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GAUSS
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ELECTRICAL ENERGY STORAGE IN MEXICO

PV + BATTERY STORAGE IN BAJA CALIFORNIA SUR

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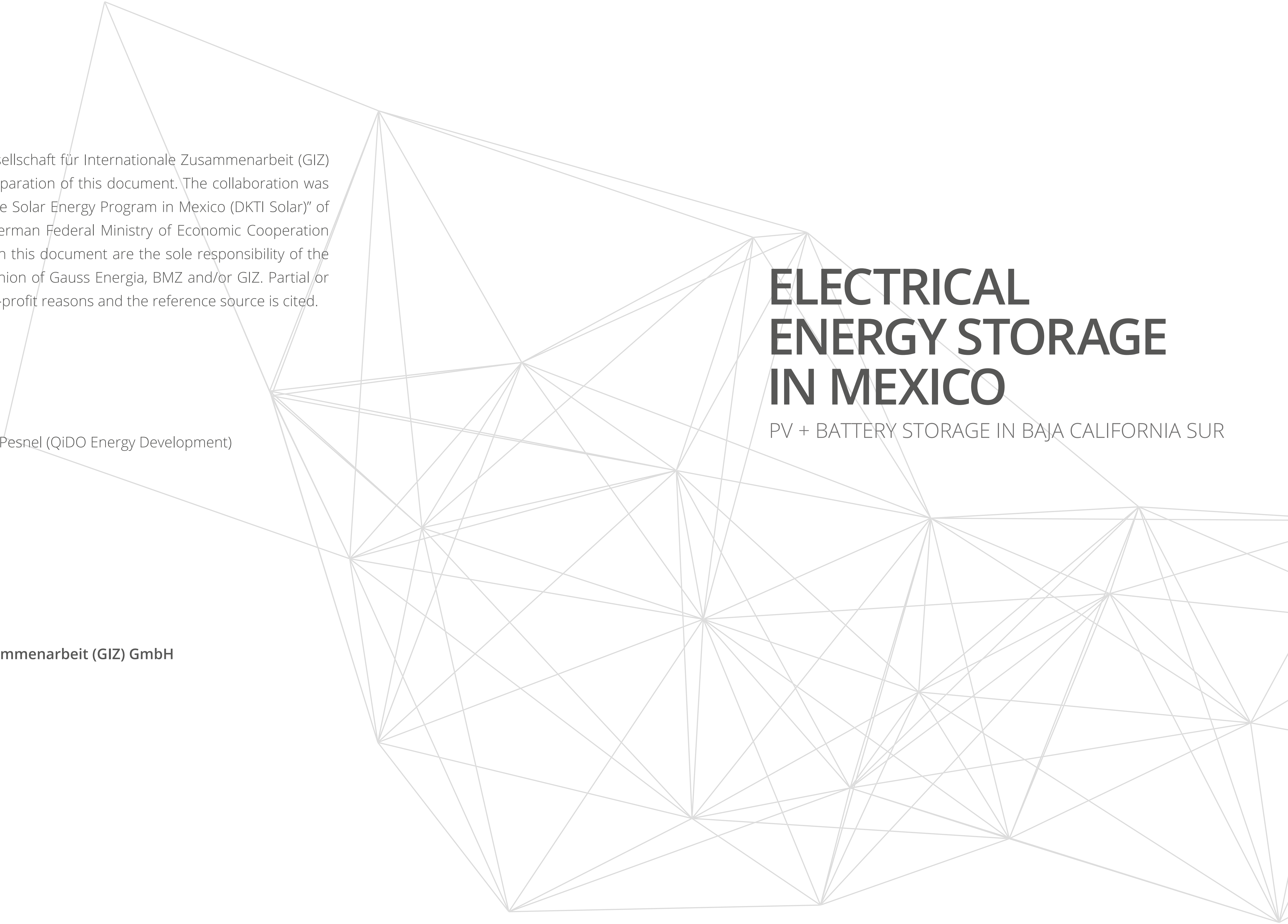

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EXECUTIVE SUMMARY

The present document introduces the results of a study carried out on the technical and commercial prefeasibility of integrating a Battery Energy Storage System (BESS) into an existing PV plant. The PV plant is a 15 MW_{DC} / 10.5 MW_{AC} extension of the existing 30 MW_{AC} Aura Solar 1 PV plant near La Paz in Baja California Sur, Mexico, that is managed by Gauss Energía.

The document is divided in 3 distinctive units, that could in essence be seen as independent from one another.

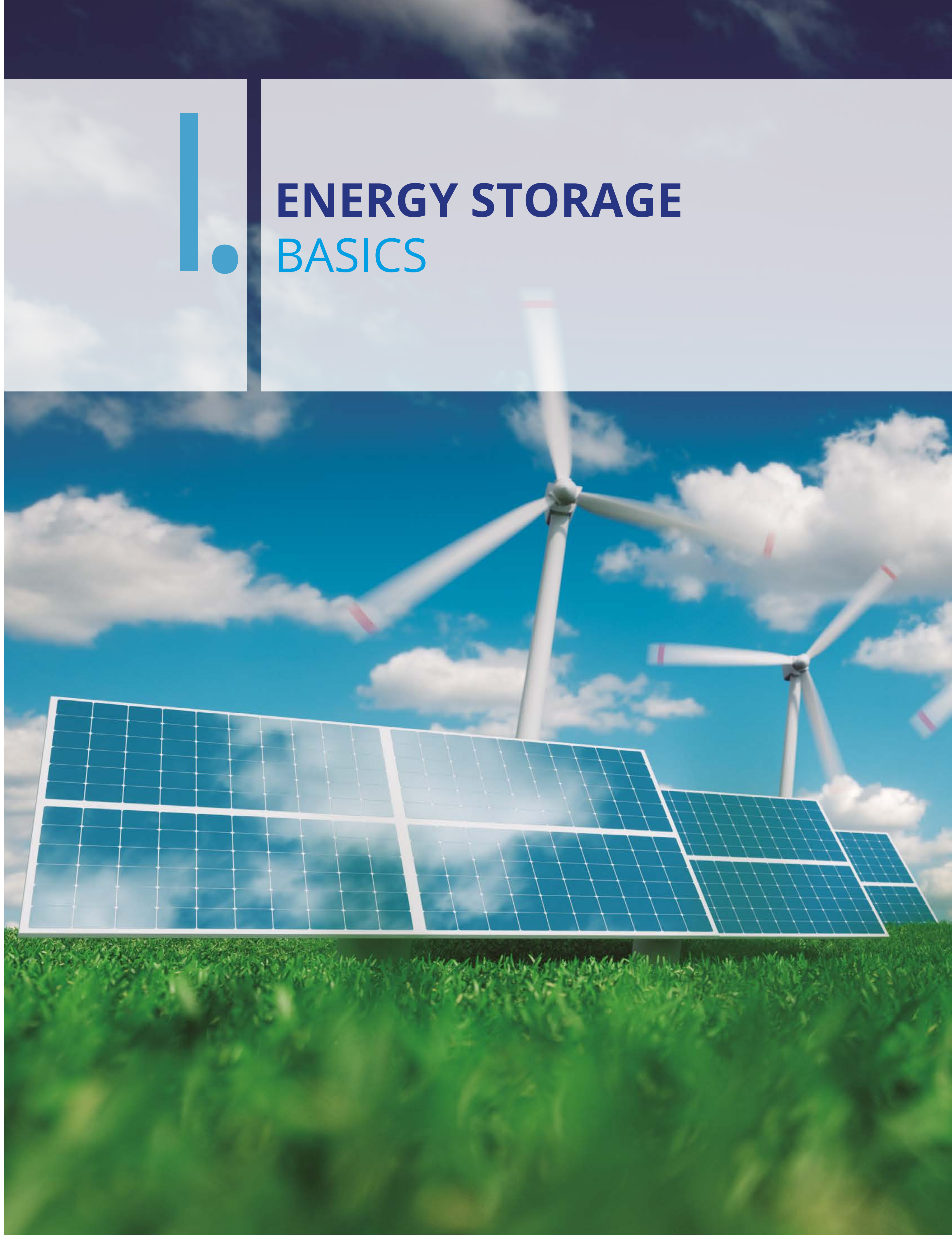
Unit 1 describes and presents some energy storage basics and is divided in three chapters. The first chapter talks about the main ways in which different energy storage systems can be divided. Chapter two details and presents technological and commercial information regarding BESS, the main focus, technology-wise, of the prefeasibility study. Chapter three provides a quick overview of the market situation for BESS.

The second Unit details the Baja California Sur case study and is likewise divided in 3 further chapters (chapters 4 to 6). Chapter four briefly introduces the reader to the case description, including the methodology that is to be followed in order to determine the technical and commercial prefeasibility. Chapter five describes in detail the business models that were analyzed, along with all the main and base assumptions and sources of information that were considered as part of the prefeasibility analysis. Chapter six describes other use-case scenarios for a BESS, specifically for operating a BESS as part of winning bids of Mexico's Long-Term Auctions.

The third and last Unit describes in detail regulatory influences on electric energy storage systems' (EESS) market development. This unit is divided in 5 chapters (chapters 7 to 11). Chapter seven describes the technical challenges that arise when the amount of variable renewable energy in the grid increases, along with solutions that are provided by energy storage systems. Chapter eight describes governmental influences on EESS deployment. Chapter nine describes different reference cases that can be of interest and that help illustrate successful and not-so-successful governmental influences on EESS market development. The reference cases described also draw conclusions that may be of interest to the Mexican case. Chapter 10 briefly describes what could be market prices, based on the current market situation in Mexico that would make BESS financially sound. Chapter 11 closes with calculations and recommendations.

I.

ENERGY STORAGE BASICS



1 CLASSIFICATION CRITERIA

Electrical energy storage systems (EESS) are often entirely and exclusively associated with energy shifting, i.e. the matching of generation with consumption, as their only or principal role in the electric grid. However, these systems are not limited to said application and can provide a broad variety of services.

To distinguish between different EESS and their respective application, a broad range of classification criteria exists. The present document will make use of and expand on the following three classification criteria: *i) by storage duration; ii) by storage application or use case; and, iii) by conversion method and storage medium*

1.1 Storage Duration

Based on their storage duration (alternatively, by their discharge time), EESS can be further classified into: i) short-term; ii) medium-term; and, iii) long-term storage. The typical discharge times, technologies and depth of discharge levels are shown in the table below.

Type	Typical discharge time	Storage technologies	Typical depth of discharge
Short-term	Up to 1 hour	Lithium-Ion batteries Lead-acid batteries Flywheels	1 - 25 % continuously
Medium-term	1 h - 24 h	Lithium-Ion batteries Lead-acid batteries Sodium-sulfur batteries	50 - 100 %
Long-term	1 - 365 days	Pumped hydro (if possible) Thermal storage Power to gas	100 %

Table 1: Overview of storage type categories by discharge duration

Depending on the present and future generation, transmission, distribution and load infrastructure, different energy storage types, with different storage durations will be required in order to ensure a stable, reliable and economic function of the electricity grid. The current main driver for the need for energy storage is the fact that renewable energies in general, and particularly photovoltaic and wind power plants (variable Renewable Energies – vRE), are increasingly entering the electricity market whilst displacing conventional technologies.

A higher renewable energy share in the electricity grid first leads to a lower levelized cost of electricity (LCOE) in the system as shown in the orange "today" curve in Figure 1 below on the left-hand side.[1]

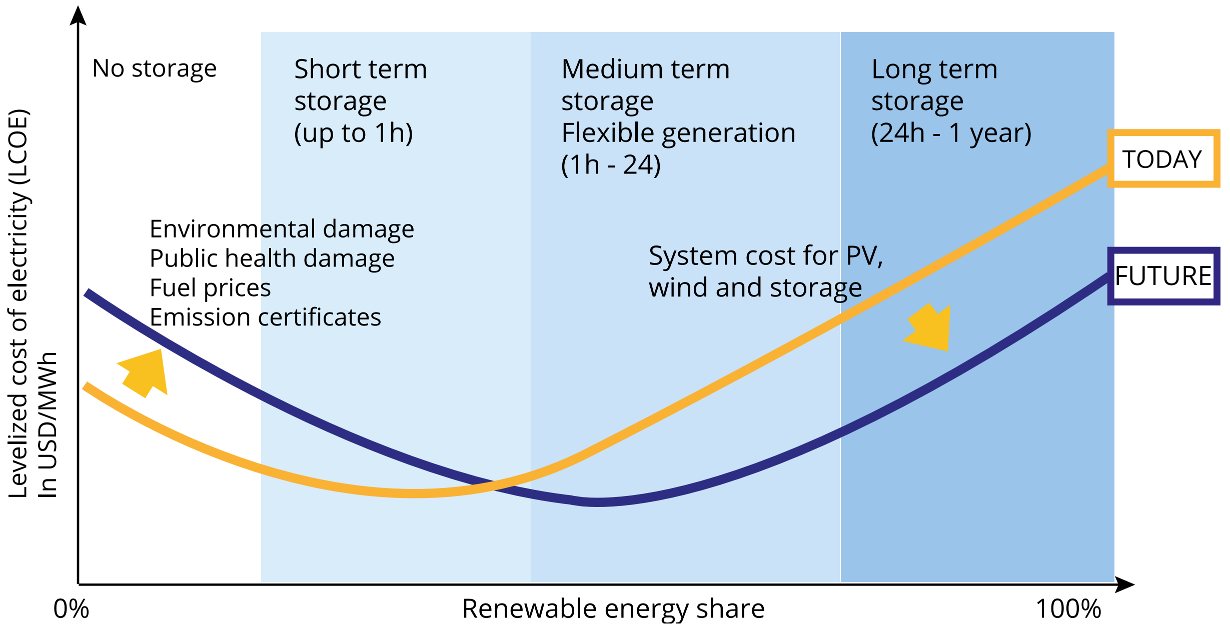


Figure 1: LCOE vs. renewable energy share

However, at a renewable energy share of around 15% - 20%[2], the transient stability of the grid voltage and frequency deteriorates due to:

- Fluctuation of renewable energy feed-in.
- Lack of dynamic speed and accuracy of the generators that supply the residual power, i.e. the difference between the renewable generation and the current load.
- Possible lack of ancillary services provided by the renewable plants.

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[1] The diagram refers to a hypothetical sample case and the actual values of the curve depend strongly on the local conditions of the electricity grid.

[2] In this document, renewable energy share refers to the share from fluctuating renewable energies such as wind and photovoltaics during the course of a year. It does not refer to controllable renewables with an integrated storage reservoir such as hydro power, concentrated solar power and geothermal power. Controllable renewables strongly rely on local circumstances and need to be considered in detail for each specific project. This percentage does not refer to the installed renewable capacity, which is generally much higher than the yearly RE energy share in the system.

