Strategies for Procuring Solar PV and Grid-Scale Battery Storage

Policy options for Malawi

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1.0. Introduction

The Government of Malawi has sought technical assistance in order to accelerate its energy transition and in particular to facilitate the government's procurement of renewable electricity projects. Given the small size of Malawi's grid, relatively high system losses, and its relatively modest electricity demand, the government is interested in exploring the procurement of hybrid or combined solar PV plus battery storage installations (so-called "solar+storage" systems).

As outlined in the scope of work agreed upon with the Ministry of Energy, the aim of this technical assistance request is thus "*to explore* ***policy solutions and practical pathways for the procurement of solar + storage projects*** *in Malawi. This will include short case studies on how other jurisdictions around the world are procuring solar+storage, what kinds of storage technologies are being deployed, an overview of the current costs and recent auction results, as well as some of the technical and other considerations involved (minimum requirements, size ratios between solar installation and onsite storage capacity, etc.)*"

Storage can provide a range of benefits to power systems, including systems with rising shares of variable renewables like solar PV and wind power. However, it should be noted at the outset that **adding solar power to renewable electricity procurement also increases project costs**, which in turn increases the cost borne by society and by ratepayers; this additional cost needs to be taken into consideration, and compared against the costs of procuring a solar PV system without battery storage.

And yet, despite the added costs entailed by adding battery storage to solar PV projects, **a range of recent auction results of solar+storage systems give grounds for hope**: the rapid decline in battery costs combined with steady declines in solar PV costs have made it possible to develop combined solar+storage projects at an economically attractive price point in many parts of the world. Indeed, a lot of media attention was attracted by recent auctions for solar+battery project in the United States and other jurisdictions around the world. At the end of 2017, Minnesota-headquartered Xcel held technology neutral auction for its long-term resource planning. The least cost technologies offered where hybrid solar+battery offers. Bids were priced at US$36 per MWh.[1] In Arizona, the lowest bids for solar+battery storage were received at $45/MWh. However, it is important to note that many U.S.-based projects benefit from federal tax incentives and occasionally from state- or utility-level subsidies

This analysis focuses on a few select jurisdiction that have already undertaken procurement processes for grid-scale battery storage in order to provide guidance to officials in Malawi about the design of their own procurement process.

Most of large-scale battery storage today is based on lithium-ion (Li-ion) technology. In the United States, for instance, currently the largest market for battery storage in the world, Li-ion technology accounts for 90% of all battery storage (US EIA 2021).

[1] https://www.energy-storage.news/news/incredible-low-prices-for-renewables-plus-storage-in-xcels-solicitation

Flexibility options for the power system

Variable renewables like solar power are weather dependent, and often considered non-dispatchable. However, even variable renewables can be relatively predictable. For instance, while the individual output of a single solar PV project is quite erratic, the aggregate output of hundreds of solar projects becomes increasingly smooth, particularly when the solar power is installed in a geographically distributed way (see Figure 1).

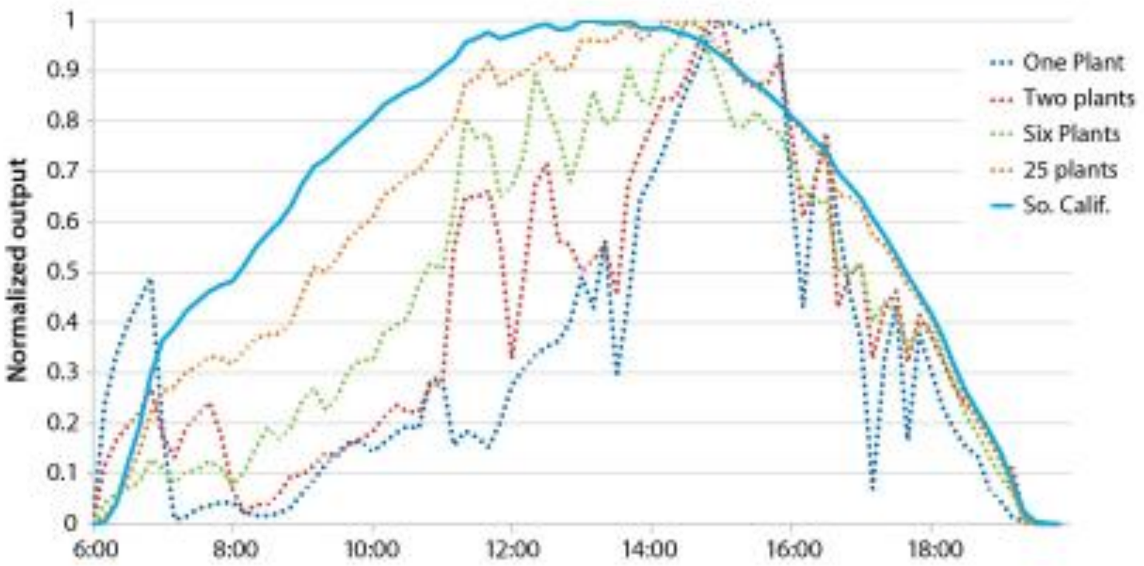

Figure 1: Output profile of different solar PV projects, including in all of Southern California

Source : NREL 2013, http://www.nrel.gov/docs/fy13osti/60451.pdf

As the share of variable renewables grows, this variability needs to be modelled, planned, and adapted into power system planning.

A key factor with the rise of solar power in particular is that it **increases the uncertainty of net load** (the net electricity demand that needs to be met after solar). As can be seen in Figure 2 below, as the share of solar power grows, the remaining daytime load that needs to be met by conventional generation continues to shrink, with the result that in the years ahead, many countries will frequently have a net ***surplus*** of variable renewable energy during the daytime.

In November 2021, South Australia achieved **net negative electricity demand** during the daytime for the first time, largely due to the high concentration of rooftop solar in the state.[2] One consequence of the growing share of renewable energy in the grid that is becoming clear as cases like South Australia become more common, is that **the need for traditional "baseload" power is starting to decline,** for the simple reason that there are a growing

[2] Parkinson, G., (November 22 2021). « Rooftop solar helps send South Australia grid to zero demand in world first, » RenewEconomy, https://reneweconomy.com.au/rooftop-solar-helps-send-south-australia-grid-to-zero-demand-in-world-first/

number of hours of the year where the "residual" electricity demand is zero, or negative, leaving no room for inflexible baseload generators. What is needed instead is **more flexible sources of power supply**, as well as flexible sources of power **demand** (including storage, demand response, etc).

