

# Deploying Storage for Power Systems in Developing Countries

## Policy and Regulatory Considerations



**An Energy Storage Partnership Report**

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This report of the Energy Storage Partnership is prepared by the Energy Sector Management Assistance Program (ESMAP) with contributions from the International Energy Agency, the International Council on Large Electric Systems, the China Energy Storage Alliance, the European Association for Storage of Energy, the United States National Renewable Energy Laboratory, and the South Africa Energy Storage Association. The Energy Storage Program is a global partnership convened by the World Bank Group through ESMAP to foster international cooperation to develop sustainable energy storage solutions for developing countries. For more information visit: <https://www.esmap.org/energystorage>

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# ABBREVIATIONS

<b>BESS</b>	battery energy storage system
<b>CAPEX</b>	capital expenditure
<b>CAR</b>	Central African Republic
<b>CCGT</b>	combined cycle gas turbine plant
<b>CEM</b>	capacity expansion model
<b>CSIRO</b>	Commonwealth Scientific and Industrial Research Organisation
<b>CSP</b>	concentrating solar power
<b>DER</b>	distributed energy resource
<b>DSO</b>	Distribution System Operator
<b>DSR</b>	demand side response
<b>ESS</b>	energy storage system
<b>EU</b>	European Union
<b>HFO</b>	heavy fuel oil
<b>IFC</b>	International Finance Corporation
<b>IPP</b>	independent power producer
<b>kWh</b>	kilowatt hour
<b>LCOS</b>	levelized cost of storage
<b>Li-ion</b>	lithium-ion (battery)
<b>MW</b>	megawatt
<b>MWh</b>	megawatt hour
<b>MWp</b>	megawatt peak
<b>NPV</b>	net present value
<b>NRA</b>	National Regulatory Authority
<b>OPEX</b>	operating expenditure
<b>PCM</b>	production cost model
<b>PHS</b>	pumped hydro storage
<b>PPA</b>	power purchase agreement
<b>PV</b>	solar photovoltaic
<b>REC</b>	Renewable Energy Certificate
<b>T&amp;D</b>	transmission and distribution
<b>TSO</b>	transmission system operator
<b>UPS</b>	uninterruptible power supply
<b>VRE</b>	variable renewable energy

All currency is United States dollar (US\$ or USD), unless otherwise noted.

# EXECUTIVE SUMMARY

- **Energy storage deployment is increasing rapidly and this trend is bound to continue:** While storage is not new in power systems – pumped hydro storage and thermal energy storage were deployed globally decades ago – battery storage use in power systems is accelerating rapidly against the backdrop of significant cost reductions (85% over the period from 2010 to 2018). This trend marks the beginning of a new phase in storage deployment, where especially battery storage is seeing widespread use.
- **Energy storage can make a substantial contribution towards cleaner and more resilient power systems:** Storage can support the grid integration of variable renewable energy (VRE), namely, wind and solar photovoltaics. This can help to maximize the use of low-cost VRE while meeting climate and other environmental goals. Storage technologies can be deployed modularly. This can help catalyze the use of distributed energy resources (DER) and increase the resilience of power systems.
- **Energy storage is particularly well suited to developing countries' power system needs:** Developing countries frequently feature weak grids. These are characterized by poor security of supply, driven by a combination of insufficient, unreliable and inflexible generation capacity, underdeveloped or nonexistent grid infrastructure, a lack of adequate monitoring and control equipment, and a lack of skilled human resources and adequate maintenance. In this context, energy storage can help enhance reliability. Deployed together with VRE, it can help displace costly and polluting generation based on liquid fuels while increasing security of supply. Storage can also help defer and/or avoid the construction of new grid infrastructure.
- **Establishing enabling frameworks for storage requires an understanding of the costs and system benefits of energy storage:** Storage can meet a wide range of system needs, so called use cases. As detailed in this report, computer-based modelling tools allow the identification of use cases with higher benefits than costs (i.e., those with a high system value). Policy, market, and regulatory frameworks then need to ensure that those use cases are also attractive from a business perspective.
- **Energy storage is usually not the only option to meet a certain power system need:** The option to invest in energy storage should always be considered alongside alternatives. These include generation capacity, enabling a more flexible demand side, and building grid infrastructure. Energy storage can involve a diverse suite of technologies (such as thermal, pumped storage hydro, or batteries). Identifying the most suitable storage technology, thus, is only possible on the basis of a concrete use case.
- **Policy, market, and regulatory frameworks often lack specific provisions for storage:** Depending on how it is used, storage can act as a generator, a flexible load, and/or substitute grid infrastructure (by improving the utilization of existing networks). This versatility challenges existing legal setups, often leading to incomplete and inconsistent frameworks that can hamper deployment.
- **Policymakers and regulators need to establish robust remuneration mechanisms for energy storage that accurately reflect its value to the system:** Where new investments in storage are targeted, sufficient long-term revenue certainty is crucial. There are three basic patterns according to which storage can be remunerated. For developing countries, the non-market and single-buyer market models are particularly relevant:

- **Non-market:** Under this model, a regulated monopoly receives regulatory approval to recover the cost of a flexibility asset from its customers. A prime example of such an arrangement is a transmission system operator allowed to invest in the electricity network collecting a guaranteed return from all grid users.
- **Single-buyer market:** Under this model, multiple suppliers compete, but there is only one buyer. For flexibility, a common example is a system operator that procures frequency control services competitively from private companies via an auction.
- **Multiple buyers and sellers, full market:** Under this model, there is competition on both sides of the market. The most relevant use of this model are wholesale markets where there are liberalized customers/retail competition.

In each power system, a combination of these remuneration models is generally present. For example, even in power systems with a full wholesale market for energy, system operators procure system services on markets where they act as the single buyer. Hence, storage can be remunerated under different models within the same power system, depending on what type of service it provides.

- **Removing non-economic barriers to storage deployment must also be a priority for policymakers and regulators:** Establishing and enabling environment critically depends on the following factors:
  - **Definitions and standards:** As a resource type in its own right, energy storage must be considered as its own legal and regulatory category and legal definitions should not arbitrarily place storage into existing categories such as generators.
  - **Permitting, commissioning, and grid codes:** As a new type of power system asset, electricity storage may not yet be subject to established rules for permitting and existing technical codes may be poorly adapted for energy storage. Under such circumstances it is important that permitting agencies and system operators do not impose excessive requirements on developers.
  - **Taxes, surcharges, and levies:** Storage can both consume electricity and function as a generator. This can lead to a problematic situation where storage assets are either obliged to pay taxes, levies, and surcharges twice or where storage has a positive business case for its owner but creates negative externalities for other customers. Policymakers and regulators thus need to review frameworks with a view to establish a level playing field for energy storage projects that reflects the value of storage from a system perspective.
- **Policymakers and regulators should adopt a proactive approach to stakeholder management:** The widespread use of energy storage technologies involves substantial change for power systems. Using them to their full potential can challenge existing regulatory setups and institutional arrangements, and could lead to negative consequences for some stakeholders. In order to maximize benefits, ensure swift progress and a broad consensus, early and comprehensive stakeholder engagement is crucial.
- **This report provides guidance:** on how to determine the value of storage solutions from a system perspective as well as policy, market, and regulatory considerations to facilitate storage deployment, particularly in countries that currently do not have regulatory frameworks unlocking the potential benefits of energy storage. It seeks to highlight relevant issues, provide guidance to policymakers and regulators in this relatively new area, and identify additional analytical requirements.
- **Future work:** Energy storage is a rapidly evolving field in which batteries play a dynamic role. Many power systems are currently experiencing the first wave of storage projects and further work in this area is needed. Such work could include:
  - **Identification of regulatory frameworks and procurement instruments tailored to standard use cases in weak grid contexts:** Examples include hybrid VRE plus storage projects with guidelines on how to compare and fairly remunerate projects with different shares of storage.

- **Cataloguing non-economic barriers and solution strategies:** As deployment of battery storage becomes more widespread, a more complete picture on the various non-economic barriers can be obtained via surveys with project developers and other relevant stakeholders. This includes regulatory considerations, safety standards (including for manufacturing, installation, and operation), and the granting of permits. Such surveys accelerate learning across countries and catalyze uptake of best-practice solutions.
- **Financing instruments for battery storage:** Battery storage requires low-cost financing to deliver electricity services at least cost. Sharing best practices for financing in developing countries, including conditions and justifications for accessing concessional finance, is key to fast track uptake and reduce costs. Warranties must take into account the operational and environmental conditions of developing countries, as well as promising new battery technologies with a limited track record.

# 1 CURRENT CONTEXT IN POWER SYSTEMS

**T**his report provides a brief overview of the role of energy storage against the background of current trends in power systems with a particular emphasis on developing countries. It introduces the different ways in which storage can help meet policy objectives and overcome technical challenges in the power sector, it provides guidance on how to determine the value of storage solutions from a system perspective, and discusses relevant aspects of policy, market, and regulatory frameworks to facilitate storage deployment. The document is intended to highlight relevant issues, provide guidance to policymakers, and regulators in this relatively new area and identify additional analytical requirements.

This report was created by the Energy Storage Partnership (ESP). The ESP aims to accelerate the availability and deployment of innovative storage solutions tailored to the needs of power grids in developing countries. As a long-term outcome, the ESP targets substantial CO<sub>2</sub> emissions reductions by enabling an accelerated uptake of variable renewable energy (VRE), while simultaneously increasing energy access and resilience for all. The document was prepared by the World Bank's Energy Sector Management Assistance Program (ESMAP) with contributions from the International Energy Agency (IEA), the International Council on Large Electric Systems (CIGRE), the China Energy Storage Alliance (CNESA), the European Association for Storage of Energy (EASE), the United States National Renewable Energy Laboratory (NREL), and the South Africa Energy Storage Association (SAESA).

## MAIN TRENDS IN POWER SYSTEMS

Globally, power systems are undergoing a period of unprecedented change. Key drivers include: the rise of low-cost renewable electricity, a growing need to increase power system resilience, and enhanced digitalization of the power system, including small-scale resources. Mitigation and adaptation to climate change is increasing the relevance and speed of these drivers.

Arguably, one of the most significant drivers of this change is the recent availability of low-cost renewable electricity, in particular wind and solar power (IEA, 2019a/b). Over the past two decades these technologies have seen dramatic cost reductions and, today, they are the cheapest source of new electricity generation in the majority of countries around the world (IEA, 2019b). These developments bring a number of opportunities for achieving energy policy objectives across a wide range of country contexts. Notably, they hold the promise of largely overcoming the classical energy trilemma that policymakers still face: the trade-off between affordability, environmental sustainability, and security of supply.

At the time of writing in mid-2020, the COVID-19 (coronavirus) pandemic has caused fossil fuel prices to decline steeply. In April 2020, the price of WTI crude oil (West Texas Intermediate, a key benchmark) fell into negative territory, albeit briefly, for the first time in history (meaning a quantifiable absence of demand such that a buyer is in effect paid to remove and store the commodity; FT, 2020). It is currently unclear how long such very low prices will persist. A continued very low price level for oil and other fossil fuels could undercut the recently achieved competitiveness of renewable energy solutions. However, historically, low oil price periods have only been temporary. Indeed, once the pandemic and its economic impacts are overcome, prices are likely to rebound to pre-crisis levels or above. It is highly likely that this rebound will occur on a timescale that is short compared to the asset lifetime of energy infrastructure. Hence, the current price environment does not fundamentally challenge the economic case for renewable energy in the medium to long term. Indeed, there is an expectation that post-crisis government stimulus packages will emphasize

low-carbon solutions and mechanisms to support developing countries: deployment of renewable energy in developing countries would be an ideal combination to achieve both, while also reducing reliance on potentially vulnerable external supply chains.

But even now that renewable energy is cost effective and has a comparably low environmental footprint compared to fossil alternatives, concurrently achieving energy security and grid stability requires a concerted effort. Wind and solar power are variable renewable energy (VRE) sources; their maximum possible output fluctuates with varying availability of their primary resources—wind and sunlight. In addition, they use a different type of technology (power electronics) to connect to the grid compared to traditional large-scale generators, which use synchronous generators that are electro-mechanically coupled to the grid. VRE are referred to as non-synchronous sources of electricity for this reason. Growing shares of VRE thus lead to a sequence of new challenges of the system, which can be addressed by an appropriate mix of technical measures; innovations in policy, market, and regulatory frameworks; and often changes to the institutional setup of the power sector (Figure 1.1, see Chapter 2 for a detailed description of the different phases).

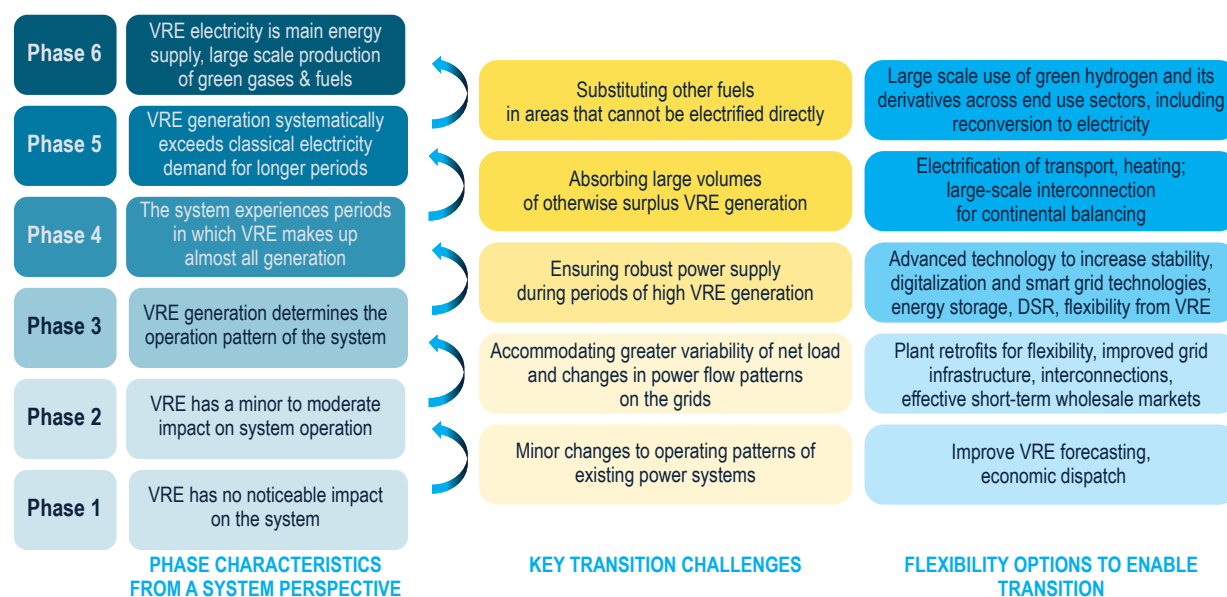
The main goal of these measures is to increase the flexibility of the power system, namely, the ability

of the system to reliably and cost-effectively manage increased uncertainty and variability in the demand and supply balance of electricity, including at high shares of non-synchronous generation (IEA, 2018a). Energy storage is one of four basic options to provide such flexibility; the other three are flexible generation, demand-side response (DSR) / load shaping, and transmission and distribution grids (including interconnection to other power systems) (IEA, 2014b, Cochran et al, 2014).