The usual first remedy for this is the curtailment of the renewable plants and the demand towards renewable plants to supply ancillary services within their capabilities. However, this remedy is only short term. The usual next step is to employ short term EESS (sometimes in combination with demand side management). These early systems are however not used to shift energy but to stabilize the short-term equilibrium between generation and consumption and to replace the ancillary services that had previously been provided by the synchronous generators of the conventional generation. With this combination, a renewable energy share between 40% and 50% can usually be achieved in a system. At the current cost of generation for renewables, this renewable share often is the economic optimum with the lowest LCOE. This short term EESS is closely related to the discussion about the need for fast frequency response from wind and solar PV plants.

A further increase in the renewable share currently leads to a rise in LCOE because medium term energy storage is required for renewable energy shares above 50%. The increase of renewable energy share means that for a given amount of electricity that is locally consumed, a higher fraction of that electricity is stored in an EESS beforehand. This is because for this share, energy needs to be shifted, e.g. from daytime to nighttime. As the fraction of electricity that is directly consumed decreases and the fraction of electricity that is stored beforehand increases, the impact of the cost of storage per energy throughput (also called levelized cost of storage or LCOS) on the LCOE increases.

For renewable energy shares above 70%, long term storage is required. This is currently only economically feasible for special conditions, e.g. where pumped hydro potential is readily available or where conventional fuel supply is not feasible.

As shown in the blue “future” curve in Figure 1, the economic optimum will gradually move to higher renewable energy shares in the future. The two main drivers for this is an increase in cost for the conventional generation and a decrease in cost for renewable generation and energy storage.

As a final remark for this section, it must be mentioned that the above considerations assume the optimum technical layout and mechanism for an electricity grid. In distributed electricity grids with market mechanisms for electricity and ancillary services, misguided incentives may lead to the fact that certain EESS categories may become economical at lower or higher renewable energy shares (more on this in Section III).

1.2 Storage Application or use case

To help understand the current business models EESS can be operated in, it is helpful to dissect the needs for storage services based on power quality and energy.

The use cases for the energy storage categories for each type of storage system are shown in the table below.

Type[3]	Use case	Benefits
Short-term storage	Virtual inertia[4]	Dynamic stabilization of the grid Replacement of must-run thermal plants
	Fast frequency control[5]	High accuracy frequency stability
	Ramp rate control	Elimination of load and generation active power gradients (e.g. during clouding)
	Reactive power control	Dynamic voltage stabilization Long-term voltage stabilization Optimum use of feeder lines
Medium-term storage	Secondary and tertiary frequency reserve[6]	Long term frequency stability
	Energy shifting	Renewable energy integration <= 70% Replacement of peaker plants
	Congestion management (feed-in and load peak shaving)	Transmission and distribution system deferral
	Black Start / Uninterruptible Power Supply	Improved electricity availability
Long-term storage	Seasonal energy shifting	Renewable energy fraction > 70%

Table 2: Energy storage use cases

1.3 Conversion Method and Storage Medium

Often neglected, storage systems offer different and very distinctive methods on how the electrical energy is stored into the EESS and how it is released. The conversion system categories, however, have a major impact on critical EESS parameters, especially:

- Speed and accuracy of the active and reactive power delivery.
- Overall storage efficiency.
- Dynamic behavior of the EESS.

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[3] See definition from previous section

[4] In traditional electricity grids, the rotating masses of the generators ensure that quick disturbances in the grid can be compensated. With more renewable generation in the grid, this functionality can be provided by energy storage, so the rotating generators do not have to keep running for this.

[5] Fast reaction to guarantee the grid stability in case of major losses of generation. Typically used in periods for 30 seconds up to 15 minutes

[6] Long term reaction guarantees the grid stability; typically used between 15 minutes and 6 hours until reserve plants can be activated

1.3.1 Primary Conversion

For EESS, the current conversion methods can be divided into rotating and non-rotating converters.

Examples of rotating converters are:

- Synchronous generators.
- Directly coupled flywheels.
- Rotating AC-DC and DC-AC converters.[7]

Examples of non-rotating converters are:

- Rectifiers and AC-DC converters to charge batteries.
- DC-AC inverters to feed in the electricity stored in batteries or generated in fuel cells.
- Rectifiers for electrolyzers.

If possible, the conversion to store and release the electrical energy is often combined into one device, as for example in a bidirectional AC/DC power conversion system (PCS) used for battery energy storage systems.

1.3.2 Secondary conversion method / storage medium

Ultimately, energy storage systems (ESS) technologies can be distinguished between different storage media. This is the most obvious and prominent way of distinguishing different ESS technologies. However, for the application of the storage system, this is a property whose influence on the actual operation of the ESS is usually minor compared to the influence of the primary conversion technology. Storage media can be distinguished as shown in the table below.

Storage	Medium examples
Electrical	Capacitors Inductors (esp. supraconducting)
Electrochemical	Lead-Acid batteries Lithium-Ion batteries High-temperature batteries Redox-Flow batteries
Chemical	Hydrogen Methane Synthetic fuels
Mechanical	Flywheels Compressed Air Energy Storage (CAES) Pumped Hydro
Thermal	Conventional thermal (e.g. water) Phase change materials Thermochemical energy storage

Table 3: Overview of storage mediums

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[7] Due to advantages in cost and efficiency, these have been mostly replaced by electronic converters

2 BATTERY ENERGY STORAGE SYSTEMS:

Technologies and commercial information

2.1 General conversion process

In most ESS, two conversion-steps take place both to store the energy and to release the energy according to the diagram below. Therefore, usually four conversion-steps are carried out in a full charge and discharge cycle. A general understanding of these processes helps to understand the major technical advantages and disadvantages of each ESS technology. The steps for the conversion are as follows:

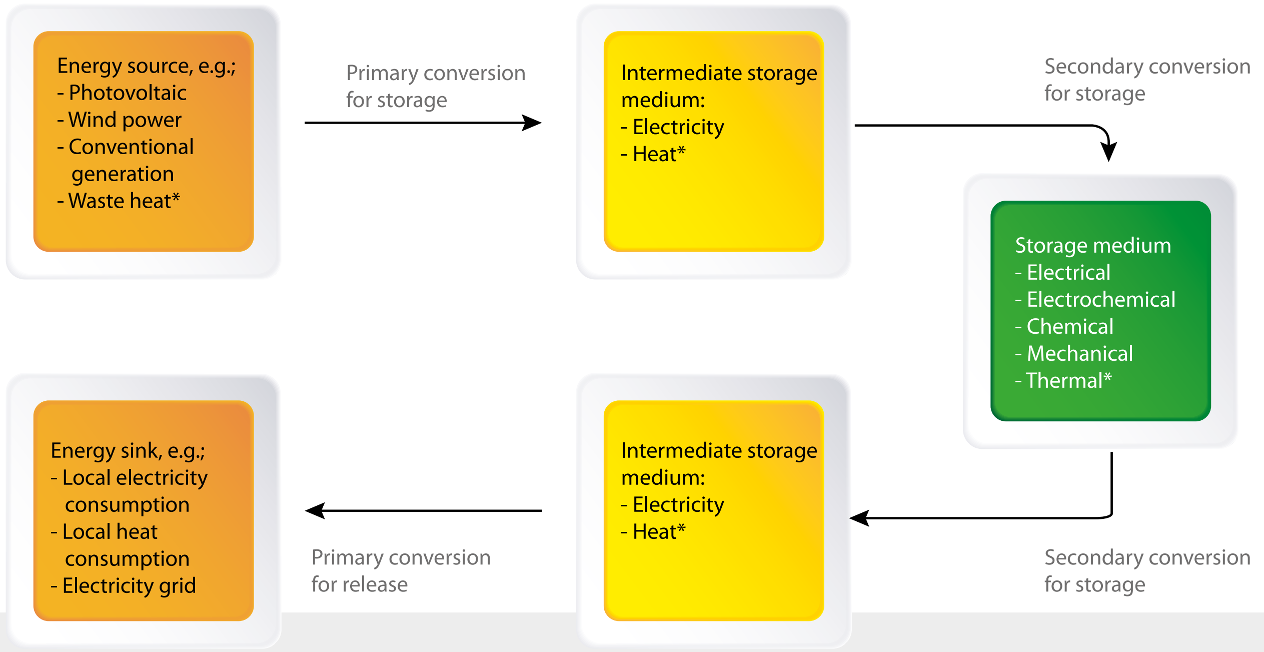

Figure 2: Energy storage conversion steps *: Heat / thermal storage only for reference

1. Conversion of the available primary energy into an energy form that can be stored into the storage medium, e.g. converting the AC voltage from an electricity grid to a DC voltage for battery applications
2. Storage of the converted energy into the storage medium via an external or integrated converter, e.g. using the electrochemical process in a battery as an integrated converter between electrical and electrochemical energy
3. Release of the energy stored into the storage medium via an external or integrated converter, e.g. by discharging the electrochemical energy inside a battery as electrical energy
4. Conversion of the released energy to the desired sink, e.g. converting the DC voltage of the battery to the grid AC voltage.

2.2 BESS characteristics and performance criteria

As described in the previous section, the performance of a BESS does not only depend on the storage medium, but on the design of the entire system. To compare different designs, the characteristics of the BESS solutions can be compared based on different criteria.

2.2.1 Technical Performance

The point of reference for the technical performance criteria listed in the table below is usually the point of common coupling with the electrical grid.

Criterion	Description	Typical values
Possible services	Depends on features of the control system, power and energy	(see 1.2)
C-rate	Ratio between the active power and the energy content of an ESS[8]	0.1 – 4
Cycles[9]	At 100% depth of discharge	500 - 15’000
	At 50% depth of discharge	1’500 - 50’000
	At 10% depth of discharge	2’500 - infinite[10]
Efficiency	Round-trip at nominal power	80% - 85%
Auxiliary consumption	At or near idle mode	0.5% - 1% of P_{nom}[11]
	At or near full power	5% - 10% of P_{nom}
Static accuracy	Difference between the desired and actual value of active and reactive power	2% - 5% of P_{nom}
Reaction speed	Time between receiving a new set point and reaching 90% of this value	0.1s - 5s

Table 4: BESS performance criteria

The tangible effects of these performance criteria for the BESS operation are:

- Poor performance in certain characteristics may lead to the BESS not being suitable for certain use cases.
- Poor performance in certain characteristics may lead to increased costs for electricity due to losses and auxiliary consumption.

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[8] Examples:
a C-rate of 0.5 allows a discharge of the ESS over 2 hours or longer
a C-rate of 1 allows a discharge of the ESS over 1 hour or longer
a C-rate of 2 allows a discharge of the ESS over 30min or longer

[9] See abbreviations and definitions at the end of document for definition. Using an arbitrary definition where end of life is when 80% of the initial capacity remains, see 2.3.2

[10] In these applications, the battery aging is usually dominated by calendaric aging (see section 2.3.2)

[11] Example: A 10 MW BESS with an auxiliary power consumption of 1% of Pnom would consume 10,000 kW * 0.01 = 100 kW in average, i.e. the yearly auxiliary consumption would be 100 kW * 8760 h/a = 876 MWh/a

2.2.2 Commercial Performance

In addition to the technical criteria, BESS can also be compared using commercial criteria as shown in the table below.

Criterion	Description	Typical values
Price per power	Excluding batteries	200 - 300 kUSD/MW
Price per energy	Low end, e.g. lead-acid or cheap Li-Ion, e.g. low-quality LiFePO4	150 - 200 kUSD/MWh
	Average, e.g. Li-Ion (e.g. high-quality LiFePO4, LMO, NMC), NaS, Redox-Flow	250 - 400 kUSD/MWh
	High end, e.g. Lithium titanate	500 - 800 kUSD/MWh
LCOS	See 2.5.1 Excluding electricity and taxes	100 - 500 USD/MWh
Operation and maintenance	Excluding electricity, licensing, taxes etc.	1% - 3% of the initial investment per year

Table 5: BESS commercial criteria

2.2.3 Efficiency Breakdown

The round-trip efficiency of a BESS connected to the medium voltage grid is usually around 80% - 85% at nominal power. The typical drivers for losses and their typical efficiencies excluding the auxiliary consumption are listed in the table below.

Stage	Step	Typical eff.
1: Primary conversion for storage	Transformer medium -> low voltage	98% - 99%
	PCS: rectifier / charger mode	95% - 98%
2: Secondary conversion for storage	Battery charging	97% - 99%
3: Secondary conversion for release	Battery discharging	97% - 99%
4: Primary conversion for release	PCS: inverter mode	97% - 98%
	Transformer low -> medium voltage	98% - 99%

Table 6: Efficiency breakdown

2.3 Battery Technologies

In comparison with other ESSS technologies, batteries show the following characteristics:

- Very high efficiency between 85% - 99% (battery only).
- High levelized cost of storage (LCOS).
- Fast typical response time of 2ms.

2.3.1 Battery Chemistry:

Lead-acid batteries

Lead acid batteries are available in any kind of sizes and a variety of power/energy ratios due to parallel and string connection of the battery cells. In general, the rated energy cannot be used by 100%, but by 60% and less, due to life restrictions. The lower the depth of discharge, the higher the cycle life. Specific relations are given by the manufactures. Lead acid can go up to power/ energy ratios of 3:1
(C-rate of 3) ; standard is 0.05:1 (C-rate of 0.05).

Life of lead acid batteries is defined by the depth of discharge, the ambient temperature and the discharge rate. At temperatures >25°C the life decreases significantly. The lower the depth of discharge (% of rated energy in kWh available to be discharged), the higher the cycle life. Specific relations are given by the manufactures. Life is also strongly dependent on discharge rates, where higher C-rates lead to a highly accelerated aging.

Lithium-Ion batteries

Lithium ion batteries are available in large variety of sizes and power/energy ratios. The main difference being the type of cell used: consumer cells (for laptops etc.) or made from automotive cells. Assembled battery packs are available from consumer size battery packs up to MW scale battery power plants. Power/energy ratios are given by cell type (power cells, energy cells) and by battery pack architecture (string or parallel connection). Lithium ion batteries are used for high power-to-energy applications due to the large variety of power/energy ratios (C-rates 0.2 - 130). Most commercial battery packs operate at 0.5 – 2 C-rates. **For all lithium ion technologies, the complete rated energy can be discharged and charged.**

The life of the battery is the main difference between lithium ion batteries made from consumer cells and those made from automotive cells. Consumer cells are typically designed for shorter lifetimes of 1 - 3 years while the design lifetime of sophisticated automotive cells is between 5 and 10 years. Life is also the main quality characteristic; large variety is available (500 – 15000 cycles of battery life; 2 – 20 years calendar life). Lithium ion batteries are available from different electrode chemistries, with the main differences being the energy density, battery life and safety. The higher the energy density the more critical are battery life and safety.

