are allocated to the private sector. In most cases, it is likely that the seller would build, own, and operate the BESS facility (and often be obligated to transfer the facility to the buyer or utility at the end of the PPP term). In infrastructure PPPs, this is referred to as a "BOO" project. Variants on this structure might include:

- Varying the extent to which the seller is responsible for **design** of the project. On the one hand both the project location and technical design could be fully specified by the buyer; on the other hand, the buyer may prescribe a service (or set of services) that prospective bidders are left to optimize their BESS design to deliver. The former is unlikely to make best use of the experience that private sector companies could bring to optimizing the design of the project. However, as noted above, it might sometimes be beneficial for the buyer to secure land for the project, especially if there are locational constraints on where the BESS project needs to be located for the required services to be provided. Note that the extent to which the design of the project is assigned to the private sector will also have a material impact on the scope of the technical

feasibility and design work that needs to be completed ahead of initiating a PPP transaction, as explained in Section 3.3.
- The project may or may not be **transferred** to the buyer at the end of the contract, as is often the case for other PPP projects, including many IPP projects in developing countries (a "BOOT" project).

The contracted term of a BESS PPP project will normally be shorter than for other infrastructure asset classes. For many infrastructure PPPs, contract terms will be 15-25 years. However, the typical operational life of a battery might only be 10-12 years. A longer contract term could still be agreed, with the developer being required to refurbish or replace the asset part way through the project. However, rapidly falling capital costs mean that it is unlikely to economically efficient to lock in those replacement costs up front. Therefore, a shorter contract term is likely to be appropriate. This also means that for most stand-alone BESS projects, transfer of the project to the public sector is less likely to be relevant, because it is unlikely to be possible to guarantee technical performance beyond a 10-12 year contract period. Rather, decommissioning and disposal is more likely to be appropriate, as discussed below.

For hybrid projects, contract term might be longer. If a BESS is paired with solar PV or wind, the operational life of the generation component of the project is likely to be much longer, so it will be appropriate to consider a longer contract term. There are a few options for how the BESS component of the project is tackled:

- The contract could define technical requirements that must be met throughout the contract. This would require the developer to replace parts to meet the requirements, and this cost would be priced into their bid. This is normally likely to be the best option, but with costs falling rapidly could again be cost inefficient as the developer is required to price in replacement costs many years in advance of them being incurred.
- An alternative would be to include a mechanism to 'reopen' the contract when major replacements are required, or to include an incentive mechanism that allows for cost upsides/downsides to be shared. This might be more cost efficient for the public sector, but it also adds some additional contractual complexity.
- Finally, the BESS component of the project could simply be defined for a shorter period than the generation component of the project.

Decommissioning (battery reuse or disposal) will also be a consideration. The contract must assign clear obligations and responsibilities (including legal and financial liability) governing the decommissioning process, both during and at the end of the term of the PPP. The decommissioning process involves dismantling and removing from site the battery, in compliance with applicable legislation and regulations governing the safe transport and disposal of hazardous waste. Few developers, owners or operators of grid-connected BESS projects have yet to gain experience in managing batteries at the end of a system's life, but they will need to comply with the applicable environmental protection legislation (which may not yet specifically cover batteries in some countries). If this responsibility is allocated to the developer (seller), this will help to address concerns over pollution that might result if the battery asset is handed over to the local utility or off-taker), although additional cost will result. Additional costs can be significant where the PPP is located in a country where disposal is especially challenging or poses transportation costs and complexities (such as an island nation).

Battery recycling, which reduces the number of batteries disposed of as solid waste, is the best approach to management of spent batteries, not just for environmental reasons, but also for resource conservation reasons. Developers, owners, and operators of grid-connected BESS projects may be able to apply lessons learned from the automobile industry's experience as it confronts the task of managing a significantly increasing stock of used lithium-ion.[31] End-of-life considerations for a PPP contract are covered further in Section 3.7.

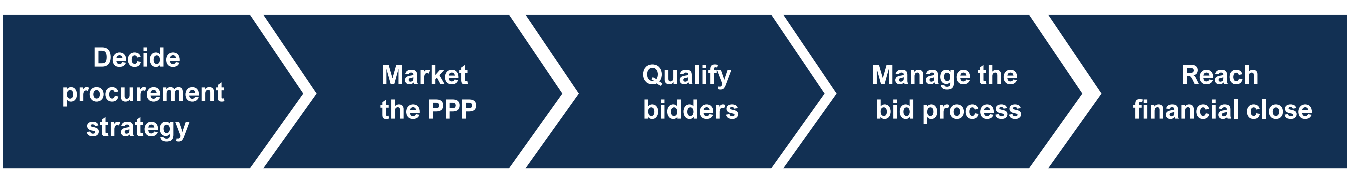
The PPP contract should be flexible, allowing the project to adapt to rapid changes in the market. As noted in Section 3.3.5, the nascent state of the electricity sector in many developing markets means that rapid changes can occur which could sometimes materially impact the business case for the provision of a given service by a BESS. While the earlier stages of PPP preparation described in this document should aim to identify project opportunities that are resilient to a wide range of credible market outcomes, this risk can also be mitigated by including some flexibility in the agreement to allow for the BESS to be asked to provide a range of services by the buyer. There are trade-offs involved in introducing such flexibility: if the BESS is required to meet a longer (and broader) set of technical requirements, this imposes additional constraints, and thus costs, when determining the most appropriate technical design for the project. These trade-offs should be considered during the feasibility assessment described in Section 3.3.

A sample Terms of Reference for a consultant to advise on the strategy for tackling many of the items discussed in this section is attached to this guidance in Appendix B.3.

3.5 PPP transaction preparation

Most elements of the transaction process for a PPP involving BESS will be similar to that for implementing any other PPP. A schematic showing the key steps in this process for a typical PPP transaction is presented in Figure 10. Where there are areas that require additional attention for BESS projects specifically, these are mostly during the initial stages of the transaction process.

FIGURE 10 | TYPICAL PPP TRANSACTION PROCESS



Source: World Bank (2017): Public-Private Partnerships Reference Guide (Version 3)

31 Chupka, M. (2020): "End-of-Life Management of Lithium-ion Energy Storage Systems", which reviews options for end-of-life management of Li-ion batteries.

The wide range of possible applications for the technology adds complexity to the procurement strategy. To ensure that the system procured is fit for purpose, it is important to ensure that the service(s) to be provided by the BESS have been identified and clearly defined. The technical requirements that need to be met for these services to be provided will need to be set out in tender documents so that bidders can ensure the system they propose meets these criteria. As noted in Section 3.4 there may be some trade-off in deciding how tightly the services and technical requirements should be defined. A tight definition might lead to a more efficient procurement outcome and a more tailored system, but a broader definition might mean the project is more resilient, being more flexible to respond to future changes in the market.

The procuring agency will need to decide how technical requirements and performance of the project will be managed through the project lifetime. Linked to the selection of a procurement strategy, the procuring agency will need to decide to what extent the system design is specified in the tender documents. Normally it will be more efficient to allocate most of the responsibility for design of the system to the private sector, with the tender documents clearly setting out the technical parameters that the project must meet, but not specifying how the project should meet those requirements. This allocation of design responsibilities will have a significant impact on the extent and timing of technical feasibility studies, as discussed in Section 3.3. The technical requirements that the project will also need to be addressed in the contract for the PPP, as described in both Section 3.4 and Appendix A.

The process for qualifying bidders may also depend on the procurement strategy selected. The evaluation of bids will need to consider the technical capabilities of the systems proposed by different bidders, and whether these are sufficient to provide the requested services. In a typical PPP procurement – where bids are first qualified or disqualified based on the technical merits of their bid, with qualifying bids then passing to a bidding process that is primarily focused on price and value for money – this assessment will take place during the initial qualification process.

Because BESS technologies will still be unfamiliar to many procuring entities, market sounding and stakeholder engagement are particularly important. Market sounding can be useful during any PPP transaction process, providing an opportunity for the solicitation of stakeholder views and refinement of the procurement strategy and the structure of the PPP. For a technology that many parties (especially procuring agencies) are not yet fully familiar with, this process can be especially valuable. An open dialogue between the buyer and private sector bidders can allow for iteration on the design of the PPP so that it reflects a fair allocation of risk and reward, with the aim of maximizing participation in a competition for the PPP award.

A sample Terms of Reference for a transaction advisor for a BESS PPP project is attached to this guidance in Appendix B.4.

3.6 Operational phase

Operational considerations will be key when drafting PPP contracts. Performance guarantees and appropriate performance tests on the entire BESS and key system components during operation should be clearly stipulated in the contract. This is to ensure the project developer guarantees that the BESS will meet minimum performance standards to deliver the requirements of the use application(s). For example, a bulk energy shifting project should have guarantees on available MWh capacity (i.e., duration) available while a project providing network services may focus on ramp rate, MW response delivered and response time. Contractual remedies including repair, replacement and augmentation of the BESS or liquidated damages to be borne by the BESS operator should be included in the contract and enforced for any shortfall against the guaranteed performance levels.

Industry standards on the testing requirements for specific BESS project types are under development. Table 11 lists some of the recommended tests during operation and their significance to the performance of a BESS project. The scope and details of the various recommended tests on BESS during operation vary widely from project to project and will generally be focused on the technical parameters specified as part of the performance guarantees set out in the contract. However, international standards relating to these tests are under development and it is expected that these will increasingly be adopted in project agreements as the technology matures. UL (Underwriters Laboratories) published its standard, UL-1973, "Batteries for Use in Stationary and Motive Auxiliary Power Applications", in February 2022. IEEE (Institute of Electrical and Electronics Engineers) is currently working on a standard specifically targeting the testing of lithium batteries in stationary applications, which is expected to be released in draft form by the end of 2023.

Testing should take place both prior to commissioning and during the operational phase of the project. Tests prior to commissioning ensure that the buyer does not start paying for services that cannot in practice be provided because of BESS performance issues. Period testing during operations (e.g., 1-3 times per year) will help the buyer to monitor sustained performance over time so that appropriate remedies can be sought if the technical performance of the system falls below the required levels.

TABLE 11 | RECOMMENDED TESTING REQUIREMENTS DURING BESS OPERATION

	Test	Brief description of test to be conducted	Significance
1	Capacity test	Discharge the BESS from the maximum state of charge to the minimum state of charge at its maximum discharge rate to validate the 'sustained' capacity as the metered MWhs. Divide by the duration to get the 'instantaneous' capacity in MW.	Confirm the actual MWh (and MW) capacity that can be discharged by the BESS.
2	Availability test	Dispatch the BESS for a specific time period (divided into settlement intervals) and determine whether the system meets the dispatch requirements within set operational limits. Total system availability is calculated as the percentage of settlement intervals during which the system operated as expected (or within set limits).	Confirm that the BESS can be dispatched according to the guaranteed technical specifications.