Flexibility is relevant across a very wide range of timescales (Table 1.1) and also has an important geographic component. For example, wind and solar resources can be far away from load centres and thus require additional transmission lines to match supply and demand. Additionally, VRE power plants are often smaller than traditional generators, requiring new approaches for the design and management of distribution grids. If implemented properly, such strategies can safeguard and, in many cases, even enhance energy security and system resilience at growing shares of VRE.

Indeed, increasing power system resilience is another important driver for changes in power systems. Reliable electricity supply is of vital importance for the functioning of societies and its importance is growing rapidly as digital solutions prevail in a growing number of sectors of the economy. In addition, accelerating

**FIGURE 1.1:** Summary of Main Challenges and Solutions at Different Phases of VRE Integration



**Key point:** System integration challenges and solutions can be grouped into different phases.

Source: Authors adaptation of the IEA's VRE integration framework.

**TABLE 1.1: The Timescales of Issues Addressed by Power System Flexibility**

	Short-Term Flexibility			Medium-Term Flexibility	Long-Term Flexibility	
Timescale	Sub-seconds to seconds	Seconds to minutes	Minutes to hours	Hours to days	Days to months	Months to years
Issue	Address system stability, such as withstanding large disturbance (e.g., losing a large power plant or other technical issues)	Address fluctuations in the balance of demand and supply, such as fluctuations in power demand	Manage ramps in the balance of supply and demand (e.g., increasing electricity demand following sunrise or rising net load at sunset)	Decide how many thermal plants should remain connected to and running on the system	Manage scheduled maintenance of power plants and larger periods of surplus or deficit of energy, (e.g., hydropower availability during wet/dry season)	Balance seasonal and inter-annual availability of variable generation (often influenced by weather) and electricity demand

Source: Authors.

climate change is leading to an increased frequency and severity of extreme weather events, including heat waves, droughts, severe storms, and related impacts such as large-scale wildfires (IPCC, 2018). In turn, the growing impacts of such events are giving further impetus to decarbonization of the power sector, the largest contributor to energy sector carbon dioxide emissions (IEA, 2019c). Energy storage can play a critical role in this domain because it can enhance resilience by providing backup power and enable the capability for local grids to maintain operations even when the main transmission system is experiencing a supply-disruption. The modularity of VRE and energy storage systems (ESS) also allow for a more distributed—and hence resilient—system design that is not dependent on fuel supply chains (NYPA, 2017).

Another trend that is linked to all of the aforementioned developments is the increased digitalization of the power system combined with the rise of distributed energy resources (DER). While digital monitoring and controls have been used routinely for the operation of the transmission system for decades, they are now increasingly being adopted on the distribution level all the way to individual electric loads (IEA, 2017a). While this opens up new opportunities to unlock power system flexibility on the demand side, it can also expose power systems to new threats, notably cyber-attacks (IEA, 2017a).

Taken together, these trends have profound implications, especially for developing countries that are currently expanding their power supply infrastructure with a view to providing energy access for their citizens. Low-cost VRE holds the promise of providing clean energy affordably, but it requires additional strategies and

technical solutions to concurrently increase the flexibility of the power system. In turn, this can also enhance the resilience of the power system, thus, boosting energy security. Finally, digitalization and the rise of DERs are important drivers for unlocking system flexibility. In conclusion, flexible resources have become a priority for the power system and, together with other flexibility options, storage has a crucial role to play here.

## POWER SYSTEM CONTEXTS: FOCUS ON WEAK GRIDS

The role of storage is likely to be magnified in the developing country context. Countries that have pioneered effective and efficient VRE integration strategies are mostly economically developed. They feature sufficient dispatchable generation capacity and operational reserves; robust and stable grids; and, in most cases, good interconnections and energy trade agreements with neighboring countries. In these contexts, cost-effective VRE integration strategies focus on the improved use of existing assets (including existing storage assets) combined with enhanced system operations (ESP, 2019).

However, most developing countries are in a very different position; they have what can be referred to as weak grids. Weak grids suffer from poor security of supply, characterized by a combination of insufficient, unreliable, and inflexible generation capacity, underdeveloped or nonexistent grid infrastructure (both within and between countries), a lack of adequate monitoring and control equipment, and a lack of skilled human resources and adequate maintenance.<sup>1</sup>

As a result, weak grids are often unable to maintain the required balance between electricity supply and consumption, leading not only to routine application of load shedding (rolling blackouts), but not infrequently to complete collapse of the grid (system black events). Moreover, frequency and voltage show strong deviations from nominal values, leading to poor power quality, which can damage the end user's equipment and inflict significant losses on the overall economy.

Weak grids typically feature outdated, inefficient, highly polluting, and costly power generation. Diesel and heavy fuel oil (HFO) generators are a case in point. Furthermore, such plants are not centrally or automatically dispatched and are frequently subject to inflexible commercial agreements. Moreover, as a result of insufficient grid infrastructure, technical losses are very high, with significant non-technical losses consequent upon poor sector governance.

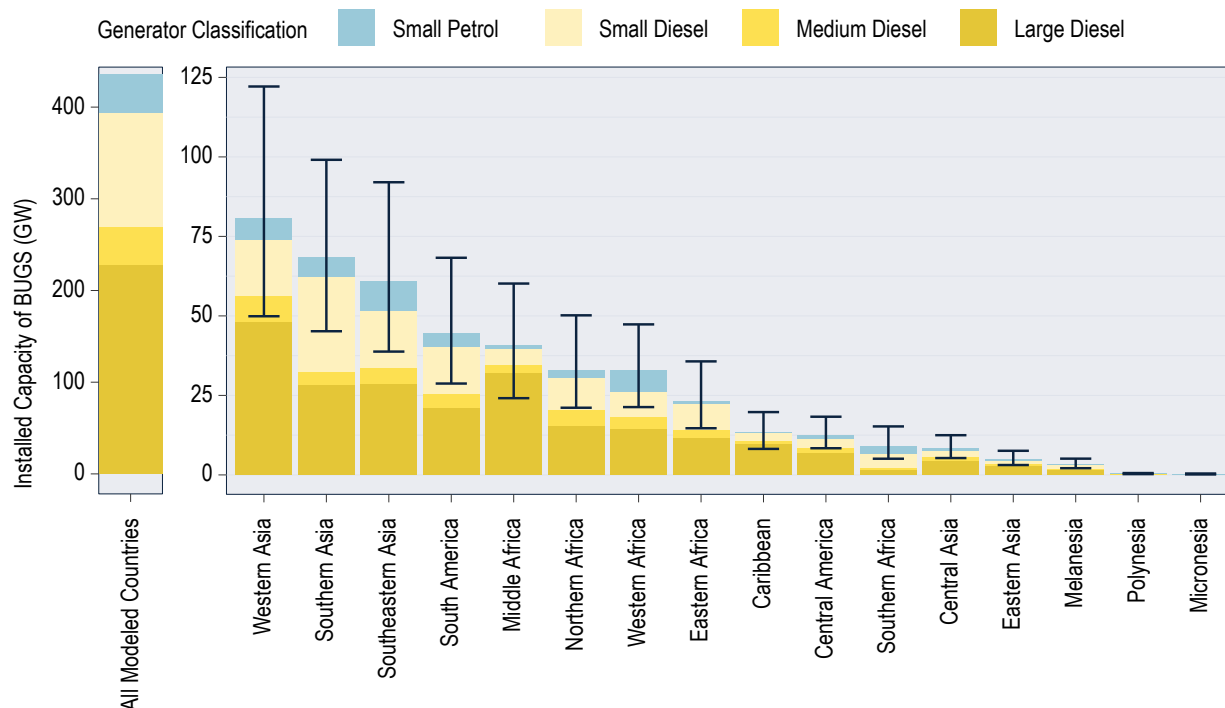
The end result is an expensive power system with low levels of reliability and flexibility. The scale of this issue is significant. A recent study by the International Finance Corporation (IFC) estimated that 350–500 GW of individually owned and operated generation capacity

supplements unreliable grid supply in developing countries (excluding China), while 75% of this capacity has some form of grid connection (Figure 1.2, IFC, 2019).

In terms of VRE integration, weak grids offer not only considerable opportunities but also challenges. On the upside, the total cost of new VRE power plants can easily undercut the fuel costs of incumbent generation assets. For example, the fuel cost of a diesel generator in a remote location with poor infrastructure access is frequently in the order of US\$250/MWh and can exceed US\$400/MWh in some cases. This compares to costs of solar PV in the order of US\$40-100/MWh at current (2020) cost levels and typical financing conditions.

However, VRE generators are not a simple, self-contained solution to the problems of weak grids. Firstly, they may not be reliably available at times of high or peak electricity demand, (i.e., they may only have a limited firm capacity contribution). Without additional measures, demand cannot be met at all times. Secondly, in terms of electrical engineering, their use can have a profound impact on weak grids, which are typically small compared to the large, interconnected networks of developed countries with dozens of

**FIGURE 1.2:** Estimated Installed Capacity of Backup Fossil Fuelled Generator, 2016



**Key point:** Global backup fossil fuelled generator capacity is estimated between 350 and 500 GW.

Note: Middle Africa includes Angola with significant diesel-based power generation.

Source: IFC, 2019.

gigawatts of average demand. In such smaller systems, a single, large VRE power plant can already have a substantial systemic impact. Short-term fluctuations in VRE output can directly translate into significant voltage and frequency deviations in this context (Box 1.1). Moreover, systems may transition directly to integration phase four (Figure 1.1) with the connection of the first large VRE plant. In turn, this can necessitate advanced solutions for maintaining grid stability, including more technical issues such as guaranteeing sufficient short-circuit ratios (SCR).

In the worst case, these issues can stifle the contribution VRE would otherwise represent in developing countries. Indeed, VRE power plants have faced curtailment as a result of insufficient system flexibility, particularly in weak grids.

Senegal, for example, shows a high reliance on HFO and diesel, supplemented by new coal. By 2030, the power system is expected to have a minimum of 30% renewables by installed capacity, (including solar, wind, and hydro). Recent stability studies on renewable energy integration concluded that in Senegal, owing to low spinning reserve and inadequate frequency regulation capacity, significant curtailment of renewable energy would be necessary to maintain grid stability.

This issue has direct relevance for consumers: power purchase agreements (PPAs) are typically “take or pay”, in which customers need to compensate VRE generators for the curtailed electricity. To reduce renewable energy curtailment, improve grid stability and facilitate a smooth integration of a large share of renewable energy generation in the grid, crucial short-term investments in the grid are urgently needed. These critical investments include a mix of energy storage solutions, grid/dispatching upgrades, and flexible generation.

These considerations serve to explain why for weak grids energy storage—in particular battery electricity storage—comes into play earlier and more urgently than for grids in developed countries. In Andhra Pradesh, India, for example, the World Bank financed a hybrid 160 MW Solar PV-Wind Power Plant with battery energy storage system (BESS). Although India has a steadily improving grid, it still faces challenges with maintaining frequency and voltage, and supply disruptions are frequent. The project combines co-located 120 MW solar PV, 40 MW wind power, 10 MW / 20 MWh of BESS, associated infrastructure, and control and energy management systems. As a first-of-its-kind at this scale for a developing country, the project is intended to demonstrate use cases

### Box 1.1

#### Solar PV and Batteries Providing Energy Access in the Central African Republic

The Central African Republic (CAR) benefits from abundant solar resources, with an annual overall solar radiation of approximately 5 kilowatt hour (kWh) per square meter per day on average, which corresponds approximately to a mean sunshine duration of 2,600 hours per year (7.1 hours per day). Because of the country's persistent electricity supply deficit, it is expected that any additional power production will be consumed. Despite this, solar power does not yet feature in the country's energy mix.

The CAR Emergency Electricity Supply and Access Project is expected to catalyze the development of solar photovoltaic (PV) by: preparing a site suitable for large-scale PV development; financing the phased installation of solar PV capacity, starting with a 25 megawatt peak (MW<sub>p</sub>) PV plant with a 25 megawatt hour (MWh) battery electricity storage system; and laying the foundation for future capacity expansion up to 40 MW<sub>p</sub>. The use of battery storage will enable the harnessing of energy produced with PV, despite fluctuations during the rainy season, and will dispatch it seamlessly to the grid, allowing it to meet evening demand peaks. This solution is the cheapest way to tackle the supply deficit swiftly and effectively.

Source: Authors.

which benefit the system and the generator: avoiding curtailment, minimizing deviation penalties due to forecasting/scheduling errors, and piloting ramp rate control benefits (World Bank, 2019).

As detailed in the next chapter, VRE, combined with battery storage, can be an effective package to meet the needs of weak grids. Thanks to falling equipment costs, this package is also becoming increasingly affordable (Gorman et al., 2020; Greentechmedia, 2020). In addition, battery storage has a number of relevant applications in power systems independent of combining them with VRE (or not) related to issues arising from deploying VRE in the power system. For example,

stationary batteries can help to avoid or defer grid investments or provide frequency management services. This is also discussed in the next chapter in the context of the different use cases.

## NOTE

1. Power system engineers use the term weak grids also in a more technically defined and narrow sense. In this context the term refers to a region of the electricity grid where the short circuit ratio is below 1 (Ghazavi et al., 2018). This report uses the term weak grid in a broader sense, going beyond this technical definition.

## 2 ENERGY STORAGE AND ITS ROLE AS A FLEXIBLE RESOURCE

### DIFFERENT ENERGY STORAGE TECHNOLOGIES

**E**nergy storage comprises a diverse range of technologies, which use different fundamental principles to store energy and are best suited for very different tasks in the power and wider energy system (IEA, 2014a). In the broadest sense, energy storage includes all technologies that allow a temporal shift for providing an energy-related service. A hot water tank, for example, can be charged using electricity and provide hot water at a later time. In this broader sense, storage not only encompasses electricity storage (including batteries, compressed air energy storage, pumped hydro storage, flywheels, and supercapacitors) but also thermal and chemical storage (such as hydrogen and its derivatives). Thermal energy storage is frequently used to enable demand-side response (DSR), while chemical energy storage is particularly relevant in the transport, industry, and heating sectors (Figure 2.1).<sup>1</sup> Because this report has a particular emphasis on the power sector, storage is defined here in a narrower sense to include all those storage technologies that return energy in the form of electricity.

A brief overview of global electricity storage swiftly reveals that the vast majority of installed capacity and energy is pumped storage hydropower (PSH). Out of a global total of some 165 GW of grid-connected electricity storage in 2018, PSH accounted for 155 GW or 94% (IEA, 2019d). Pumped storage hydropower will remain an important electricity storage technology (Box 2.1). However, battery electricity storage—notably Li-ion technologies—have seen dramatic cost reductions in past years and very strong growth rates (Schmidt et al., 2019). Costs have decreased by 85% over the 2010–18 period (BNEF, 2019b). This development was driven to a large part by a sharp increase in battery use in electric mobility, which, in turn, was spurred by policy support (IEA, 2019e). In 2018, installed grid-connected stationary battery storage grew by 3 GW, boosting total installed capacity to 9 GW/17GWh (BNEF, 2019a). Stationary battery storage is forecast to grow significantly and attain 1095GW/2850GWh by 2040 (BNEF, 2019a).