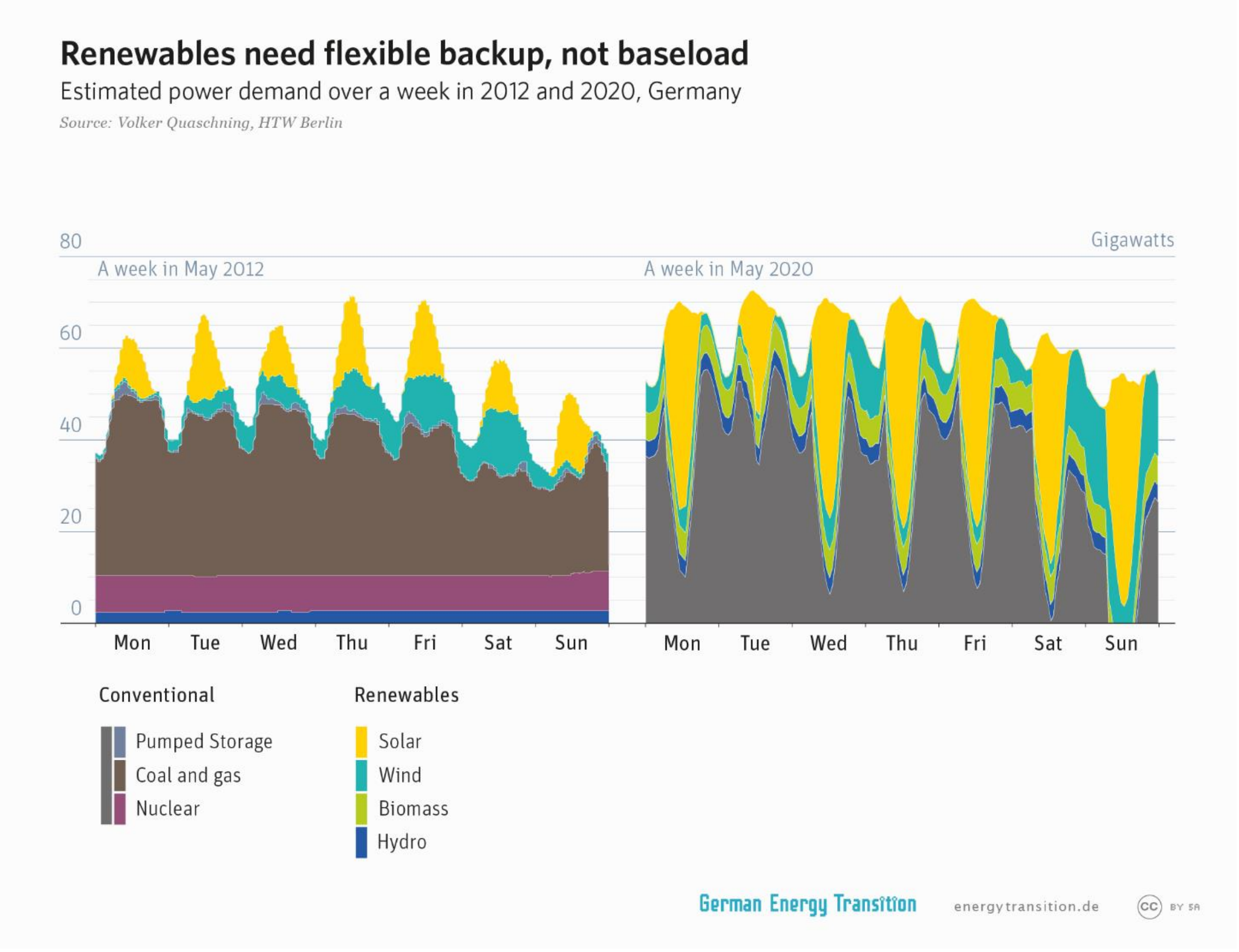

Figure 2: *Illustration of Power Demand Patterns in Germany 2012 and 2020*

Source: https://www.researchgate.net/figure/Renewables-need-flexible-backup-not-baseload-Estimated-power-demand-over-a-week-in-2012_fig10_283624511

What this means in practice is that it is vital to start planning for **increasing power system flexibility.** For countries with excellent solar resources like Malawi, the challenge in the coming years is to transition the power system to become more flexible, while phasing-in abundant renewable energy resources like solar, all while continuing to meet electricity demand growth and ensuring reliability.

Flexibility can come from a wide variety of sources, including from flexible generation (open-cycle gas turbines, or hydro dams, for instance) or from increasing the flexibility of demand (ramping down loads where the system is constrained). Another alternative is to increase the availability of storage, whether thermal storage, hydro storage (e.g. pumped hydro), synthetic gas storage, or battery storage. In the worst-case scenario, power system operators resort to load shedding when power system operations are insufficiently flexible (or power supply is insufficient available) to meet real-time power demand.

Indeed, **power system flexibility is emerging as one of the most important aspects to ensuring a successful energy transition**.

Overview of storage technologies

As highlighted above, storage technologies provide one way in which to increase power system flexibility. There is a wide range of storage technologies available on the market:

- Pumped hydro storage
- Compressed air storage
- Molten salt storage (e.g. used in concentrating solar power plants)
- Other forms of thermal storage
- Flywheels
- Battery storage (using various chemistries, including sodium, lithium, zinc, flow batteries, cobalt, etc.)

This analysis focuses specifically on **battery storage** technologies, and their potential applications in a country like Malawi.

Table 1: Battery storage systems: Key terms
Rated Power Capacity: the total possible capacity (in kW or MW) that a battery can discharge from a fully-charged state **Energy capacity:** the maximum amount of stored energy (in kWh or MWh) that a battery contains **Storage duration:** the amount of time storage can discharge at its rated power capacity before being fully depleted (a battery with 1MW of capacity and 5MWh of energy can deliver at its full capacity for 5 hours. **Cycle life/battery lifetime:** the amount of time (or cycles) a battery storage system can provide before failure or significant degradation.
Source: NREL (2019). "Grid-Scale Battery Storage: Frequently Asked Questions," Greening the Grid, https://www.nrel.gov/docs/fy19osti/74426.pdf

The role of battery storage in electricity markets

As can be seen in Figure 3 below, there are many functions that battery storage can provide to the electricity system.

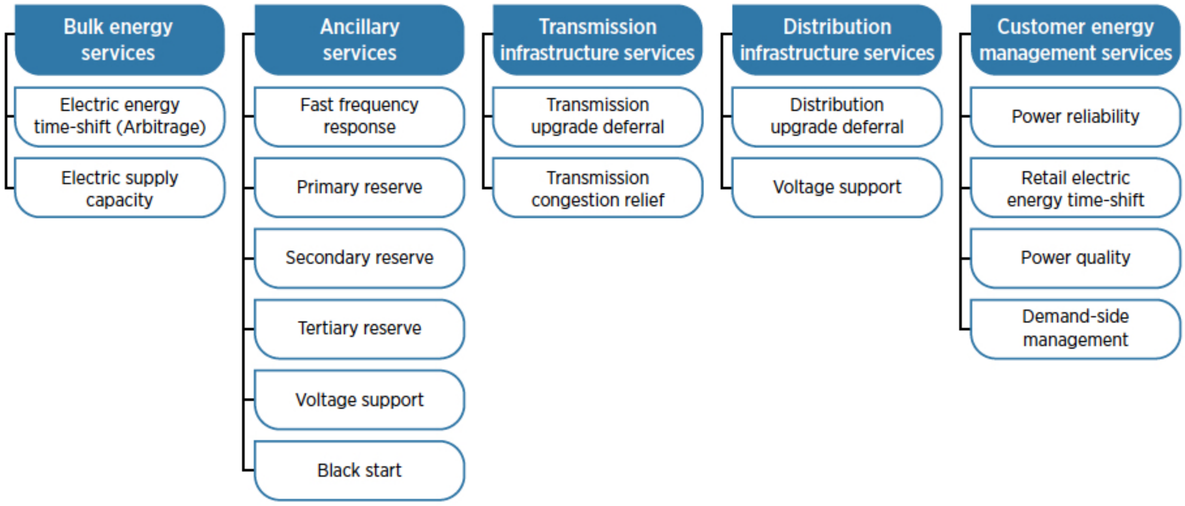

Figure 3: Functions of battery storage

Source: IRENA 2020. "Electricity Storage Valuation Framework: Assessing system value and ensuring project viability", International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_storage_valuation_2020.pdf

Understanding these various services can help Malawi plan for how to best procure storage, and how storage in particular can deliver value to the system.