High-temperature sodium batteries

High temperature batteries are available in modular sizes depending on the storage technologies. Sodium-Nickel-Chloride (also abbreviated NaNiCl or NaNiCl2) batteries from FZSoNick (battery manufacturer formerly known as FIAMM) are available in kW packs and cabinets as well as in 500kW/1MWh containers. Sodium-Sulfur (also abbreviated NaS) batteries from the Japanese manufacturer NGK are available in 500 kW/4MWh compartments but are sold only by MW. Transportation issues may arise with the larger 500 kW modules.

Power/energy ratios are fixed and given by cell technology and by battery pack architecture. In general, FZSoNick batteries are available in a power/energy of 1:2 and NGK batteries in a power/energy ratio of 1:8, with a higher power module (1:3) coming soon.

Both technologies NaS and NaNiCl2 exhibit long lives of at least 15 years without degradation. Life guarantees are available from both suppliers. Life is not dependent on temperature but only on cycling (minimum 5000 without degradation), as both technologies operate at high temperatures. High temperature batteries are ageing while being used. Batteries are self-discharging while being in idle mode due to energy being consumed for battery heating.

Redox-Flow batteries

Despite the theoretical independence in power and energy scaling that is often used to market the advantage of Redox-Flow batteries, manufacturers must provide fixed ratios due to fixed product design. Vanadium-Redox-Batteries (also referred to as VRB) are available from the manufacturer Glex (former Gildemeister energy storage) with 200kW/-400/800/1600kWh and ZnBr from Redflow with 240kW/600kWh.
While electrolyte life is endless, the battery life is restricted due to mechanical damage and decay of pumps, sealing and electrodes. These types of batteries are new in the market and have yet to prove their real life.

Other technologies

Nickel-Cadmium and Nickel-MH have been in use until 2005 - 2010 but were rarely applied for stationary application. They have been replaced in most industrial applications by Lithium-Ion batteries.

A lot of public attention is focused around new materials or even completely new battery technologies promising drastic cuts in cost and dramatic increase in energy and power density. However, these advantages often only have been proven on a laboratory scale, if at all. Caution must be taken since the time to market between the first commercial prototype of a battery chemistry and its common use in the stationary ESS market is between 15 - 25 years. This has for instance been proven with Lithium-Ion and NaS batteries, which both became commercially available in the early 90s, yet their use in large scale commercial projects has only started to grow in the years between 2005 and 2010.

2.3.2 *Battery Aging:*

Effects of battery aging

The effects of battery aging in the technical and commercial performance of stationary BESS can be as following:

- **Loss of capacity:** loss of capacity results in the BESS still being able to fulfill its functionalities, but at a reduced energy capacity. The result of this effect is that the BESS can either discharge its nominal power, but for a shorter duration, or discharge its nominal discharge duration, but at a reduced power. Therefore, the BESS service is still fulfilled, but with a lower degree of performance.
- **Increase of internal cell resistance:** the increase in the internal resistance of the BESS leads to a reduced capability to deliver high powers, especially when discharging at a low state of charge or when charging at a high state of charge. As the typical C-rates used in stationary BESS are between 4 and 0.1 and therefore much lower than in high-power applications such as hybrid vehicle batteries with C-rates up to 40, this effect is only secondary in stationary applications.
- **Loss of safety function:**[12] poorly designed cells may exhibit the loss of safety functions that had been present at the begin of life of the cells. Mature technologies with an appropriate quality management during development, testing and manufacturing should not show a loss of safety functions.

All these factors lead to an end of life of the battery. Conditions for end of life are not fixed but depend on the application. Reasons for an end of life may be:

- The remaining state of health of the battery provides insufficient energy to fulfill the desired service.
- The increased internal resistance of the cells leads to a reduction in active power that is insufficient active power for fast frequency response.
- The loss of safety functions leads to hazards during the BESS operation.

It should however be noticed that, with exception of the loss of safety functions, the BESS may:

- remain in the same application with reduced benefit,
- be used for another application, and
- be refurbished with additional battery power and capacity.

Reasons for battery aging

While battery aging is specific to each battery chemistry, it can generally be examined from two points of view:

- The study regarding the internal electrochemical effects happening inside the battery that cause the aging,
- The study regarding the external influences that cause certain degradation in the battery.

The appropriate countermeasures for the first effect can only be taken by the battery supplier while countermeasures against the second effect must be considered during the system design and operation by the system integrator, the EPC and the BESS operator. As most of these influence factors remain outside the accessibility of the BESS operator, the responsibility for the degradation of the battery performance should always remain with the BESS EPC or battery supplier in the form of a suitable performance guarantee.

The aging influences on batteries can be split into cyclic aging and calendaric aging.

Cyclic aging

The major aging influence of BESS applications with frequent use and high depth of discharge is cyclic aging. In this aging effect, the properties of the cell deteriorate due to the usage. The major influences on cyclic aging for a given cell technology are:

- The number of cycles.
- The depth of discharge: a lower depth of discharge extends the battery lifetime and increases the overall possible energy throughput before reaching end of life. E.g., the aging effect of two consecutive 50% cycles is usually considerably lower than one 100% cycle. This behavior is very similar to an S-N-diagram, also known as Wöhler-curve in mechanical engineering.
- C-rate of charge and discharge: higher C-rates lead to an accelerated cyclic aging. High-power-batteries are more robust towards cyclic aging due to high C-rates.

As explained in section 2.2, cells with up to 15’000 full cycles are commercially available and have proven their performance. However, these cell types are rarely employed due to four reasons:

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[12] These cell safety functions serve as a last measure against hazards from the battery. They are usually only triggered if all super ordinated safety functions such as the SCADA safety, electrical protection and protection by BMS fail. Usually they include protection against: overcharge voltage, deep discharge voltage, internal overpressure, internal cell faults, over temperature and under temperature. Usually, if the cell’s safety functions are triggered, the cell returns to a safe state but cannot be used anymore.

i. Most applications don't require such a cycle number. Fast frequency response BESS almost never carry out full cycles and even a PV peak shifting system with one full cycle per day will only carry out approx. 7500 full cycles over a 20-year lifespan.

ii. The corresponding battery technologies **are considerably more expensive.**

iii. **Calendaric aging (more on this later) may exceed the cyclic aging** therefore leading to an end of life that is not dominated by cyclic aging.

iv. **Current BESS are designed for shorter lifetimes between 5 - 15 years.** Reasons for this are:

   - in a few years, today's BESS will be competing with BESS that have benefitted from the cost degradation that has occurred until then,
   - reduced market risk from future market changes and technological disruptions, and
   - high net present value of an expensive investment that is carried out today vs in the future.

Calendaric aging

Battery cells also degrade when they are not being used or during light cycling. This deterioration is called "calendaric aging". The calendaric aging for a given cell chemistry is mainly dependent on:

- Duration of the period without storage.
- Cell temperature: generally, an increase of 10ºC cuts the calendaric lifetime in half, but temperatures below 10ºC are also detrimental[13].
- State of charge the cell stays in. For most cells a state of charge between 30% and 70% considerably extends the lifetime.

2.3.3 Battery testing

As the battery development lifecycles are much shorter than the desired use span, a long-term testing over 1, 2, 5, 10 or even 20 years is not feasible. Due to this, cell manufacturers usually carry out accelerated aging tests at elevated temperatures and higher C-rates and try to extrapolate the real-world behavior of the cells under normal conditions.

2.3.4 Battery performance warranties

Battery performance guarantees can only reasonably be given by the cell manufacturer as he is the only one to have the required specific knowledge. Three types of performance guarantees are usual in the market:

- **Generic performance warranty only limited to a certain lifetime:** This is the most basic type of performance guarantee where no limitation is given to the operation profile or cycling of the battery. Due to this, this type of guarantee is often limited to six months up to two years and therefore rarely used in the BESS market.
- **Performance warranty with limited energy throughput:** for this application, the overall energy throughput is measured and compared with a limit. As the cell manufacturer usually considers the worst-case condition (i.e. 100% depth of discharge) for this type of warranty, the warranty conditions will be conservative. As an example, a cell manufacturer could limit the performance warranty for a 1 MWh battery to a maximum energy throughput of 5 GWh until the performance guarantee ends. He would then guarantee that until that limit, the battery will retain a state of health of 80% or more. The BESS owner could then decide if he wants to use that battery in 5,000 full 100% depth of discharge cycles or 10,000 50% depth of discharge cycles depending on the desired BESS service.
- **Performance warranty based on depth of discharge and/or specific operational profiles:** In this case, a clause considering the beneficial impact of partial cycles onto the battery lifetime is considered. This type of warranty condition is the most difficult to negotiate but suits the requirement of BESS for ancillary services with low depth of discharge best. Specific operational profiles may for example include a cycle number between certain states of charge or a limited duration the battery can remain within certain state of charge levels.

When negotiating the performance guarantee with a supplier it is important to consider the following points:

- Determine the type of warranty as described above.
- Negotiate what happens when the limits of the performance guarantee have been reached, e.g. if the specified number of cycles has been exceeded
  - **Option 1:** Performance guarantee becomes completely invalid.
  - **Option 2:** An accelerated aging is permitted. This is advantageous for the BESS owner as it does not create an all-or-nothing risk. However, the negotiations and clauses for such a type of warranty are much more complicated.
- Determine the consequence if the battery performs worse than negotiated in the performance warranty. Options are:

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[13] Battery chemistries that are sensitive to extreme temperature or temperature variations are usually operated in closed buildings, containers or enclosures equipped with air conditioning in order to control the ambient temperature they are operated in. For extreme conditions, these air conditioning units increase the auxiliary power consumption and thereby the OpEx of the BESS.

    - penalty payment;
    - complete replacement (unusual); or
    - refurbishment of the existing capacity. This option is the most complicated as the old cells can rarely be connected directly to the added cells. Possible options for this are to install a new PCS or to free the capacity of an existing PCS by distributing a part of the old cells within the existing plant.

- Negotiate side conditions, especially:
    - ambient temperature limits;
    - inclusion or exclusion of technical defects (product warranty - is often much shorter than the performance warranty), and
    - required maintenance intervals and qualification.

2.4 SCADA System

The role of the supervisory control and data acquisition system (SCADA) within a BESS is **much more relevant than in PV and wind power plants.** This is due to the following reasons:

- The quality of the grid service is mainly dependent on the quality of the SCADA algorithms.
- Advanced SCADA systems may carry out simultaneous BESS use cases at once, greatly and drastically improving its business case.
- Through the dispatch of active and reactive power requests between the PCS units, the SCADA has a degree of freedom that is not present in PV and wind plants and that has a considerable impact on:
    - battery aging;
    - losses and auxiliary consumption, and
    - required size of the BESS energy capacity.

As the costs for all effects mentioned above increase with storage size, but the cost for the SCADA system remains roughly the same, the commercial benefit of a sophisticated SCADA grows with the size of the BESS. Furthermore, as all BESS EPCs usually pay the same prices to their major component suppliers, **the performance of the BESS SCADA is a defining factor in gaining a competitive advantage over the competition.**

2.5 General Cost Structure

A sample cost structure for a generic 10 MW / 10 MWh Li-Ion battery system is shown in the figure below.

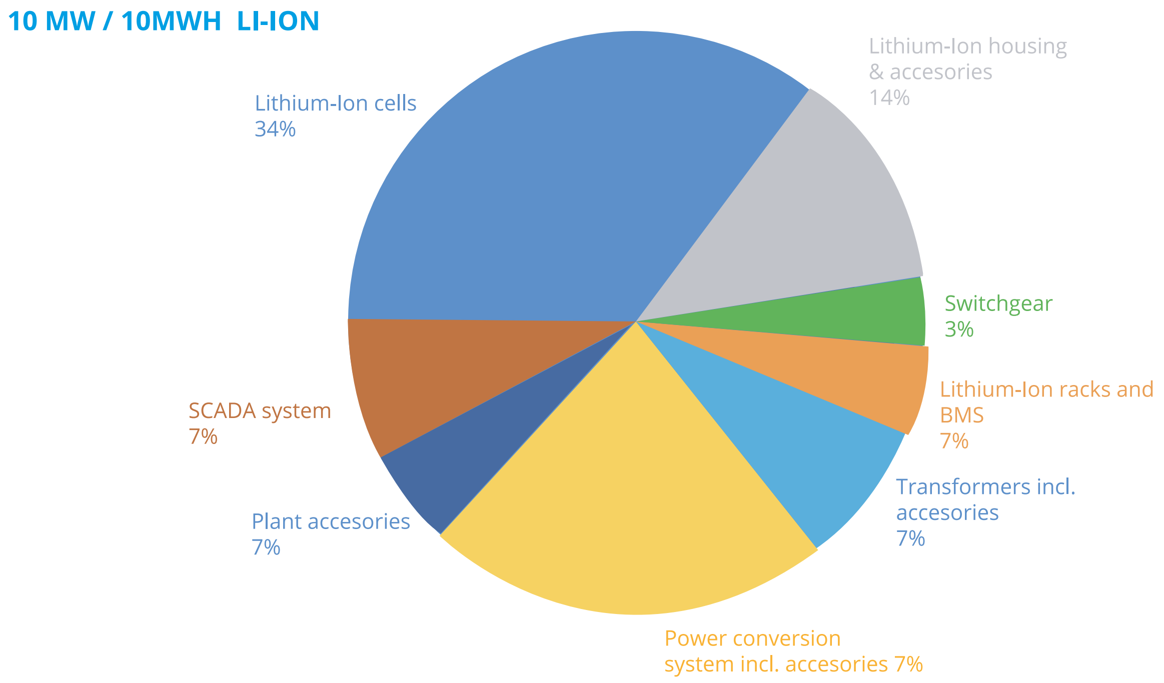

Figure 3: Generic BESS cost structure. Source: IFE Sternkopf

When adjusting this cost share to BESS of different sizes, three different types of cost components need to be considered, as shown in the table below.

Cost types	Examples	
Costs that scale linearly with active power of the BESS. E.g., when doubling the active power of the BESS, the cost for these components will double.	▪ Switchgear ▪ Transformers ▪ Power conversion system	▪ Battery cells, racks, BMS, housing and accessories[14] ▪ Plant accessories: parts of the HVAC system
Costs that scale linearly with the energetic capacity of the BESS. E.g., when doubling the required energy for the BESS, these costs will double	▪ Battery cells, racks, BMs, housing and accessories	▪ Plant accessories: parts related to the battery section
Costs that do not scale or that do not scale linearly	▪ SCADA ▪ General plant accessories ▪ Most engineering tasks during the project	

Table 7: BESS cost scaling

2.5.1 *Levelized cost of storage (LCOS)*

As shown in this section, the properties of different BESS technologies vary widely. To get a good understanding of the commercial performance comparison between the technologies, the levelized cost of storage is a valuable tool. This concept is closely related to the levelized cost of energy in renewables and simply evaluates how much it typically costs in system installation, wear and tear and maintenance to charge and discharge a certain amount of energy, typically a kWh or a MWh.