### ELECTRICITY STORAGE AS A FLEXIBLE RESOURCE

When considering the role of electricity storage in the power system, it is vital to recognise that storage is only one of several technical flexibility options—flexible generation, DSR, and grid infrastructure are the others. Moreover, policy, market, and regulatory frameworks, as well as the institutional setup in the power sector, are critical for determining if investments in new technical resources will take place in time and if existing resources will be used effectively (IEA, 2018a). Indeed, electricity storage should be seen as one element in an integrated strategy to boost power system flexibility and resilience and thereby achieve energy policy objectives (PNNL, 2019). For any given system, such an approach should take into account its current level (phase) of VRE integration (Figure 2.2):

**Phase 1:** The first set of VRE plants are deployed, but they are basically insignificant at the system level; effects are very localized, for example at the grid connection point of plants.

**Phase 2:** As more VRE plants are added, changes between load and net load become noticeable. Upgrades to operating practices and better use of existing system resources are usually sufficient to achieve system integration.

**Box 2.1****The Role of Hydropower as an Energy Storage Resource**

Pumped storage hydropower (PSH) is an important and cost-effective source of flexibility in the power system and still the largest contributing technology to electricity storage installed to date (both in terms of capacity and energy). In addition to energy arbitrage, PSH is capable of providing system services to maintain the stability of the power grid. These services include black-start capability, ramping and quick start, spinning reserve, reactive power, and frequency regulations.

Certain PSH plants can operate in a special mode called hydraulic short-circuit pumped storage (HSCPS), with the main feature of simultaneously generating and pumping. It enables the plant to contribute to system inertia and frequency regulation. If the plant is operating in either generator or pump mode, it is capable of switching between operation modes very quickly, without having to reverse the rotation (IEA, 2017b).

The ability to simultaneously operate in both turbine and pump mode provides greater flexibility to the grid. The power plant is seen by the grid as controllable load, with a power regulation range equal to that of hydropower turbines in operation. The contribution to inertia depends on the inertia of the unit, while frequency regulation depends on the turbine response. HSCPC has been in operation in hydropower plants in Austria, Switzerland, the Canary Islands, and Wales (Cavazzini and Perez-Diaz 2014; Koritarov and Guzowski 2013; IEA 2017b). But even in a conventional operation mode, PSH frequently provides system services including fast-acting reserves that can mitigate the impact of contingencies. One example is Lithuania's Kruonis pumped storage power plant, which has been activated to compensate for a failure on a large DC-connector to the Swedish power system (DELFIN, 2016).

Where topology allows, PSH can be an important component for hybrid power plants to supply smaller remote grids, as well. For example, PSH has been identified as an important component for

achieving the ambitious target to convert 100% of the energy supply of the Faroe Islands to renewable energy by 2030 (Norconsult 2013). Moreover, the smallest of the Canary Islands, El Hierro, has a hybrid wind-PSH system. This completely covered the island's power demand for more than 24 consecutive days in July 2019 and renewables met 54% of the overall electricity demand of the island (Renewablesnow 2020).

Reservoir hydropower can also show important synergies with variable renewable energy (VRE), even if not equipped with pumping functionality. For example, a study investigating hydro-wind-solar synergies for West Africa found that combining technologies while also improving connectivity between power systems can bring important synergies for the system across a wide range of flexibility time scales (Sterl et al. 2020). Interconnections allow exploitation of the spatial synergy between solar and wind potential in the north of West Africa and hydropower potential in the south, enabling a balanced mix with all three resources contributing substantially. In addition, there is a seasonal complementarity: the VRE resources in the north produce more during the dry season, leading to a more balanced overall production. Finally, oversizing wind and solar capacity and adding pump-back capabilities to hydropower reservoirs were found to increase system resilience to climate change related droughts (Sterl et al. 2020).

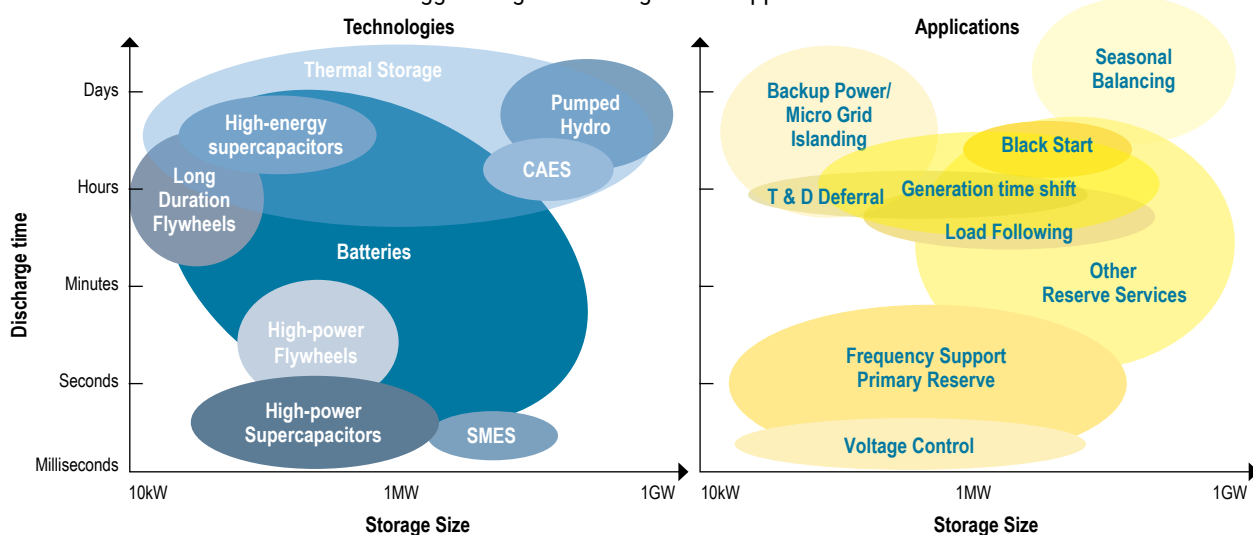
Similar synergies were found in a recent study carried out for Brazil (Tractebel/PSR 2018). Here, again, an important driver behind such synergies are negative correlations between water and wind/solar availability. Such synergies can also help with managing the seasonal variability of large hydropower plants that are operated as run-of-river plants (i.e., where reservoir sizes are small). In the case of Brazil, the 11 GW Belo Monte Dam is a case in point. Wind power production in the region has a seasonal maximum when water flows are low, so that the combination of hydropower and wind resources jointly have a more stable output profile.

a. This operation mode is possible in ternary pumped storage units where a separate turbine and pump is located on a single shaft with an electrical machine that can operate in generator or motor mode. The electrical motor and generator is a synchronous machine.

b. The transition time between the mode of operation is in the range of 0.5 to 1 minute compared to 1.5 to 5 minutes in normal pumped storage (Koritarov and Guzowski 2013).

Source: Authors.

FIGURE 2.1: Overview of Different Energy Storage Technologies and Applications

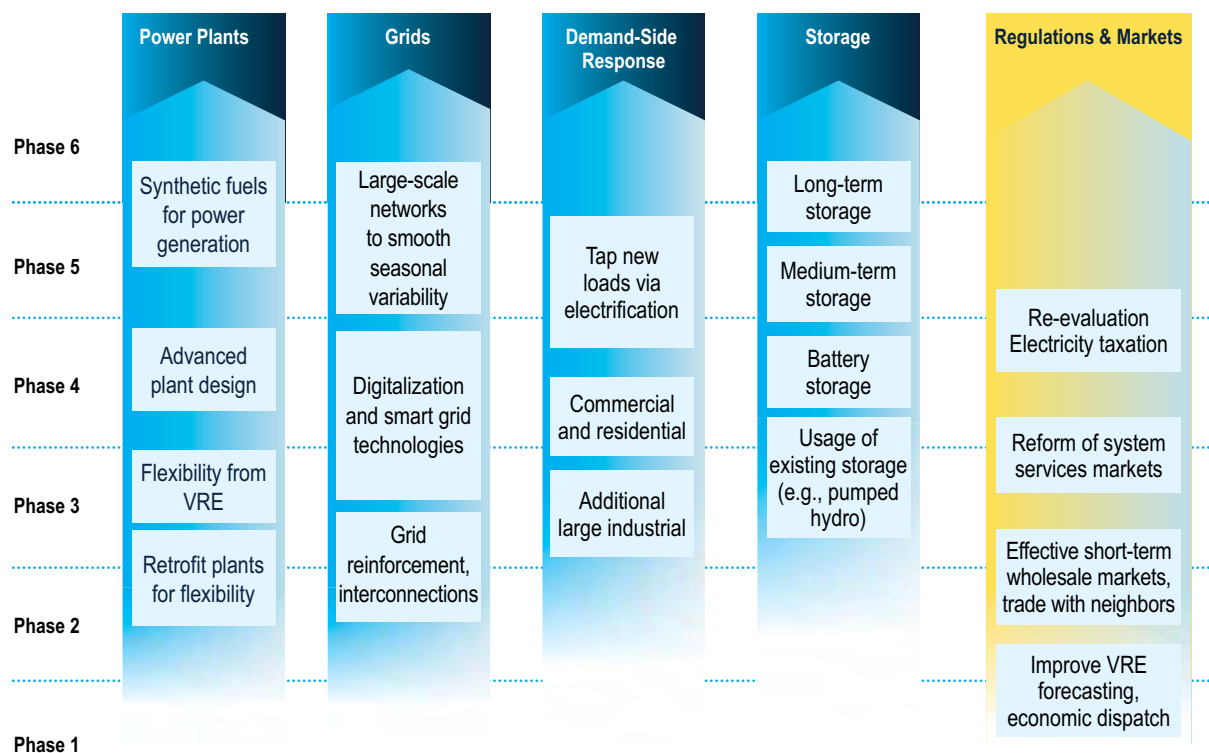


**Key point: Energy storage encompasses a suite of technologies that match different applications.**

Note: CAES = compressed air energy system; SMES = superconducting magnetic energy system; T&D = transmission and distribution

Source: Adapted from IEA, 2014.

FIGURE 2.2: Different Flexible Resources Differentiated by Deployment Phase



**Key point: The four flexible resources are power plants, grids, demand-side response, and storage.**

Note: DSR = Demand Side Response; Time-scales are defined in Table 1. Timing by phase is indicative—exact needs and timing will be system specific.

Source: Adapted from IEA, 2018a.

**Phase 3:** Greater swings in the supply-demand balance prompt the need for a systematic increase in power system flexibility that goes beyond what can be fairly easily supplied by existing assets and operational practice.

**Phase 4:** VRE output is sufficient to provide a large majority of electricity demand during certain periods (high VRE generation during times of low demand); this requires changes in both operational and regulatory approaches.

**Phase 5:** Without additional measures, adding more VRE plants will mean that their output frequently exceeds power demand and structural surpluses of negative net load would appear, leading to an increased risk of curtailment of VRE output. Shifting demand to periods of high VRE output and creating new demand via electrification can mitigate this issue. Another possibility is to enhance interchange with neighboring systems. In this phase, it is possible that in some periods the demand is entirely supplied by VRE without any thermal plants on the high-voltage grid.

**Phase 6:** The main obstacle to achieving even higher shares of VRE now becomes meeting demand during periods of low wind and sun availability, as well as supplying uses that cannot be easily electrified. This phase thus can be characterised by the potential need for seasonal storage and use of synthetic fuels, such as hydrogen.

These considerations notwithstanding, battery storage is an important and new frontier for flexibility in power systems (IEA, 2019a). Battery storage is one of the technologies best suited to provide short-term flexibility from milliseconds to several hours due to its dispatch ability, fast response time and, under certain conditions, contributions to system adequacy (IEA, 2019a; US DOE 2019).

Indeed, battery cost reductions are changing how the electricity system accommodates the rise of VRE, in particular solar PV, in the power mix. In the 2019 World Energy Outlook, projections for battery storage capacity were raised by close to 50% compared to the previous year, hand in hand with increases for solar PV deployment (IEA, 2019a). Depending on projections, costs for four-hour storage systems are projected to fall from US\$400 per kilowatt-hour (kWh) to less than US\$200/kWh by 2040 (IEA, 2019a) or even 2030 (US DOE, 2019). Prices in China are already in the order of US\$270/kWh to US\$320/kWh for Li-ion technologies

(see Box 2.2). Longer duration battery costs would be even less per kilowatt hour. This has led to increased interest also in other developing countries with a strong increase in renewable energy uptake, such as India (see Box 2.3).

It has already been pointed out that power systems have a diverse range of requirements and that different electricity storage technologies are best suited to different types of applications. A clear understanding of these possible requirements is critical for selecting the right type of flexible resource. The following section elaborates this point further, introducing the concept of use cases to capture the diverse power system needs.

## DEFINING USE CASES AND APPLICATION CASES

This report has so far focused on general aspects of the contribution of electricity storage to power system needs. However, more detailed analysis will be needed to unlock this contribution in practice. This section takes this next step, introducing a number of relevant concepts.

A **use case** is defined as a specific power system need, which occurs frequently in most system contexts, and which is significant enough to justify the deployment of a technology solution tailored to meet it. As an example, the provision of frequency control services constitutes a use case. Use cases *do not* imply a specific technology solution, (i.e., energy storage may or may not be the best suited option for a particular use case). However, there are certain use cases where storage offers distinct advantages over alternative options.

Identifying which use cases are relevant in a power system is crucial for implementing an appropriate power system flexibility strategy, but it is only a first step. Picking up the example of frequency control, it is clear that all AC power systems require a suite of frequency control reserves. However, the exact product definition (response time, how long service has to be provided, prequalification conditions) depends on system specific factors. Policy, market, and regulatory frameworks are crucial for determining what entity can provide such reserves and how these are compensated.

Thus, it is useful to consider what can be referred to as **application cases**. An application case is a given use case, tailored to the specific technical needs of a power system and subject to its particular policy, market,

**Box 2.2****Measuring the Cost of Battery Storage Use Cases**

The cost of energy storage systems and the potential for cost reduction are the basis for evaluating the economics of energy storage technologies.

Generally, when evaluating the initial investment for energy storage projects, the cost of installation (CAPEX) is considered. The table below shows the CAPEX of main energy storage technologies.

**CAPEX OF MAIN ENERGY STORAGE TECHNOLOGIES IN CHINA**

Technology	US\$/kWh	
	low	high
LFP Li-ion	270	310
NMC Li-ion	300	325
NaS	540	595
PHS	115	140
Lead Carbon Battery	210	240
VRB	450	500

However, a comparison based on such an aggregate figure can be misleading. Storage can be used for a variety of different use cases, each with a very different usage profile. Therefore, a more complete picture can be obtained by considering the levelized cost of storage (LCOS). For conventional generation technologies, the levelized cost of electricity is already a well-known metric. In the context of electricity storage is the energy storage cost calculated after leveling the cost of energy storage over its entire life cycle expressed per unit of energy returned from the storage.

A very common application of LCOS are use cases related to energy arbitrage, i.e., charging when prices are low and discharging when electricity prices are high. Assuming a certain usage pattern (e.g., one fully cycle per day) and including the cost of electricity used for charging, LCOS then indicates the peak electricity price level at which storage becomes economic.