2.0. Use Cases for Battery Storage

Why procure battery storage?

At the heart of procuring grid-scale battery storage is the question of what the storage capacity is intended to accomplish. Many government officials around the world continue to think of battery storage simply as a form of modular hydropower dam or a pumped hydro station, one that can be "filled up" and "emptied" as needed in order to adjust to changing patterns of power demand. However, as experience with battery storage systems grows in markets ranging from California and South Australia to India and China, **a more multi-faceted view of the role of grid-scale battery storage is emerging.**

In order to better understand the role that battery storage can play in support power systems and overall power system transformation, it is helpful to look at the range of services that battery storage systems can provide; this range of services can be thought of as a "value stack" – in some jurisdictions, only certain elements of this value stack are currently valued by the utility, while others remain uncompensated, or under-utilized. However, in certain parts of the world, several battery-related services can be monetized and compensated, either directly "behind-the-meter" for battery system owners, or "in-front of the meter" by providing services outwardly to the grid (IRENA 2019).[3]

Table 2: Overview of the various services that battery storage can provide

	System Service	Description
1.	**Providing rapid-response ancillary services**	Battery storage systems are capable of rapidly and accurately changing their charging and discharging rates in response to external signals. By quickly changing their operation, battery storage systems can provide a range of ancillary services such as **voltage and frequency control**. These ancillary services are particularly important in systems with large amounts of variable renewable energy generation, as system operators must be able to respond to unexpected changes in energy supply. Currently, ancillary services are predominantly provided by conventional generators. However, using battery storage systems to provide ancillary services can help increase the flexibility of the power system while reducing the need for **spinning reserves**, a service typically provided by conventional resources.
2.	**Providing capacity services**	System operators need to ensure they have an adequate supply of power generation capacity to reliably meet demand throughout the day, including during high demand periods. This peak

[3] IRENA (2019). Utility-scale batteries: Innovation landscape brief. International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Utility-scale-batteries_2019.pdf

		demand is typically met with higher-cost generators; there is a growing opportunity to provide help meet peak demand using battery storage systems instead. Storage systems may not need to be co-sited with solar PV, though many project developers opt for co-siting.
3.	**Arbitrage**	In some jurisdictions (particularly those with competitive electricity wholesale markets), battery storage can be deployed to purchase electricity when it is less expensive (such as during the daytime when solar power is abundant) and sell it when prices rise (such as in the early evening hours). Such arbitrage opportunities can be attractive in areas with significant variations between daytime and nighttime power prices.
4.	**Mitigating curtailment**	Battery storage systems can be used to help balance short-term differences between demand and supply, and therefore help solar projects (for instance) avoid curtailment caused by issues or bottlenecks in the grid. In this way, storage can help reduce the volume of power lost to curtailment events. In addition, battery storage systems that are co-sited with renewable resources like solar can also reduce the required transmission capacity to integrate the solar power into the system.
5.	**Deferring Transmission and Distribution Upgrades**	Transmission and distribution infrastructure needs to be dimensioned to meet peak demand, even though peak demand may only occur for a few hours of the year. When peak demand exceeds the grid's existing transmission and distribution capacity, power outages typically follow, pointing to a need for new investments to upgrade equipment and expand power system infrastructure. However, a growing number of utilities around the world are realizing that the deployment of battery storage systems can help **defer or avoid the need for new transmission investments** by helping to meet peak demand with energy stored from lower-demand periods. Doing so can also help reduce congestion during periods of stress on the network and improve overall transmission and distribution asset utilization.
6.	**Black start capability**	When ramping up and coming online, large electricity generation stations typically need an external source of electricity to perform key functions before they can begin generating power. The capability to provide this power is referred as "**black start capability**". During normal conditions, the electricity required to get generation units going can be provided by the grid itself (i.e. by other generation plants). However, immediately after a grid failure or power outage, the situation often arises in which the grid is unable to provide this power, and generators must be started using an on-site source of electricity. On-site battery storage systems can provide this service while saving the associated fuel costs, reducing emissions, as well as avoiding the need for onsite fuel storage infrastructure (e.g. diesel). For

		countries with a relatively weak grid, this black start capability can be quite valuable to system operators, and to utilities.

Sources: https://greeningthegrid.org/energy-storage-toolkit/topics-resources/grid-services-and-value-stacking and https://www.nrel.gov/docs/fy19osti/74426.pdf

In order to better understand the range of services that battery storage can provide, it is helpful to think of the various **timeframes** over which the services can be provided, or called upon. These different timespans range from milliseconds to hours and days, as shown in Figure 4 below :

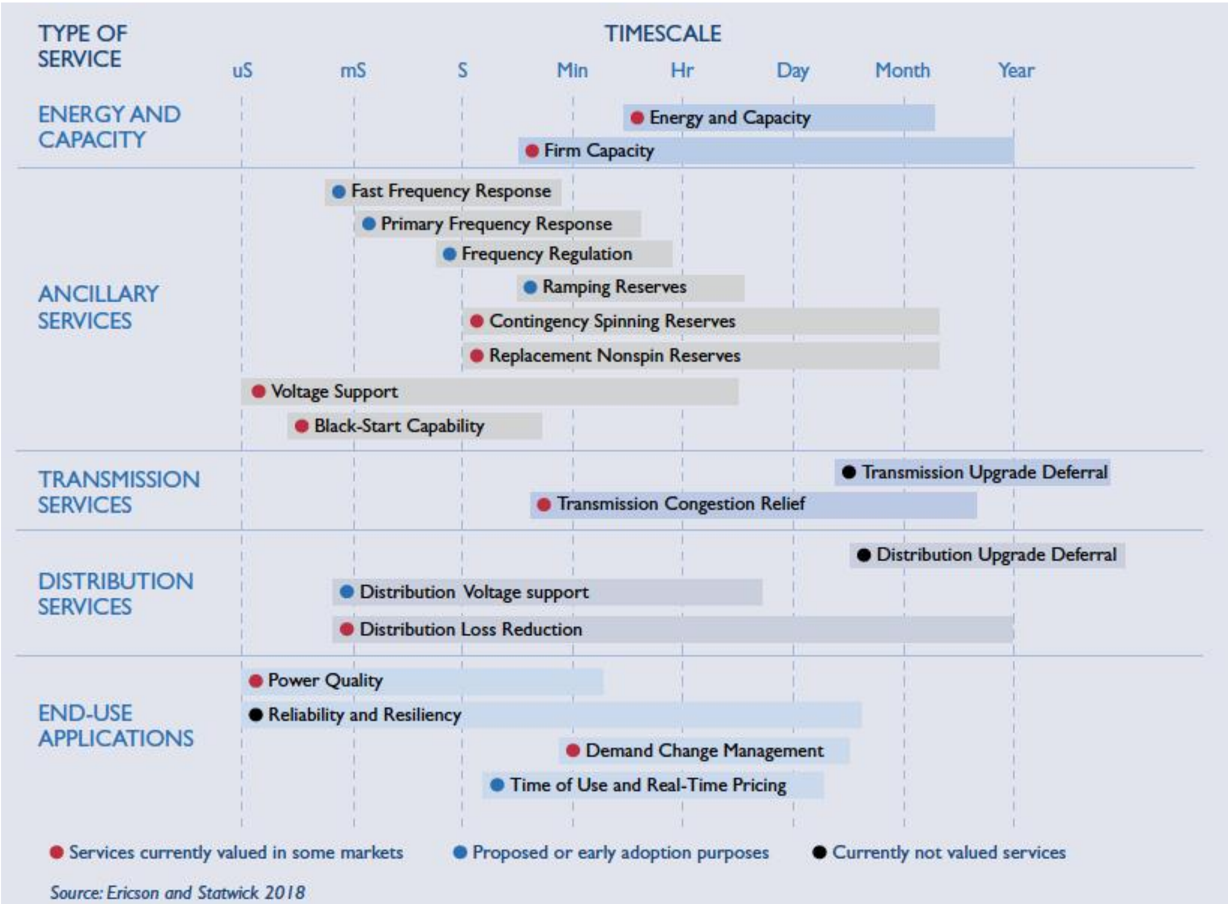

Figure 4: Timescale over which different battery storage services are provided

Source : USAID 2020, https://pdf.usaid.gov/pdf_docs/PA00X4KB.pdf

Another important consideration for policymakers and utility officials is where the storage should be located. Broadly speaking, there are four main options:

1. **For islands and remote areas** (i.e. off-grid)
2. **At the customer's premises**

3. **At the generator** (co-sited with solar PV or wind power, for instance)
4. **At strategic locations on the grid** (e.g. substations, or at hydro dams)

The decision-making process can be represented via a decision tree:

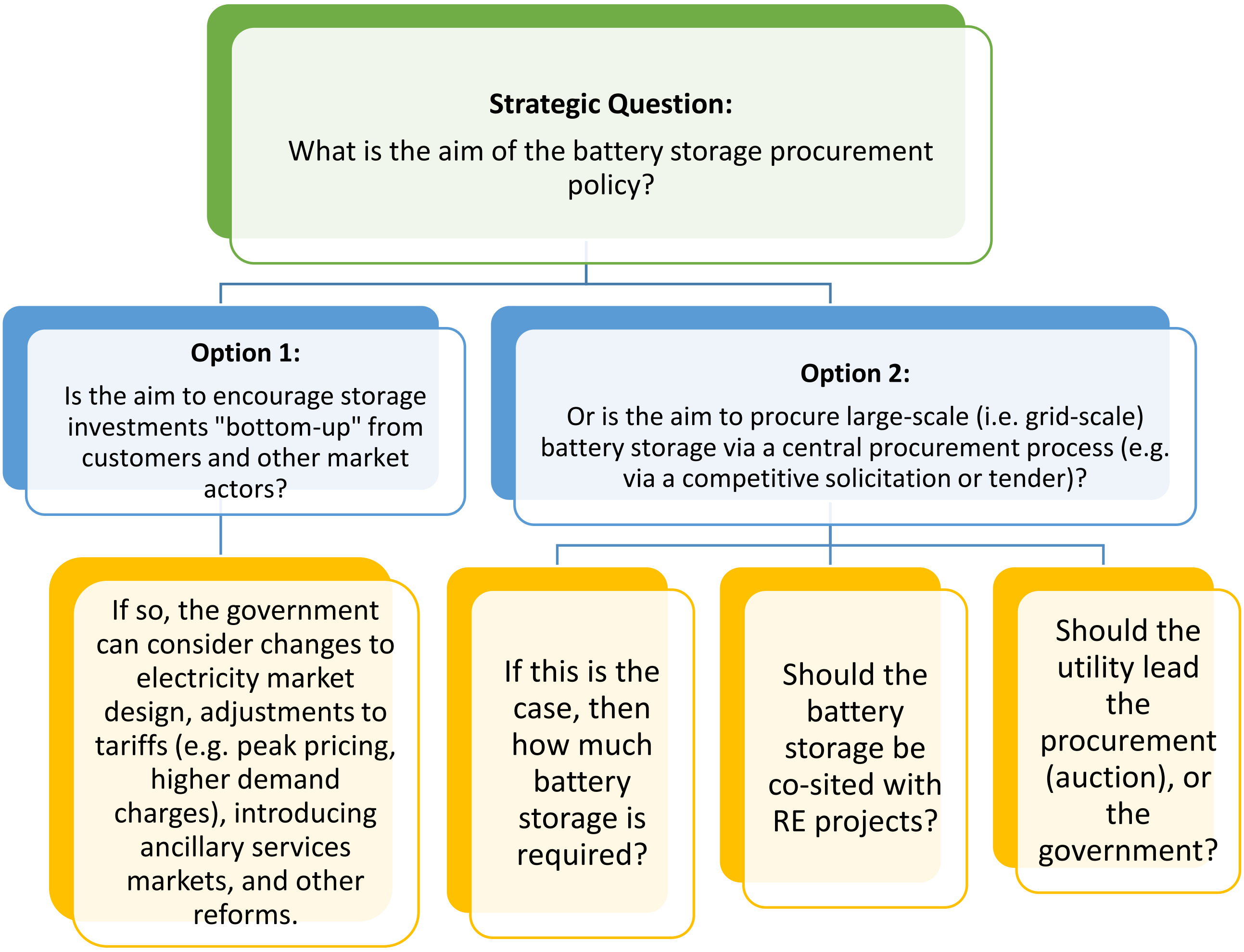

Figure 5: Key questions for storage procurement

What is the aim of procuring battery storage?

Broadly speaking, there are a number of different specific functions, or use cases, that are emerging for battery storage applications. For Malawi, the main use cases can be summarized as follows:

1. Replace firm, fossil fuel-based generation capacity
2. Deliver power during peak hours
3. Reduce the curtailment of variable renewable energy (VRE) resources
4. Provide ancillary services

5. Defer transmission and/or distribution grid investments

This section will look at each of these use cases in turn.

2.1. Replace firm, fossil-based generation capacity

In regions with weak grids or limited interconnections with neighboring jurisdictions, providing firm power generation capacity typically ranks as one of the top policy priorities. In such cases, the auctions that are conducted to procure new power generation capacity are typically structured to ensure that the generating unit(s) and storage capacity can provide, when combined, firm power (for more details on auction design for storage, see Section 3 below). A related benefit of adding storage to VRE generators like solar PV projects is that it can reduce the variability of power output, reducing the impacts on voltage and other factors, thereby facilitating grid integration.

When using storage to replace firm capacity, it is necessary to ensure that sufficient storage capacity is included in relation to the size of the generating unit(s). For instance, India is currently in the process of implementing its auctions for “round-the-clock” power supply from solar+storage installations. In its first auctions launched in May 2020 (with contract signing during the summer of 2021), India procured a PPA at a range of roughly USD 3.9 cents/kWh, indexed to increase by 3% per year for 15 years, and then to remain flat for the following 10 years (for a total PPA duration of 25 years) (Gupta 2021).[4] The solar PV and wind project, when combined with storage, will have to meet a combined annual plant load factor (capacity factor) of 80% (with a minimum monthly capacity utilization of 70%), with estimates suggesting that the project will involve 400MW of solar PV and 900MW of wind power capacity.