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[14] Only if the maximum permissible battery C-rate would otherwise be violated. If this is the case, the indication is that a high-power instead of a high-energy battery is required for the desired use case

3 MARKET SITUATION

3.1 BESS Value Chain

The main participants in the value chain of a BESS and their respective contribution are shown in the figure below. Often multiple roles in this chain are taken by one company.

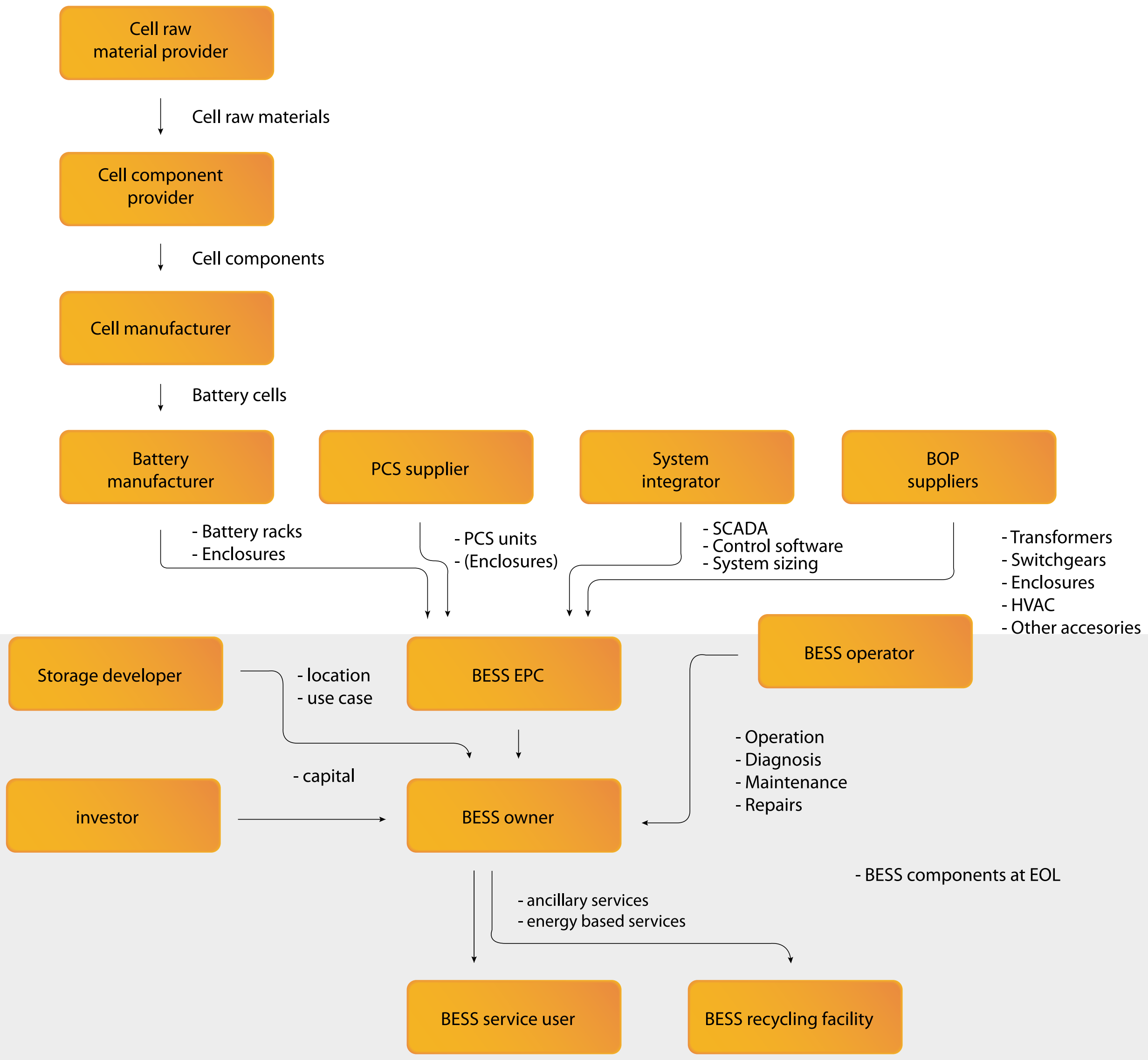

Figure 4: BESS value chain

3.1.1 Sample companies[15]

A brief overview on some sample companies for each position in the value chain is given in the table below.

Company	Country	Battery manuf.	PCS supplier	System integrator	Storage developer	BESSEPC	BESS owner	BESS operator	Investor	BESS service user	BESS recycling	Remarks
BYD	CHN	●										Li-Ion
Samsung SDI	KOR	●										Li-Ion
Hoppecke	GER	●										Lead-acid
FzSoNick	ITA	●										NaNiCl2
NGK	JAP	●										NaS
Gildemeister	AUT	●										Red.-Flow
Tesla / Panasonic	USA	●		●	●	●						Li-Ion
Parker	USA		●									
Sungrow	CHN		●									
Indrivetec	CHE		●									
SMA	GER		●	●								
Greensmith	USA			●	●							→ Wärtsila
Younicos	GER			●	●			●				→ Aggreko
AES	USA				●	●	●	●				
RES	USA				●	●						
GRIPS	GER				●				●			
NYISO	USA									●		
Futama Wind	JAP				●	●	●	●		●		
Umicore	BEL										●	

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[15] BOP manufacturers are not mentioned since they are the same suppliers as for renewable systems

3.1.2 Strengths and weaknesses of companies

The companies in the value chain come from two different points, which create distinctive characteristics that make them advantageous or disadvantageous for certain types of cooperation.

Component suppliers

The first kind of companies comes from the product-based business and views the BESS market as another place to sell their components. Examples of this kind are battery suppliers that open a second market for their automotive cells in the stationary BESS business or PV PCS suppliers that adapted their PCS units for BESS applications.

The advantage of these companies is that they have a deep understanding of the function and design of their components.

The first disadvantage is that they feature a poor understanding of how their components will be used, e.g. a lack of awareness for ancillary service requirement or the lack of understanding that unlike in automotive applications, the charging of the battery is considered a BESS service. The second disadvantage is that these companies have a strong incentive to sell as many of their products as possible instead of providing therequired ESS function with the minimal possible set of equipment.

Grid-focused companies

The second kind of companies come from the grid side and view ESS as another option for flexibilization.

The advantage of these companies is that they have a good understanding of the ESS applications and that they have a commercial incentive to supply the desired ESS service with as little equipment as possible. The disadvantage of cooperating with these companies is that they have a low barrier to enter other parts of the value chain and may thus quickly become competitors.

3.1.3 Battery recycling

Unlike often suggested, technologies exist to recycle all components of a battery cell. However, the value of the materials that can be recovered through recycling sets a practical limit to the recycling quota. The remaining materials are typically incinerated, and the remains are used as fillers for construction materials.

A general listing of materials that are and aren't recycled is shown in the table below.

Cell chemistry	Materials recycled	Materials not recycled
Lead-acid	▪ Lead ▪ Sulfuric acid ▪ Polypropylene housing ▪ Metal conductor	**None**
Lithium-Ion	▪ Aluminum and copper	**Lithium**
	▪ Cobalt ▪ Nickel ▪ Steel (casing)	**Separator** **Electrolyte** **Manganese**

Table 9: Battery recycling

3.2 Ownership models

Currently, there are three general schemes for ESS ownership: i) by plant owner; ii) by grid operator; and, iii) by a third party (TPO).

3.2.1 Ownership by plant owner

The ownership by the plant owner is the straight forward option for ESS ownership. In this model, the owner of a generation plant and/or a load center owns and operates the ESS. Possible commercial motivations for this ownership model are:

- The owner of a PV or wind power plant is required by the grid operator to provide grid services such as fast frequency response and ramp rate control and he determines that an ESS is the most economical option to do so.
- The owner of a PV plant or Wind power plant wants to avoid curtailment.
- The owner of an industrial plant wants to avoid paying excessive grid connection fees for his peak consumption and decides to deliver the peak power through an ESS.
- The owner of an industrial plant wants an uninterruptible electricity supply (UPS) in the case of a grid outage.

3.2.2 Ownership by grid operator

The ownership by the grid operator is often employed if the grid operator wants to mitigate problems caused by renewable energies or by delayed grid extension. Possible commercial motivations for this ownership model are:

- The transmission grid operator wants to provide ancillary services by himself.
- The distribution grid operator wants to deliver peak loads to consumer through ESS instead of extending power lines and transformers.

It must be mentioned **that in most decentralized markets, the grid operator is not allowed to own nor operate generation plants**. Depending on the grid regulations, ESS may or may not be considered as generation plants. Therefore, in a lot of grids, the grid operator is not allowed to own ESS by himself but must contract their services.

3.2.3 Third party ownership (TPO)

In the third-party ownership model, a company takes the role that is comparable to the independent power producer (IPP) in renewable energy projects. The ESS owner then contracts the service to plant owners or grid owners.

Just as in the case of independent power producers for renewable, this model has distinctive advantages:

- The ESS user only must specify his functional requirements towards the storage and does not need any expertise in ESS technology.
- The third-party owner can bundle different standard ESS products with the benefits of volume contracts with suppliers and service personnel.
- The portfolio of the third-party owner is big enough to be bankable and to pass due diligence tests by financial investors thereby attracting capital.

However, the market for ESS TPO is currently mainly developed for services provided to the grid operator via an explicit market scheme, such as for fast frequency response in the electricity grids of the USA and Europe. This situation is comparable to the early days of renewable energy. This is due to the following circumstances:

- There are multitude ESS business cases, most of them are more complicated than the “price per MWh” used for renewable energy contracts.
- Most of the ESS business cases do not generate a direct revenue but instead enable other revenue streams (e.g. by avoiding curtailment or by allowing to connect more renewables than what was possible without ESS).
- ESS is considered a “new” and “immature” technology by investors. This is especially true for the prognosis of battery aging.
- Renewable independent power producers for PV and wind have a lack of knowledge around ESS.

II. BAJA CALIFORNIA SUR CASE STUDY

4

INTRODUCTION

BCS case description

The ***Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)*** in Mexico, in collaboration with Gauss Energía, commissioned a study to determine the commercial feasibility of increasing the capacity of an existing PV plant whilst adding an Energy Storage System (ESS) to store said increment in installed capacity. The PV plant analyzed is a 15 MW_{DC} / 10.5 MW_{AC} extension **(from this point forward referenced as the "new PV plant")** of the existing 30 MW_{AC} Aura Solar 1 PV plant near La Paz in Baja California Sur, Mexico, managed by Gauss Energía. The plant is part of the Baja California Sur Interconnected System, a system isolated from the National Interconnected System.

Figure 5: Satellite image of the area for the planned extension of the Aura Solar 1 PV plant

The study adhered to the following considerations:

1. The current Small Producer[16] regime allows Aura I to supply a maximum capacity of 30 MW_{AC} to the electric grid, delivered through the PV array installed on 80 hectares.
2. For the BESS project, Gauss foresees up to 15MW_{DC} of additional solar PV capacity (this is limited by the already available, but unused land). The envisioned BESS is to be fed by the additional 15MW_{DC} of solar PV capacity, storing the electricity generated during the day for delivery at peak hours by using the existing solar inverters if possible, as shown in the following layout:

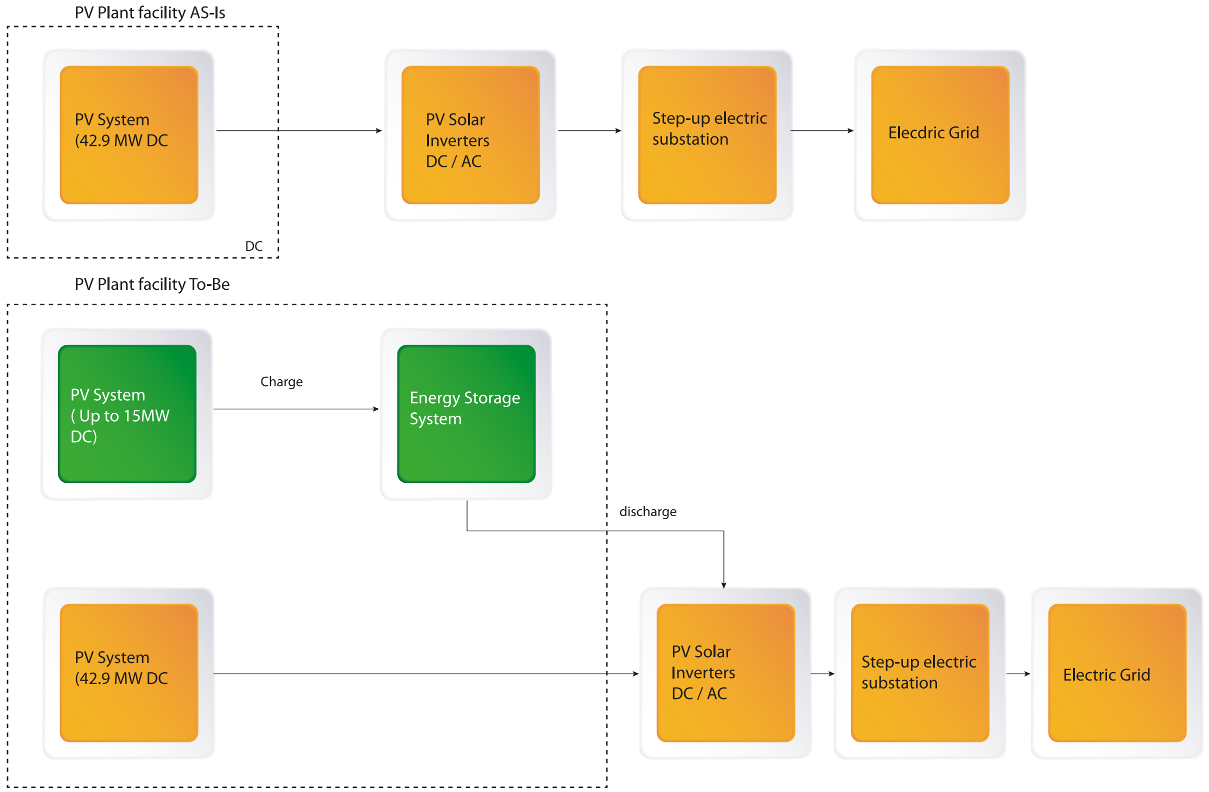

Figure 6: PV Plant as is and as expected after the ESS.