Bloomberg New Energy Finance's levelized cost for battery storage for H1 2020 is US\$150 /MWh on average globally, inclusive of charging costs and assuming one cycle per day. Where CAPEX for battery storage is particularly low, LCOS can be as low as US\$115 /MWh. This means that four-hour duration battery storage today can challenge gas-fired peaking power on costs where natural gas is imported, such as in Japan or Europe.

Sources: China Energy Storage Alliance (CNESA, 2020a) , Bloomberg New Energy Finance (BNEF, 2020).

and regulatory framework, as well as institutional setup. Calculating the economic viability of a storage project and deciding technology and engineering details is only possible on the basis of an application case.

It is possible to use one and the same asset to serve multiple application cases. This is sometimes referred to as benefit or value stacking. Value stacking can be beneficial for project economics and maximize

the benefit of an asset for the system: because the investment is used in an optimal fashion, the cost of meeting each use case is reduced. While this concept is straightforward in theory, there can be practical barriers to its realization. Policy, market, and regulatory frameworks have a critical role in whether or not such stacking is possible and if all value streams can be accessed by the same entity. This is discussed in the next section

**Box 2.3****Snapshot of Regulatory and Policy Review for Battery Storage in India**

India is currently experiencing a rapid increase of variable renewable energy (VRE) capacity against the backdrop of an ambitious target to reach 175 GW of renewable energy capacity by 2022 and a long-term commitment to reduce the carbon intensity—and ultimately overall emissions—of its economy. The current context in India highlights the challenges in setting up a consistent, suitable regulatory structure for the many different use-cases that storage can provide while simultaneously demonstrating how auctions for renewable energy and storage hybrid systems can be effective in providing both flexibility and green electricity to grids.

**Main drivers and experience in procuring energy storage**

Several modelling efforts have established the need for flexibility to extend beyond existing sources in the supply and demand sides, if a predominantly VRE-led future is envisaged in India (CEA 2017; CPI 2019; NREL 2017). It is understood that existing potential sources of flexibility in the grid will be inadequate in meeting the grid balancing requirements under high VRE scenarios of the future. The debate, so far, has been confined to when and to what extent the country should commit to battery storage systems (BESS) in light of its current costs, which have been declining rapidly. In addition, there are ambitious plans to increase the installed capacity of pumped storage hydropower in India (Economic Times India 2019).

In March 2019, the Union Cabinet approved the establishment of an integrated, multi-disciplinary National Mission on Transformative Mobility and Battery Storage to drive clean, connected, shared, sustainable, and holistic initiatives by promoting local manufacturing. India's current grid-scale commissioned BESS capacity stands at around 11.25 MW. Additional tenders have been announced for more than 1,400 MW of BESS projects in the first half of 2019 throughout country. These projects were launched mainly with the objective to control variability of solar and wind power. Experience in recent tenders has shown that the BESS are becoming competitive. In Jan 2020, two companies won the auction to supply 1,200 MW of clean power in one of the largest renewable-cum-energy storage power purchase tenders through a reverse auction method. Greenko was awarded 900 MW after quoting a peak power tariff rate of Rs 6.12 (~\$0.086) per

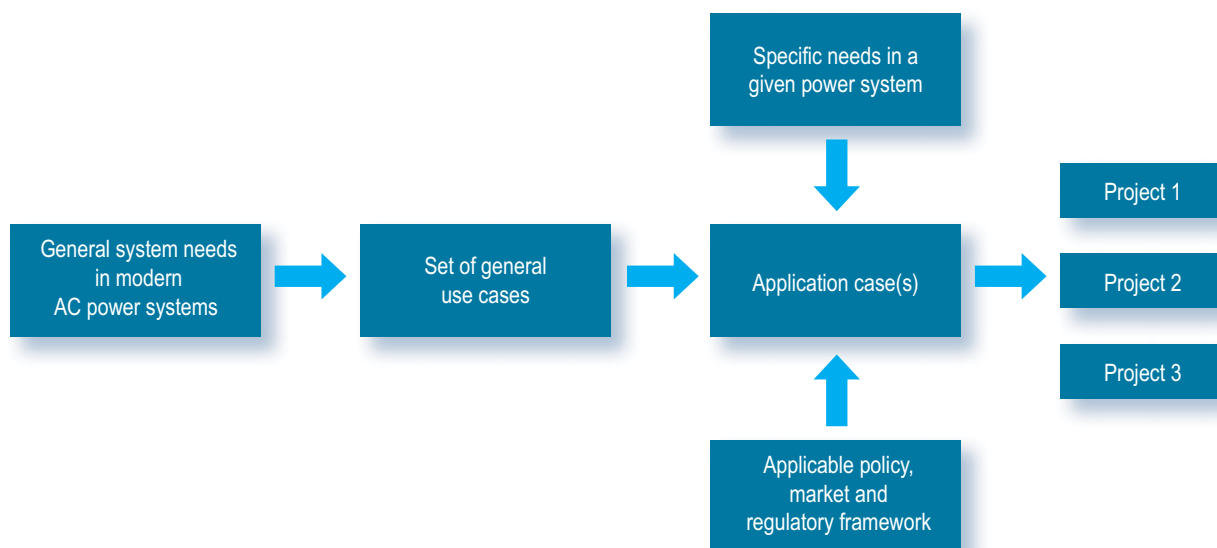
kilowatt hour and ReNew Power bid for peak tariff came at Rs 6.85 (~\$0.096) per kilowatt hour.

**Challenges for establishing a consistent regulatory framework**

The Electricity Act, 2003 covers the generation, transmission, and distribution of electricity, but it does not specifically cover the storage of electricity. This means that there are uncertainties regarding regulatory jurisdictions of appropriate commissions, as well as regulatory jurisprudence of certain applications of the BESS. For example, if a distribution utility brings in cost efficiency to supply electricity to consumers by using BESS, the State Electricity Regulatory Commission (SERC) can consider the investment as appropriate. However, regulatory treatments would differ when the same distribution utility would add different applications of BESS. For example, when 50% of the BESS cycles are used for energy arbitrage and 50% of the BESS cycles are used to reduce deviation settlement mechanism penalties, the treatment for regulatory jurisprudence will differ. Similarly, if a BESS is installed by an inter-state transmission utility and this entity executes service agreements with system operator (for ancillary services support), renewable energy generators (capacity firming) and distribution utilities (energy arbitrage), it is unclear at the moment if this falls under the jurisdiction of the Central Electricity Regulatory Commission (CERC) or SERC.

The CERC's staff paper on the introduction of electricity storage systems in 2017 was an important document discussing such issues and the possible interpretations of CERC in similar situations. In addition, several regulatory provisions have been introduced over the years with long- and short-term implications for battery storage resources in the country. Some of the key regulatory provisions include: (i) real time market (CERC 2019), (ii) a draft Indian Electricity Grid Code (CERC 2020), and (iii) the new market design for ancillary services. The need for a well-established regulatory oversight that will direct the investment in the area of storage technologies is understood and various options to address issues around grid connectivity of storage devices, tariff structure including depreciation rates, cost recovery methods, incentives, and rebates, etc., are being analyzed.

Source: Authors.

**FIGURE 2.3:** Relationship Between System Need, Use Case and Application Case

**Key point: The combination of use case and system specific factors defines an application case.**

Source: Authors.

in more detail in the context of system and project value (see Chapter 3).

Another use case is the provision of firm capacity to meet peak demand. It depends on the duration of this demand, and here flexible resources are in principle extremely useful. In turn, the policy, market, and regulatory frameworks determine which options will actually entail a viable remuneration structure to unlock investment. The relationship between system needs, use case, and application case are illustrated in Figure 2.3.

## GENERAL USE CASES

A number of different categorization systems for use cases exist (see CIGRE, 2018, Chapter 4). While they are generally quite similar, differences can arise depending on the degree to which the list of use cases applies only to a subset of system contexts. For example, frequency control is a universal use case that any AC power system requires. However, some categorization systems further differentiate, for example, the provision of regulation reserves and load following reserves. While both these reserves contribute to frequency control, they are defined in some but not all power systems. This report adopts a general definition of use cases that apply to all AC power system contexts, based on the different flexibility timescales defined in the introduction. The emphasis is on use cases that, in principle, can be met

via electricity storage. Note that while all of these use cases are provided, the size of each use case for most systems is highly variable. The need for reserve products and ancillary services would be much smaller than peaking power or energy arbitrage for example (Table 2.1).

The different use cases can be differentiated on the following bases: whether storage acts on the generation side (similar to a generator), or on the customer side (similar to a responsive load), or on the network (similar to a network asset). This distinction is not always completely clear-cut: for example, transmission systems generally feature network assets that can provide voltage control (e.g., components referred to as Flexible Alternating Current Transmission Systems, FACTS) and customer side resources can be aggregated to bid on the wholesale market similar to a generator. Hence, the following allocation to broader categories is indicative. Also, note that a generation-side service does not imply that it must be co-located with generation; rather, these are services that have been traditionally associated with generation-side resources.

### Selected generation-side services

**Frequency and voltage control** is the use case driving a large proportion of grid-scale storage projects in the power systems of developed countries. The required services are generally segmented into different sub-categories, reflecting different system needs and

TABLE 2.1: Use Cases as a Function of Flexibility Timescale

	Short-Term Flexibility			Medium-Term Flexibility	Long-Term Flexibility	
Timescale	Sub-seconds to seconds	Seconds to minutes	Minutes to hours	Hours to days	Days to months	Months to years
Relevant asset characteristic	Response latency Capacity	Capacity / Energy	Energy		Large energy volume	
Use Cases	Generation Based					
	<ul style="list-style-type: none"><li>Frequency and voltage control</li><li>Short circuit current</li><li>VRE ramp control</li></ul>		<ul style="list-style-type: none"><li>Frequency control</li><li>VRE forecast error correction</li><li>Firm capacity</li><li>VRE generation time shift</li></ul>		<ul style="list-style-type: none"><li>Black start</li><li>Firm capacity</li></ul>	<ul style="list-style-type: none"><li>Balancing seasonal and inter-annual variability</li></ul>
	Customer Based					
	<ul style="list-style-type: none"><li>Uninterruptible power supply</li></ul>		<ul style="list-style-type: none"><li>VRE self-consumption optimization</li><li>Demand response</li><li>Time of use optimization</li><li>Network charge reduction</li><li>Micro grid islanding</li></ul>		<ul style="list-style-type: none"><li>Backup power / Micro grid islanding</li></ul>	<ul style="list-style-type: none"><li>Backup power / Micro grid islanding</li></ul>
	Network Based					
	<ul style="list-style-type: none"><li>Grid congestion relief &amp; T&amp;D avoidance / deferral</li></ul>					

Source: Authors.

regulatory environments. Usually there is a service that: (i) responds (almost) instantaneously to any deviation of system frequency from its nominal value (inertial response, frequency containment reserves); (ii) responds automatically in response to a control signal from the system operator (frequency restoration reserves); and (iii) manually at the request of the system operator (replacement reserves). Slower acting reserves generally relieve faster acting reserves in order to recover the system's response capability. Voltage control is generally differentiated by services during normal operations (steady state reactive power) and during system disturbances (dynamic reactive power and short-circuit current). Generators, storage, and demand-side resources can be used in this use case.

**VRE ramp control** refers to limiting the speed at which a VRE plant may change its power generation in response to a change in resource availability, by absorbing excess energy or discharging during periods of low output. Grid connection codes for VRE plants include such requirements in order to limit short-term variability, especially on smaller systems or weak grids. This use case generally requires a limited amount of energy storage with sufficient capacity rating. Note that these

ramps become more pronounced with very high levels of solar power in a particular on the system.

**VRE forecast error correction** is relevant for systems where VRE plants have an obligation to report short-term generation schedules and face penalties if their real-time output deviates substantially from schedules. If grid codes require plants to adhere to schedules at the point of connection, electricity storage is in a privileged position for this use case. However, if VRE generators can be pooled in a portfolio, forecast errors can be corrected by trading on short-term markets and relying on system-wide frequency control, which is generally more efficient.

**Firm capacity** is a broad category generally referring to the ability of (aggregate) generation capacity to meet load at all times. Dispatchable generation generally has a substantial contribution to firm capacity, and depending on the load structure (duration and frequency of demand peaks) demand-side resources can reduce the need for firm capacity, and/or storage assets can supply it.

**(VRE) Generation time shift** refers to a use case where a flexible resource is combined and possibly co-located

with a (VRE) power plant to (partially) shift its output to a later time. Storage is the only resource that can provide this use case—a solar PV system with a battery to meet demand after sunset is the most common example. It is not necessary for storage and generation to be co-located.

**Black start** capability is needed following a system wide blackout. Black start capable resources do not require any external power supply to energize the electricity network, gradually building supply and adding demand. Generation and storage can be used to provide the supply-side component of black start capabilities.

**Balancing seasonal and inter-annual** variability is a use case that becomes relevant at very high shares of variable supply (which includes reservoir hydro at these timescales). This can be achieved by chemical storage technologies (hydrogen and its derivatives), very large-scale thermal energy storage (such as underground storage in aquifers) or batteries that can decouple rated capacity and energy storage volumes, such as flow batteries.

### Most relevant demand-side use cases

**Uninterruptible power supply (UPS)** provides a customer seamless switching between grid electricity and a backup system in case of loss of grid power. Batteries are the only flexible resource that can provide the required rapid response combined with sufficient energy volumes for this use case.

**Backup power / micro grid islanding** refers to the capability of a smaller, often privately owned, grid to use its own generation resources when grid power is not available. The main difference between this use case and UPS is that backup solutions may allow for an interruption of power, but generally aim to supply power for longer periods of grid unavailability. Micro grids may be designed to operate fully autonomously under normal conditions—a use case that is especially relevant for electricity access in remote and smaller communities.

**VRE self-consumption optimization** is relevant for customers with their own (behind-the-meter) generation who can arbitrage between using self-generated power and grid electricity. Demand side resources and storage can help maximize the share of demand that is met by self-generated electricity.

**Time of use optimization** aims at shifting customer demand to times when electricity prices are comparably low. This requires that electricity tariffs differ depending on when electricity is consumed. This case is similar to implicit demand response (see below).

**Demand response (DR)** requires the customer to shift or shed electricity consumption either in response to a price signal (implicit DR) or as part of a contractual agreement (explicit DR). In many cases, thermal energy storage enables DR but electricity storage can, in principle, be used for this case, as well.

**Network/demand charge reduction, or demand charge reduction**, also requires shifting consumption in time. However, the main objective is not to move a certain amount of energy but rather limit the maximum consumption (at specific time periods). This use case is relevant for larger customers that are metered at short intervals.

### Grid-related use cases

**Grid congestion relief** can be achieved by a number of options. Dynamic line rating and other measures on the electricity network itself can help to boost transmission capacity and thus reduce congestion. Storage can also be used to meet demand peaks at the end of an otherwise overloaded line.

**Transmission and distribution (T&D) deferral or avoidance** is similar to grid congestion relief, but it refers to the investment timescale on the grid. This use case is sometimes referred to as non-wire alternatives and can be met by demand-side resources, (distributed) generation, and storage.