Table 3: ***PV-Battery Hybrid Power Plants in Island Regions***
Some island nations have replaced existing diesel-based power generation entirely with solar PV and battery solutions. One prominent example is American Samoa. Ta'u, one of five volcanic islands that make up the U.S. territory of American Samoa, relied entirely on diesel-based power generation until 2016. In the same year, a 1.4MW PV system in combination with a 6 MWh lithium-ion battery was installed, thus serving the entire power needs of this small island (including the hospital, public schools, fire and police stations, local businesses, residences). A series of additional solar+storage projects are being developed in island regions throughout the Pacific as well, including New Caledonia, which is now operating at close to 100% renewable energy due to the combined use of wind, solar, and storage.[5]

[4] Gupta, U. (August 10 2021). “Indian developer signs PPA for 400MW round-the-clock energy supply,” PV Magazine, https://www.pv-magazine.com/2021/08/10/indian-developer-signs-ppa-for-400-mw-round-the-clock-energy-supply/

[5] Colthorpe, A. (January 7 2021). “France’s island territories get solar-plus-storage at average price below EUR 100/MWh in latest auction,” Energy Storage News, https://www.energy-

2.2. Deliver power during peak hours

Rather than procuring round-the-clock power supply, certain auctions and procurement processes are being designed specifically to procure peak power supply to reduce strain on the system, minimize load shedding, and improve power system reliability. In addition, since providing peak power is typically associated with high costs, as it relies on low-utilization power plants and assets, adding storage can help provide a cost-competitive alternative to traditional peaker plants. In jurisdictions with electricity tariffs that vary according to the time of day, or that have competitive wholesale markets, storage systems can also engage in **arbitrage**, filling up when power is cheap or abundant, and discharging when prices are higher.

Since solar power generates electricity during the daytime, and peak demand in many countries occurs in the early evening hours, a number of jurisdictions are starting to look at various forms of storage in order to increase supply during the early evening hours. For instance, in both Morocco and in Spain, concentrating solar power (CSP) projects are being equipped with molten salt storage to provide between 4 hours and 9 hours of energy storage, enabling the CSP projects to continue generating power into the evening hours (SolarPACES 2020).[6] In Spain's case, it was found to be more economic to retrofit existing CSP plants to add molten salt storage than to build new solar PV projects equipped with battery storage.

2.3. Reduce VRE curtailment

As wind and solar power grow within power systems that were designed around less flexible, baseload generation sources and with limited demand-side flexibility, curtailment has become a growing issue. Grid constraints and bottlenecks have also exacerbated the issue further. And even in markets with adequate transmission capacity, there can be times of the day when the system operator (or utility) cannot accommodate all solar PV and wind power output, resulting in curtailment. Combining such solar PV and wind projects with onsite storage can be one way of helping reduce curtailment – however, it is important to note that doing so significantly increases the costs of solar and wind, and arguably saddles renewable energy technologies with the task (and costs) of adapting to the *inflexibility* of existing generation assets.

In Hawaii, for instance, a number of procurements by Hawaiian Electric Company (HECO) have been launched to procure battery storage to mitigate curtailment, and enable the state to achieve higher shares of renewable energy in its power mix. Indeed, in October 2021, HECO announced that it plans all future auctions of solar power to be coupled with storage (Colthorpe 2021).[7]

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storage.news/frances-island-territories-get-solar-plus-storage-at-average-price-below-e100-mwh-in-latest-auction/

[6] SolarPACES (June 17 2020). "Spain's first CSP to get novel thermal+electric storage retrofit," https://www.solarpaces.org/spains-first-csp-to-get-novel-thermalelectric-storage-retrofit/

[7] Colthorpe, A. (October 21 2021). "Hawaiian Electric wants all solar in next procurement round to be paired with battery storage," Energy Storage News, https://www.energy-storage.news/hawaiian-electric-wants-all-solar-in-next-procurement-round-to-be-paired-with-battery-storage/

2.4. Provide ancillary services

The term ancillary services covers a wide range of system services including frequency regulation, voltage control, and black-start capability. As power markets become increasingly sophisticated, processes and procurements are being created to enable different market actors (not just traditional incumbent utilities) to supply ancillary services and improve grid reliability. While ancillary services markets have long favored rapid-response generators such as single-cycle natural gas plants, a number of recent procurements in California and in Australia are starting to show that battery storage can be not only cost-competitive but can also provide some ancillary services even more effectively than gas or coal plants.

A recent expansion to the Hornsdale storage complex in Australia, specifically to provide greater inertial support in addition to its ongoing provision of frequency control.[8] Battery storage systems operating elsewhere in Australia, as well as in California, in New York, in Spain, and in Germany are providing a wide range of system services.

2.5. Defer transmission and/or distribution grid investments

Local increases in power demand can put significant strain and grid infrastructure and lead to a need for grid expansion or grid strengthening, both of which can be costly and time-consuming to implement. In response, some jurisdictions are starting to install battery storage at strategic locations within the grid, enabling utilities to better manage growing demand while deferring the need for significant grid investments.

When storage installations are located at, or near, substations, they can mitigate congestion in the transmission and distribution system. On the island of Nantucket (U.S.) rapid electricity demand growth has put significant strain on the island's transmission grid. Instead of investing over USD $100 million in upgrading the transmission system, the local utility chose to invest in a 6MW/48MWh battery energy storage system, saving a total of USD $5.7 million per year while also unlocking a range of ancillary services (USAID 2021).[9]

Table 4: Key Findings: Battery Storage
• Today, battery storage is being added to grids around the world in a growing range of stationary applications, some stand-alone, and others co-sited with renewable energy assets such as solar and wind projects. • Battery storage solutions can be paired with solar PV projects to provide **firm generation capacity** as well as a range of other services to the grid, including a wide range of ancillary services. • IRENA estimates that the market for stationary battery storage applications will **grow by more than 3x** by 2030 (IRENA 2017).

[8] Parkinson, G., (December 22 2020). « South Australia doubles size of reserve capacity deal with Hornsdale battery, » RenewEconomy, https://reneweconomy.com.au/south-australia-doubles-size-of-reserve-capacity-deal-with-hornsdale-battery-94726/

[9] USAID (2021). "Hybrid renewable and battery energy storage (BESS) auctions," https://pdf.usaid.gov/pdf_docs/PA00X4KB.pdf

Table 5: Select Battery Energy Storage Projects

Jurisdiction (Year of COD)	Project Details	Price ($/kWh)	Contract length	Further Reading
India "Round-the-clock" auction **(2021-22)**	400MW firm capacity, including solar, wind, and storage	USD $0.04/kWh	25 years	https://www.pv-magazine.com/2021/08/10/indian-developer-signs-ppa-for-400-mw-round-the-clock-energy-supply/
Australia **(2017; expanded in 2020)**	**Hornsdale Power Reserve:** 315MW of wind power with 130MW/129MWh of battery storage	USD $0.055 – 0.066/kWh	10 years	https://hornsdalepowerreserve.com.au/ https://reneweconomy.com.au/revealed-true-cost-of-tesla-big-battery-and-its-government-contract-66888/
Florida **(late 2021)**	**Manatee Energy Storage Center:** 409MW of solar PV + 900MWh of battery storage	N/A (utility-owned)	N/A (utility-owned)	https://energyindustryreview.com/renewables/manatee-energy-storage-center-worlds-largest-solar-powered-battery-75-complete/
Chile **(2021 – 2023)**	**Engie Chile**:1500MW of renewables with storage in time-differentiated blocks with solar+storage:	USD $0.024/kWh	40-year concession agreement	https://www.energy-storage.news/engie-chile-wins-1-5gw-of-hybrid-wind-solar-storage-development-rights/
Portugal **(2021-2022)**	483MW of solar PV + storage	USD $0.04/kWh	15 years	https://www.pv-magazine.com/2020/09/02/analysis-initial-results-of-portugals-solarstorage-auction/
Israel (2022)	168MW of solar PV + storage	USD $0.058/kWh	23 years	https://renewablesnow.com/news/israel-awards-168-mw-in-first-solar-storage-quota-tender-706570/

3.0. Auction design and necessary modifications for RE plus battery procurement

Auction design for renewable energy technologies has been discussed in detail by many policy reports in the past decade (for instance, see Maurer and Barroso 2011, GIZ 2015, Eberhard and Naude 2016, IRENA 2015). Malawi has already successfully procured solar PV and other renewable energy technologies via competitive procurement.