3. The target operation mode should not be mistaken as a peak-shifting nor as an energy arbitrage mode of operation given that the entire production from the 15MW_{DC} expansion should be fed into the BESS to be supplied at hours of high demand at peak hours, while the energy generated from the 30MW_{AC} system is to be fed, in its entirety, when-available to the grid.
4. In the given application, **no thermal sources and sinks are currently planned.** As thermal energy storage is only commercially viable where there is either a thermal source (such as in concentrated solar power / CSP), a thermal sink (such as a district heating) or both, this report will not cover thermal energy storage systems in detail.
5. Only technologies that are currently commercially available with a proven track record will be considered.
6. For further consideration, **this report will focus on Battery Energy Storage Systems (BESS)** as the most sensible technology for the application. Firstly, this is due to the widespread common use and technological proliferation of these technologies allowing to pass a commercial due diligence check. Secondly, this technology can be erected in most ambient conditions reducing the required background checks of the location and on-site-assessments.

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[16] According to article 36, section IV, of the Electrical Energy Public Service Act.

The purpose of adding a BESS is to generate additional revenue by:

- Storing new energy that would otherwise need to be curtailed because of the current feed-in limit of 30 MW, and selling this energy at a later time, at higher prices in the evening.
- Adjusting the hourly delivery of the PV plant to the day-ahead forecast with a maximum error of +- 5% in order to benefit from a higher remuneration factor applied below the local marginal pricing
- (i.e 98% factor vs 95% otherwise applied to forecasts ranging out of +-5% of uncertainty) Any other sources of additional revenue that may be realized based on the applicable legal and regulatory framework.

For this analysis, the following steps were carried out:

1. Identify all use cases applicable to Aura Solar I with regards to BESS based on its legal and regulatory framework centered around the Electrical Energy Public Service Act (LSPEE).
2. Once the sources have been identified, determine the optimum operational strategy to generate the maximum revenue from each BESS use case under the given market conditions.
3. Analyze the commercially optimum BESS active power and nominal energy configuration, within ranges up to 15 MW and 100 MWh.
4. Financial modeling and sensitivity analysis of the three selected BESS technologies.

Chapter six analyzes the feasibility of operating BESS as part of Long-term Auctions in Mexico based on the services that these systems are able to provide and, on the auctions' legal and regulatory framework.

5

BUSINESS MODELS

Technically feasible services

The goal of the present chapter is to provide the reader with a general overview of the service or services that are commercially and technically feasible to provide with the combination of the new 15 MW_{DC} PV expansion plant and the planned storage system.

Under the LSPEE, five use-cases were identified as viable sources of income for the planned BESS + solar PV setup:

- Energy trading with 100% energy storage: any electricity generated from the new PV plant ($15MW_{DC}$ expansion) will be stored directly in the BESS and later sold under favorable PML market conditions. I.e. no energy from the new PV may be directly sold to the PML market (under the Small Producer scheme, the plant sells its energy at a discounted market price CTCP / PML).
- Energy trading with mixed revenue: If the overall generation of the existing PV plant and the new PV plant is below 30 MW, this energy is directly sold to the PML market. If the generation exceeds 30 MW, the surplus energy is stored into the BESS and later sold under favorable PML market conditions. Both cases pursuant to the underlying PPA conditions.

- Curtailment avoidance: When the grid operator CENACE limits the permissible feed-in, the surplus energy will be fed into the BESS and released as normal supply as soon as the PML market price exceeds the estimated levelized cost of storage (LCOS).
- Maximized pricing factor resulting from an accuracy of forecast within +/- 5%. The capability of the BESS to import and export active power is used to adjust the output of the old and new PV plants to the output that was submitted to the grid operator CENACE as a forecast.
- Ancillary services: The capability of the BESS to import and export active power and reactive power is used to generate additional revenue from the ancillary services market.

For each use case, an explanation on the rationale of the storage dispatch is given. Based on this, a calculation for the estimated costs and revenues for these use cases is provided. The results from these calculations are also used to determine major influences on potential upside and downside scenarios to show risks and opportunities.

5.1 Base assumptions

5.1.1 *Storage Design*

To justify the assumptions and calculations employed, a few best practices from BESS design are followed. These best practices are described in the three following subsections.

Storage size

If the generation cost of the source the BESS is charged from is much lower than the LCOS of the BESS, then the **storage system is usually undersized**, i.e. it is intentional that a considerable portion of the generated energy may be curtailed occasionally because the BESS is fully charged. The goal of this is to ensure that the BESS is used as often as possible during its lifetime. A general rule of thumb is that an optimum economic operation for medium term storage requires **at least 100 to 200 cycles at full depth of discharge in every year.** Otherwise, if the BESS storage usage is too low, the calendaric aging exceeds the cyclic aging and the LCOS increases significantly.[17]

Storage efficiency

If the generation cost of the source the BESS is charged from is much lower than the LCOS of the BESS, then BESS technologies with lower LCOS and lower efficiencies are preferred before BESS technologies with higher LCOS and higher efficiencies. This, due to the fact that with generation technologies permitting lower generation costs, the ratio of cost lost due to efficiency losses vs. the LCOS decreases. An extreme example of this concept is excess energy that is curtailed due to lack of demand or due to grid capacity: the commercial value of this energy is just the marginal cost for wear and tear. In wind power plants and even more in PV power plants, that marginal cost is near zero. At this cost, increased losses from a storage with lower LCOS are less significant commercially. However, this selection is often restrained by the commercially available BESS technologies for the given application.

Storage life

The general approach is to match a storage technology with a use case where the BESS will likely reach its end of life condition around the time of the commercial consideration. This time span of commercial consideration is currently usually chosen to be around 10 - 15 years. Shorter lifetimes do not justify the required project overhead and longer lifetimes increase the technical and commercial risks of the project. Therefore, the projected storage lifetime is often shorter than in wind and PV. An exception is if the operation of the BESS is tied to the PPA the wind or PV plant is operated under, e.g. because ramp rate control or fast frequency response must be delivered. In this case, the storage lifetime is usually chosen to be equal to the PV or wind lifetime dictated by the PPA duration.

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[17] This is also the reason why seasonal storage where the ESS is not used all year long but only during specific moments of the year is rarely economical: the costs due to calendaric aging of the ESS cannot justify the small revenue of 1 - 20 cycles per year.

5.1.2 *Cost of storage estimation*

To determine the estimated costs and revenues of the use cases, the preferred method is to carry out the calculations without using any assumptions on the actual storage power and energy to give a comparable overview. The common method for this is to use the levelized cost of storage (LCOS) approach, where a cost is assigned to storing and releasing a defined amount of energy (e.g. one kWh or one MWh) in a certain application without consideration of the actual size of the ESS.

Cost modeling

The costs are modeled considering these system costs:

- LCOS: see next section
- Generation costs (PV): care must be given not to double count this cost with the cost for ESS charging. Common LCOS analysis may contain a fraction of the cost used to charge the ESS. If this is the case, these costs need to be deducted from the LCOS if they are considered in the financial calculations.
- Costs due to storage losses.
- Taxes: not considered in this study.
- Licensing fees: not considered in this study.

LCOS modeling

To achieve this goal, levelized cost of storage (LCOS) is used as the main tool. Previous experience and literature (such as [4] Lazard 2016 - Lazard's levelized cost of storage Rev. 2.0) is used to determine what it costs to charge and discharge a specific amount of energy. For this it is necessary to determine an estimated depth of discharge (DOD) and number of cycles per day or year. From these numbers, comparable use cases from other projects can be used to determine the aging costs due to cyclic and calendaric aging. Care must be given to use comparable C-rates, DOD and cycle numbers.

5.1.3 *Revenue modeling*

The total revenue is modeled based on the potential revenue from the corresponding market at the given time. As different revenue models are used for each use case, in the following sections they are explained in detail.

5.2 Analysis

In this section, for each use case, the conditions, methodology and – if applicable – corresponding estimated costs, revenues and technical[18] profits are explained.

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[18] Technical profits only consider the difference between revenue from selling at PML and cost of generation from the PV and ESS, without any other non-technical factors such as financial or commercial costs.

5.2.1 *Use case 1: Energy trading with 100% energy storage*

For this use case, it is assumed that the BESS will be the only sink the new 15 MW PV expansion plant feeds. The electricity will only be sold at the PML market from the BESS.

Conditions

The following costs and revenues are considered:

- Revenue: selling energy to the PML market at the maximized price for accurate forecast at a level of 98% of the current merit order market price.
- Cost: Energy used for ESS charging, losses and curtailment is priced at the generation cost of the PV plant.
- Cost: LCOS cost is assumed according to generic LCOS aging cost for comparable applications.

PML market data

To determine if this mode of operation is feasible, the PML market price for the Olas Altas node for 2016 and 2017 has been analyzed. For the first analysis, it is assumed that a direct market participation would allow to earn this price through the selling of the energy. This analysis must be taken into consideration with care since the PML market is currently only operative for a little more than a year and might not have settled with stable market conditions yet. The prices since establishing the market are shown in the figure below.

In the following section, the price levels and their hourly distribution are analyzed. This information is then used to determine whether the PML price follows characteristic patterns.

These patterns and their price data are used in the later sections to estimate possible operation rationale for ESS systems.

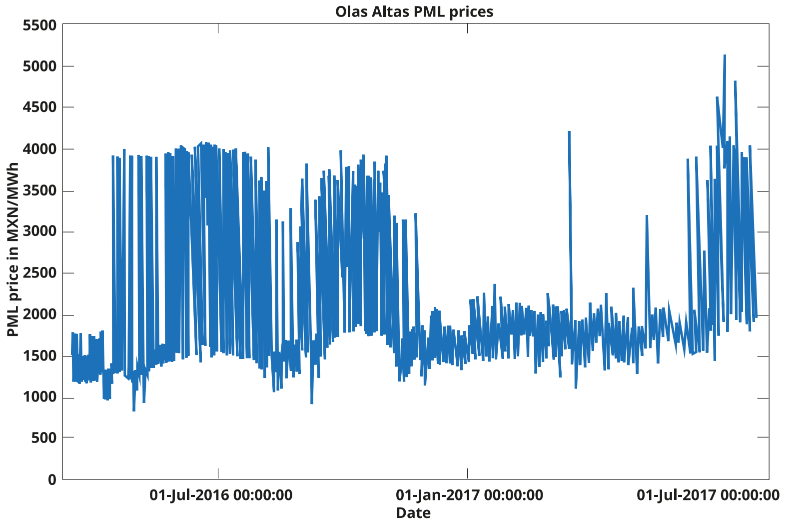

Figure 7: Baja California Sur grid PML market data for Olas Altas node

As another major fossil power plant entered operation in the BCS grid in fall of 2016, resulting in a drop of PML prices, market conditions after this introduction cannot be aggregated with the previous market conditions for conducting a sound analysis.

Therefore, only 2017 market data will be considered in the following analysis.

It was found that there are periods with low market prices between 1500 - 2500 MXN/MWh and with high market prices between 3500 - 5500 MXN/MWh. Market prices between 2500 MXN/MWh and 3500 MXN/MWh are rarely seen. The distribution of prices is shown below.

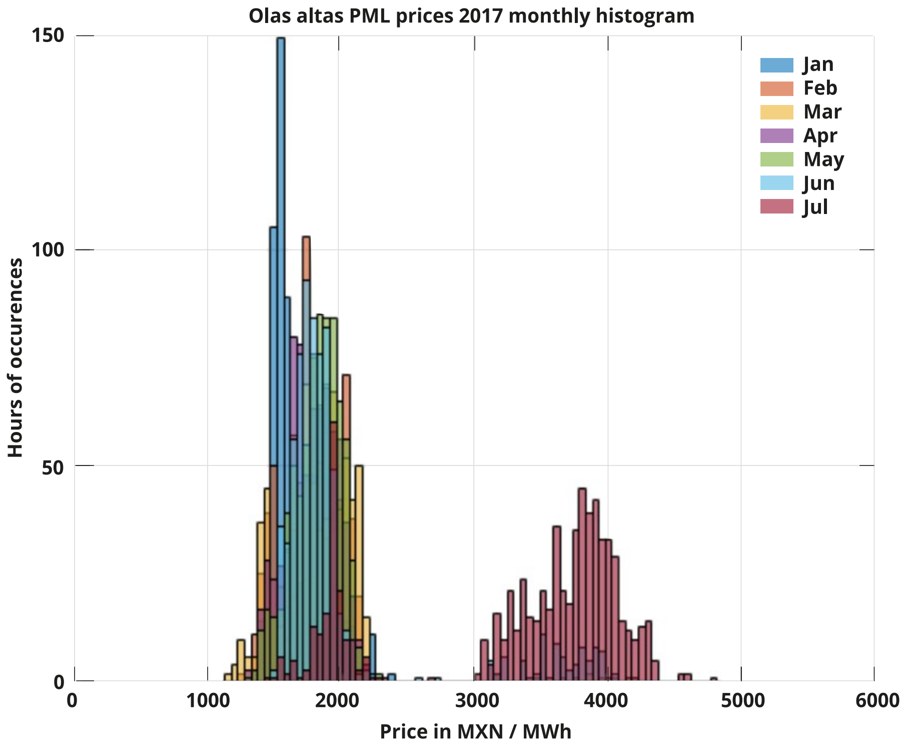

Figure 8: PML price histogram for Baja California Sur grid for Olas Altas in 2017

In general, high PML prices only occur in summer. This price characteristic matches the behavior observed by other market experts, too. The likely reason for this is that during the lower electricity demand in the winter months, only generation plants with lower marginal costs win within the market. In the case of the Baja California Sur (BCS) grid, these are probably heavy fuel oil power plants. When the demand is higher, notably in the summer months, plants with higher marginal costs get their bids accepted in the market and the overall market price quickly rises. For the BCS grid, these are probably turbogas power plants currently being fueled by diesel.

Pattern analysis of PML price profiles

When analyzing the daily profiles, three distinctive patterns of days can be seen:

- "Low PML price days": Days with overall low market prices of less than 2500 MXN/MWh - 172 of the 212 first days of 2017
- "High PML price days": Days with overall high market prices of 3500 MXN/MWh and upwards - 9 of the 212 first days of 2017
- "Fluctuating price days": Days with market prices of less than 2500 MXN/MWh and more than 3500 MXN/MWh in the same day - 31 of the first 212 days of 2017. In these days, the low market prices usually occur between morning and midday and the high prices occur in the afternoon and night. However, this distribution is not equal on all days but may be shifted by various hours.

The overlay of the daily price profiles for these day categories is shown in the figures below.

In 2017, High and Fluctuating price days only occurred starting in July. This is likely linked to increased energy demand in the summer months. Other correlations of PML price day types (e.g. correlation with certain weekdays) have not been observed.