## USE CASES IN WEAK GRIDS

There are a number of use cases that are of particular relevance in weak grid contexts of developing countries. These include:

- (VRE) Generation time shift can help to meet a larger portion of electricity demand via VRE/other generation thus reducing load shedding and/or decreasing the reliance on expensive generators running on diesel and/or HFO.
- Frequency control services can also be a relevant use case. However, the specific application case is likely to be different in weak grids compared to

frequency control in developed countries, reflecting differences in technical requirements and framework conditions (see next section).

- In systems that struggle to maintain stable frequency and voltage, ramp control for VRE can be a relevant use case.
- Depending on the load structure, providing firm capacity can also be an important use case.
- Mini-grids are relevant use cases in low access areas, including small island states, areas only weakly connected to the main grid, or in weak-grid environments.

- Behind-the-meter use cases for commercial and industrial applications aim at UPS and backup options to increase reliability of supply. The same is relevant for providing backup power to critical infrastructures.

## FROM USE CASE TO APPLICATION CASE

Use cases are deliberately general and capture generic applications. By themselves, use cases do not define a given flexibility project, thus further steps are required to move to a specific application case, against which

### Box 2.4

#### South Korea's Battery Storage Development

South Korea is one of the leading countries in battery storage with approximately 4.8 GWh installed in 2018—accounting for almost half of the global market. Generous government support for research, demonstration, and project development contributed to the creation of a domestic battery storage market.

In 2009, the Government of South Korea announced the Green Growth policy to promote a synergistic relationship between economic growth, green transformations, and international efforts to fight climate change. Battery storage was featured in the Energy New Business initiative of 2014 with a roadmap to 2030 and in the Korea Energy Storage Technology Development and Industrialization Strategy 2020 (K-ESS 2020) which set the target of reaching a 30% share of the global market by the year 2020.

As part of the Renewable Portfolio Standard (RPS) scheme, renewable energy projects that included energy storage could benefit from a higher multiplier for the Renewable Energy Certificates (REC). Solar PV plus battery storage projects were granted a REC weight of 5.0 and wind projects a REC weight of 4.5, where the price of one REC was roughly US\$73/MWh. Additionally, public buildings were mandated to install energy storage systems (five% of peak power) accompanied by various financial incentives. These incentives prompted the proliferation of battery storage systems across the country.

As a result, South Korea saw a sharp increase of battery storage systems from 1.2 GWh in 2017 to nearly 4.8 GWh in 2018. However, the market temporarily stopped during investigation into the cause of more than 23 fire incidents in battery systems. The investigations were completed in summer 2019 with the announcement that the causes were: (i) inadequate battery protection against electric shock; (ii) inadequate control of operating environment; (iii) faulty installation; and (iv) inadequate overall systems control and protection.

As of spring 2020, the REC weighting for energy storage systems connected to wind power ranged from 4.5 to 5.5. The country expects to continue growing its battery storage installations, including new safety measures, for which the government is providing financial support.

*Sources:* Authors based on Korea Energy Agency (2020), World Bank (2020b), and EY (2020).

projects can be designed and developed (Figure 2.3). There are two main additional components needed for this.

Firstly, a more detailed, system specific, techno-economic assessment is required to provide further insights into the different use cases. For use cases that fall into the generation based and network-based use cases this assessment takes place on the power system level. For the customer-based use cases such an assessment is needed based on the customer's load profile, supplemented by selected system level data. For example, all AC power systems require frequency control. However, smaller systems with relatively low synchronous inertia may require very fast responding frequency control, which is not needed in large systems with more synchronous inertia. As explained in the next chapter, a detailed study is needed to determine which type of frequency control provides value to the system. The same is true for the other use cases.

Secondly, policy, market, and regulatory frameworks determine project requirements, including what is needed to obtain relevant permits, what performance requirements the flexibility asset needs to meet and what revenues a project can achieve. Storage is frequently hampered by regulatory frameworks that are not geared towards storage (e.g., see CNESA, 2020b, for a discussion on barriers in China).

## NOTE

1. Chemical energy storage is also of importance in the power sector for bridging multi-day shortfalls of renewable electricity production via reversion to electricity. This application is relevant once VRE provides the large majority of electricity on an annual basis and is beyond the scope of this report.

### 3 UNDERSTANDING PROJECT AND SYSTEM VALUE

Cost-benefit analysis has long been a standard decision-making tool in the power sector (CPUC, 2001). Traditionally, the entire power sector was viewed as a natural monopoly, which in turn required regulators to approve investment plans of utilities on the basis of cost-benefit assessments. In many jurisdictions, this has been changed by unbundling (different ownership of generation, transmission, distribution, and supply in varying combinations) and wholesale market liberalization (allowing private companies to compete for generating electricity). However, there still remains an important role for (indicative) planning, policy, and regulation. For grid infrastructure, planning is crucial in all types of governance setups and leads to binding investment plans.

Especially in developing countries the electricity sector is still structured around a vertically integrated utility, which either invests directly in new assets or procures these from independent power producers (IPPs) via long-term contracts. In this context, regulators will need to approve investment plans and there may also be questions regarding fair remuneration of different flexibility use cases. In many countries, even where markets have been liberalized, there remains an important role for system operators acting as single buyers for system services (frequency and voltage control, black start). Regulators also have a crucial role in approving tariffs for monopolistic parts of the system such as networks (and frequently also retail tariffs).

Consequently, a proper understanding of the economic value a certain use case can bring to the system is indispensable. This is captured by the notion of system value (IEA, 2016a). System value captures the aggregate benefit to the power system following the addition of a new resource. This can be a generation and/or flexibility asset. For example, deployment of electricity storage may help reduce load shedding, which has a direct economic value. This monetary value is one component of the storage asset's overall system value. Other factors, such as deferred T&D investment may further increase system value. In order to specifically calculate the system value of a technology, one must first specify which factors need to be taken into account. For example, a calculation may or may not include positive externalities of technologies that do not rely on fuel that sees significant price fluctuations and associated risks (IEA, 2016a; ENTSOE, 2020).

It is important to note that the system value of a given asset is not static, but can change along with changing demand patterns or shifts in the asset structure of the system. For example, along with the general economic principle of diminishing returns, the system value of adding more of a certain technology tends to diminish as more and more capacity is deployed. While this is a general principle that holds for all resources, the speed at which value saturates depends on the asset type and use case (see Denholm et al., 2018, for an example of storage providing peaking capacity in California).

Comparing the system value of an asset to its direct cost allows determining if building the asset is desirable from a total cost perspective or not. Calculating the system value of an asset requires a reference case—which assumes that the asset is not built—and a case where the asset is present. The aggregate change of costs in the system (excluding direct costs of the asset itself) is the system value of the asset.

A favourable system value, however, does not indicate if an investor (this could be a private or public entity) will be able to obtain sufficient remuneration to actually invest in the asset. The financial attractiveness of a flexibility asset from this perspective is captured by the notion of project value. The project value is composed of the different revenue streams that can be tapped by the project minus costs incurred. Project value is often expressed by net present value (NPV) (i.e., discounted revenues minus discounted costs). Another metric of project viability is the internal

rate of return. The internal rate of return of the project needs to be above a certain threshold, referred to as the hurdle rate, for an investment to go ahead. In turn, the hurdle rate is set by the weighted average cost of capital (WACC) of the project.

It is a fundamental task of policy, market, and regulatory frameworks to ensure that projects with a positive system value also have a favorable project value.

## ASSESSING TECHNO-ECONOMIC SYSTEM VALUE

Analysing the system value of a power system asset frequently requires a detailed assessment based on advanced modelling tools (sources). The level of detail at which the power system is represented will depend on the specific question. For example, where an asset clearly reduces the amount of unserved energy, a rough estimate of the avoided unserved energy will be sufficient to approximate the system value. However, in many cases the issue will be more complex, requiring a more comprehensive assessment. In general, such an assessment is carried out in the following order (Figure 3.1; see IEA 2018b, for a detailed discussion):

**Step 1:** Establish a model of the current power system (generation, grids, and demand) alongside a set of different options for future investments. This step involves collecting a large amount of techno-economic data about the power system and selecting an appropriate power system model. This will often be a so-called capacity expansion model (CEM), which is capable of determining the least-cost mix of new investments over the long-term. CEMs create least-cost power generation portfolios in future years with detailed considerations of capital expenditure (CAPEX) but an incomplete picture of power system operations (and thus, operating expenditure, OPEX). CEMs have the advantage of capturing long-term planning timescales but this comes at the cost of less spatial and temporal granularity. Thus, they need to be combined with a more detailed model that builds on the results of the CEM.

**Step 2:** In the next step analysts first create a reference case scenario using the CEM, which relies on reasonable, fairly conservative predictions of future technology and market conditions. This reference scenario will ultimately serve as a point of comparison with scenarios that include additional flexibility considerations. To fully develop this scenario, it must first undergo an iterative

validation process using a production cost model (see Step 3). This reference scenario must be clearly defined in terms of system composition, operational rules and reliability levels.

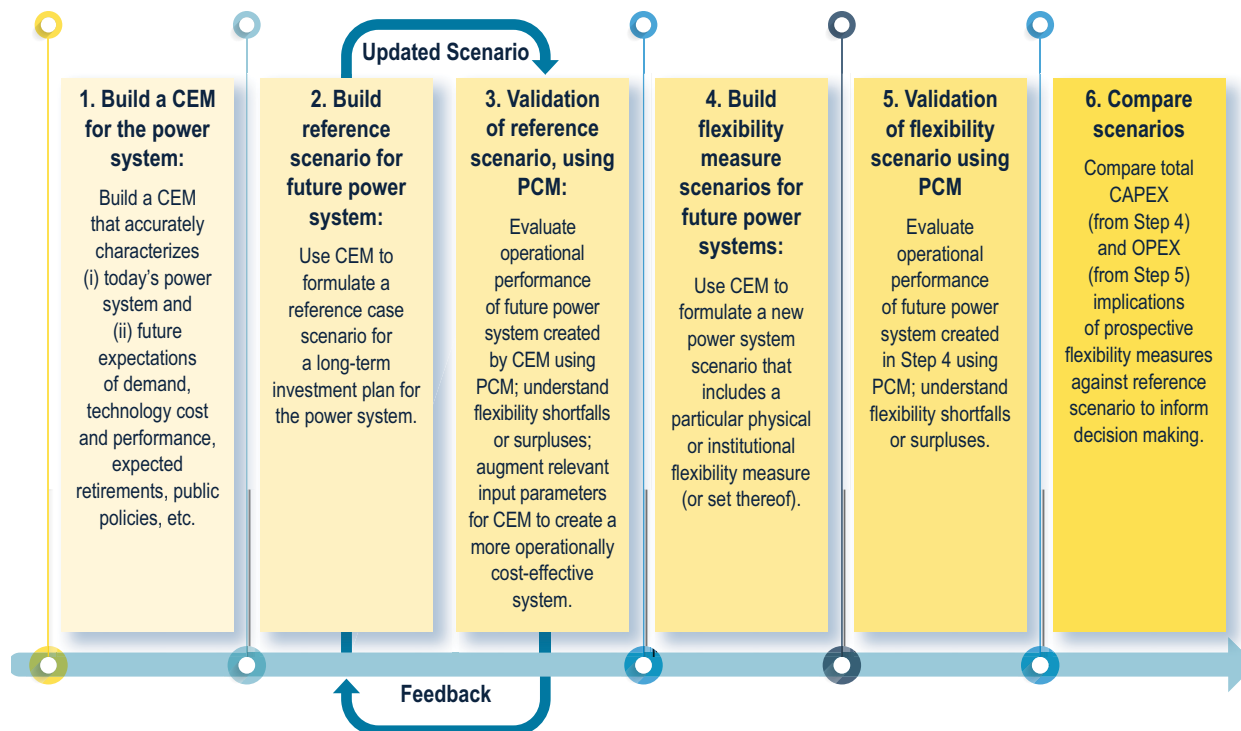
**Step 3:** A production cost model (PCM; also known as dispatch or unit commitment model) is a model that specialises in representing the operation of the power system often at the level of individual power plants and a disaggregated representation of demand (e.g., one demand curve for each substation). PCM also frequently includes operating reserves and other short- and medium-term flexibility options. It is worth noting that including storage in a PCM is a recent focus of model development and legacy tools will not be fit for purpose (Bhatnagar et al. 2013). In step 3, the PCM is used to refine the results of the CEM using the results of the PCM in an iterative process.

**Step 4:** As a next step, the capital cost implications of various flexibility measures can be tested. A new measure can be incorporated into the CEM framework as an input condition, and thereafter the model can formulate a long-term investment plan. For a fair comparison, the reference and flexibility scenarios should satisfy the same demand at the same level of reliability. Where flexible resources reduce load shedding, this should be valued at the value of lost load. Costs and benefits accruing in the future need to be discounted and converted to NPV.

**Step 5:** Next, a PCM analysis is used to evaluate operational costs and/or savings of the flexibility measures in question. The new PCM results are benchmarked against the reference PCM scenario established in Step 3. This step enables analysts to precisely evaluate how the new measures would impact system flexibility and operational costs, and to identify flexibility surpluses or shortfalls that can be addressed by modifying input conditions of the CEM in the previous step.

**Step 6:** At this stage, the CAPEX and OPEX implications of various flexibility measures can be compared and contrasted with the reference scenario (and relative to one another) to inform long-term planning pathways. Also here, costs need to be discounted and are usually expressed as NPV.

A number of experimental models have been developed lately combining the long-term time scope and decisions of a CEM with the operational detail of PCMs, largely reflecting the impact of plant operations

**FIGURE 3.1:** Modelling the Techno-Economic System Value of Power System Assets

**Key point: Modelling system value requires a sequence of steps using different modelling tools.**

*Note:* CEM = Capacity Expansion Model, PCM = Production Cost Model

*Source:* Adapted from IEA 2018b.

on investment decisions. While these models avoid to a large extent the iterative cycles between CEMs and PCMs, PCMs are typically used to test that the proposed expansion plan is technically feasible at all levels, including transmission considerations. Use of these models is not widespread yet, but they may become more common in the future as computational capacity increases and commercial solutions become available.

There are a number of details that are not fully captured by this general description. For example, additional analyses using specialized models to investigate very short-term effects (system stability) are often needed, especially in weak grids, and assessing impacts on grid infrastructure may also require the use of dedicated models. This can include power flow models to capture how the power system responds under periods of high stress, such as peak demand days or after large generators trip offline.

The flexibility scenarios should give due consideration to a range of options both across flexible resource categories (storage, demand response, flexible generation, grids) as well as within categories (different storage

technologies, different discharge times). For example, there is a different value (and cost) for different durations of storage (2 hrs vs. 10 hrs), depending on the specific system (de Sisternes, Jenkins, and Botterud 2016). Modelling frameworks should also allow for the deployment of one asset for multiple use cases. These aspects unavoidably render the modelling environment rather complex, in that an accurate picture of the flexibility contribution requires consideration of multiple sources of value (de Sisternes, Jenkins, and Botterud 2016).

In addition, sensitivity analyses can be carried out to determine how much capacity/energy of a certain resource should be deployed. This is relevant, because flexible resources generally face diminishing marginal returns (i.e., the first unit of flexibility generally has a higher system value than adding more flexibility to an already flexible system). For example, when investigating the system value of adding batteries to a system, a set of cases should be considered with varying capacities of storage in order to see how system value evolves at different capacities.