However, when procuring grid-based battery storage in combination with renewable energy technologies, some of the auction design elements need to be modified (see also Maurer et al. 2020). These modifications will be discussed in the section below. Even though additional research will be required for the detailed design of the procurement process and the auction documentation, this initial research is intended to help policymakers in Malawi to avoid potential pitfalls.

The following auction design elements typically need to be modified when developing auctions for renewable energy + battery storage:

- Level of expected competition (Section 3.1)
- The auctioned quantity (Section 3.2)
- The auction production (Section 3.3)
- The eligible technologies (Section 3.4)
- The location of the generation units (Section 3.5)
- The pre-qualification requirements (section 3.6)
- The award criteria (Section 3.7)
- The penalties and bid bonds (Section 3.8).

3.1. Auctions or direct negotiations: What level of competition can be expected?

First, policymakers in Malawi need to assess whether the level of competition in a planned “RE plus battery storage” auction will be sufficiently high. Auctions only work well under high levels of competition. In other words, there should be considerably more supply (in terms of projects and capacity/energy offered during each bidding round) than demand (e.g., the amount of capacity/energy requested by the Malawi regulator/utility).

An analysis of the market and a pilot auction (for a limited amount of energy/capacity) can help to determine the level of competition. If the level of competition is deemed to be insufficient, the government/regulator might also opt for direct negotiations with project developers offering solar PV plus battery storage. However, the sharply decreasing battery and solar PV costs will likely create severe information asymmetries, meaning that the project developer will likely have information about the actual technology costs that the regulator does not have. Therefore, bi-lateral negotiations should be avoided – if possible – especially in the case of rapidly evolving technologies like solar PV and batteries.

Generally speaking, the Malawi government can increase the level of competition in all clean energy auctions by various means. First, Malawi can increase participation in private sector RE project by de-risking investment (see also, Couture et al. 2018). Second, the number of interested (international) actors can be increased by assuring that a larger number of auctions rounds will be held over the coming five to ten years. A preview of several auction rounds will increase participation because loosing the first auction round will not lead to immediate "stranded investments" related to the bid preparation process. The already pre-developed project can be submitted again in future auction rounds. Third, the government can ensure that the barriers to participate in the auction are not too high (e.g. with high upfront bid bond requirements, or overly restrictive pre-qualification requirements).

Key Findings: Expected level of competition

- The level of competition for solar PV plus storage projects in Malawi should be analyzed at the start (via market research or a pilot auction).
- If the level of competition is deemed to be too low, bilateral negotiations may prove to be the only way forward. However, it should be clear that the information asymmetries between the private project developer and the regulator/ministry in Malawi might be severe, especially with costs for battery and solar PV plummeting in recent years.
- Auctions for solar PV+storage projects that have taken place in island regions around the world, as well as in other markets like Australia and the U.S. indicate a large and growing number of companies competing in this space. This suggests that provided the auction is well designed, and the barriers to participation are not too high, that sufficient competition can be secured.

3.2. Auctioned quantity: How much capacity/volume to auction?

The amount of auctioned capacity or energy needs to reflect the Malawi electricity system's requirement for battery storage but also the expected level of competition. When planning auctions, it is crucial to assure a high level of participation from bidders and potential power producers. Ideally, the auctioned capacity or amount of energy should be substantially oversubscribed, i.e., one should receive 2-3 times more bids than the energy or capacity being auctioned. For instance, in an auction for 50 MW of firm PV plus battery capacity, ideally the ministry or regulator in Malawi would receive bids for 150 or 200 MW of potential projects. This way, cost competition can be assured and Malawi can benefit by selecting the proposals that yield the highest score in terms of price and technical criteria.

If Malawi has made positive experiences with the level of competition for renewable energy auctions (solar PV), it is likely that the level for competition in solar+storage auctions will also be high. Nonetheless, the level of competition might be slightly lower in "RE plus battery storage" auctions since solar PV plus battery storage projects are not yet as standardized as "normal" renewable energy projects. Therefore, it is recommended to first auction a relatively small RE plus storage project in order to assess the level of competition and ensure a sufficiently high level of competition (see also Lackner et. al. 2019).

Key Findings: Auctioned quantity

- Since “RE plus storage” project and not yet as standardized as normal renewable energy projects, the number of potential participants in the auction and thus the level of competition might be lower.
- Therefore, Malawi should start by auctioning relatively small “RE+storage” projects (e.g. 20 MW firm capacity).

3.3. Auction product: What is auctioned?

An important question related to auction design is linked to the auctioned product. Typically, renewable energy auctions target a specific amount of installed capacity. For instance, an auction for solar PV can target 200 MW of installed capacity. In addition, renewable energy producers are typically remunerated for their actual power **output** but not for their availability.[10]

As such, most traditional renewable energy auctions do not incentivize (battery) storage, since the payments for delivered energy (on a per megawatt-hour basis) are usually not sufficient (or sufficiently differentiated via time-of-day factors) to incentivize battery storage. Moreover, the producer is not required to produce the electricity at a requested period of time. In line with the characteristics of so-called variable renewables, the electricity is typically produced when the weather conditions allow (e.g. solar radiation and ambient wind speeds).

In the case of battery or PV+battery procurement, the auctioned product as it needs to be defined by the Ministry or regulator in Malawi will be different. In order to incentivize battery storage, firm power provisions[11] or requests for power delivery during certain hours (e.g, peak load hours) typically need to be included in the bidding documents. These requirements reflect the demand (patterns) of the given electricity system.

The provision of firm power is important for small and isolated electricity systems as in Malawi, since other flexibility options (e.g. grid expansion, cross-country interconnections, etc.) are limited.

This type of procurement has also been termed as “**system friendly procurement**”, meaning that the RE plus battery units will be able to support the electricity system at time periods when the system is constrained or congested. In this way, the regulator shifts the responsibility of balancing variable renewable energy sources from the utility/grid operator onto the independent power producers. It should be noted that this will likely be beneficial for the utility, but might not be the most cost-effective way of managing the power system, since other flexibility options (e.g. using coal-, gas-, or hydro-based power plants for balancing variations

[10] Most renewable energy auctions around the world ask for kilowatt-hour prices from the participating bidders (how many €/kWh do you need to realize your wind project). Some countries use alternative auction products, namely a price for the installed capacity (€/kW).

[11] Firm power contracts require power producers to make guaranteed commitments to deliver an agreed amount of power at all times over a specific period (Maurer et al. 2020).

of renewables) will not be incentivized (for a discussion of various flexibility options, see IEA-RETD 2016).

Similarly, it is important to note that battery storage systems can provide a range of services beyond simply energy (see Section 2 above). Even though this has not yet been widely implemented yet, auctions can also be designed in a way that battery operators are also remunerated for the provision of additional services, such as black start capability, or frequency and voltage control. Currently, these services are either remunerated via market design (e.g., allowing storage to participate in ancillary services markets) or simply requested via technical regulation, e.g., grid codes. In principle, the contract documents signed with the winner of a given auction could include provisions and payment terms for the provision of certain services, particularly in electricity markets that retain a single buyer or a vertically integrated supplier.