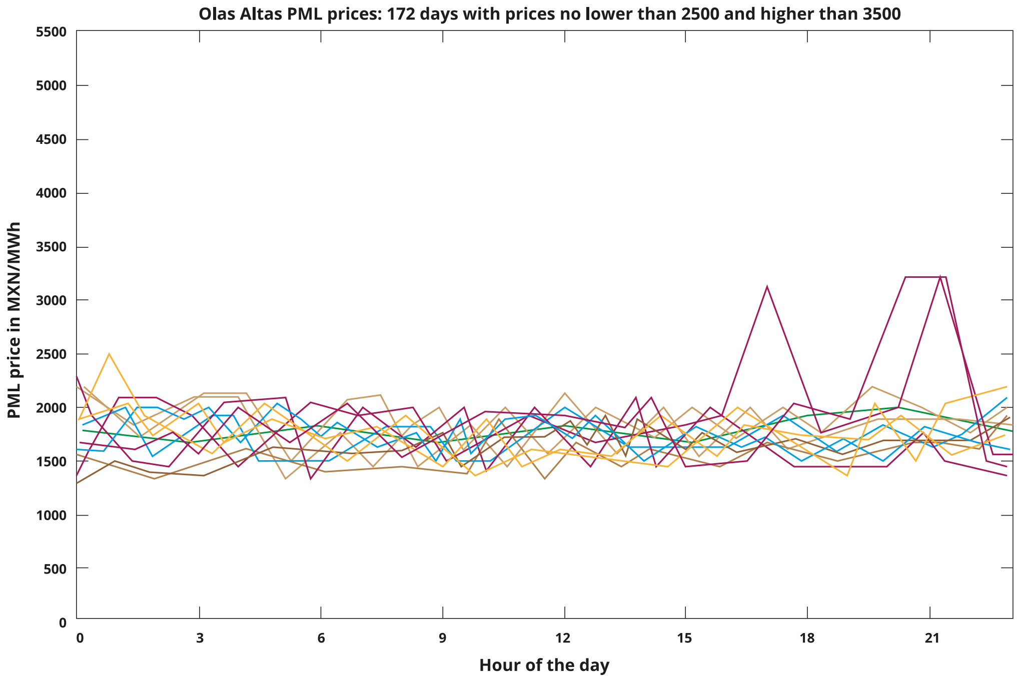

Figure 9: PML low price profile days

Figure 10: PML high price profile days

Figure 11: PML fluctuating price profile days

Rationale

The rationale is to charge the BESS with all the energy available from the 15 MW PV expansion plant (whenever available), unless the BESS is fully charged. If the BESS is fully charged, the excess energy is curtailed. The charging logic is shown in the figure below.

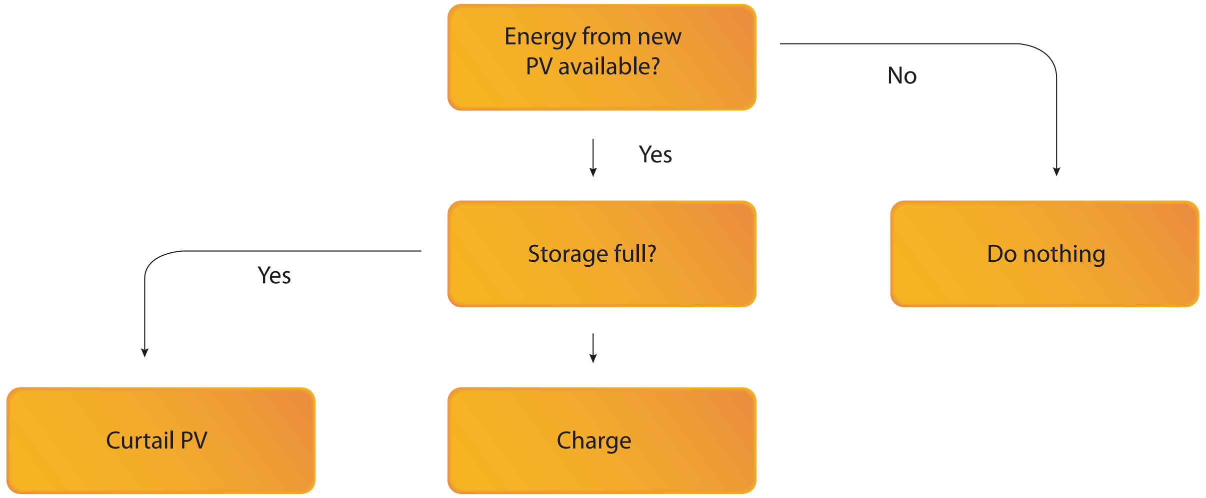

Figure 12: Rationale for charging the BESS for energy trading when storing 100% of the PV energy

The rationale for discharging the BESS is to sell energy to the PML market during target hours only if the PML market price exceeds the combined marginal costs of the PV generation used to charge the BESS and the LCOS due to cyclic aging of the BESS. If the PML market price is lower than these marginal costs, the energy stored in the BESS would not be sold because the battery aging cost would be higher than the potential revenue thereby causing economical loss. The discharging logic is shown in the figure below.

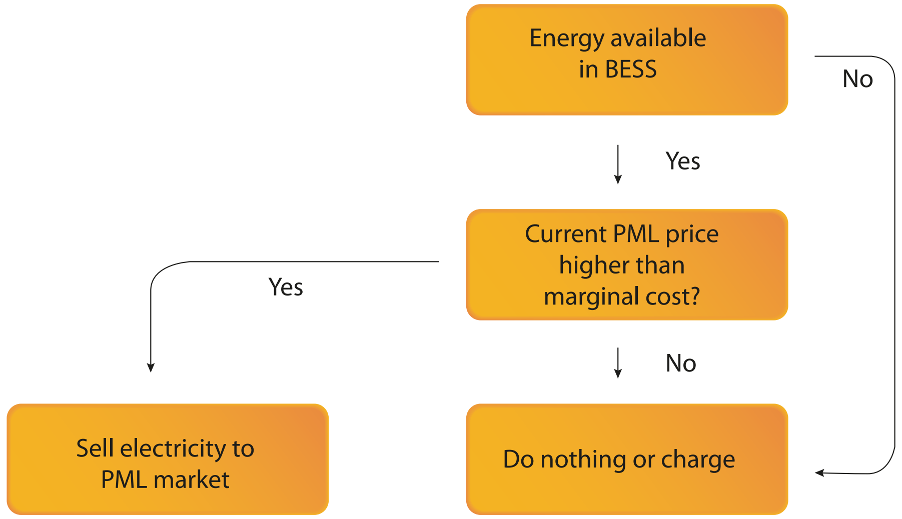

Figure 13: Rationale for discharging the BESS for energy trading

Calculations

With the above market data and appropriate technical and cost assumptions for the BESS, various calculations were carried out to determine if the use case is commercially attractive under three assumed scenarios: Pessimistic, Realistic and Optimistic. A brief overview over the scenarios is given in the table below.

Assumptions	Pessimistic	Realistic	Optimistic	Unit
Days with high PML prices in the evening / night	**90**	**120**	**180**	**days/year**
Exchange rate USD - MXN	**17.00**	**17.00**	**17.00**	**MXN/US$**
Generation cost from PV	**1018**	**1018**	**1018**	**MXN/MWh**
Average revenue at high PML price periods	**4000**	**4200**	**4400**	**MXN/MWh**
Storage efficiency	**85%**	**85%**	**85%**	
Yearly energy production from extended PV plant	**27 869**	**27 869**	**27 869**	**MWh/year**
Application specific LCOS	**171**	**171**	**171**	**US$/MWh**
LCOS scaling	**110%**	**100%**	**90%**	
Fraction of PV curtailment by undersized storage	**10%**	**10%**	**10%**	

Table 10: Use case 1: energy trading with 100% storage: Assumptions and profitability

The assumptions for the days with high PML prices were extracted from the general observations of the PML prices performed in section 5.2.1.

The assumption for the levelized cost of storage were obtained from [4] Lazard 2016 - Lazard's levelized cost of storage Rev. 2.0. As the LCOS from the source material are given is US$/MWh, this value is used as an assumption and converted through the US$ to MXN exchange rate given in the table above. The assumed scenario from this report was peak shaving with low-end lithium ion batteries including capital cost and O&M. Charging costs have not been included in this value since they are already considered in the present calculation as generation costs from PV. Taxes have not been included in the technical cost analysis. The assumed efficiency was chosen according to the information found in section 2.2.3. The feasible LCOS scaling is determined based on the experience of price variations from existing BESS projects. The production of the extended PV plant section was estimated by scaling down the production of the existing plant to a 15 MW_{DC} plant.

Results

The resulting commercial losses and revenues for the Pessimistic, Realistic and Optimistic scenario are shown in the table below.

Assumptions	Pessimistic	Realistic	Optimistic	Unit
Fraction of PV curtailment due to low PML price	75%	67%	51%	
Losses from curtailed energy	-869	-785	-618	MXN/MWh_{PV}
Profit by delayed selling	-120[19]	-81	-43	MXN/MWh_{PV}
Total profit per MWh from PV	-989	-866	-575	MXN/MWh_{PV}
Result: Profit per year	**-27,561,999**	**-24,134,167**	**-16,024,418**	**MXN/year**

Table 11: Use case 1: energy trading with 100% storage: results

The combination of PV and the BESS did not return any positive outlook for profit in this use case. The main reasons for this result being:

- Due to the limited occurrence of days with high PML price, the PV plant and the BESS were rarely selling electricity to the PML market. Therefore, a lot of PV energy was curtailed due to the BESS not being discharged in evenings due to low PML prices.
- The rare selling of electricity results in a poor storage usage, therefore the effects of calendaric aging are likely to dominate the storage costs. Unlike cyclic aging, calendaric aging is a mechanism that doesn't return any revenue on its costs.

Therefore, it appears unattractive to use the new PV extension plant and the BESS in this use case.

As an alternative to the lithium ion batteries, thermal storage was considered as well. For thermal storage, the reduced LCOS of 155 US$/MWh could not compensate for the reduction in revenue due to energy lost through the assumed thermal storage efficiency of 50%. This was true for the Pessimistic, Realistic and Optimistic case.

Nonetheless, the analysis of this scenario **showed that, when operated, the BESS is likely able to generate profit. The main losses result from the PV curtailment.** Therefore, an operation rationale to decrease the curtailment will be analyzed in the next section.

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[19] Under pessimistic and realistic assumptions, the costs for generation from PV, storage losses and storage aging exceed the pessimistic assumption on revenue. Therefore, it is not possible to sell stored energy profitably in this scenario.

5.2.2 Use case 2: Energy trading with mixed revenue

In this use case, and considering the conclusion of the previous use case, the additional energy generated from the new 15 MW PV extension plant is directly fed into the grid until the overall limit of 30 MW is reached. Only after reaching this limit, the excess energy will be stored in the BESS for delayed sale during high PML price periods.

Conditions

In addition to the previous use case, the following revenues are considered:

- Revenue from direct sale of PV energy produced by the new PV plant extension.
- The PML market conditions are assumed to be identical to the previous use case.

Rationale

The rationale for charging the BESS is shown in the figure below.

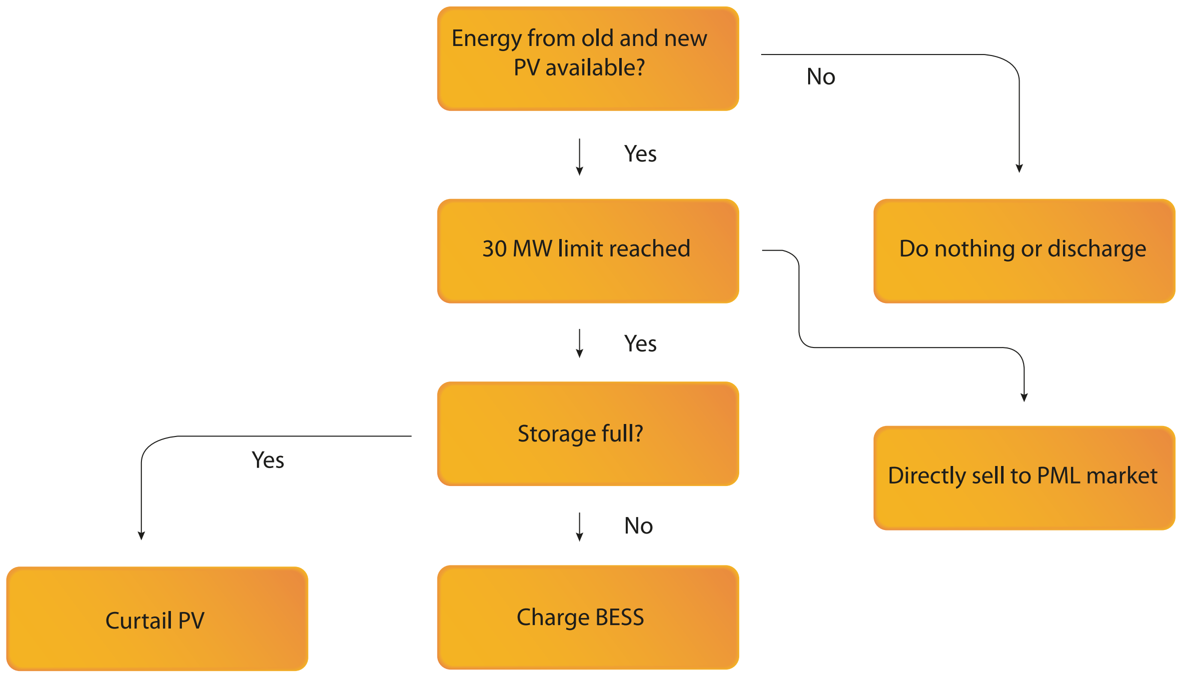

Figure 14: Rationale for charging the BESS for energy trading when using mixed revenue

The rationale for discharging the BESS is similar to the first use case. For a better understanding, three sample days and the corresponding reaction of the energy storage control system are shown below.

Sample day a): Full charge and full discharge

A full charge and discharge cycle per day appears to be the optimum storage usage for this use case. A sample daily profile with the conditions for this operation is shown in the figure below.

The BESS had been discharged in the previous evening or night. In the morning hours, both the existing PV plant (red line) and the PV planned 15 MW_{DC} PV plant extension (yellow line) directly sell their produced energy to the grid (yellow plus orange area). Once the production exceeds the limit of 30 MW (orange line), the excess energy is charged into the BESS (dark blue area) and the BESS state of charge starts to rise (black line). Once the BESS is fully charged, the remaining excess energy is curtailed (red area) due to the economic undersizing of the BESS explained in section 5.1.1. When the PV production decreases below the 30MW limit in the evening again, the entire energy is again directly sold to the grid. At a later time in the evening, the energy stored in the BESS (light blue area) is sold to the grid as soon as the PML market price exceeds the combined marginal cost for the PV generation and the LCOS.