Different system value assessments may consider different costs and benefits. Hence, a conscious and explicit prior choice must be made about which categories to include, bearing in mind that assessments are only comparable to the degree that they consider the same costs and benefits (Box 3.1). The following, non-exhaustive list provides examples of costs and benefits that may be considered.

**Benefits:** reduced fuel costs, reduced load shedding, reduced or deferred costs for investments in new generation/grid infrastructure, reduced wear and tear especially for conventional generation, reduced VRE curtailment, lower CO<sub>2</sub> and other pollutant emissions, and indirect effects such as job creation and economic benefits (Delgado et al. 2018). A further benefit can be improved resilience of the system.

**Costs:** costs of enabling technologies for system operation; and negative environmental impacts.

## ASSESSING FINANCIAL PROJECT VALUE

The complexity of assessing the financial value of a project will vary depending on the use of storage and the power system in which it will be operating. In single-use applications with predefined revenue sources, financial evaluations generally do not require the same level of modelling complexity as techno-economic evaluations. Assessments are generally carried out in spreadsheet based models that capture various cost and revenue items over time. These are then discounted according to the return requirements of the investor, factoring in the risk profile of the project. However, if a system could potentially access several revenue streams by participating in spot or balancing markets, for example, the analysis would require forecasting of future market prices, involving complex models.

In general, if it is to receive a favorable assessment, the higher the risks a proposed project faces, the more profitable it needs to be.

Such assessments consider a broad range of costs, including those for required engineering studies and permits, direct equipment costs, costs for operation and maintenance, as well as any applicable taxes and so forth. Risk assessment is also a crucial aspect of project evaluation. This can include technology risk (will the asset perform as expected?), project development risks (will required permits be secured in time and as planned?), construction risk (can the asset and all required supporting structures be completed on time and on budget?), counterparty risk (will the off-taker/purchaser pay as expected and remain in the contract as foreseen?), and regulatory risk (will applicable taxes, tariff structures, or surcharges remain constant or change?). Where offtake is not ensured via a long-term contract, projects will be exposed to market risks. These can be significant, especially when the price structure and required system services change as part of the transformation of the system. Higher risks generally drive up the profits an entity expects for the delivery of a certain product or service. This includes, most importantly, the cost of financing. As a result, a robust understanding of the risks to which a project is exposed and their mitigation must underpin not merely project development but also policy, market, and regulatory frameworks.

There are crucial interdependent links between system techno-economic value, a project's financial value and policy, market, and regulatory frameworks. Ultimately, the task is to ensure that, in any given project, all relevant factors that drive system value can be monetized to achieve an alignment with project value. Put differently: a good framework will render those projects with a high system value more attractive than rival options.

**Box 3.1****Jordan's Analysis of Different Energy Storage Technologies to Add Flexibility to the System**

This case study illustrates to what extent storage solutions contribute to optimal electricity generation as envisaged in Jordan's investment plan for the period up to 2035. In particular, it examines the economic benefits of Li-ion batteries and concentrating solar power (CSP) associated with thermal storage to assess which storage option is the most suitable.

The baseline scenario comprises all main electricity sources: gas, oil, waste, solar PV (fixed/tracked), wind, CSP associated with thermal storage, and batteries. For comparison purposes, another scenario allows for batteries as the only storage option available, and a third scenario does not allow for storage solutions at all.

As the need for flexibility increases with variable renewable energy penetration, CSP provides an interesting alternative to a combined cycle gas turbine plant (CCGT), specifically with its ability to cover evening peak periods. In the baseline scenario, CSP enters the energy mix in 2030, replacing CCGT as baseload to the extent that, in 2035, most of the electricity is produced by solar and wind. Although more costly at first, investing in CSP rapidly and significantly decreases the total system cost by 7% in 2030 and up to 33% in 2035 as compared to the scenario without storage. Furthermore, the overall installed capacity in 2035 amounts to 10.9 GW (including 3.6 GW of CSP), making it 15% smaller than without storage.

Batteries would entail uncompetitive costs and fewer hours of storage than CSP, making them less able to cover evening peaks properly. For instance, 20% lower costs would be needed to enable their deployment alongside CSP, leading however to low utilization rates and installed capacities.

Preliminary modelling studies conclude that Jordan's cheapest energy trajectory heavily relies on solar and a viable flexibility source such as CSP instead of batteries. This not only satisfies energy security considerations, as it comprises mostly domestic resources, but also complies with the country's renewable energy targets. Such results demonstrate the importance for countries to consider several flexibility sources and individually tailored solutions during their quest for the optimal electricity investment plan.

*Source:* Authors based on internal World Bank documents.

# 4 POLICY, MARKET, AND REGULATORY CONSIDERATIONS

A fundamental objective of policy, market, and regulatory frameworks is to provide an environment in which projects with a favorable system value also have a business case alongside the basic conditions that allow for project development, construction, and operation. This chapter first discusses three fundamental ways in which assets can be remunerated. The discussion then turns to broader issues of policy design.

## REMUNERATION OPTIONS

The common binary distinction between vertically integrated monopoly systems, on the one side, and competitive market systems, on the other, fails to capture important aspects of remuneration structures in the electricity system.

The assets needed for electricity systems fall into different economic categories. For example, electricity grids are natural monopolies while generation assets are not. In addition, electricity systems need more than megawatt hours to supply customers: a variety of additional system services are needed to reliably operate the system.

As a result, different remuneration models are generally present in an electricity system. In the following discussion, the concept of a remuneration model does not refer to the entire power system, rather, it is meant in relation to remunerating a specific use case. For example, when it is stated that frequency and voltage control cannot be implemented in a market with multiple buyers and sellers, the statement refers only to the submarket for these services. It is possible to have a wholesale market with multiple buyers and sellers while, in the same system, the market for frequency and voltage control is organized as a single-buyer market (with the system operator acting as single buyer on this market).

Indeed, most vertically integrated systems (where generation, transmission/distribution, and supply are in one hand) allow for participation of independent power producers (IPPs). IPPs compete amongst each other, bidding on tenders where the vertically integrated monopoly is the single buyer. In this example, the remuneration model for the IPPs is a single-buyer market. Conversely, even where the wholesale market is liberalized and multiple generators can sell to multiple off-takers, the transmission grid is still a regulated monopoly business.<sup>1</sup>

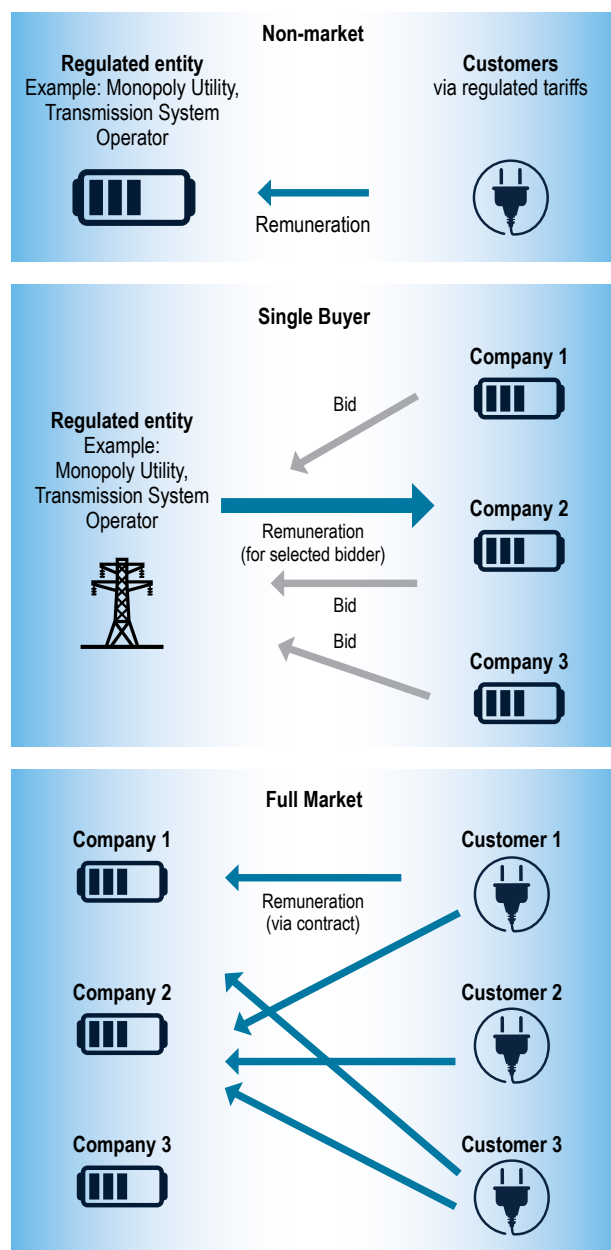
Flexibility options, notably electricity storage, can be used across different parts of the electricity system. For example, they can trade on wholesale markets like buyers and sellers of bulk electricity, they can substitute network investments, or they can provide frequency and voltage services. Consequently, the standard, system-wide distinction (competitive market vs. regulated monopoly) fails to take sufficient account of remuneration options. Depending on the use case, electricity storage could be subject to different remuneration models, even within the same country. In summary, a different way to categorize remuneration models is needed.

Fortunately, there are only three different categories of remuneration models. It is important to note that in each country, multiple arrangements or combinations of these models are possible. They jointly constitute the overall market, policy, and regulatory framework for remunerating assets in these systems. These are:

**Non-market:** Under this model, a regulated monopoly receives regulatory approval to recover the cost of a flexibility asset from its customers. There is no dedicated commercial transaction linked

to flexibility provision, there is no buyer and no seller—hence a non-market. A prime example of such an arrangement is a transmission system operator that is allowed to invest in building and operating the electricity network up to a certain reliability level and can collect a guaranteed return from all users of the grid.

FIGURE 4.1: Illustration of Remuneration Models



**Key point: There are three basic remuneration models that can be combined for different services.**

*Note:* Contract arrows illustrate different possible constellations. Full market transactions are frequently handled via a clearing house (exchange).

*Source:* Authors.

**Single-buyer market:** Under this model, multiple suppliers compete, but there is only one buyer. The buyer in this case is generally a regulated entity. The crucial aspect is that there is a contract between the selected seller and the buyer. An example from generation assets is a power purchase agreement with an IPP. For flexibility, a common example is a system operator that procures frequency control services competitively from private companies via an auction.

**Multiple buyers and sellers, full market:** Under this model, there is competition on both sides of the market. The most relevant use of this model are wholesale markets where there are liberalized customers (retail competition). Here several generators compete to supply a number of different customers. Contracts can take the form of hourly auctions on spot-markets or long-term, bilateral contracts. For simplicity, this model is referred to as full market in the following text. Examples for flexibility include energy service companies that offer an integrated efficiency and flexibility package to cut bills for a customer based on a mutually agreed contract.

This report now examines the three basic remuneration structures that can be applied for flexible resources including electrical energy storage. The basic setup is illustrated in Figure 4.1. The following examples illustrate how the different remuneration options can be implemented for different use cases.

## Non-market based remuneration

In countries where there is a regulated, vertically integrated utility that covers generation, transmission, distribution, and supply, all use cases (with the exception of customer based use cases) can be implemented by allowing the utility to recover the cost of the flexibility asset via regulated tariffs. It is paramount that any regulatory approval for such an investment is based on a robust cost-benefit assessment to ensure that the system value of the project is favorable. An advantage of such a setup is that the utility can use flexibility assets in a highly integrated way, maximizing the simultaneous provision of different use cases. However, implementing this option may require adjusting the regulatory framework to the characteristics of innovative flexible resources including battery electricity storage (Chattopadhyay et al. 2019).

Network based use cases can be implemented under a non-market based setup even in systems that

feature liberalized electricity markets and unbundling. In this case system operators must also demonstrate that a given option (e.g., battery electricity storage) is the most economic option compared to deferral or avoidance of grid investments. However, depending on the specific unbundling rules of the system, this may preclude storage from participating in other use cases. In this case, it can be more efficient for a transmission/distribution company to procure a service via the single-buyer model rather than owning and operating the asset (D. Chattopadhyay et al. 2019).

### Single-buyer based remuneration

Single-buyer based remuneration arguably is currently the most important remuneration stream for electricity storage. The reason behind this is that the majority of battery projects are currently used to provide system services (IEA 2019f) and these services are usually procured by system operators as single-buyers in systems that have dedicated frequency control products in

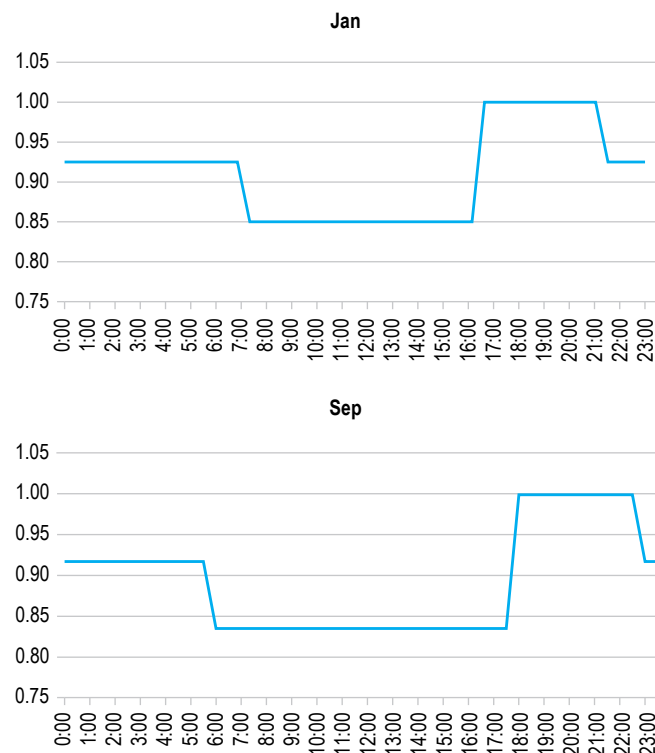
place. Another relevant market, which is also frequently organized according to a single-buyer model, is that for firm capacity, where electricity storage can qualify in some cases.

But other use cases can also be implemented using single-buyer based remuneration. For example, in markets that feature single buyers for bulk power, electricity purchases are usually implemented via long-term power purchase agreements (PPA). Such PPAs can include different price patterns, depending on time of day and season (Figure 4.2). Such time-of-generation PPAs can provide a strong incentive for co-developing VRE and storage and have been used successfully in projects deployed in Morocco, South Africa, and the United States.

### Market-based remuneration

Customer based use cases are usually implemented via market based remuneration models, because investments take place behind the meter.<sup>2</sup> However, this does

**FIGURE 4.2:** Sample PPA Structure Using a Time of Use Based Multiplier for Two Selected Months



**Key point: PPAs can align system and project value by paying time-dependent prices.**

*Note:* Bidders submit an offer based on US\$/MWh during peak hours. Generation during regular and off-peak hours receives only 93% and 85% of the ask price, respectively.