TABLE 11, CONT. | RECOMMENDED TESTING REQUIREMENTS DURING BESS OPERATION

	Test	Brief description of test to be conducted	Significance
3	Charge rate/ time test	Time taken for the BESS to charge from its minimum state of charge to its maximum state of charge at the maximum charging rate.	Confirm the actual charging rate of the BESS.
4	Discharge rate/test	Time taken for the BESS to discharge from its maximum state of charge to its minimum state of charge at the maximum discharging rate.	Confirm the actual discharging rate of the BESS.
5	Efficiency test	Compare the metered MWhs to charge the BESS from its minimum state of charge to its maximum state of charge and the metered MWhs when discharged thereafter to return to its minimum state of charge to derive the 'energy lost' by the BESS.	Confirm the energy losses within the BESS during a full charge/ discharge cycle, and thus the round-trip efficiency.
6	Ramp rate test	Time taken for the BESS to change between set power input and output levels during charging and discharging. Change in power input/output can be divided by the time taken to derive the ramp rate.	Confirm the ability of the BESS to ramp its power input and output during charging and discharging between different set points.
7	Response time test	Time taken by the BESS to go from an off-line state to its maximum charging rate and discharging rate.	Confirm the ability of a BESS to respond to dispatch commands from an off-line state.
8	Auxiliary load test	Metering consumption of auxiliary loads over a specified time.	Confirm the amount of energy consumed by the BESS itself.
9	Subsystem test	Specific tests on the performance of BESS subsystems.	Confirm the ability of BESS subsystems to operate as expected for example SCADA, HVAC, fire suppression systems.

3.7 Project closure and handover

Typically, BESS projects will have contracts lasting 8-10 years to match the maximum lifetime of available battery technologies. In comparison to most electricity generation technologies used in IPP projects that last at least 20-25 years, BESS projects will have shorter lifetimes so the considerations during project closure and handover such as the transfer of assets and project decommissioning will be a more material consideration in many cases. Recycling 'environmentally sensitive' materials such as battery modules will be vital. This section sets out the requirements for managing the PPP contract for a BESS project at the end of its life.

The shorter lifetime of BESS projects means that it will normally be less appropriate to transfer the assets at the end of the contract term, compared to other types of infrastructure PPP. Build-Own-Operate-Transfer (BOOT) is a common structure for many types of infrastructure PPP. However, part of the rationale for using a BOOT structure is that the infrastructure will still be in service and will be operated and maintained by the state at the end of the contract. The much shorter lifetime of batteries, as noted above, means that this is less appropriate. Rather, it is likely to make more sense to require the operator to safely decommission the project at the end of the contract term. This section sets out the requirements for managing the PPP contract for a BESS project at the end of its life: first considering the case where assets are transferred, then considering the requirements for decommissioning.

3.7.1 Transfer of assets

The transfer of assets at the end of a BESS PPP project might still be appropriate under some circumstances. As noted above, in many cases it is unlikely to be appropriate to transfer battery assets at the end of a PPP, because they will have reached the end of their operating life. However, there are limited exceptions to this rule.

Ownership of the assets might be transferred to the offtaker prior to the start of operations. While this is an uncommon structure, PPPs can be developed as Build-Transfer-Operate (BTO) projects. In this case, the developer is still responsible for operating the asset for whatever contract term is agreed, but legal ownership of the asset is passed to the buyer immediately after construction. Normally, BTO structures are used in countries where there are specific legal prohibitions regarding private ownership of certain types of infrastructure. In this case, the PPP contract could still be structured such that the private sector party is responsible for performance of the asset and is required to remedy any failure to meet agreed performance criteria. In any case where performance risks are transferred to the public sector, the rigour of the testing prior to commissioning described in Section 3.6 will be especially important.

Later transfer of the assets is unlikely to be appropriate for stand-alone BESS projects. The relatively short operational lifetime of battery assets, when compared to other infrastructure asset classes, means that the asset will likely have undergone substantial degradation by the end of the contract life. For the asset to continue providing services beyond the contract term, it is likely that refurbishment or replacement will be required. In theory a PPP contract could require the battery to be handed over to the public sector counterparty at the end of the contract term. However, this is likely to add risks and costs for the private sector developer, who will need to may need to include contingency for batteries to be replaced late in the PPP contract. Alternatively, the project could be handed over to do the public sector for decommissioning, although this is likely to be appropriate as the project operator is likely to have more access to the expertise required to responsibly decommission the BESS.

For hybrid project, transfer considerations could be more relevant. Where BESS is combined with solar PV or another technology, the total project lifetime might be longer, as explained in Section 3.4.2. For this type of project, it is possible that the PPP agreement will consider the replacement of BESS-related components. In this case, the BESS might be required to meet certain technical performance requirements at handover. These technical requirements would likely mirror those outlined in Section 3.6, although the quantification of these requirements should make reasonable allowance for expected degradation of the assets over the operational phase. Testing would take place ahead of transfer (as would be the case for the solar PV or other assets), allowing time for the operator to remedy the system's performance if required. However, it should be noted that the rapid decrease of battery costs might mean that it is more efficient for performance requirements at the end of the contract term to be light. Locking in performance requirements at today's prices might be less efficient that procuring asset upgrades or rehabilitation later.

3.7.2 Battery decommissioning

While some battery technologies (for instance, lead-acid) are easily recyclable, other widely used technologies such as lithium-ion are more challenging to recycle. Recycling processes are currently highly inefficient, costly, prone to fire safety risks from residual energy, suffer from limited recycling capacity, and are far behind the production rate. The diversity of the battery cells utilised in lithium-ion battery applications require unique physical and chemical processes for recycling, exacerbating the gap in recycling capacity. Further, only a fraction of the components in the battery cells are recyclable; for example, while the metallic parts can be recycled into usable metallic alloys, the majority of the other components such as the lithium compounds, electrolytes, plastics and organic materials cannot be easily recovered for re-use. Given that these components are hazardous to the environment when improperly disposed of, there is a greater need for BESS projects to incorporate recycling considerations into project design.

As discussed in Section 3.4.2, the PPP contract should clarify the obligations and responsibilities for different parties during decommissioning. Sometimes the project might be handed over to the buyer / offtaker, whereas in other cases, the seller / developer might be required to decommission the project and to responsibly dispose of or recycle the equipment used. In most cases, where the seller / developer has more expertise in this area, the latter arrangement will be preferable. The approach taken during recycling will need to be scrutinized to ensure minimal impact on the environment. There will be a trade-off between cost, complexity and energy efficiency to arrive at a recycling process that maximises the recovery of materials that can be re-introduced into the production process so as to reduce the consumption of resources associated with the production of raw materials and achieve a 'circular economy'. This will be key for the sustainable deployment of BESS.

It might be appropriate for the PPP to require a decommissioning fund or bond. If the cost of decommissioning is expected to be met by the seller / developer and this is expected to be substantial, if might be appropriate to require a fund to be accumulated or a performance bond put in place, to ensure the funds are available to reinstate the site should the project developer fail to meet their obligations.

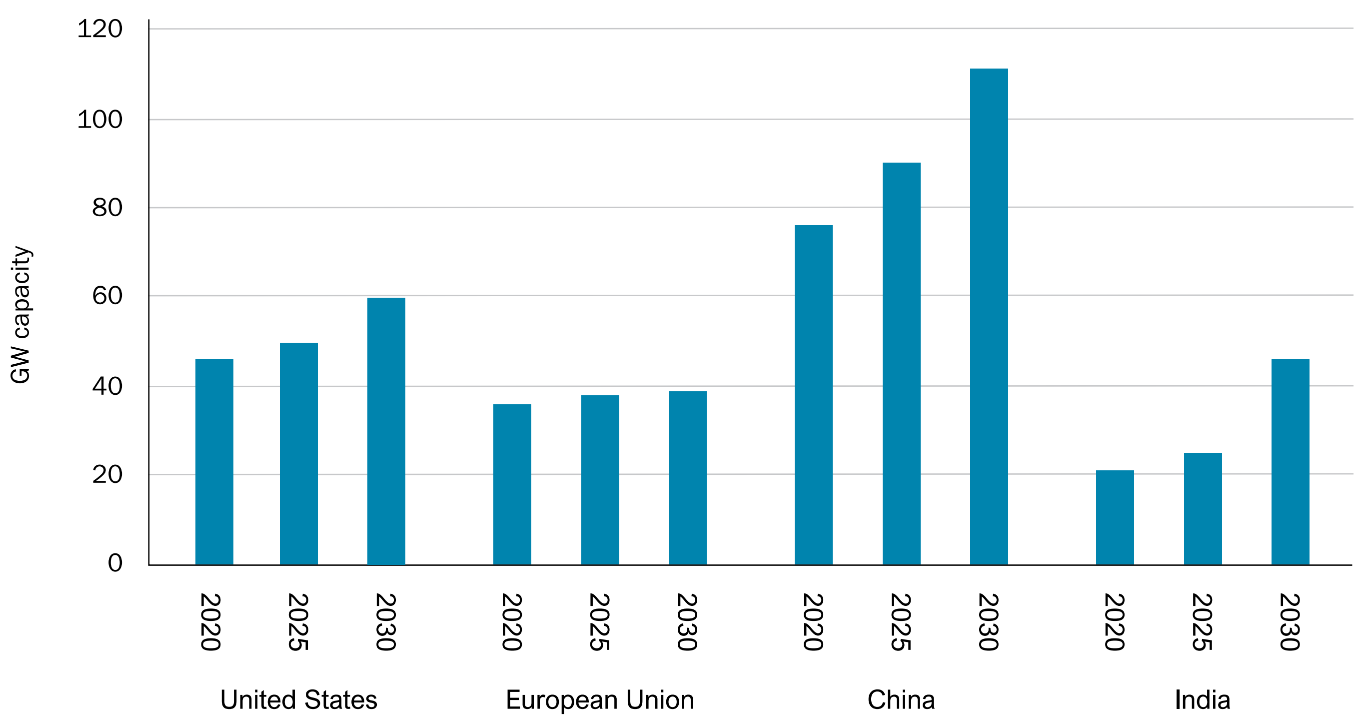
It is expected that battery recycling will come to the fore in coming years when many BESS projects currently online will reach their end of life. Project developers should be adequately incentivized to adopt the most effective approach to recycling during project decommissioning while adhering to national and international environmental management standards.

4 | FUTURE TRENDS AND THEIR IMPACT ON THIS GUIDANCE

4.1 Driving towards net zero

The growing role of intermittent renewable generators will lead to increasing demand for sources of flexibility in the electricity system. Solar PV and wind generation technologies are amongst the primary tools being used in decarbonizing the electricity sector and driving forward progress on meeting net zero policy goals. A more flexible system is required to accommodate the high intermittency of these weather-dependent technologies. Figure 11 illustrates this point as it shows an estimate from the IEA's World Energy Outlook 2020 of the increase in the hour-to-hour ramping requirements, based on the top 100 hourly swings in net demand. The figure only shows results for selected geographies, but this shows large increases in the ramping requirement in China and India.