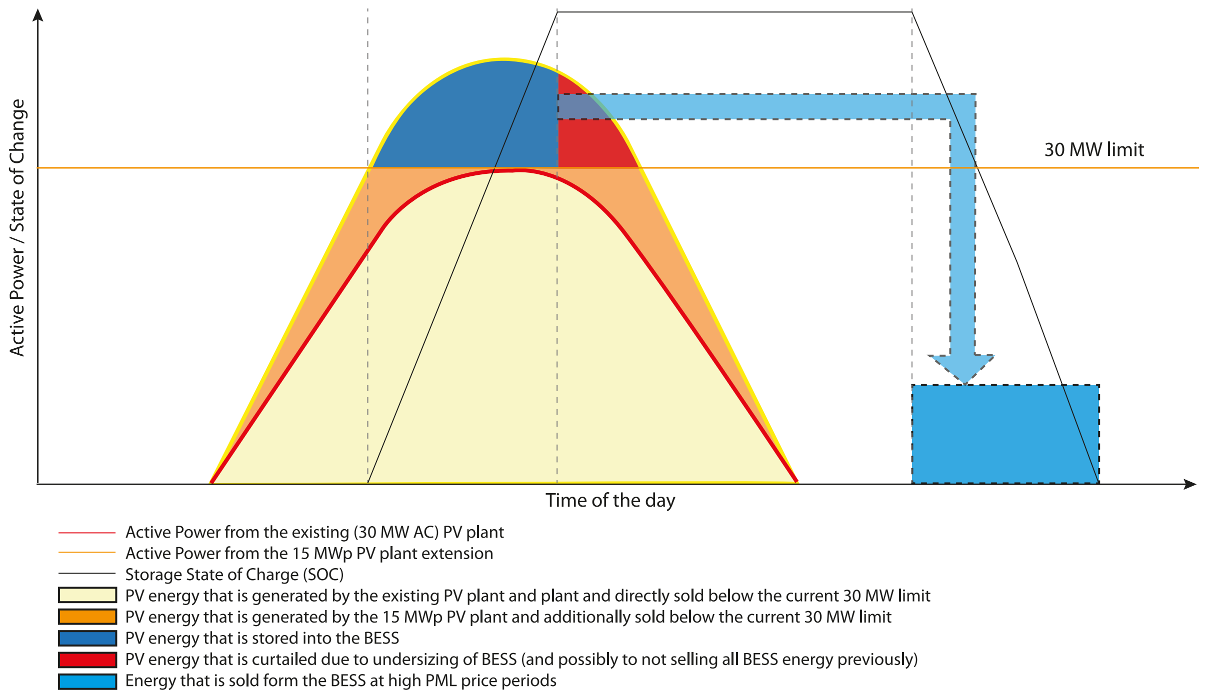

Figure 15: Energy trading sample day a) full charge and discharge of the BESS

Sample day b) full charge and partial discharge

This case corresponds to situations where the period with high PML prices in the evening and night is too short to sell all the electricity stored in the BESS, and therefore only part of it is sold.

A sample daily profile is shown in the figure below. During the daytime, the PV plant and BESS behavior is identic to sample day a). However, at night not all the energy is sold to the grid (blue area is smaller) and the state of charge at the end of the day is higher than zero (right hand black line is not at zero). Depending on the occurrence or non-occurrence of high PML prices it is also possible that no energy will be sold to the grid in this evening. In both cases, the BESS will not be fully discharged before the next day starts.

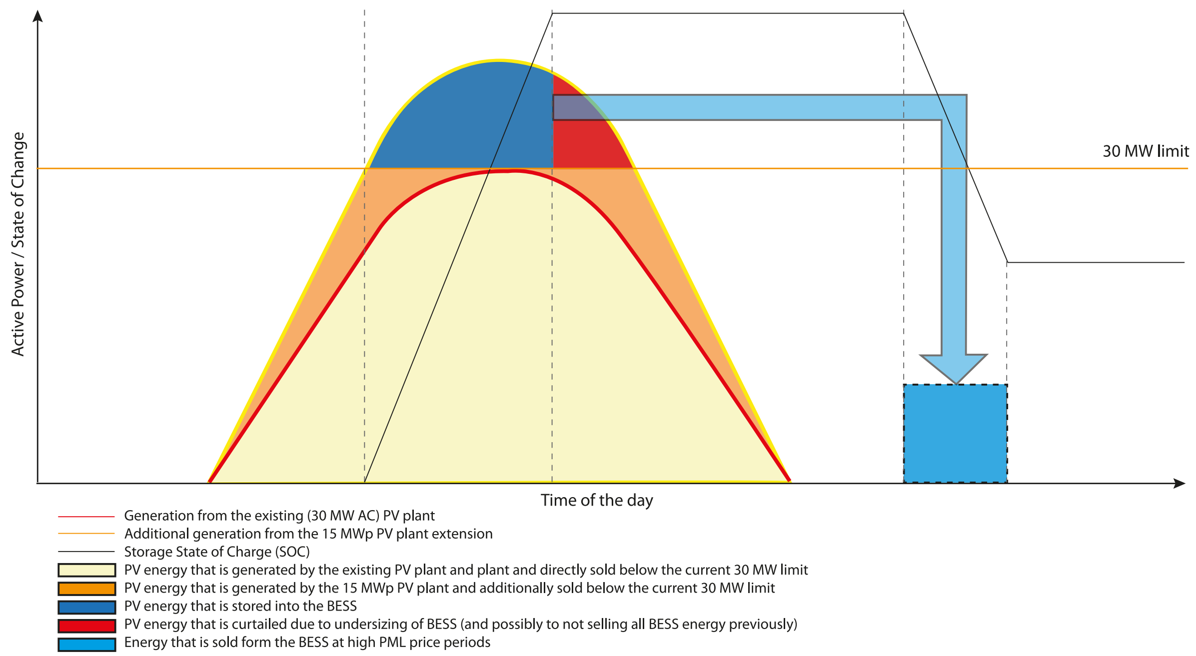

Figure 16: Energy trading sample day b) full charge and partial discharge of the BESS

Sample day c) partial charge and complete discharge

Sample day c) shows a day following a day of sample day b). As it was not economical to sell all the stored energy in the previous day, the storage is not fully discharged at the beginning of the day (black state of charge line is not at zero). At first, the behavior of the PV plants and the BESS is comparable to sample days a) and b). However, the BESS reaches its end of charge condition much earlier (dark blue area is smaller) and more energy must be curtailed afterwards (red area is bigger).

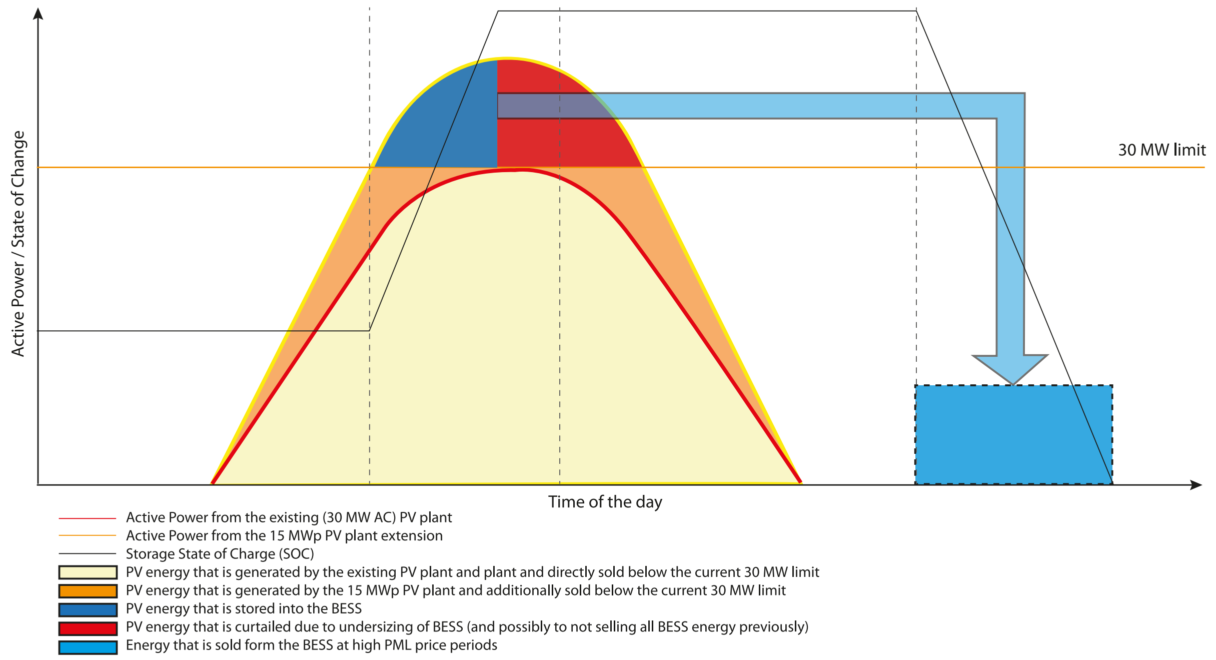

Figure 17: Energy trading sample day c) charging of partially discharged BESS and full discharge

Other scenario variations

Variations in these scenarios are possible, too. These include:

- Storage is not fully charged because of insufficient PV energy produced, e.g. due to clouding: According to the generation profile, this situation is unlikely to occur together with a fully discharged BESS. If the analyzed use case proves attractive, this downside effect will be considered in the future tasks.
- Storage not discharged at all because no high PML prices occur on that day: special variation of scenario b).

Calculations

Based on the given market conditions and Pessimistic, Realistic and Optimistic assumptions, it was evaluated whether the explained use case is economically feasible. The additional assumptions added in comparison with the previous use case and the results of the calculation are shown in the table below.

Assumptions	Pessimistic	Realistic	Optimistic	Unit
Days with high PML prices in the evening/night[20]	90	120	180	days/year
Exchange rate USD - MXN	17.00	17.00	17.00	MXN/US$
Generation cost from PV	1018	1018	1018	MXN/MWh
Average revenue at high PML price periods	4000	4200	4400	MXN/MWh
Storage efficiency	85%	85%	85%	
Yearly energy production from extended PV plant	27 869	27 869	27 869	MWh/year
Application specific LCOS	171	171	171	US$/MWh
LCOS scaling	110%	100%	90%	
Fraction of PV curtailment by undersized storage	10%	10%	10%	
Fraction of PV energy that is directly sold	15%	20%	25%	
Fraction of PV curtailment by small storage	20%	10%	5%	

Table 12: Use case 2: energy trading with mixed revenue: Assumptions

Results

The table below shows the results from the calculations based on the given assumptions.

Results	Pessimistic	Realistic	Optimistic	Unit
Fraction of PV curtailment due to low PML price	60%	47%	26%	
Losses from curtailed energy	-818	-582	-312	MXN/MWhPV
Profit from direct selling	267	396	545	MXN/MWhPV
Profit from delayed selling	-38	-81	48	MXN/MWhPV
Total profit per MWh from PV	-589	-267	281	MXN/MWhPV
Result: Profit per year	**-16,414,578**	**-7,440,904**	**7,831,064**	**MXN/year**

Table 13: Use case 2: energy trading with mixed revenue: Profitability results

- Under pessimistic and realistic assumptions, the combination of the PV plants and the BESS for this application returns a negative profit, i.e. the use case would not be feasible.
- Under optimistic assumptions, the BESS operation returns a considerable economic profit

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[20] For the current estimation, these are assumed to be pure type a) sample days as explained above. Other types of sample days can only be considered in the detailed simulation.

However, under all considerations the calculated cyclic storage life will be 20 to 30 years because of comparatively low cycle numbers per year. These storage life durations increase the project risk due to market risks, regulatory risks and cannibalization effects by future storage technologies. Furthermore, under these durations, the calendaric aging will have a considerable negative impact on the business case. To decrease the project duration, it should be investigated whether this use case can be combined with other profitable use cases or if a cheaper BESS with a lower cycle number can be profitable.

Just as in the previous use case, the lower LCOS of thermal storage could not compensate for the lost revenue by less efficiency caused by this technology in comparison with lithium-ion batteries. Based on these calculations, the described use case should be assessed in detail under commonly agreed realistic assumptions to determine whether the estimated profit can be validated.

5.2.3 *Use case 3: Curtailment avoidance*

In this case, it is to be analyzed whether it is economical to store energy in the BESS from the PV plant that would otherwise be curtailed.

Conditions

Currently, curtailment in the Aura Solar I PV plant occurs in two conditions:

- Any PV generation over 30 MW is completely curtailed due to the Small Producer regime the PV plant is operated in.
- If the grid operator CENACE expects excessive feed-in fluctuation from the PV plant due to clouding, it may limit the PV power to be exported in compliance to grid reliability rules.

This limitation is commanded externally, and no precise technical or meteorological preconditions are given for the limitation. However, as there seems to be minor clouding at the PV plant location, few occurrences of this type of limitation have been observed.

Both curtailment mechanisms are shown in the figures below for two sample days. Unfortunately, no numerical estimation exists of how much energy is curtailed due to these two mechanisms.

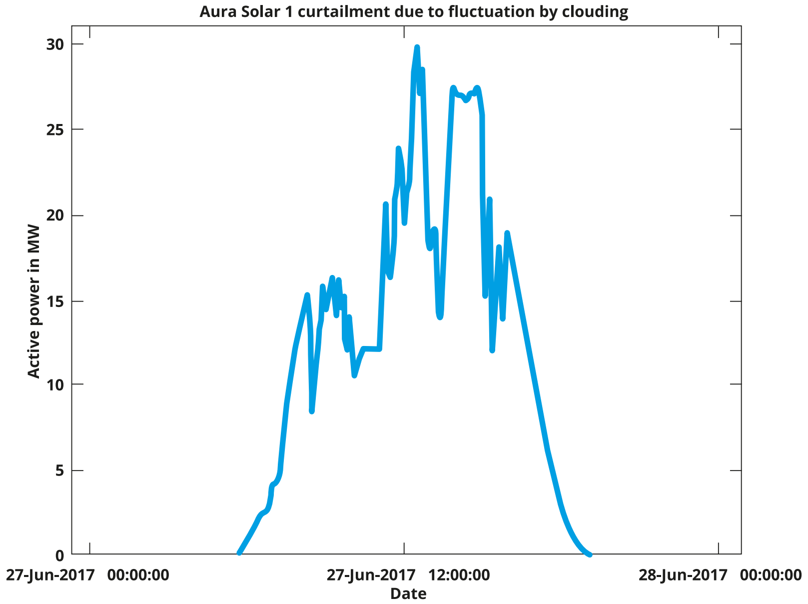


Figure 18: Curtailment due to fluctuation caused by clouding (shortly before 12:00)

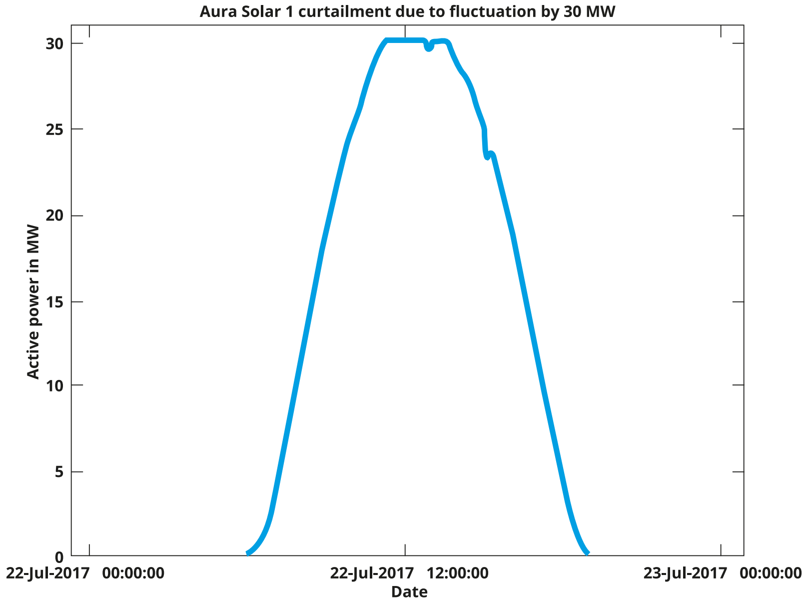


Figure 19: Curtailment due to 30 MW limit (approximately between 11 AM and 1 PM)

Rationale and conclusion

It is not feasible to use a dedicated BESS only to store the curtailed electricity. This is due to the following reasons:

- The peak curtailment will occur at the same time as the curtailment of the new 15 MW PV plant. Therefore, the BESS's active power would need to be oversized to buffer the peak production from the existing PV plant.
- The peak generation of the existing PV plant is limited by the installed PCS active power. Therefore, the excess energy is currently "trapped" in the DC circuit. Further investments in PCS DC/AC inverter units or DC/DC converters would be required to extract the energy of these rare peak generation events.
- Regarding the curtailment due to fluctuations, the lack of predictability of this curtailment would mean that a dedicated portion of the BESS would need to be reserved. This portion would remain unused unless called for curtailment storage. By extrapolating the 2017 data, less than 50 usage cycles per year are likely for this application, which is significantly lower than the minimum amount of cycles per year to make ESS economically feasible as explained in section 5.1.1.