*Source:* Authors.

not mean that policy, market, and regulatory frameworks do not matter for these use cases. Indeed, the opposite is the case: behind the meter investments are valued against grid-electricity tariffs. Hence, the design of electricity and network tariffs have a strong influence on what types of flexibility investments go ahead (Milis et al. 2018). This issue has led to some controversy in markets where customers can use battery storage to optimize their self-consumption of self-generated electricity against grid electricity prices (DIW 2017). In the context of developing countries, this can be particularly relevant because customers paying higher electricity tariffs have the strongest incentive to displace grid electricity consumption. This can erode the financial health of the power sector by reducing fixed customer charges and/or cross subsidies which are crucial to ensure overall revenue sufficiency (RMI 2014).

Many of the generation based use cases can also be implemented via the market remuneration model, if a liberalized wholesale market is in place. A primary example is using electricity storage for arbitrage on wholesale markets: charging when electricity prices are low (e.g., mid-day in systems with a lot of solar PV) and discharging when the system needs power most (e.g., during evening hours when PV generation is dropping away and demand is picking up). However, generally this use case is far from economically straightforward under current market conditions (D. Chattopadhyay et al. 2019).

This remuneration model is particularly sensitive to wholesale market design, notably pricing during periods of tight generation capacity compared to demand. Introducing capacity remuneration mechanisms that recognize and compensate firm power capacity additions, or removing price caps and introducing administrative scarcity pricing (e.g., via operating reserve demand curves) are options to better align project and system value (IEA 2018a).

### Combining multiple revenue options

A single asset may capture revenues under different arrangements. For example, under certain conditions it is possible to provide system services via a single-buyer contract while also using the asset to reduce VRE imbalances on the spot market or implement arbitrage use cases. It is important to distinguish between use of the same asset under different revenue structures at different times (not usually problematic, but may be hampered

by ill-adapted regulations) or use of the same asset for different purposes simultaneously (which can compromise the ability to deliver certain services reliably).

It can be a challenge to establish a framework in which one asset can access remunerations under different remuneration options. In California, there are proposals for regulations whereby the regulated entities could use storage as grid assets (non-market revenues) while also participating in the wholesale market. The revenues achieved in the market would then be returned to customers (Delgado et al. 2018). However, the complexities of implementing this in practice led this process to be postponed in 2019 (CAISO 2019). Benefit stacking is less complex when single-buyer and multiple buyers/sellers markets are combined. For example, the Hornsdale battery in South Australia uses part of its capacity to perform energy arbitrage on the wholesale market while keeping part of its capacity reserved for frequency control services (AEMO 2018).

There is a link between remuneration structure and the importance of carrying out an assessment of system value: such an assessment is crucial when deciding on the regulatory approval for a non-market remuneration. It can also be important for the single-buyer model to decide cost ceilings for competitive procurement and/or determining the quantity of a specific service that should be procured.

While storage can provide a variety of services, it cannot provide them all at once, and some services are mutually exclusive (i.e., it is not possible to provide firm capacity and frequency response with the same unit of storage capacity). Choosing which suite of services to provide requires understanding possible value streams, and checking these against operational capabilities. Based on this an optimisation can find the best dispatch strategy.

## OWNERSHIP AND OPERATION: DIFFERENT POSSIBLE SETUPS AND REMUNERATION STRUCTURES

It is worth noting that one crucial role of policy, market, and regulatory frameworks concerns the allocation of rents between different actors in the power system, notably customers on the one side and utilities and other companies active in the sector on the other. A project that has a favorable system value brings a net benefit from a total cost perspective—this cost reduction

**Box 4.1****Who Can Own and Operate Storage Assets? Experiences from the European Union****European Union Regulatory Framework**

In the European Union (EU), the Third Energy Package (2009) required the separation or ‘unbundling’ of vertically integrated energy companies into the different stages of energy supply: generation, transmission, distribution, and retail (CEER). Since energy storage was not explicitly mentioned, it was unclear whether it should be considered as a generation or transmission/distribution asset and how the unbundling rules should apply. This uncertainty constituted a major barrier to investment in energy storage and led to a fragmented approach across different Member States.

The newest package of EU energy legislation, the ‘Clean Energy for All Europeans’ Package, finalized in 2019, clarified the ownership and operation of energy storage facilities by regulated entities (transmission system operators, TSOs, and distribution system operators, DSOs)—a major step forward for the energy storage sector in Europe. The Recast Electricity Directive (EC 2018) (Art. 36 and 54) states that in general, TSOs and DSOs should not “own, develop, manage or operate energy storage facilities” (unless these facilities are considered ‘fully integrated network components’\* and the National Regulatory Authority (NRA) has given its approval).

However, regulated entities can be allowed to own and operate energy storage facilities after obtaining a derogation: if there is no market party willing to build a storage device, the NRA may introduce a derogation to allow TSOs and DSOs to own and operate an energy storage facility. The regulated entity must prove that this facility is necessary to ensure efficient, reliable and secure operation of the transmission or distribution system. Moreover, energy storage facilities cannot be used to buy or sell electricity in the electricity markets.

If the derogation is applied, the NRA must run a public consultation at least every five years to assess whether a market party is interested in investing in energy storage facilities. If market parties come forward, the system operator must phase out their activities in energy storage within 18 months (TSOs and DSOs may receive compensation to recover the residual value of their investment in the energy storage facilities).

**Insights and Lessons Learned**

Clarifying who may own and operate energy storage facilities in the context of unbundling is critical for the development of the energy storage sector. In the EU, the discussions on ownership of storage were contentious, and the relevant articles were heavily debated until the final agreement on the Clean Energy Package was reached by the European institutions in early 2019. The final text provides much-needed clarity, but still leaves room for improvement.

For instance, rather than determining which players may own and operate storage facilities in general, it would be easier to consider which entities are allowed to provide specific energy storage applications or services. Applications deemed to be market services, such as arbitrage, could be clearly defined so that only market players be allowed to own or operate energy storage facilities for their provision. The regulatory framework should also clearly allow energy storage facilities to provide applications that fall under the category of infrastructure services (services which are already provided by regulated

*(continued)*

**Box 4.1 (Continued)**

entities using other technologies, for instance by building a line). In situations where market-based service procurement is not feasible, ownership of energy storage by regulated entities (e.g., for the provision of system services) in the absence of competitive supply should be allowed on an exceptional and temporary basis, subject to periodic review.

This approach—reframing the discussion in terms of use cases and related ownership and operation issues, rather than ownership and operation of a storage facility—is a compromise solution that is flexible enough to provide clarity without limiting market growth. It can also allow for new commercial arrangements to emerge. For instance, ‘multi-service business cases’ (arrangements between different market players and, potentially, regulated entities) could enable an energy storage facility to provide both market and regulated services. This would maximize the value of the storage facility to the system and enable regulated entities to make use of energy storage to provide specific services without distorting the market (EASE 2019).

Finally, in addition to clarifying energy storage ownership, it is also important for policymakers to address other principles related to storage and system operators. According to the Clean Energy Package, TSOs and DSOs must consider energy storage in their network planning and are encouraged to move towards market-based tendering of flexibility services as an alternative to grid extension. This is essential to allow energy storage to access more revenue streams, building a more robust business case, and creating a level playing field between the different flexibility options.

*Source:* European Association for Storage of Energy (EASE).

\* Defined in the recast Electricity Directive, (Article 2, para 51) as ‘network components that are integrated in the transmission or distribution system, including storage facility, and are used for the only purpose of ensuring a secure and reliable operation of the transmission or distribution system but not for balancing nor congestion management’. Exemptions to the unbundling requirements (and therefore, restrictions on energy storage ownership) are also possible for small connected systems and small isolated systems (recast Electricity Directive, article 66).

can either increase the profit margin of companies at constant prices for consumers or it can be used to lower costs for customers at constant profitability for companies. As a rule of thumb, frameworks will aim to split benefits between both sides to maintain incentives for companies while also allowing customers to enjoy the benefit of lower costs.

Which type of remuneration can be adopted depends on the market structure of a power system and, most importantly, the ownership rules for flexible resources, including storage. For example, if storage can be owned and operated by a transmission or distribution system operator or a vertically integrated utility, it can be remunerated via a non-market setup. Policymakers face trade-offs when deciding how flexible resources can be remunerated and even within one power system all three different structures can be in place in parallel.

Storage assets can have more value for society if owned and operated by an entity that can tap different value streams. Alternatively, it is possible to co-own the asset to achieve the same effect. For example, a market participant, who can use storage in other commercial activities, such as de-carbonized backup capacity, can tap a value stream that a network operator cannot. Therefore, procuring services can be more efficient for a transmission/distribution company than owning and operating a battery (D. Chattopadhyay et al. 2019).

In the case of a fully vertically integrated utility, for example, it is straightforward to stack benefits, because all cost savings accrue with a single entity. However, this arrangement faces some of the classical problems of regulated monopolies: there is always an information asymmetry between regulators and utilities, which can lead to overinvestments, inefficient operation with few incentives to reduce project costs. Conversely, relying on market based revenues alone—for example, by using

a battery for arbitrage on wholesale markets—does provide strong efficiency incentives, but can expose investors to unduly large risks, which can in turn increase financing costs.

In sum, energy storage may be owned, dispatched, and connected to the grid by different entities. Each entity is impacted by the energy storage system's operation in a different way; similarly, each entity has different interests in when and how the energy storage system can or should be dispatched. This multi-party coordination can result in a complex interaction in which multiple standards and constraints are applied to a single energy storage system (Draft ACES 2019).

Policymakers need to be aware of such trade-offs and navigate them against the backdrop of their specific system context. It is clear that different system stakeholders could have a powerful incentive to lobby governments to move ownership and operation into their domain.

## OVERVIEW OF REMUNERATION OPTIONS FOR DIFFERENT USE CASES

The previous discussion included a number of examples of the application of different types of remuneration to different use cases. The link between use cases and type of remuneration is not automatic—not all use cases can be combined with a given remuneration model. Conversely, certain use cases can only be implemented with some of the remuneration models (Table 4.1). For example, there is generally no market demand (i.e., demand from private market actors) for frequency and voltage control, hence a purely market-based remuneration is not possible here. In this case, system operators frequently act as single buyers for frequency and voltage control in liberalized markets. Conversely, uninterruptible power supply is generally a behind-the-meter solution, procured by customers from private companies. Of course, there can be certain preconditions for a remuneration option to be available for a use case. For example, remunerating VRE generation time shifting on a market basis requires the existence of a wholesale spot market and the ability of a VRE storage operator to access this market and capture more attractive electricity prices via the time shift.

## REQUIREMENTS FOR APPROPRIATE REMUNERATION STRUCTURES AND PROCUREMENT

The three remuneration models imply different priorities for the detailed design of remuneration structures. In the non-market case, the most crucial point is the overall regulatory framework for the utility and a robust cost-benefit assessment before allowing a regulatory pass-through of costs to customers. The broader aspects of monopoly utility regulation are beyond the scope of this report (but see IEA 2016b for details). The basic elements of cost-benefit analysis are discussed in Chapter 4.

In the single-buyer model, the duration of awarded contracts is a critical consideration. For example, a system operator can tender a multi-year contract for system services, which could then be awarded to a company that builds, owns, and operates the plant in order to supply the requested services. The advantage of a long-term setup is that it gives remuneration certainty over a longer period, which can be required to unlock investments. However, this locks in the system operator for a longer period, during which more favorable options may become available. Shorter term contracts have the advantage of effectively keeping the window open for new options. Very short-term contract periods for system services (in some countries this can be as short as a five-minute interval) broaden the base of possible providers, notably demand-side response (DSR) options. While there are many considerations that will go into deciding contract duration, a rule of thumb is that multi-year contracts are better at mobilizing investments in new solutions while short contract periods are better when there is already a pool of possible providers with existing assets.

In the full market setup, contracts, in principle, can be freely negotiated between suppliers and customers. Similar considerations apply regarding contract duration as in the single-buyer case, but there is a higher degree of flexibility.

In the context of developing countries, a very relevant situation is the procurement of flexibility assets via a tender. This can be either the procurement of the physical asset, which then will be owned and operated by the vertically integrated utility (non-market) or it can be a tender for a multi-year contract to provide a certain service (single buyer).

The World Bank has established a set of procurement guidelines with a focus on battery electricity

**TABLE 4.1: Possible Combinations of Use Cases and Remuneration Options**

Use Case	Remuneration Option			Comment
	Non-Market	Single Buyer	Multiple Buyers & Sellers	
<b>Frequency and Voltage Control</b>	Option possible	Option possible	—	Only system operator has demand for frequency and voltage control services. This means either system operator has to procure service (single buyer) or provision is mandated (non-market)
<b>VRE Ramp Control</b>	Option possible	Option possible	Option possible	Can also be required via grid connection code or power purchase agreement
<b>VRE Forecast Error Correction</b>	Option possible	Option possible	Option possible	Can be required implicitly via power purchase agreement
<b>Firm Capacity</b>	Option possible	Option possible	Option possible	Market based remuneration based on capturing very high energy prices during periods of scarcity
<b>VRE Generation Time Shift</b>	Option possible	Option possible	Option possible	Can be incentivised in single buyer model via time -based electricity pricing in PPAs
<b>Black Start</b>	Option possible	Option possible	—	No market demand for such services
<b>Uninterruptible Power Supply</b>	—	Option not possible	Option possible	Customer-side option paid by customer; a market where customers can generally choose from multiple providers
<b>VRE Self-Consumption Optimization</b>	—	—	Option possible	Customer side option, electricity and grid tariffs crucial for determining economic viability
<b>Demand Response</b>	—	Option possible	Option possible	Explicit demand response via single buyer model, implicit demand response via market-based model
<b>Time of Use optimization</b>	—	—	Option possible	Customer side option, electricity and grid tariffs crucial for determining economic viability
<b>Network Charge Reduction</b>	—	Option possible <sup>a</sup>	Option possible	Customer side option, grid tariffs crucial for determining economic viability
<b>Backup Power / Micro Grid Islanding</b>	—	—	Option possible	Customer side option, paid by customer(s)
<b>Grid Congestion Relief</b>	Option possible	Option possible	—	No market demand for such services. Only system operator has demand for such a service
<b>Transmission and Distribution (T&amp;D) Deferral</b>	Option possible	Option possible	—	No market demand for such services. Only grid owners / planners have demand for this option

a. In the U.S., distribution utilities that operate within a reorganized market pay a network charge based on their demand at peak periods throughout the year, which compensates transmission system owners. Several utilities, particularly in the northeast, have begun deploying energy storage to reduce peak demand and reduce these network charges.

Source: Authors.

storage (World Bank 2020a). Tenders should be issued as soon as functional requirements are specified—this includes the identification of the use case—based on a system value assessment as discussed in Chapter 4. Once the system is specified, the actual tender can take place. The tender should cover all relevant requirements, notably:

- Technical requirements: charging and discharging power, usable energy capacity, lifetime of the system (both calendar and cycle lifetime), end-of-life (EOL) criteria, converter requirements, response time, efficiency, and other relevant technical parameters for the BESS
- Physical requirements: operating temperatures, humidity, dimensional restrictions
- Safety requirements
- Cyber security requirements
- Environmental requirements, including decommissioning and EOL disposal
- Regulatory requirements including grid codes
- Relevant standards
- Control requirements, including communication channels and protocols (requirements to communicate with DSO/TSO control systems of active

network management schemes), data and cyber security and communications (of alarms) between subsystems

Further details are beyond the scope of this report, but can be found in the aforementioned document.