FIGURE 11 | IEA ESTIMATE OF HOUR-TO-HOUR RAMPING REQUIREMENTS



Source: IEA World Energy Outlook 2020

Battery storage can play a role in meeting this need. Especially in countries where most flexibility is today provided by polluting thermal power plants, the need for more flexibility combined with the need to decarbonize will increase the demand for technologies such as battery storage.

However, the size of the opportunity for battery storage will interact with the roles played by other technologies. In some markets, flexible reservoir hydro or pumped storage might be able to provide many of the services that would otherwise be provided by batteries, depending on the seasonal availability of water resources and the management practises adopted for operating the plants. The extent and nature of network development will also impact the size of the opportunity, and this could change rapidly in less developed countries where the network is constantly under development. New technologies will also impact the opportunity for utility scale battery projects. Electric vehicles could have a wide range of possible impacts: on the one hand inflexible charging of vehicles could add to the ramping requirement highlighted above; conversely, smart charging and vehicle-to-grid technologies could compete with utility-scale, centralized storage. In some countries, this uncertainty is reflected in the range of projections for BESS capacity. In Great Britain, National Grid's Future Energy Scenarios (FES) present different pathways reflecting anywhere between 12.5-25.3 GW of BESS capacity in 2050 under three scenarios, each of which achieves net zero by 2050.

Most BESS projects today are focused on short duration applications. Most systems installed today have a duration of 0.5 up to ~4 hours. BESS projects are normally focused on short-term shifting of energy and/or the provision of fast-response ancillary services.

As electricity systems become increasingly decarbonized, the focus might shift towards longer duration applications. In electricity systems that depend heavily on intermittent renewables, solutions will be required for whole days, or longer periods of time, when the wind doesn't blow, and the sun doesn't shine. The options available to meet these system needs will again vary from country to country. In some countries flexible hydro will provide a useful option. Non-electrical storage technologies and the use of green hydrogen might provide new sources of flexibility. However, longer-duration BESS installations might also help to meet this need, especially if new technologies (such as flow battery technologies), well-suited to such applications, become more widely used. The impact of technological developments is discussed further in Section 4.3.

The uncertainties noted above highlight the important of flexible PPP structures. As discussed in Section 3.4, the rapidly changing nature of electricity systems in many developing countries could result in changes to how a BESS installation might be used over its lifetime; i.e., it might be required to provide different services to those originally envisages. It is important that sensitivity analysis performed during feasibility assessments consider a wide range of possible market pathways. Where possible, both the technical design of the project and the contractual terms agreed should accommodate any change in service provision anticipated by the scenario analysis.

4.2 Evolving energy markets

Even in liberalized energy markets, the procurement of most utility-scale BESS projects has been centralized. Many of these projects have been procured by system operators to provide ancillary services, such as frequency response. However, whereas in liberalized markets these centralized procurements often take place through an established market for certain system services, in many less developed countries, such markets for ancillary services do not exist.

As such markets are developed, this will affect the way in which some BESS projects are procured. Many of the services that can be provided by BESS projects can also be delivered by other technologies, so BESS may compete against those technologies in ancillary service markets. In some cases, the length of contract available from ancillary service markets might be shorter than the lifetime of the project. Unless the market is very well established, to the extent that the price a BESS might achieve in future procurements can be reliably forecast, it is likely to be difficult for projects to attract substantial amounts of debt, because of the increased route-to-market risk under such an arrangement.

In most markets it will be difficult to move away from longer-term contracting for bulk energy shifting applications. The business case for this type of project often relies on volatility in the marginal cost of power generation on the system. In liberalized electricity markets this will be reflected in the wholesale market price. However, the inherent uncertainty in volatile wholesale prices means that even in more mature markets it is uncommon for projects to take on merchant risk. Rather, project developers will typically sign longer-term agreements with an energy trader or a large utility, able to manage risk across a portfolio of market positions.

Therefore, longer-term contracting is likely to remain a requirement for BESS projects in developing markets in the short to medium-term. Even as markets do become more liberalized, the complexity of the BESS asset class and the services provided means that investors are likely to continue to need revenue certainty through a long-term contract for the foreseeable future.

4.3 Technological developments

Existing and new batteries are being developed to be cost-competitive, have higher power and energy densities, deeper discharge, longer lifespans, and the ability to scale. The limitations in the supply chain of key battery materials and their environmental implications will limit the large-scale deployment of some battery technologies; new and more sustainable chemistries are also being developed to tackle these challenges.

Lithium-ion batteries have been deployed widely in recent years due to their high energy density, high efficiency, and long lifecycles at deep discharge. While it is now an established technology, improvements are still being made to lithium-ion batteries. Current developments are focused on increasing energy density, increasing operational flexibility (for example reducing the impact of high discharge rates, overcharging and complete discharge on the battery’s lifespan), improving thermal integrity and safety at large power capacities, reducing the environmental impact of extraction of raw materials and battery disposal, and reducing costs further. Lenders' relative familiarity with lithium-ion technologies and their advanced use in other storage applications (like electric vehicles) make them well placed to take up a large share of the BESS deployment in coming years.

There is potential for other technologies, including vanadium redox flow batteries, to also achieve large scale deployment in the future. Many alternative battery technologies are being developed, although there remain supply chain challenges, and technical challenges to overcome in many cases. Some of these technologies have the potential to ease demand for other minerals (such as lithium, or cobalt) whereas other technologies could be used to develop batteries with different technical characteristics, such as much longer durations.

Cost reductions, improvements in existing technologies, and the development of new technologies could all act to increase the role of batteries in the future energy system. Cost reductions will act to improve the business case for projects that are already being considered, and it may mean that some projects that currently have a weak business case today can move forward. New technologies could mean that new applications become more technically feasible. For example, the development of flow battery technologies could increase the potential for longer-duration BESS projects able to engage in a wider range of bulk energy shifting applications. Together, these factors are likely to result in further growth of the opportunity for BESS projects.

APPENDIX A: HEADS OF TERMS

This appendix contains indicative Heads of Terms of BESS projects, reflecting the guidance presented on transaction structure in Section 3.4. The appendix is split into two sections:

- Appendix A.1 presents Heads of Terms for stand-alone BESS projects, covering the first two project types identified in this guidance document: **bulk energy shifting** and **network and system services**. The Heads of Terms are not intended to be complete; rather, they are intended to cover the key elements of a PPP contract that might be specific to a BESS project.
- Appendix A.2 focuses on **hybrid** projects. The commercial terms for these projects are likely to be set out in a typical renewable energy Power Purchase Agreement. However, the PPA will need to include some additional terms, some of which are identified in this appendix.

Guidance comments on use of the Heads of Terms are provided in blue boxes; areas where a different approach should be taken depending on the type of project being implemented are indicated by red boxes.

As noted above, the Heads of Terms focus on contractual terms that are likely to be specific to BESS projects. There are many other sources of guidance that provide more general advice on 'boilerplate' terms that are likely to be similar to other infrastructure asset classes, and in particular are likely to be similar to the terms included in a PPA for and IPP project. Guidance on some of these terms can be found in:

- The World Bank's PPP Reference Guide,[32]
- Power Africa's "Understanding Power Purchase Agreements",[33] and
- Power Africa's "Understanding Power Project Financing".[34]

32 World Bank (2017): Public-Private Partnerships Reference Guide (Version 3). Link.

33 Power Africa (2017): Understanding Power Purchase Agreements (https://www.usaid.gov/powerafrica/ppahandbook)

34 Power Africa (2018): Understanding Power Project Financing (https://cldp.doc.gov/sites/default/files/UnderstandingPowerProjectFinancing.pdf)

Appendix A.1 | Outline Heads of Terms for stand-alone BESS projects

Seller	The **Seller** is the party responsible for delivering the **Services** as defined in the “Sale and Purchase” section of this **Agreement**.
Buyer	The **Buyer** is the party responsible for purchase of the Services as defined in the “Sale and Purchase” section of this Agreement. In most countries in which with WB operates, the Buyer will be a utility. Where utilities have been unbundled, the Buyer is likely to be the utility responsible for system operations and/or wholesale power purchase.
Scope of the Agreement	The Seller agrees to develop (design, finance, construct, operate and maintain) a battery energy storage system (the **BESS**), which will provide the Services and will be located at the project **Site** (the **Project**). One of the following options may be included, depending on where operational control for the project is to sit. This is covered further under “Operational control and dispatch.” The Seller grants the Buyer the right to use the BESS, which the Buyer will optimize and operate to provide the Services. OR The Seller will optimize and operate the BESS to provide the Services to the Buyer. Details of the location of the site should also be included. This might also refer to a Schedule containing a site diagram. Note that the site might not be identified at the tendering stage if bidders are asked to find suitable sites for the Project. The Project will be located at [ADD DETAILS] (the Site).
Conditions Precedent	Key obligations of the parties to the Agreement will be conditional upon satisfaction of certain conditions precedent (CPs). The CPs will depend to some extent on the prevailing regulatory conditions in a market, but would include items including the following: • Permits, licenses and authorizations required, both covering the project and for doing business; • Evidence of land rights having been secured; • Grid connection agreement; • Any separate wheeling arrangements or other project documents; • Successfully reaching financial close; • Agreeing any detailed terms that have not yet been specified in the Agreement, such as technical requirements for provision of the Services. The CPs should also include waiver provisions and a longstop date, in line with what would be expected for a typical infrastructure PPP.

Construction Period	Contractual terms relating to management of the construction period, inclusion of a **Target Commercial Operation Date (COD)**, **Longstop COD**, and the process for keeping the Buyer up-to-date on progress made through the **Construction Period** are all likely to be very similar to those contained in a typical PPA for an IPP project. One area that might be different is around testing of the system, which is covered separately below.
Testing and Commissioning	Ahead of **COD**, the Buyer shall be entitled to schedule as many **Commercial Operations Tests** as are necessary to meet the **Minimum Technical Criteria** for delivering the Services. It is a requirement that the BESS meet the Minimum Technical Criteria ahead of COD. The Minimum Technical Criteria should be defined, probably in a separate Schedule to the Agreement. The Minimum Technical Criteria will depend on the exact Services being provided, but might include: • **Available Response** (MW); • **Available Duration** of response at maximum output (hours); • **Response Time** (ms); • Definition of any response functions for frequency regulation services (defining the relationship between response required and frequency deviation). These Minimum Technical Criteria may or may not be required if the BESS is providing Bulk Energy Shifting. This is likely to depend on the extent to which the market has been liberalized. If the market remains centrally dispatched (likely to be the case in most countries in which the WB operates), criteria may be needed that set out the Project's requirement to follow **Dispatch Instructions** from the Buyer. The need for **Liquidated Damages** should also be considered in defining the Commercial Operations Tests. In some cases, a criterion might be an imperative for it to be possible to provide the Services, in which case Default and Termination might be a more appropriate course of action. In a case where the Service can be provided, but less capacity is available than expected, payment could be scaled accordingly if this is acceptable to the Buyer. Definition of Liquidated Damages also needs to consider the implications if the COD is delayed; if the Buyer will be required to procure the Services from a more expensive source to cover the delay, or if service quality to end consumers of electricity will suffer, the Buyer will seek to recover the excess costs from the Seller.
Term	The **Term** of the Agreement is [ADD DETAILS] years. Compared to the PPA for an IPP project, which might be expected to have a term of 15-25 years, the period is likely to be shorter, reflecting the shorter life of a BESS system. The battery asset itself might only have an expected lifetime of 10-12 years, although this will depend on how the BESS is operated. The battery could be replaced mid-way through the contract, but it is unlikely to be commercially advantageous to lock in these costs at the start of the contract given rapidly changing capital costs. However, this argument should be considered alongside the benefit of spreading other capital costs over a longer term.