In this section, we focus on the two most widely used options for system friendly procurement (USAID, 2020), namely:

1. **Time-slot based procurement** (e.g., for certain hours of peak demand daily or annually)
2. **Around-the-clock electricity delivery** (e.g., a certain percentage of full-load hours/capacity utilization factor)

In the case of time-slot based procurement, electricity needs to be provided during certain hours of the day (e.g., during peak demand periods).

Using storage capacity to meet peak demand: The case of Australia
In 2016, the Hornsdale Power Reserve was the largest Li-ion battery installation unit at time of construction. The 100 MW/129 MWh battery in Southern Australia provided frequency regulation and was primarily used to cover peak electricity demand, benefiting from high wholesale market prices during those hours (arbitrage business). 30% of the battery capacity was allocated for this type of business (IRENA 2020a).

In the case of “around the clock” electricity delivery, power needs to be provided during most hours of the year (e.g., 80% of the time, expressed as the annual capacity utilization factor, see case study India below). In Thailand, for instance, bidders were required to operate power plants at 98% or more of their proposed capacity during peak periods and 66.3 percent during off-peak periods (Maurer et al. 2020).

Around-the-clock “renewable” auctions: The case of India
India started a new set of auctions in 2020, targeting a combination of renewable energy technologies plus battery storage. Instead of procuring only a certain amount of capacity, the auction documentation made specific requirements for the power output. A capacity utilization factor of 80% was required,

meaning that the power plant (including storage) would need to provide power 7,008 hours of the year (of the total of 8,760 hours). In other words, the regulator did not determine the size ratios between the renewable installations and battery storage directly, but rather left this choice and optimization to the project developer.

The capacity utilization factor of 80%, as determined in the auction documentation, has to be met on a monthly and annual level. This means, that there is still room for daily variations in output (e.g., when a power plant or battery needs repair).

In the case that capacity utilization factor is lower in a given time period, penalties need to be paid. In the case that the target power supply is exceeded (more than 120% of the committed energy), the excess electricity can be sold to the grid at the standard PPA tariff (USAID 2019).

The first auction of this type was considered to be successful as it was able to deliver "firm" electricity at cost below the average offtake price (USD 47.65/MWh as a levelized tariff over the 25-year period) The winning projects consisted of a combination of solar PV, plus wind energy, plus electricity storage units that were also located at different sites (Bloomberg 2021).

Key Findings: Auctioned product

- Instead of prescribing in detail the amount of battery capacity auctioned, Malawi can include a requirement for the capacity utilization factor (e.g., 80% or 85% CUF). Alternatively, electricity provision during peak demand periods can be prescribed (so-called time-slot based procurement).
- Also, auctions can theoretically be designed to procure more than simply energy: payment terms for a range of other services such as black start capability and frequency control could be included within the tender documents and the final contracts signed.
- This way, the private project developer will figure out the best way of how to meet these requirements in a cost-optimal way, by combining solar PV with battery storage and potentially other renewable energy power generation technologies.
- When adopting this approach, penalties for not complying with these requirements will also need to be determined.

3.4. Eligible technologies: Which technologies can participate and in which combination?

When designing clean energy auctions, it is important to determine which technologies are allowed to participate. Previously, renewable energy auctions were frequently technology-specific, i.e. the regulator/utility requested bids for solar PV projects in one specific auction round and bids for wind energy in a different auction round.

However, technology neutral auctions have become increasingly common. This way, different renewable energy technologies are competing against each other and the cheapest technology or the technology that can offer certain requirements (e.g., in terms of providing electricity around peak load hours, or “around-the-clock”) will win.

Although adding battery storage increases the overall levelized costs of a particular project, bidders can be encouraged to add battery storage to their projects by including specific technical or performance-related requirements within the auction round. For instance, instead of prescribing in detail which technologies are allowed to participate in the auction and which combination technologies are eligible, the utility or regulator can simply prescribe certain requirements (in terms of availability of electricity supply during certain hours of the day or set out a requirement for “around-the-clock” electricity supply, as in the case of India). In this case, the project developer needs to figure out the best combination of technologies and the best combination of power generation and electricity storage to meet that requirement (for an example from the U.S. state of Colorado, see Xcel Energy 2017).

Even though this report primarily discusses the procurement of battery storage in combination with renewable energy sources, Malawi could decide to procure battery storage individually. There are certain advantages of individual procurement of battery storage. First, the storage units can be located at the grid nodes where storage units are most useful from a system perspective (e.g., close to load centers where auxiliary services of battery units are most useful) (Bowen et al. 2019). This can also be achieved by allowing private investors more flexibility regarding the location (see section 3.5). Second, the amount of battery storage can be better planned as part of integrated resource planning.

Key Findings: Technology neutral auctions with specific requirements in terms of electricity supply

- Many auctions that procure battery storage are technology neutral, meaning that the specific technology mix of generation unit and storage capacity is not prescribed.
- Instead of prescribing a detailed mix of power generation technologies and storage capacity, policymakers can determine specific requirements on power supply and let the project developer chose of how to fulfil those requirements.
- Alternatively, individual procurement battery storage can be pursued to determine the optimal location of the storage unit within the electricity grid.

3.5. Location of generation units: Allowing for multiple sites?

In standard renewable energy auctions, the bidder needs to indicate to concrete location of the planned renewable energy projects. When targeting a combination of renewable energy technologies plus storage, it might be useful to ease the requirements regarding the selected sites. Allowing project developers to select multiple sites for their “combined” power plants (RE+storage) might be beneficial from a cost perspective and an electricity system perspective.

Since good wind resources and solar PV resources might not be available in the same location, combining RE installations from various sites might lead to lower costs. Since placing battery storage at a certain "node" within the electricity grid can be beneficial for grid stability, this type of flexibility can further increase the "system friendliness" of the asset.

Key Findings: Allowing for multiple sites

- The auction documentation should allow for a certain degree of flexibility regarding the location of the renewable energy units and the battery units.
- Allowing for multiple sites for the RE units and the storage unit can be beneficial, since solar PV and other renewable energy resource might not be available

3.6. Material and financial pre-qualifications: Who can participate in the auction rounds?

One of the primary ways to assure that proposed projects in bids will eventually be realized is to have substantial pre-qualification requirements. Only bidders that meet these pre-defined requirements can participate in the auction process.

Two forms of pre-qualification requirements have been used for renewable energy auctions in the past. These can also be implemented for RE plus battery storage auctions.

1) Financial pre-qualification requirements:

This typically takes the form of a bid deposit or bid security that has to be submitted to the auction agency and is returned upon successful completion of the project, or if the bidder is not selected (see "Penalties and bid bond" in the section below); this security is often set at 5%-10% of the project's investment cost, or of the project's expected lifetime revenue (Kreiss et al. 2017). The bid security is usually defined as a certain value per capacity bid (e.g. 50€ per kW).

When assessing the financial strength of participants, bidders sometimes also need to show that they have already realized several similar projects elsewhere in the world, or even within the same region (e.g., 10 solar PV projects in Southern Africa). However, these types of requirements should be scaled down for RE plus storage auctions, since such projects are currently not very widespread on the African continent. These types of requirements could significantly reduce the number of participating bidders and thus hinder competitive price-finding (see section 3.1.)