While remuneration structures are a crucial component for unlocking investments in flexible resources, including battery electricity storage, they are only one aspect of the broader policy, market, and regulatory framework that is needed for successful deployment.

## OTHER OPTIONS TO ENSURE SUFFICIENT PROJECT VALUE

In addition to remuneration of storage via different contracting arrangements, it is possible to put in place obligations or quotas to ensure deployment of energy storage or other flexibility assets. For example, California introduced a mandate for energy storage systems in 2013 and, since then, multiple jurisdictions in the United States have adopted dedicated policies for storage.<sup>3</sup> The integrated resource plan issued in 2019 in South Africa has a dedicated allocation for storage (SAFR DOE 2019).

While such mandates can be effective in stimulating deployment, volumes and targets must be based on thorough analysis of present and future system needs to ensure customers do not pay for superfluous assets.

Other possible mechanisms are up-front capital grants or tax credits. For example, in the United States, solar PV investment tax credits also apply to storage that is co-located with solar PV and installed at the same time. This can be combined with state level support systems, such as the California Self-Generation Incentive Program. This provides a rebate of up to US\$250/kWh of installed energy capacity for new battery storage systems (Energysage 2020). An investment tax credit for stand-alone storage projects is currently under discussion in the United States.

## TACKLING NON-ECONOMIC BARRIERS

Successful deployment of electricity storage projects depends on the interplay of various policy, market, and regulatory aspects. In addition, different stakeholders need to engage appropriately to create an enabling

environment to unlock investments and real-life projects. The final section of this report discusses these aspects, covering so-called non-economic barriers. These include: definitions and standards; the granting of permits; grid codes; taxes, surcharges and levies. The final subsection highlights who and how to engage in electricity storage deployment.

## Definitions and standards

Legal definitions are fundamental for placing energy storage within an existing policy, market, and regulatory framework. As a resource type in its own right, energy storage must be considered as its own legal and regulatory category and legal definitions should not arbitrarily place storage into existing categories such as generators (Delgado et al. 2018).

For example, the states of Colorado and Nevada in the United States have introduced legislation that prohibits discriminatory rate structures and interconnection policies (PNNL 2020). Europe's recent Clean Energy Package gives storage its own technology neutral legal definition. This is important to allow existing and emerging energy storage technologies to compete on a level playing field. The Clean Energy Package also aims to remove barriers for market participation (as well as for other flexibility options) and requires TSOs/DSOs to consider storage as an alternative for grid reinforcements based on competitive procurement of storage services (see Box 4.1).

Standards and other documents, such as codes and guidelines, that collectively establish criteria by which safety, performance, and reliability can be documented and verified, can have a direct impact on the cost of an energy storage system (ESS) and its installation in terms of material and manpower costs (ACES 2019). Standards are required for ensuring safety of the installation and ensuring reliable performance. In turn, this requires testing and certification procedures that are reflective of real-world operating conditions. Chapter 5 of CIGRE TB provides the main international standards in place, or being developed, related to BESS interoperability and communication and BESS testing and performance measurements. Standards are relevant for manufacturing, installation, and operation in particular to ensure safety of installations.

A new area of standardization relates to cyber security. As energy storage assets become more widespread and better integrated into the electrical grid,

cybersecurity will need to extend to all aspects of the control systems, especially the operation and maintenance monitoring systems that touch on all aspects of the system. This will be of even more importance at those smaller, more remote facilities that do not have a maintenance staff on site (ACES 2019).

## Permitting and grid connection codes

A permit allows a developer to construct, develop, install, operate, and maintain an energy storage project subject to conditions that often require continued compliance while the permit remains in effect. Revisions or other changes to project design may require an amendment to the permit, even if the proposed revision or change does not seem to be material (ACES 2019).

As a new type of power system asset, electricity storage may not have established rules for permitting in place. Under such circumstances, it is important that permitting agencies do not impose excessive requirements on developers. It can be useful, for reference purposes, to propose benchmark processes, maybe borrowed from more standard renewable energy projects (ACES 2019), but these should first be sense checked for their applicability to storage. For example, as electricity storage is unlikely to interfere with bird wildlife, certain environmental strictures could be adapted.

Another relevant area concerns grid connection codes. To ensure proper coordination of all components, a set of rules and specifications needs to be developed and adhered to by all parties. This set of rules is referred to as a grid code. Grid codes cover many aspects of system operation and planning (IRENA 2016). Grid codes may need to be updated to appropriately include electricity storage—in particular battery storage.

The existence of a grid code is not in itself sufficient. Its enforcement is key. The extent to which grid codes are enforced depends on their legal status, which can vary across countries and jurisdictions. In some countries such as Australia, grid codes are mandated and established by law; therefore failure to comply with grid code requirements could result in fines. In some other countries, grid connection codes are not mandated in law; rather they are guidelines and applicable rules for generators connected to the system (IEA 2016a).

Regardless of legal status, there should be a process to verify that generators comply with grid code requirements. Checking and certifying grid code

compliance requires various resources, including technical capacity and legal competence. Ideally, compliance verification should be performed throughout a VRE project, from planning, installation, and commissioning, through to the end of operating life (IEA 2016a).

## Taxes, surcharges, and levies

Storage can both consume electricity and function as a generator. This can lead to a problematic situation where storage assets are obliged to pay taxes, levies, and surcharges for both loads and generation assets. This can lead to double-charging and other unintended consequences. Policymakers and regulators, thus need to review frameworks with a view to establish a level playing field for energy storage projects.

Taxes also provide an opportunity for supporting energy storage projects via tax credits. In the United States, energy storage resources can also benefit from certain federal tax incentives, including accelerated depreciation. Tax rebates or incentive payments exists in eight states in the United States: Arizona, California, Maryland, Massachusetts, New York, Nevada, Vermont, and Virginia (PNNL 2020).

## WHO AND HOW TO ENGAGE IN THE ROLL-OUT OF ENERGY STORAGE TECHNOLOGIES?

Energy storage technologies—notably batteries—bring substantial change for power systems. Using them to their full potential can challenge existing regulatory setups and institutional arrangements that may lead to negative consequences for some stakeholders. In order to maximize benefits, ensure swift progress, and a broad consensus, early and comprehensive stakeholder engagement is crucial. Depending on the different roles of stakeholders, the following points are most relevant:

**Energy ministries** need to articulate an overall strategy for energy storage within the countries' broader energy strategy and policy goals. Setting credible and ambitious targets can provide certainty for the sector and ensure broad engagement. Depending on policy targets, dedicated support instruments can be considered. Ministries and/or energy agencies also play a key role in organizing stakeholder engagement processes and ensuring appropriate funding for regulators,

## Box 4.2

### Australia—Energy Storage Roadmap Preparation

In 2016, Australia launched its Electricity Network Transformation Roadmap identifying the complex challenges facing Australia's electricity system and setting a strategy for the future, as well as a deliverable plan to achieve it. The roadmap, which took two years of collaborative work, details milestones and actions to guide an efficient and timely transformation over the 2017-27 decade with modelling out to 2050.

Energy Networks Australia and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) developed the roadmap together with more than 200 different industry representatives. To advance constructive collaboration between stakeholders, a Customer Engagement Handbook was developed with input from consumer representatives and CSIRO social science experts. The Handbook provides practical, industry-endorsed guidance that supports energy network businesses to foster transparent dialogue with their customers. It identifies meaningful performance measures to assist in tracking engagement performance over time.

The Handbook recognizes that engagement practice and expertise evolve over time and there is important ongoing work that should take place between all participants in the energy system to share experience and local expertise, fostering more efficient and effective engagement practices, and supporting the sustainability of engagement through corporate culture, organizational capability, and increasing engagement based on trust.

*Source:* Authors based on Energy Networks Australia (2016/17).

planners, and permitting administrations. Regional and local policymakers can play an important role, ensuring public support and helping craft policies that can speed up decarbonization strategies and storage deployment in specific contexts (such as islands and isolated areas).

**Regulators** are crucial for levelling the playing field for electricity storage. This includes proactively updating regulations with a view to remove barriers to electricity storage and enabling fair remuneration of services that could be offered by storage. They also have an important role in flagging inconsistencies within policy, market, and regulatory frameworks with a view to update frameworks swiftly.

**System planners** have an important role in assessing the different use cases in which energy storage can help reduce overall system costs. This is likely to require upgrading of planning tools and creating detailed technology databases that include relevant techno-economic characteristics.

**System operators** should balance their obligation to ensure security of supply—which usually implies a more conservative approach—with recognition of the future

contribution that energy storage can bring to meeting systems needs. One important practical element is upgrading prequalification criteria for providing system services in order to level the playing field.

**The permitting process and the entities granting them** are an often overlooked aspect of the project development ecosystem. However, the permit can make the difference between successful implementation and project failure. Prior to implementation, prospective permitting rules should be compared to international practices in advanced jurisdictions with a view to consolidate the number of required permits (a 'one-stop-shop' approach).

**Storage manufacturers** can support successful roll-out in developing countries by considering these countries' specific requirements and adapting product specifications and characteristics in line with countries' needs. Relevant points include ease of transportation and installation, simple maintenance protocols, and resilience under adverse climatic conditions.

**Project developers and investors** can help to create a sustainable market environment by communicating transparently regarding possible shortcomings in the regulatory systems and other ‘on the ground’ experiences. Speed of implementation and a focus on lowest cost should not negatively impact performance and sustainability of installations. Investors can facilitate sustainable deployment by focussing on low-cost financing options and minimizing the cost of capital.

## NOTES

1. However, there exist a variety of ways in which this is implemented in practice with different levels of market competition. In some countries, for example, individual lines can also be built by private companies (following tenders) that may also retain ownership of the assets.
2. Notable exceptions are flexibility/efficiency programs that are offered to customers by a vertically integrated utility. Under such a program, the utility partners with customers and both share the value of the flexibility / efficiency asset.
3. A database of policies for storage in the United States is available at <https://energystorage.pnnl.gov/regulatoryactivities.asp>

## 5 NEXT STEPS FOR POLICYMAKERS AND REGULATORS IN DEVELOPING COUNTRIES

**E**nergy storage deployment is increasing rapidly and this trend is bound to continue. Battery storage use in power systems is accelerating against the backdrop of rapid cost reductions of 85% over the period from 2010 to 2018. While storage is not new in power systems—pumped hydro storage and thermal energy storage have seen significant deployment globally decades ago—recent trends mark the beginning of a new phase, with battery storage seeing widespread use. Battery electricity storage is not a ‘silver bullet’ that can solve all and any challenges in 21<sup>st</sup> century power systems. Nevertheless, storage is opening an increasing number of opportunities for developing countries to meet energy policy objectives at least cost.

Battery storage is particularly well suited for developing countries’ power system needs in the era of large-scale deployment of low-cost VRE in these countries. Developing countries frequently feature weak grids. These are characterised by poor security of supply, driven by a combination of insufficient, unreliable and inflexible generation capacity to meet demand, underdeveloped or nonexistent grid infrastructure, a lack of adequate monitoring and control equipment, and a lack of skilled human resources and adequate maintenance. In this context, batteries can help enhance reliability. Deployed together with VRE, they can help displace costly and polluting generation while increasing security of supply.

Establishing good market, policy, and regulatory frameworks for storage requires understanding costs and system benefits of energy storage. Storage can meet a wide range of use cases. Computer-based modelling tools allow identifying which use cases have higher benefits than cost (i.e., have a high system value). Policy, market, and regulatory frameworks then need to ensure that those use cases are also attractive from a business perspective.

Policy, market, and regulatory frameworks often lack specific provisions for storage. Depending on how it is used, storage can act as a generator, a flexible load, and/or substitute grid infrastructure (by improving the use of existing networks). This versatility challenges existing legal setups, often leading to incomplete and inconsistent frameworks. This means that policymakers and regulators have an important role in adjusting frameworks to make the best of the opportunities storage brings.

- **Policymakers can facilitate sustainable deployment by:**
  - **Adopting a system view on energy storage:** Battery storage changes how power systems need to be best planned and operated. This means that policymakers should adopt a comprehensive approach when adjusting policy, market, and regulatory frameworks. This means less focus on single, high-profile projects and an increased emphasis on establishing a robust framework based on data.
  - **Identify what services are needed—and allow flexibility on how these can be provided:** This report highlights the different use cases needed in power systems. The more clarity there is on what kind of services are needed for the system, the more it is possible to identify the best technology solution to meet this need at least cost. By contrast, trying to push a specific solution or technology as a means in itself can lead to inefficiencies and challenges in meeting actual system needs. In turn, this calls for establishing sufficiently independent (and sufficiently resourced) planning organizations.
  - **Setting credible and ambitious targets:** This can provide certainty for the sector and ensure broad engagement. Depending on policy targets, dedicated support instruments can be considered.

- **Regulators can facilitate sustainable deployment by:**
  - **Taking an enabling approach to technology innovation:** Regulations cannot foresee technology progress and new developments may arise in an area where policy is not fully clear or consistent. Regulators have an important task in ensuring reliability and affordability of the system. This core mission can be compatible with driving innovation by taking a positive view on change to established structures and procedures. Such an innovation friendly approach can help identify how existing rules and regulations can allow for new technologies to be deployed efficiently.
  - **Identifying and highlighting regulatory gaps and inefficiencies:** It is often regulators who see where existing policy, market, and regulatory frameworks are no longer fit for purpose. It is important that regulators are empowered to systematically communicate this knowledge in order to inform policymakers and the general public of what changes are needed. Market rules should be clear about ownership and participation of storage in the market, enabling remuneration in line with the value offered to the system.
  - **Working with government and industry to find new solutions:** Regulators have an interface with both government and industry. This positions them well for also developing new solutions and proposals, which can help to achieve policy objectives via market responses.

Battery storage is a rapidly evolving field and many power systems are currently experiencing the first wave of projects in this area. This means that new challenges and solutions are arising dynamically across a wide

range of jurisdictions and country contexts. International sharing of experiences, of what works and does not work, is particularly valuable in such a situation. Consequently, this report can only be an intermediate step and further work is required. Possible next steps in this area include:

- **Identification of regulatory frameworks and procurement instruments tailored to standard use cases in weak grid contexts:** As more experience is collected, it is very likely that 'typical' application cases can be identified with a more standardized set of remuneration models and wider regulatory specifications. Examples include hybrid VRE plus storage projects with guidelines on how to compare and fairly remunerate projects with different shares of storage, and provide remuneration that secures investments at low cost.
- **Cataloguing non-economic barriers and solution strategies:** As deployment of battery storage becomes more widespread, a more complete picture of the various non-economic barriers can be obtained via surveys with project developers and other relevant stakeholders. Such a survey could help accelerate learning across countries and catalyze uptake of best-practice solutions.
- **Financing instruments for battery storage:** Battery storage requires low-cost financing to deliver electricity services at least cost. Sharing best practices for financing in developing countries is key to fast track uptake and reduce costs.

The Energy Storage Partnership will continue to work on these topics with a view to accelerate the uptake of solutions to provide affordable, reliable, and clean energy for all.

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