Sale and purchase	Both this section of the Heads of Terms, and the next section covering Pricing, will depend on the structure adopted in the PPA. As discussed in Section 3.4, this can adopt three broad structures: • A tolling agreement structure; • A capacity fee structure; or • A capacity and energy fee structure. The latter is least likely to be adopted in World Bank client countries and would only be appropriate for bulk energy shifting projects.
	Tolling agreement For the duration of the Term, the Seller shall make available to the Buyer the BESS and the Buyer shall control dispatch of the BESS. The Buyer shall supply all electricity required for charging of the BESS. OR Capacity fee structure For the duration of the Term, the Seller shall make available to the Buyer the **Contracted Capacity** of the BESS and shall ensure that the BESS is available to provide the Services.
	The capacity sales agreement may in practice be very similar to a tolling agreement. However, it typically does not include a commitment that the Buyer pays for all energy required to charge the BESS. Typically, it is likely to be more cost effective for the Buyer to manage this risk, and hence to opt for a tolling structure, unless the dispatch of the BESS (and hence the amount of energy required for charging over the Term) is highly predictable.
	OR Capacity and energy fee structure For the duration of the Term, the Seller shall make available to the Buyer the **Contracted Capacity** of the BESS and shall ensure that the BESS is available to provide the Services. When the BESS is dispatched in accordance with a **Dispatch Instruction** issued by the Buyer, the Buyer shall procure the **Electrical Output** delivered to the meter point **(Metered Output**).
Pricing	Tolling agreement The Buyer shall pay the **Tolling Fee** of [•] $/kW of **Available Capacity** in each **Billing Month**. Dependable Capacity will be equal to the **Available Response** from the latest **Performance Test**, de-rated to account for any periods in which the BESS was technically unavailable or was unable to meet the Minimum Technical Criteria during the Billing Month. OR Capacity fee structure The Buyer shall pay the **Capacity Price** of [•] $/kW of **Available Capacity** in each **Billing Month**. Dependable Capacity will be equal to the **Available Response** from the latest **Performance Test**, de-rated to account for any periods in which the BESS was technically unavailable or was unable to meet the Minimum Technical Criteria during the Billing Month.

Pricing	OR Capacity and energy fee structure The Buyer shall pay the **Capacity Price** of [•] $/kW of **Available Capacity** in each **Billing Month**. Dependable Capacity will be equal to the **Available Response** from the latest **Performance Test**, de-rated to account for any periods in which the BESS was technically unavailable or was unable to meet the Minimum Technical Criteria during the Billing Month. Additionally, the Buyer shall pay the **Energy Price** of [•] $/MWh of Metered Output. Under any of the contract structures, the Agreement could allow for fixed and/or floating components of pricing.
Operational control and dispatch	Option 1 — full operational control of dispatch The Buyer shall have full control of the **Energy Management System**, which controls the dispatch and state of charge of the BESS. Dispatch of the BESS must adhere to the agreed **Standard Operating Constraints**. OR Option 2 — Seller follows dispatch instructions issued by the Buyer The Buyer shall issue Dispatch Instructions to the Seller according to an **Agreed Dispatch Protocol**, which the Seller is required to adhere to. The Dispatch Instructions issued by the Buyer must adhere to the agreed Standard Operating Constraints. These two options are most likely to apply to BESS projects in WB client countries. Standard Operating Constraints would be attached in a separate Schedule to the Agreement. The constraints would likely mirror the terms included in the warranty for the BESS, such as maximum number of cycles, limits of State of Charge, to avoid causing damage to the BESS that is not covered by the warranty. Alternatively, or in addition, additional costs for the Buyer could be triggered in the event that certain thresholds (such as number of cycles) are crossed. In the case of Option 2, a protocol for issuing Dispatch Instructions will need to be agreed. For very fast response services, dispatch decision might need to be made very rapidly, or automatically, which might point towards adoption of Option 1. OR Option 3 — Self dispatch The Seller shall nominate its intended dispatch volume (**Nominated Volume**) ahead of **Gate Closure**. The Nominated Volume shall include two values: one for charging; the other for discharging. An **imbalance penalty** of [•] $/MWh shall apply to any deviation between the Nominated Volume and actual Metered Output from the BESS. The self-dispatch option is unlikely to be relevant outside of countries with a liberalized wholesale market. In these cases, provision might also be made for balancing actions, where the Buyer requires the Seller to deviate from the Nominated Volume to meet system requirements.

Operational control and dispatch	In more liberalized markets, a combination of the above models might also be used; for example, if Dispatch Instructions are issued for the BESS to provide a system service during some hours, while the Seller provides other services during other hours. In these more complex cases, the Agreement will also need to specify the Seller's responsibilities in ensuring that that the BESS maintains a state of readiness (e.g., an appropriate state of charge) so that it can provide the contracted system services when required.
Operational performance	After COD, the operational performance of the BESS may be tested by the Buyer up to [•] times per year, at times mutually agreed between the Seller and the Buyer. Such tests will be conducted to ensure that the BESS continues to meet the Minimum Technical Criteria. As noted in the "pricing" section of the Heads of Terms, capacity fees or tolling fees might be de-rated to account for any shortfall in performance during testing (probably with an opportunity for the Seller to remedy the fault), especially on the Available Response parameter. For many BESS technologies the Available Duration can be expected to fall over time. Most battery manufacturers will provide a degradation curve describing how duration declines as the BESS is cycled, and this will often form part of the warranty. This can be reflected in the PPP Agreement, but typically it is likely to be more efficient to instead specify a minimum duration requirement and to allow the Seller to manage this risk. This is because the Seller might choose to manage the risk in multiple ways; for example, swapping out individual cells in the battery, or oversizing the battery and allowing the degradation to take its course. The Agreement might also include provisions detailing how maintenance events are managed, as would typically be included in the PPA for an IPP project.
Decommissioning	At the end of the contract Term, the Seller is required to decommission the Site (or during the term when the battery requires replacement) and dispose of or recycle the BESS in line with local legal and regulatory requirements and environmental rule s. The requirement for this clause may vary depending on whether the Site is transferred back to the Buyer at the end of the Term. The detailed requirements of the clause will depend on local regulatory requirements and may need to be subject to change as decommissioning requirements are developed.
Default and Termination	Most of the terms relating to default and termination in the Agreement are likely to be materially similar to those included in a typical PPA. However, example additional considerations might include: • A **Seller Default Event** to cover non-performance against the Minimum Technical Criteria. • In the case of a project where the Buyer has full operational control of dispatch, including a **Buyer Default Event** to cover non-compliance with the Standard Operating Constraints defined in the Agreement.
Other boiler-plate terms	As noted at the start of this Appendix on page 57, most of the 'boilerplate' terms to the Agreement will be materially similar to those included in the PPA for an IPP project. The guidance on page 57 lists several sources that provide useful guidance on these areas.

Appendix A.2 | Outline Heads of Terms extracts for inclusion in a PPA for a hybrid project

As discussed in Section 3.4 the key project document for a hybrid project, involving a BESS combined with solar PV or wind, is likely to be a Power Purchase Agreement. Most of the PPA will follow the terms typically included in the PPA for any other VRE project (with the addition of BESS installation). The Heads of Terms extracts included below are focused only on areas that would likely differ in the case of a hybrid project.

Scope of the Agreement	The Seller agrees to develop a project involving [•] (the **Generation Facility**) and a battery energy storage system (the **BESS**), which will provide the Services and will be located at the project **Site** (the **Project**). The Project will be located at [ADD DETAILS] (the Site).
Testing and Commissioning	Ahead of COD, the Buyer shall be entitled to schedule as many Commercial Operations Tests as are necessary to meet the Minimum Technical Criteria when delivering energy. It is a requirement that the BESS meet the Minimum Technical Criteria ahead of COD.
	This requirement to meet certain performance criteria is similar to other types of BESS project. But in this case the Minimum Technical Criteria are likely to be different and focused on the energy delivered by the **Generation Facility**. These might include: • **Maximum ramp rate** (MW/minute); • **Dispatchability requirement** (ability to dispatch up to [•] MWh or [•]% of Metered Output during the period [•] to [•] (the **Dispatch Window**). The need for any **Liquidated Damages** should also be considered in defining the Commercial Operations Tests. In some cases, a criterion might be an imperative for it to be possible to provide the Services, in which case Default and Termination might be a more appropriate course of action.
Term	The **Term** of the Agreement shall be for [ADD DETAILS] years.
	Because the primary driver of the project is the Generation Facility, the Agreement term is likely to be longer than in the case of other BESS project types — in line with other VRE projects. This is more likely to mean the Seller will need to replace key components of the equipment during the Term. However, this is a risk that should typically be managed by the Seller.

Pricing	In the case of a hybrid project, the cost of meeting the Minimum Technical Criteria will often simply be covered by the Seller in their calculation of the **Energy Price**. Sometimes the additional cost associated with the BESS might be split out as a **Battery Adder** to the Energy Price, but payment of this component of the price is on the same basis as for the main Energy Price. Occasionally, the Energy Price might be multiplied by a **Time-of-Use Multiplier**, which would attribute higher value to energy generated during peak periods, compared to off-peak period. This structure provides an incentive to introduce some dispatchability to a VRE project and might in some cases replace the need for the inclusion of the Minimum Technical Criteria described above. The Agreement could allow for fixed and/or floating components of pricing.
Operational control and dispatch	Some PPAs for VRE projects include a forecasting requirement. Normally this is an information requirement to help with system operations, but there is not normally a penalty regime associated with forecast errors. This could also apply in the case of hybrid projects, although the Seller's forecast for energy exported from the Site will need to consider the expected dispatch of the BESS to meet the Minimum Technical Criteria. Occasionally, the BESS might be included in the project as the Seller's response to the inclusion of a forecast error penalty in the PPA for a VRE project.
Curtailment	The description of Curtailment rights will differ from a PPA that does not include BESS, reflecting the fact that the Seller will be better able to manage periods when (for instance) the grid or delivery infrastructure is unavailable.
Operational performance	After COD, the operational performance of the BESS may be tested by the Buyer up to [•] times per year, at times mutually agreed between the Seller and the Buyer. Such tests will be conducted to ensure that the BESS continues to meet the Minimum Technical Criteria. The Agreement might also include provisions detailing how maintenance events are managed, as would typically be included in the PPA for an IPP project. Note that this might need to allow for a more major maintenance event involving the BESS, because of the likely mismatch between the tenor of the Agreement and the lifetime of the BESS.
Default and Termination	Most of the terms relating to default and termination in the Agreement are likely to be materially similar to those included in a typical PPA. However, example additional considerations might include a **Seller Default Event** to cover non-performance against the Minimum Technical Criteria.