2) Material pre-qualification requirements:

This often takes the form of secured land, construction plans, obtainment of construction permits, successful environmental impact assessment, secured grid access, etc.

The table below provides an overview of the different requirements:

Table 6: Overview of pre-qualification requirements

Financial Prequalification Requirements	Material Prequalification Requirements
Bid deposit	Technical and commercial viability
Financial strength, previous project realizations	Grid access and connection
Demonstrated access to finance (bank letters)	Permits and securing land-use rights

Source: authors' own depiction

It should be noted that the level of pre-qualifications impacts both the realization rate (how many of the winning project will actually be realized?) and the level of participation in the bidding round (how many project developers will submit a bid?). Therefore, the pre-qualification should not be excessively high because otherwise this will reduce the level of competition and in so doing potentially jeopardize the success of the auction.

Key Findings: Pre-qualifications

- The material and financial pre-qualifications used for renewable energy auctions can also apply for RE plus battery storage procurement.
- However, given the desire to encourage wide participation in the auction and strong competition, both the financial and technical pre-qualification requirements should be adjusted to ensure they are not too onerous.

3.7. Award criteria: Based on which parameters will winners be selected?

Most renewable energy auctions select the winner exclusively based on the price offered. In these price-only auctions, the bidders with the lowest bids are selected. As shown in Figure 6 below, all participating project that fulfill the pre-qualifications are ordered according to their price offered. In a second step, all projects that are required to meet the initially targeted installed capacity are selected as winners of the auction.

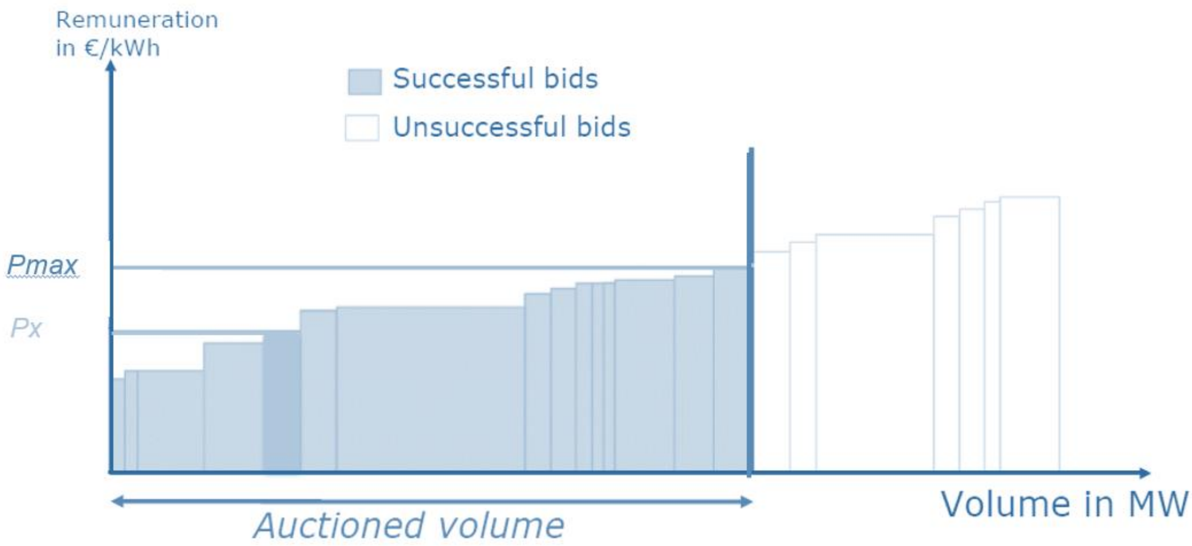

Figure 6: Selection of winning bids based on price-only

Source: IET

However, in RE plus storage auctions, frequently the award criteria for selecting the winning bid are more complex. The list below includes the most frequent options.

Table 7: Award criteria for RE plus storage auctions

Lowest electricity price per kilowatt-hour	Australia
Lowest firm power prices (around-the clock)	Brazil/Thailand
Lowest firm power price (per time block)	Chile (Time Variant)
Lowest capacity payment (Euros/MW/year)	Portugal

Source: Author based on Maurer et al. 2020

Depending on the auction *product* (see, Section 3.3, What is auctioned?), for Malawi an evaluation based on the “lowest firm power prices around-the clock” or the “lowest firm power prices per time block” are likely the most attractive options. In other words, the project developer bids on the basis of the total levelized costs they will incur for operating the renewable energy plant and the storage unit to provide the requested service, and offering an aggregated price per kilowatt-hour for the mixed services.

Key Findings: Award criteria

- The award criteria for RE+storage are more complex than in the case of normal RE auctions.

- Depending on the auction product, Malawi could opt for “lowest firm power prices around-the clock” or the “lowest firm power prices per time block”, thus shifting the responsibility of optimizing the combination of RE and battery storage onto the project developer.

3.8. Penalties and bid bonds: How to assure that project will be built, and power will be delivered on time?

Bid bonds constitute a particularly relevant tool to assure that only serious bidders will participate in the auction and that projects will eventually be completed. Bid bonds can be thought of as an upfront deposit that is required prior to the bidding stage to assure and confirm a developers’ means to actually go through with the project should it be awarded.

Usually, the bid bond represents either a percentage of the price of the contract or is determined as a payment per unit of installed capacity (e.g., 50 USD/kW). It is usually refunded when a developer does not receive the contract, or once the contracts are signed. Some countries have also implemented construction bonds that are only refunded the project construction has been finalized.

As such, bid bonds exist to demonstrate commitment on the part of project developers. Bid bonds also provide additional security to the off-taker (and the system planner) as there is a higher likelihood that the project will be realized and power will be delivered on schedule. However, policymakers need to keep in mind that despite penalties and bid bonds, it is always possible that not all projects will be realized on schedule, and that some shortfalls can result. Assuming an 80% realization rate, policymakers need to auction 100 MW of capacity in order to get 80 MW build. However, auctions in many jurisdictions recently have achieved even lower realization rates, and given the additional complexity of RE+storage projects, policymakers should plan on the basis of a lower realization rate (e.g. 60-70%).

Several key dimensions need to be acknowledged at the time of defining bid bonds requirements as a means to support renewable energy tenders. First, the amount deposited by bidders is crucial in order to achieve to the desired result: if the bid bond is too high, the risk premiums rise and may push away potential participants. Second, bid bonds act not only as a proof of financial health, but they also define the penalties that a project developer stands to face if a project is not fulfilled within the agreed timeframe.

Bid bonds for solar PV plus battery storage project are typically higher than those of “normal” renewable energy projects. This is due to the higher total investment costs. The example of Germany shows that in the case of solar PV plus battery auctions (60€ per kW) are twice as high as the bid bonds required for wind energy projects (30€ per kW) (see Table 8). Since battery storage is frequently procured via technology-neutral auctions (see Section 3.4), bid bonds need to be defined for various technologies.

Table 8: Bid Bonds and similar Penalties for Wind Energy and solar PV plus storage projects in selected Countries

	Brazil (wind)	**Germany (hybrid battery PV auction 2021)**	**Germany (EEG 2017, wind)**	**Italy (lowest bid auction)**
Bid bonds as part of pre-qualification requirements?	Yes First: 1% of project costs Second: 5%	Yes Between €60 per kW)	Yes 30€/kW	Yes 5% of estimate investment costs upon application

Source: IET based on (EWEA 2015; Wigand, et al. 2016, Energate 2021)

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