APPENDIX B: TERMS OF REFERENCE

This appendix contains draft Terms of Reference (TOR) for key studies that might be commissioned, or advisors that might be hired during the process of developing a BESS PPP.

- Appendix B.1 contains the TOR for a techno-economic study, to assess where (and whether) BESS provides a good flexibility solution for a country's electricity system.
- Appendix B.2 contains TOR for a technical feasibility study for a BESS project.
- Appendix B.3 contains TOR for hiring a strategic PPP advisor, who would be tasked with determining the best PPP option for implementing the project.
- Appendix B.4 contains TOR for hiring a transaction advisor, who would develop the selected PPP option further and advise throughout the process of taking the transaction to market.

These TOR are examples and could be split up or aggregated in different ways, depending on what is most appropriate for the project being implemented. Throughout the example TORs, guidance comments on use of the templates are provided in blue boxes; inputs required when preparing the TORs are highlighted by red boxes.

Appendix B.1 | Techno-economic study

As discussed in Section 3.4 the key project document for a hybrid project, involving a BESS combined with solar PV or wind, is likely to be a Power Purchase Agreement. Most of the PPA will follow the terms typically included in the PPA for any other VRE project (with the addition of BESS installation). The Heads of Terms extracts included below are focused only on areas that would likely differ in the case of a hybrid project.

Background

Include an overview of the context in the country in which the study is to be completed. This overview might include:

- *Information on the supply/demand dynamic in the country's electricity sector and any recent developments.*

In recent years, battery storage technologies have developed rapidly, and the cost of the technology has declined. This has resulted in battery storage technologies becoming increasingly attractive as a resource to be used by energy system planners. Battery Energy Storage Systems (BESS) can now be competitive against other technologies in the provision of a wide range of services. A recent World Bank report[35] identifies some of the core 'use cases' for BESS as follows:

- **Frequency and voltage control** — this covers a range of services, from very fast acting frequency containment services to slower acting reserve products. Some services, such as voltage control, are likely to be locational in nature.
- **Smoothing / VRE ramp control** — this limits the speed at which output from a VRE plant can increase or decrease. Sometimes this will be a requirement imposed through the Grid Code.
- **VRE forecast error correction** — this is relevant for systems where generators are required to submit short-term generation forecasts. In this case, generators may face penalties if their forecast is inaccurate; a BESS can be used to manage this exposure.
- **Firm capacity** — this refers to the BESS being used as firm capacity to meet system peaks.
- **(VRE) generation time shift** — output from non-dispatchable power generation capacity is shifted to a later period; e.g., shifting output from off-peak to peak hours.
- **Black start** — the use of the BESS to restart the power system after a system-wide black-out.
- **Balancing seasonal and inter-annual** — although battery storage technologies are generally unlikely to be commercially viable in providing these services today.
- **Grid congestion relief** — this covers the use of a BESS to tackle a specific grid constraint; e.g., meeting peak demand at the end of an over-loaded line.
- **Transmission and distribution (T&D) deferral or avoidance** — similar to congestion relief, but the BESS is explicitly used in place of reinforcement of the grid.

35 Energy Sector Management Assistance Program (ESMAP) (2020): Deploying Storage for Power Systems in Developing Countries: Policy and Regulatory Considerations (https://documents1.worldbank.org/curated/en/738961598380536870/pdf/ESP-Policy-Manual-Aug-2020.pdf)

Demand-side or behind-the-meter use cases could be added to this list but will not be within the scope of this assignment, which is focused on utility-scale application of BESS.

Further country-specific context, such as:

- *Whether battery storage has been used at scale in the country, and if any initiatives have evaluated the opportunity.*
- *Information on the genesis of the project – who has initiated the project and why?*

Objectives of the assignment

The purpose of this assignment is to evaluate the opportunity for implementing Battery Energy Storage System (BESS) projects in [country or region]. Where opportunities for BESS projects are identified, the size of the opportunity will be evaluated.

Scope of work

The Consultant will perform three tasks in completing this assignment:

Task 1: Evaluating the opportunity for BESS

The Consultant will evaluate the opportunity for implementing BESS projects for each of the use cases listed above in [country or region], together with any other utility-scale applications that the Consultant deems to be relevant. The analysis will consider the characteristics of [country or region]'s electricity market and consider whether these indicate whether each use case is appropriate in the market. The analysis will evaluate:

- The likely size of the market opportunity for implementing the use case, i.e., how many MW/MWh of capacity might be needed?
- The sensitivity of the opportunity to different sources of uncertainty; e.g., are there proposed large generation projects (or network infrastructure projects) that might materially impact the need or opportunity for BESS projects?
- Where the projects are needed: are they providing locational services, or can the BESS be located anywhere on the electricity system?
- Whether there are specific BESS technologies that should be used (or a sub-set of technologies that should be considered) for implementing each of the identified project opportunities?

The Consultant will present a summary of the opportunities for BESS in [country or region] during an Interim Results Workshop. The Consultant will also present a suggested ranking or prioritization for the identified opportunities, using criteria to be suggested by the Consultant.

Task 2: Identifying specific project opportunities

For each of the opportunity categories identified in Task 1, the Consultant will identify specific projects that could be implemented. Where the number of short-listed opportunity categories is large, this will focus on the opportunities assigned the highest ranking or prioritization scores as part of Task 1. It is expected that a maximum of [10] specific projects will be identified by the Consultant as part of this task.

For each of the identified project opportunities, the Consultant shall provide:

- A description of the proposed project and how it is expected the project will operate.
- A high-level specification of the BESS. A full technical assessment is not expected (this would be completed as part of a later feasibility study); rather, the specification will focus on the likely sizing of the BESS, the technology to be used, and any other characteristics of the project likely to have a material impact on cost and feasibility.
- An estimate of the cost of implementing the project. It is not expected that detailed quotes are sought or prepared; rather, the Consultant is expected to leverage their own experience, together with benchmark costs available to them.

Task 3: Initial assessment of the business case

Using the outputs from Task 1 and Task 2, the Consultant will perform an initial evaluation of the business case for the identified project opportunities. It is expected that the evaluation will be indicative; a more detailed assessment will be performed as part of any later feasibility study. This indicative assessment will include an initial quantification of the benefits of each project, which will be compared against the costs evaluated in Task 2. It is expected that it will be possible to complete this high-level assessment using spreadsheet-based models, unless the Consultant has other modelling tools that are 'ready to use'. It is not expected, for example, that the Consultant will start to build a full Production Cost Model (PCM) using bespoke market modelling software as part of this assessment.

Throughout the assignment, the Consultant may need to obtain data or to discuss characteristics of the electricity system with [utility name]. The World Bank (WB) team will introduce the Consultant to key individuals in [utility name] at the start of the assignment. The Consultant should list any data or other information that they believe will be required from [utility name] in their technical proposal.

Deliverables

The Consultant will prepare the following deliverables in completing the assignment:

- An **Inception Report**, which will be completed within 2 weeks of contract signing. The inception report will confirm the approach to be taken by the Consultant, as well as defining any data inputs required by the Consultant from [utility name] or from the WB team.
- Presentation materials for an **Interim Results Workshop** which will be held 6 weeks after contract signing. The workshop will provide an opportunity for the results from Task 1 to be presented and for the ranking of opportunities proposed by the Consultant to be discussed.

- A **Draft Final Report** will be completed 3 months after contract signing. The draft final report will present the completed outputs from the assignment, including analysis of the identified specific projects.
- A **Final Report** will incorporate any comments from [utility name] and the WB team on the draft report. This will be completed by the Consultant within 2 weeks of the comments being provided to the Consultant by the WB team.

Organization

The Consultant is expected to be a Firm with extensive experience in the economic and technical analysis of electricity systems, including BESS projects. Specifically, the team proposed by the Consultant should include:

- An **Energy Economist**, with at least 10 years of experience performing economic analysis of project opportunities in the electricity sector, ideally including BESS.
- A **Technical Specialist**, with at least 10 years of electrical engineering experience, including experience advising on the configuration and design of BESS projects.

The above role descriptions are indicative, and the Consultant can propose alternative team configurations covering the skill requirements set out above.

Appendix B.2 | Feasibility study

Background

Include an overview of the techno-economic study conducted to provide justification that the BESS is the most adequate solution. This overview might include:

- *Intended use application(s) of the BESS and associated project requirements;*
- *High level specification of the BESS with an initial view of the size and technology to be used; and*
- *Procurement strategy to be adopted; whether the services to be provide by the BESS will be procured based on system requirements or a detailed engineering design.*

A Battery Energy Storage System (BESS) has been identified as a suitable option to provide services to [utility name] as detailed in the report on the techno-economic study. An initial high-level assessment of the business case has also been completed as part of the techno-economic study. A detailed feasibility study is required as part of the project preparation with a view to structuring a PPP for implementing the project.

Objectives of assignment

The objectives of this assignment are to:

1. Ascertain **whether the project is technically feasible** i.e., its implementation does not adversely affect the normal operation (stability and security) of the grid.
2. Quantify the **technical inputs that contribute to the business case** developed in the techno-economic study.
3. Perform a **quantitative cost-benefit analysis** of the proposed project.
4. Finalize a **detailed design of the BESS** and develop front end engineering designs (FEED).

Scope of work

Task 1: Technology selection and BESS sizing

The consultant shall make an initial selection of the technology to be adopted by conducting a **robust analysis** of available options based on a mapping of the technology characteristics to the project requirements. Both technical and commercial considerations shall be made when selecting the technology with attention paid to the most recent trends in technological advancements.

The consultant shall then advise on the appropriate sizing of the BESS. The consultant will use their own analysis and/or bespoke models to advise on the optimal MW and MWh capacity of the system to meet the project requirements, leveraging publicly available tools where appropriate.

The feasibility will be conducted in an iterative manner so the selected technology and the BESS size arrived at this stage can be revisited depending on results from subsequent steps of the feasibility.

Task 2: System Assessment

The consultant shall conduct an in-depth review of the following:

1. The grid code, related technical regulations, and institutional setup to provide an operating context for the integration of the BESS project to the grid.
2. National and international standards (including safety and environmental requirements) to be adhered to in the host country relating to the deployment of batteries.
3. System reports and other technical documentation provided by the regulator and system operator on the performance of the grid, generation balance, level of transmission and distribution infrastructure development (historical and projected), system load and demand profiles.
4. Collection and analysis of available data regarding the system from previously conducted studies, and masterplans for generation planning, transmission and distribution network expansion, and load forecasting.

The scope of the in-depth review to be conducted in order to characterize the demand-supply system will depend on the project type and whether the proposed BESS will provide system-wide services or services limited to a given part of the network. Additionally, generation-based applications will require a system-wide scope while customer-based and network-based applications will typically be limited to a specific part of the network as summarized in Table 12.

The in-depth review with equip the consultant to characterize the demand-supply balance at the different system nodes to identify any demand-supply Imbalances and grid constraints from existing and projected network development. The characterization of supply resources shall consider the operating regime for all generators, taking into account all relevant operating constraints for system dispatch, including the non-dispatchability of VREs, ramp rates, minimum downtime/runtime, emissions, etc. The demand characterization shall include the historical and projected demand levels of different consumer groups at different grid supply points.

TABLE 12 | SCOPE OF DEMAND-SUPPLY CHARACTERIZATION FOR DIFFERENT PROJECT TYPES

Scope of the demand-supply characterization		
Bulk energy shifting	**Ancillary and grid infrastructure services**	**Hybrid/co-located projects**
System-wide for most applications	Has to be system-wide for provision of ancillary services but can be limited to the part of the network requiring the grid infrastructure services	Can normally be limited to the part of the network affected immediately affected by the proposed project

Task 3: Power flow analysis

The consultant shall conduct power flow analyses using internationally accepted simulation software packages like PSSE and DigSilent based on actual power system data provided by the system operator. The power flow simulations shall assess the impact of the introduction of the BESS on transmission and distribution facilities during steady-state, contingencies/short-term disturbances, and critical periods. The power flow simulation shall solve for the following:

1. Load flow analysis (including harmonics) using generally accepted approaches (such as Newton-Raphson, Gauss- Seidel, Fast Decoupled, Forward/Backward Sweep based Algorithm[36]) to determine the optimal system states that ensure frequency stability is maintained in all scenarios when the BESS is integrated to the grid. The load flow analysis should analyze the line flows in the affected part of the network and quantify any benefits (from reduced line flows) to the system from the BESS integration.
2. Short-circuit analysis to derive the short-circuit levels at affected system nodes when the BESS is integrated and determine the BESS operational state that maintains the fault levels within levels that can be arrested by existing protection systems.
3. Dynamic stability analysis to analyze the voltage ranges at all system buses when BESS is integrated to ensure that maximum and minimum voltage limits are not exceeded during steady state. Voltage support applications can further be investigated in this analysis to highlight the improvement to voltages (reactive power compensation) at proposed buses and voltage stability across all buses.
4. Reliability analysis to analyze the impact of BESS on standard reliability indices like the System Average Interruption Duration Index (SAIDI), the System Average Interruption Frequency Index (SAIFI) and Energy Not Supplied (ENS) based on forecasts of changes in number and duration of outages.

36 For more details, refer to Ghiasi, Mohammad. (2018). A Detailed Study for Load Flow Analysis in Distributed Power System. 1. 153-161. 10.22111/IECO.2018.24423.1027

The simulations shall be conducted to compare different BESS options to determine the most optimal configuration to integrate the BESS to the grid without compromising grid stability and security while offering the required grid services,

The business case for some project types (for example grid services to relieve grid congestion and/or to defer T&D upgrades) may depend on reduced line flows that can only be quantified in a load flow analysis. In this case the consultant shall ensure these potential benefits are analyzed and quantified.

Task 4: Site assessment and environment impact

The consultant shall conduct a detailed assessment of the proposed site to ascertain its suitability to meeting project requirements. The site assessment shall take into consideration the aspects below:

5. Review of information on the proposed site including space, topography, environmental conditions, weather.
6. Review of electrical infrastructure required to connect the BESS to the grid substation.
7. Review of site access roads and related services for delivery of project material and personnel during construction and operations.
8. Geotechnical surveys to examine the soil composition of the proposed site and its suitability for the civil and structural works involved on the project.
9. Assessment of the environmental and social impacts of the BESS project including vegetation management, waste disposal during construction and operation, end of life disposal and recycling of the BESS components, socio-economic impact on host communities, and any other factors that the consultant deems to be important for the assessment.

In instances where a site for the project has not been identified at the feasibility stage, the consultant shall instead describe the key requirements of a site to be selected by the project developer.

Task 5: Economic Cost-Benefit Analysis

Leveraging outputs from the technical feasibility analysis performed thus far, the Consultant will evaluate an economic cost-benefit analysis of the proposed project. It is expected that the Consultant will complete the following steps in performing this analysis:

1. Perform an assessment of the project costs, covering capital costs but also operating and maintenance costs and decommissioning costs.
2. Identify the benefits of the project and propose a methodology for quantifying those benefits. The assessment of the benefits should cover electricity generation cost savings, savings made in the procurement of system services, avoided/deferred expenditure on network infrastructure, improvements in quality of supply, and any other benefit types identified by the Consultant.

3. Where possible, value the project benefits using the proposed methodologies. This analysis should make reference to alternative means by which the services delivered by the BESS could be provided, with the objective being to ensure the BESS is the least cost option for providing the proposed services.
4. Consider whether any economic externalities, such as greenhouse gas emissions, should be included in the analysis and propose an approach for quantifying such effects.
5. Combine the findings from this analysis to assess the net benefit delivered by the project.
6. Consider the major uncertainties in the analysis and, where possible, perform sensitivity analysis to quantify the impact of these uncertainties on the net benefit from the project.

As noted previously in Section 3.3.5, the benefits that should be quantified will vary according to the type of project(s) being proposed. The above scope outline could be tailored to reflect the areas likely to be most relevant to the proposed assignment.

Task 6: Detailed Front End Engineering Design

Depending on the procurement strategy to be used, this detailed design may not be required during feasibility. If the intention is to procure services, with detailed design to be determined by the project developer, this step would not be completed by the procuring authority; rather, a clear definition of project requirements will be required. When the utility intends to procure a project developer to implement a BESS that has already been specified, a detailed design as described below will need to be completed. This would then form a part of the tender documentation.

The consultant shall develop a detailed Front-End Engineering Design (FEED) of the BESS that shall be used during construction. The FEED shall be done following prudent engineering practices and shall include but not be limited to the specification of the following:

1. Technical characteristics of the battery modules i.e., nominal capacity (MW and MWh), round trip efficiency, number of cycles (and degradation curve), charging/discharging time and rate, minimum state of charge, and response time.
2. Configuration of the battery modules, mounting and connection to power conversion units.
3. DC/AC power conversion units that connect the battery to the grid and coupling requirements for hybrid projects.
4. Balance of system components including air conditioning, cabling, earthing details, switchgear, etc.
5. Electro-mechanical works to be conducted to fully connect the BESS.
6. Electrical distribution/transmission infrastructure required to connect the BESS to the grid substation.
7. Civil and structural works required to implement the project.
8. Applicable international and national standards to be adhered to during construction.[37]
9. Construction and supervision schedule including required licenses and permits.

37 A list of international standards prescribed for BESS projects is attached to the end of this terms of reference.

The FEED shall be summarized into a single line diagram for all the system components, an equipment layout to visualize the arrangement of the components in the HV station, and a volume containing all the detailed technical specifications and applicable standards required to supply and install the BESS.

In addition, the consultant shall design the supervision control and protection systems described below to be compatible with the battery packs and power conversion units to be supplied and the grid SCADA system:

1. An energy management system to control power flow through the battery and thermal management system well integrated to the air conditioning/cooling system. The energy management system shall stipulate the dispatch order clearly and enable integration of automatic metering infrastructure acceptable to the counterparty.
2. Design of the battery protection schemes that will detail the battery protection circuits at the cell, string, module, and grid integration level and their connection to relays and protection devices to ensure safe and reliable dispatch of the BESS.
3. Design of cooling and fire suppression systems that guarantee the safety of the BESS from thermal runaway of the battery cells and ultimately fire of the installation. Adequate alarm systems shall be incorporated to the design.

Deliverables

The Consultant will prepare the following deliverables in completing the assignment:

- An **Inception Report**, which will be completed within 2 weeks of contract signing. The inception report will confirm the approach and methodology to be taken by the Consultant, as well as defining the data inputs required by the Consultant from [utility name] or from the WB team.
- A **Draft Technical Feasibility Report** will be completed 2 months after contract signing. This report will present the completed outputs from Task 1-4 of the assignment, including reports on the BESS sizing and technology selection, system assessment, power flow analyses, and site assessment.
- A **Draft Environmental and Social Impact Assessment (ESIA) Report** will be completed 3 months after contract signing. The ESIA will present environmental and social impacts of the BESS and mitigation strategies to be considered during construction and operation.
- A **Draft Economic Cost-Benefit Analysis Report** will be completed 3 months after contract signing. This report will present economic cost-benefit analysis of the proposed project from Task 5 of the assignment leveraging outputs from the technical feasibility report.
- Presentation materials for a series of **Interim Results Workshops** which will be held within 2 weeks from the submission of each of draft reports above. The workshops will provide an opportunity for the results from the feasibility to be presented to [utility name], WB team, and other key stakeholders highlighting the key risks and how they will be allocated in the PPP structure.
- **Front-End Engineering Designs** (FEED) for the BESS will be completed 4 months after contract signing. The FEED will present outputs from Task 6 of the assignment detailing the technical design of the specified BESS.

- A **Final Report** will consolidate all the draft reports and incorporate any comments from [utility name] and the WB team on the draft reports. This will be completed by the Consultant within 2 weeks of the comments being provided to the Consultant by the WB team.

Organization

The Consultant is expected to be a firm with extensive experience in conducting feasibility studies for energy projects, including specific experience with BESS projects. Specifically, the team proposed by the Consultant should include:

- **Team Leader:** A transmission and distribution planning and design engineer in with more than 10 years' relevant experience in leading feasibility studies of grid projects having completed at least 5 assignments of similar nature.
- **Electrical engineering specialist(s)** in the analysis of the functioning of electrical networks with 10 years' experience in the modelling and simulation of power systems.
- **Battery energy storage system specialist(s)** with 10 years' experience in the electricity sector and 5 years' specific experience in the deployment of BESS.
- **Economic and financial analysis specialist(s)** with 10 years' experience in evaluating the economic feasibility of energy projects.
- **Environmental specialist** in the environmental and impact assessment of energy projects with 10 years' experience in conducting feasibility assessments.

The above role descriptions are indicative, and the Consultant can propose alternative team configurations covering the skill requirements set out above.

Applicable standards for finalizing the FEED

The IEEE 1547 standard and its complementary standards listed below provides the universal requirements for the application of various technologies and techniques for distributed generators and energy storage systems:

- IEEE Std 1547–2003 (reaffirmed 2008), IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
- IEEE Std 1547.1–2005, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
- IEEE Std 1547.2–2008, IEEE Application Guide for IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
- IEEE Std 1547.3–2007, IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems
- IEEE Std 1547.4–2011, Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems
- IEEE Std 1547.6–2011, Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Network
- IEEE P1547.7, Guide to Conducting Distribution Impact studies for Distributed Resource Interconnection (under development)

- IEEE P1547.8, Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Std 1547 (under development)

The IEEE 2030 standard and its complements listed below focus on achieving interoperability between energy technologies with information technology within a smart grid defining alternative approaches and best practices in controlling and monitoring power applications for smart grids:

- IEEE Std 2030–2011, Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads
- IEEE P2030.1, Guide for Electric-Sourced Transportation Infrastructure
- IEEE P2030.2, Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure
- IEEE P2030.3, Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications.

Appendix B.3 | Strategic PPP advisor

Background

An overview should be presented of the work performed to date on the BESS project, including all studies and feasibility analyses performed so far. Before tendering for this role, it should be possible to clearly set out in this background section:

- *Intended use application(s) of the BESS and associated project requirements;*
- *Likely parameters for defining the requirements from the BESS with an initial view of the size and technology to be used;*
- *The depth of the feasibility analysis that has been performed, e.g., whether the analysis has led to preparation of a FEED, or whether design of the BESS is likely to be left to bidders; and*
- *Key challenges and risks highlighted by the feasibility analysis.*

A Battery Energy Storage System (BESS) has been identified as a suitable option to provide services to [utility name]. Detailed analysis of both the technical and economic feasibility has already been completed and this shows that BESS projects are likely to be particularly important in providing [ADD DETAILS] services. The studies performed to date will be provided to the Consultant selected to complete this assignment.

[Utility name], together with the Government of [Country], has determined that the BESS project should be procured as a PPP, to leverage and benefit from the expertise on implementing BESS projects that exists in the private sector. Therefore, the next stage in implementing the proposed BESS project(s) is to prepare a strategy for implementing such a PPP, which will include determining the most appropriate allocation of key project risks between the parties.

Objectives of the assignment

The objective of this assignment is to develop a strategy to procuring the proposed BESS PPP. Specifically, this will include developing an approach for allocating key project risks between [utility name] and private sector bidders and developing the strategy for the procurement itself. The final procurement strategy recommendations will be presented to [utility name] as well as key officials from the Government of [Country].

Scope of work

<u>Task 1: Risk assessment and risk allocation</u>

Technical reports and relevant studies associated with the project feasibility analysis will be shared with the appointed Consultant upon contract signing. The Consultant will also be introduced to key staff at [utility name], who have been deeply involved in the work performed to date. The objective of this task is to ensure that all key risks that will need to be addressed in the PPP contractual arrangements are identified. This might include factors that would be common to other infrastructure PPPs and IPPs; for example:

- Construction risk and the risk that the Commercial Operations Date (COD) is delayed;
- Foreign exchange, the risk that exchange rates move materially and/or it is not possible to move funds in or out of [Country]; or
- Credit risk and the risk that [utility name] is unable to keep up with payments due under the PPP contract.

The risk analysis will also cover risks specific to the BESS technology:

- Demand risk and uncertainty over utilization of services to be provided by the BESS;
- Performance risk and ensuring the BESS is always technically capable of providing the services contracted under the PPP; or
- Degradation risk and managing the interaction between long-term performance of the asset and the operating regime that the system is required to follow.

The risks listed above are just examples. It is expected that the Consultant will identify a much longer list of risks that need to be managed for the PPP to be bankable.

The Consultant will then prepare a risk matrix, which will list each of the identified risks. The matrix will be used to identify which party is best placed to manage the risk and identify options for managing this allocation of risk through the PPP agreement(s). The risk matrix will be kept up-to-date and will be treated as a 'living document' throughout the remainder of the assignment.

Task 2: Procurement strategy

In many cases, some of the key decisions regarding procurement strategy may have been provisionally determined at an earlier stage in the process. In particular, a decision might have been made on which party will be responsible for detailed design of the BESS, i.e., whether this will be prescribed by the buyer or not. To the extent that such decisions have been made, they should be summarized here. The proposed text below might need to be updated to reflect this.

The most fundamental procurement strategy decision, which the Consultant will advise on, is the definition of what is to be procured through the PPP. This is likely to involve clear technical definition of the services that the BESS will be required to deliver, and the technical requirements that the BESS must meet throughout the contract life. However, the Consultant might recommend that [utility name] should prescribe other technical attributes of the battery, such as the technology to be used or the size of battery required.

The Consultant will also consider the impact of risk identified during Task 1 on the definition of what is to be procured. For example, to manage battery degradation risk the Consultant might recommend procuring a service that guarantees a given duration of response, or it might instead be recommended that a degradation curve should be written into the PPP contract itself.

As well as defining the strategy for defining what is to be procured, the Consultant will develop a strategy for the overall procurement process. This will consider factors including:

- Broad timescales for the procurement,
- How bidders will be evaluated: will there be a two-round evaluation process or a single round?
- How will the evaluators ensure that the selected winning bid is technically able to provide the required services?
- If an auction is to be used in selected a winning bid, what type of auction should be used?
- Any other factors that the Consultant deems to be important.

Once the Consultant has developed an initial draft of the procurement strategy, this will be tested by the Consultant with developers and investors, including lenders, who might be credible bidders or financiers of projects participating in the procurement. The Consultant will leverage their own network to arrange the market sounding.

Task 3: Refinement and finalization of the strategy

The Consultant will prepare a final report that presents the procurement strategy as defined through Tasks 1 and 2. This report will ultimately be endorsed by Government of [Country] before the PPP procurement process is formally initiated. The Consultant will be responsible for an initial round of consultations with Government stakeholders covering key components of the strategy. This will include bilateral meetings with [TO COMPLETE] and a 1-day workshop to present the proposed strategy and to allow for discussion and debate between the stakeholders.

After this engagement with key stakeholders, the Consultant will update the strategy to reflect feedback collated during the meetings and workshop.

Deliverables

The Consultant will be responsible for preparing the following deliverables:

- An **Inception Report**, which will be completed within 2 weeks of contract signing. The inception report will confirm the approach to be taken by the Consultant, as well as defining any data or information required by the Consultant for the assignment.
- A **Risk Matrix**, which will list the project risks identified during Task 1, along with the risk management solutions identified and recommended by the Consultant. An initial version of the risk matrix will be submitted 5 weeks after contract signing. The matrix will be maintained and updated through the remainder the assignment, and a final version will be submitted at the end of the assignment, along with the final report mentioned below.
- A **Draft Report**, which will outline the proposed procurement strategy defined through Task 2. The report will be submitted 10 weeks after contract signing.
- **Workshop Materials** will be submitted alongside the Draft Report. These will be prepared in PowerPoint and will be used for facilitating the bilateral stakeholder discussions as well as the multi-stakeholder workshop.

- A **Final Report**, which will incorporate feedback on the Draft Report received by the Consultant during the stakeholder consultations. The Final Report will be submitted 16 weeks after contract signing.

Organization

The Consultant is expected to be a firm with extensive experience in advising on PPP projects in the energy sector. Ideally, the Consultant will have specific experience with BESS projects. Specifically, the team proposed by the Consultant should include:

- A **Team Leader** with at least 15 years of experience advising on procurement strategies and PPP/IPP design in the electricity sector.
- A **Legal Specialist** with extensive experience advising on energy sector transactions over at least 10 years. Ideally, the Legal Specialist should have previously advised on battery storage projects that have successfully reached financial close.
- A **Technical Specialist** with at least 8 years of experience in the energy sector, and who has previously worked on multiple projects involving battery storage. The Technical Specialist should be familiar with the key technical risks that will need to be addressed through the PPP agreement(s).
- Any additional team members that the Consultant wishes to add.

The above role descriptions are indicative, and the Consultant can propose alternative team configurations covering the skill requirements set out above.

Appendix B.4 | Transaction advisor

Background

An overview should be presented of the work performed to date on the BESS project, including all studies and feasibility analyses performed so far, together with any work performed on developing the procurement strategy for the BESS project. Before tendering for this role, it should be possible to clearly set out in this background section:

- *Intended use application(s) of the BESS and associated project requirements;*
- *Likely parameters for defining the requirements from the BESS with an initial view of the size and technology to be used;*
- *The depth of the feasibility analysis that has been performed, e.g., whether the analysis has led to preparation of a FEED, or whether design of the BESS is likely to be left to bidders;*
- *Key challenges and risks highlighted by the feasibility analysis; and*
- *A broad overview of the likely procurement strategy for the project, although this will be reviewed and refined during the early part of this assignment.*

A Battery Energy Storage System (BESS) has been identified as a suitable option to provide services to [utility name]. Detailed analysis of both the technical and economic feasibility has already been completed and this shows that BESS projects are likely to be particularly important in providing [ADD DETAILS] services. Initial work has also been performed to analyze the project risks to be managed through the project agreement(s) and to advise on the procurement strategy for the BESS project. All the studies performed to date will be provided to the Consultant selected to complete this assignment.

[Utility name], together with the Government of [Country], has determined that the BESS project should be procured as a PPP, to leverage the expertise on implementing BESS projects that exists in the private sector. Therefore, the next stage in implementing the proposed BESS project(s) is to finalize the PPP transaction structure and proceed with the transaction. This assignment is intended to solicit the services of a transaction advisor to support this process.

Objectives of the assignment

The objective of this assignment is to assist [utility name] and Government of [Country] in procuring the PPP. This will involve finalizing the strategy for procurement and the structure for the transaction, preparing all necessary documentation for the transaction, running the transaction process itself, evaluating the bids received, and assisting [utility name] in its final negotiations with a preferred bidder, with the ultimate objective being to successfully reach financial close.

Scope of work

Task 1: Finalize procurement strategy

This component of the scope could in some cases include parts of Task 2 from the Terms of Reference included in Appendix B.3.

The Consultant will review the procurement strategy final report that has already been prepared by consultants engaged by the World Bank. The final report was accepted by [utility name] and Government of [Country] after extensive engagement with Government stakeholders. The report has two main components:

- An analysis of key project risks and how these should be allocated between the parties.
- An outline of the procurement strategy, which covers the definition of the services to be procured under the PPP, the procurement process itself, and the proposed evaluation process.

Further detail might be provided here, depending on the scope of any previous work covering the procurement strategy for the PPP.

The Consultant will attend introductory meetings with key Government stakeholders involved in the process to date. Any proposed amendments or additions to the procurement strategy will be submitted by the Consultant and discussed and agreed with the relevant stakeholders.

Task 2: Prepare a detailed procurement plan

Building on the procurement strategy refined through Task 1, the Consultant will prepare a detailed plan that identifies all the key tasks involved in completing the procurement exercise, as well as the phasing of those tasks. At a minimum, the plan will cover the detailed sub-tasks required to complete each of the tasks outlined below as part of this Scope of Work. The Consultant will identify any additional tasks that it believes are not covered by this Scope of Work and will allow sufficient time in the plan for securing any required Government approvals.

The project plan will be presented as part of an inception report, which will be discussed with key Government stakeholders to confirm the approach to be taken during the remainder of the assignment.

Task 3: Prepare project agreements and RFP documents

The Consultant will prepare the contractual documents that will govern the relationship between the parties to the PPP. This will be focused on the main PPP contract, but may also include additional contracts that the Consultant deems to be required for the PPP to be bankable. In drafting the contracts, the Consultant will be guided by the aforementioned risk analysis that has already been completed, together with any amendments to this analysis proposed and agreed during Task 1 of this assignment.

The Consultant must ensure that the draft agreements are bankable and that they comply with local laws and regulations. The Consultant is encouraged to engage in market sounding consultations throughout the drafting process to test proposed contractual solutions to managing key risks with developers and investors who might engage with this procurement process.

In addition to preparing the draft project agreements, the Consultant will prepare the Request for Proposals (RFP). If decided upon, an Expression of Interest (EOI) stage may be desired, in order to qualify only serious bidders for the RFP. The RFP will be prepared in accordance with best industry practice for PPPs, and it will pay particular attention to explaining the requirements that the BESS system must meet. The RFP will specifically include material covering the following:

- The specification requirements of the project, i.e., the minimum technical requirements that the BESS must meet,
- Requirements that bids and bidders must meet for a submission to be deemed to be compliant,
- The PPP contractual structure and the allocation of key project risks within the structure,
- The revenue model / payment mechanism included in the PPP agreement,
- The process for bidding, covering submission requirements and the evaluation framework,
- Timelines for the remainder of the process until commercial operations, and
- Any other matters that the Consultant believes should be included in the RFP.

Depending on the procurement strategy adopted, additional documents such as a request for Expressions of Interest might also be required.

Task 4: Financial modelling

Before commencing the transaction process, the Consultant will prepare a financial model for the proposed PPP transaction. While it is noted that some inputs to the financial model will be somewhat uncertain (for example project costs, which will depend on the project configurations proposed by bidders), the objective of the model will be to evaluate the range of bid values that the Consultant might expect to be submitted. The financial model may also be used during the evaluation process to interrogate and compare the bids submitted, especially if the Consultant determines that bidders are required to submit a financial model.

The financial model will take into account all factors that the Consultant believes will be important in determining the pricing of bids, including financing arrangements. Where factors are identified that are both uncertain and could have a material impact on pricing, sensitivity analysis will be performed to quantify this impact. The Consultant will summarize the outputs from the financial modelling in a short briefing paper to be presented to [utility name] and Government of [Country] before the transaction process is launched.

Task 5: Execution of the bidding process

The Consultant is to provide all necessary support to [utility name] and Government of [Country] for the efficient and professional management of the transaction process. This will include, but is not limited to:

- Managing a data room and/or other communication processes for sharing of project information and data with bidders.
- Launching the RFP and ensuring this is seen by as many credible potential bidders as possible.
- Managing and presenting a bidders' conference and/or bilateral bidder engagement, depending on the processes set out in the detailed procurement plan as described under Task 2.
- Responding to bidder queries.
- Receive bidder submissions and ensure that all submissions are managed in a secure and appropriate manner reflecting the confidential nature of the information.
- Oversee evaluation of the submitted bids and ensure that the evaluation follows the agreed procurement strategy and the process outlined in the RFP.
- Recommend a preferred bidder, with whom final contractual negotiations shall proceed under Task 6.

The Consultant will prepare a succinct report to be submitted to [utility name] and Government of [Country], recommending the selection of a preferred bidder. By comparing analysis of the selected bid against the financial model prepared under Task 4, the Consultant will also provide an opinion on whether the bid represents value for money to [utility name]. This report will be used by [utility name] and Government of [Country] to approve selected of the preferred bidder.

Task 6: Final PPP negotiations

The scope of this task will depend on the details of the procurement strategy and the extent to which negotiation on the terms is appropriate. Ideally, the terms should mostly be fixed ahead of the launch of the RFP so that all bidders are compared on the same basis. The scope for bidders to re-negotiate the terms should therefore, ideally, be limited.

The Consultant will assist [utility name] and Government of [Country] in final negotiations with the selected preferred bidder. This will include responsibility for the following tasks at a minimum:

- Assembling teams for the negotiation.
- Analyzing any issues for negotiation that have been submitted by the preferred bidder and recommending a strategy for responding to the bidder's submission.
- Preparing mark-ups to the PPP agreement(s) to reflect any agreed changes.

The Consultant will require access to a qualified law firm to advise on complex legal/contractual issues. The Consultant will be responsible for preparing the final version of the documents in a form ready for final approval by [utility name] and Government of [Country]. The Consultant will provide any clarifications required for final approvals to be secured and for financial close to be successfully achieved.

Deliverables

The Consultant shall be responsible for preparing the following deliverables:

- An **inception report**, which should contain a finalized version of the procurement strategy and a detailed procurement plan, based upon the Consultant's initial consultations in completing Tasks 1 and 2. The inception report will re-confirm the approach to be taking in completing the remaining tasks for this assignment. It will be completed within 2 months of contract signing.
- Draft versions of the **project agreements** and **RFP documents** shall be completed within 3 months of submissions of the inception report. Up to two rounds of comments will be integrated to the documents by the Consultant and a final version of each document will be prepared within 1 month of the final set of comments being provided.
- The **financial model** and accompanying **briefing paper** will be submitted alongside the final project agreements and the RFP.
- A **report recommending selection of a preferred bidder** will be prepared within 1 month of final bids being received.

Organization

The Consultant is expected to be a firm with extensive experience in advising on PPP projects in the energy sector. Ideally, the Consultant will have specific experience with BESS projects. Specifically, the team proposed by the Consultant should include:

- A **Team Leader** with at least 15 years of experience advising on PPP/IPP transactions in the electricity sector, including experience advising on transactions including BESS technologies.
- An **International Legal Specialist** with extensive experience advising on energy sector transactions over at least 10 years. Ideally, the Legal Specialist should have previously advised on battery storage projects that have successfully reached financial close.
- A **Local Legal Specialist** with at least 10 years of experience practicing law in [Country], with a significant portion of that experience being focused on energy sector projects.
- A **Finance Specialist** with at least 10 years of experience advising on the financing of projects in the electricity sector, including the preparation of financial models.
- A **Technical Specialist** with at least 8 years of experience in the energy sector, and who has previously worked on multiple projects involving battery storage.
- Any additional team members that the Consultant wishes to add.

The above role descriptions are indicative, and the Consultant can propose alternative team configurations covering the skill requirements set out above.

APPENDIX C: REFERENCES

China Energy Storage Alliance (2020): CNESA Global Energy Storage Market Analysis – 2020, Q3 (http://en.cnesa.org/latest-news/2020/11/17/cnesa-global-energy-storage-market-analysis2020q3-summary)

Chupka, M. (2020): End-of-Life Management of Lithium-ion Energy Storage Systems

Clean Energy Ministerial (2018): Thermal Power Plant Flexibility (https://www.cleanenergyministerial.org/sites/default/files/2018-06/APPF%20Campaign_2018%20Thermal%20Power%20Plant%20Flexibility%20Report_cleanenergyministerial.org__0.pdf)

Energy Sector Management Assistance Program (ESMAP) (2018): Innovative Approaches to PPPs for Smart Grids (English). Energy Sector Management Assistance Program Washington, D.C. World Bank Group. (http://documents.worldbank.org/curated/en/363151595914878255/Innovative-Approaches-to-PPPs-for-Smart-Grids)

Energy Sector Management Assistance Program (ESMAP) (2020): Deploying Storage for Power Systems in Developing Countries: Policy and Regulatory Considerations (https://documents1.worldbank.org/curated/en/738961598380536870/pdf/ESP-Policy-Manual-Aug-2020.pdf)

European Commission (2017): Guidance on the preparation of the Environmental Impact Assessment Report (https://ppp.worldbank.org/public-private-partnership/library/guidance-preparation-environmental-impactassessment-report)

Ghiasi, Mohammad. (2018): A Detailed Study for Load Flow Analysis in Distributed Power System. *International Journal of Industrial Electronics, Control and Optimization; Vol. 1, No. 2, pp153-161, DOI: 10.22111/IECO.2018.24423.1027*

International Energy Agency (2020): Energy Storage. (https://www.iea.org/reports/energy-storage)

International Energy Agency (2020): World Energy Outlook 2020. (https://www.iea.org/reports/world-energy-outlook-2020)

International Energy Agency (2021): The Role of Critical Minerals in Clean Energy Transitions. (https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions)

International Energy Agency (2022): World Energy Investment 2022. (https://www.iea.org/reports/world-energy-investment-2022)

International Energy Agency (2022): World Energy Outlook 2022. (https://www.iea.org/reports/world-energy-outlook-2022)

IFC (2019): The Dirty Footprint of the Broken Grid: The Impacts of Fossil Fuel Back-up Generators in Developing Countries. (https://www.ifc.org/wps/wcm/connect/industry_ext_content/ifc_external_corporate_site/financial+institutions/resources/dirty-footprint-of-broken-grid)

IRENA (2017), Electricity Storage and Renewables: Costs and Markets to 2030, International Renewable Energy Agency, Abu Dhabi. (https://www.irena.org/publications/2017/oct/electricity-storage-and-renewables-costs-and-markets)

Lazard (2020): Levelised Cost of Storage Analysis – Version 6.0 (https://www.lazard.com/media/451566/lazardslevelized-cost-of-storage-version-60-vf2.pdf)

Power Africa (2018): Understanding Power Project Financing (https://cldp.doc.gov/sites/default/files/UnderstandingPowerProjectFinancing.pdf)

Sabihuddin (2015): A numerical and graphical review of energy storage technologies. Energies; Vol. 8, pp. 172-216. (https://doi.org/10.3390/en8010172)

Šimić, Z, et al. (2021): Battery Energy Storage Technologies Overview, International Journal of Electrical and Computer Engineering Systems. (https://ijeces.ferit.hr/index.php/ijeces/article/view/23/22)

US Department of Energy (2020) Grid Energy Storage Technology Cost and Performance Assessment Technical Report Publication No. DOE/PA (https://www.pnnl.gov/sites/default/files/media/file/Final%20%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf)

World Bank (2017): Public-Private Partnerships Reference Guide (Version 3) (https://ppp.worldbank.org/public-private-partnership/sites/ppp.worldbank.org/files/documents/PPP%20Reference%20Guide%20Version%203.pdf)

World Bank (2020): Economic Analysis of Battery Energy Storage Systems (https://openknowledge.worldbank.org/bitstream/handle/10986/33971/Economic-Analysis-of-Battery-Energy-Storage-Systems.pdf?sequence=1&isAllowed=y)

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