Therefore, it is recommended not to consider curtailment avoidance as a BESS use case.

5.2.4 *Use case 4: Maximized pricing*

Under the current market conditions in which the Aura Solar I PV plant operates, there is a higher remuneration if the actual feed-in of the PV plant is close to the forecasted day-ahead feed-in. This mechanism entails an improved pricing factor applied as pursuant to the power purchase agreement rules (ie 3% increased factor above the 95% base pricing factor, resulting in 98% adjustment factor applied to CFE market marginal price) Its potential profitability is investigated for the existing 30 MW_{AC} PV plant as the maximized pricing for the selling of stored energy from the new PV plant fraction is already considered in the use cases 1 and 2.

Conditions

The PML price conditions are identical to the conditions for both energy trading use cases explained in sections 5.2.1 and 5.2.2.

As a remuneration, 95% of the hourly PML price is paid to the PV plant operator for any energy fed into the grid. If the PV plant feed-in during an hour is within +- 5% of the forecast that has been submitted by the PV plant operator to the grid operator CENACE, the PV plant receives 98% of the hourly PML price.

Rationale

There is a 3% PML price bonus on the entire PV plant production, but the storage only must supply the power difference between actual feed-in and forecast, a considerable increase in PV selling revenue is feasible with a comparatively low ESS power and energy.

For the preliminary analysis of this use case, only feed-in hours during the daytime are considered. It is assumed that in a fraction of these hours (e.g. 50%) a deviation of more than 5% from the forecast exists and that the BESS either exports or imports the required energy to reduce this forecast error to 5%. For the analysis, it is assumed that each forecast error is in the opposite direction from the previous hour and the BESS only has to provide the compensation energy for one hour per usage.

Calculations and results

Various analysis using Pessimistic, Realistic and Optimistic assumptions have been carried out. The calculations are shown in the table below.

The levelized costs are lower compared to the energy trading scenario as multiple charge/discharge cycles are carried out by the BESS in all applications. This frequent cycling reduces the levelized cost of storage because the calendaric aging only plays a minor role in these use cases. To represent this, the LCOS for low end fast frequency control lithium-ion BESS from the Lazard's report [4] have been assumed.

Assumptions	Pessimistic	Realistic	Optimistic	Unit
PV days per year	350	350	350	days/year
PV hours per day	10	10	10	hours/day
Fraction of hours with forecast error	30%	30%	30%	
Actual forecast deviation that is corrected	12%	10%	8%	
Production of Aura Solar 1 PV plant	79,890	79,890	79,890	MWh/year
Application specific LCOS	153	153	153	US$/MWh

Table 14: Use case 4: maximized pricing accuracy through the BESS: Assumptions

Results

The results based on the calculations using the assumptions mentioned above are presented in the table below.

Results	Pessimistic	Realistic	Optimistic	Unit
Cycles per day	1.5	1.5	1.5	cycles/day
Energy throughput per cycle	1.60	1.14	0.68	MWh
Cost: storage aging per year	-3,836,601	-1,779,084	-578,227	MXN/year
Cost: storage losses per year	-562,800	-309,000	-118,400	MXN/year
Additional revenue per year	2,013,224	2,157,026	2,300,828	MWh/year
Result: Profit per year	**-2,386,177**	**68,942**	**1,604,201**	**MXN/year**

Table 15: Use case 4: maximized pricing accuraccy through the BESS: Results

The BESS operation was only profitable under Realistic and Optimistic assumptions. The Pessimistic and Realistic scenario showed a high yearly cycle number. Therefore, either BESS technologies with high cycle life numbers are likely to be appropriate or the BESS should not be operated in 100% depth of discharge cycles in order to reduce the accelerated aging caused by deep cycling.

The result of the described rationale is that the installation and usage of an BESS provides the highest revenue if the average forecast error exceeds 5% by a small margin. This is due to these mechanisms:

- If the average forecast error is less than 5%, the BESS does not provide any useful advantage because the PV plant already achieves the maximized pricing from the accurate forecast.
- If the average forecast error is substantially higher than 5%, a lot of energy is charged and discharged through the BESS thereby generating high LCOS but the revenue from the maximized pricing remains the same

The break-even point with the realistic assumptions is around 10% forecast error. Therefore, a separate analysis for the cost of a more accurate forecast is recommended as a combined solution together with an BESS used for maximized pricing.

Using thermal storage, the optimistic scenario for maximized pricing could also return a profit under the assumption of an LCOS of 115 US$/MWh for the thermal storage system. However, this assumption is very favorable for the thermal storage and the profit is still lower than the profit with the standard lithium-ion assumptions.

5.2.5 Use case 5: Ancillary services

As a potential source of additional revenue, ancillary services were analyzed regarding their potential profitability in combination with a BESS system.

Conditions for fast frequency response and reactive power

The provision of active power in accordance with the grid frequency fluctuations, i.e. fast frequency response, and the supply of reactive power are currently minimum technical requirements for any generation plant that want to operate to the CENACE controlled grid. Those ancillary services currently do not generate any additional revenue, and the addition of a BESS to provide them would make no sense economically.

Conditions for secondary frequency response and reserve

The regulator CRE established an ancillary service market in the Baja California Sur grid for the following services:

- Secondary frequency response
- Spinning and non-spinning 10-minute reserve
- Spinning and non-spinning supplementary reserve

However, according to the statements of various experts on the BCS grid, it is unclear how the provision of these services would work, i.e. what power over what duration the BESS would have to deliver. Furthermore, no economical valuation of those services is available, preventing any modeling.

Conclusion

No reliable assumptions on the LCOS for ancillary service delivery in the BCS grid can be made. Furthermore, no estimations on the potential revenue for these services currently exist. Therefore, the delivery of ancillary services through a BESS is currently not economically feasible due to unclarity in the market situation. However, due to the inherent multi-purpose design of BESS with an appropriate control system, the retrofit of ancillary services functions is feasible. These services could especially be attractive when the BESS is not used anyways, e.g. during the night time after being discharged for the energy trading.

5.3 Summary of Results

The estimated profits in of the analysis for each use case are shown in the table below.

Use case	Pessimistic assumptions	Pessimistic assumptions	Pessimistic assumptions
PV Energy trading with 100% storage	-27,561,999 MXN/year	-24,134,167 MXN/year	-16,024,418 MXN/year
PV Energy trading with mixed revenue	-16,414,578 MXN/year	-7,440,904 MXN/year	7,831,064 MXN/year
Maximized pricing	-2,386,177 MXN/year	68,942 MXN/year	1,604,201 MXN/year

Table 16: Overview use case profitability

The conclusion for the use cases are:

- Delayed energy trading of the energy produced from the new PV plant with the BESS is only economically feasible if it is combined with a direct selling during the times where the overall production of the existing and the new PV plant does not exceed 30 MW.
- The avoidance of curtailment is not an attractive use case due to the rare occurrence of curtailment and the fact that the LCOS are much higher than the generation costs from the PV plant.
- The usage of a BESS to achieve maximized pricing for the existing PV plant is possibly economical because a relatively small BESS could increase the overall PML price revenue of the entire PV plant from 95% to adjustement factor.
- The provision of ancillary services through a BESS is currently not feasible because technical requirements and market conditions are not yet set for this kind of services. It could however be economically feasible to retrofit the BESS control in the future in order to supply these services.
- The replacement of lithium-ion batteries with thermal storage would mean lower costs due to storage aging but also result in lower efficiency. The resulting profit was lower than the reference scenario using lithium-ion batteries.

Therefore, an economic operation of a BESS with the existing Aura Solar 1 PV plant and the planned extension could be possible based on the use cases energy trading with mixed revenue and maximized pricing.

5.3.1 Next steps

An in-depth techno-economic simulation for the energy trading and maximized pricing use cases was undertaken in order to verify the preliminary positive results of their use case analysis.

Due to the confidential nature of this analysis, only the following key points are presented:

The main result of the analysis is that, if an energy storage system is to be installed for the specific case of Aura Solar I, the commercially optimum configuration is a 10 MW / 10 MWh BESS with Lithium-Manganese-Oxide or Lithium-Iron-Phosphate battery technology. The BESS should be coupled to the PV plant via AC coupling in order to minimize the technical risk and to be able to provide multiple BESS services. However, the financial analysis of the projects showed that none of the considered PV + BESS combinations could bring the expected IRR.

Performing a sensitivity analysis on the most plausible technical BESS solution (LMO AC) highlighted only one situation where the IRR would be met, when the PML average price would increase by 35% (considering no drop in the BESS CapEx) or by 28% (if the BESS CapEx drops by at least 5%). This market situation is considered very unlikely to happen.

This result is conclusive considering the project in its entirety, with the following factors preventing the project to the reach the Client's IRR requirements:

- The project is adding a PV and a BESS system inside a PPA that is capping the active power injected to the grid, and this cap is already met with the existing Aura I plant.
- The benefit of this innovative PV + BESS system cannot be fully harvested due to the high percentage of curtailment during the PPA period. The non-PPA period, during which all energy produced can be sold, is not long enough (7 years) to allow a durable maximization of the revenues thanks to the arbitrage that the BESS can provide.
- Neither the PPA nor the general market framework allow for payment of typical ancillary services that storage can provide. Those ancillary services usually provide complementary revenues needed to build a business case and to make BESS attractive.
- The calculated levelized cost of storage (LCOS) for the project is much higher than the prices that can foreseeably be achieved on the PML market.

6

OTHER USE-CASE SCENARIOS:

Energy storage within long-term auctions

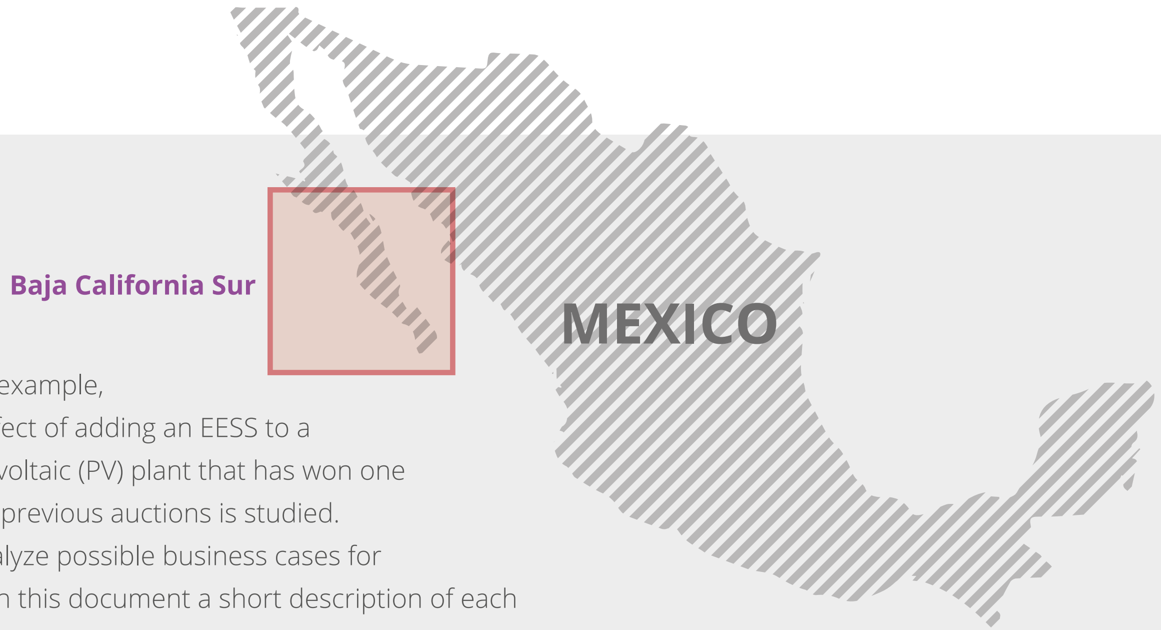
This chapter analyzes the possibility of operating an EESS (in this case, the energy storage system is not limited to battery storage systems) under the current legal and regulatory framework, specifically under Long-term Auctions.

6.1 Long-term Auctions

Long-term Auctions (LTA) take place at least once a year and have proven to be a key mechanism of the recent Energy Reform to deregulate and liberalize the Mexican energy sector. LTAs include three separate products that may be bought and sold:

- Energy – tendered for a duration of 15 years
- Clean energy certificates (CEL by its Spanish acronym) – tendered for a duration of 20 years
- Firm Capacity – tendered for a duration of 15 years

Within the scope of the GIZ analysis about the economic condition for the use of Electric Energy Storage Systems (EESS), in Mexico in general, and in the Mexican isolated grid of Baja California Sur in particular, an analysis has been carried out on the potential of these LTA.



As an example, the effect of adding an EESS to a photovoltaic (PV) plant that has won one of the previous auctions is studied. To analyze possible business cases for EESS in this document a short description of each product is given. This includes the general framework conditions, results of past auctions and the possible application of EESS under the framework.

Figure 20: Location of the Baja California Sur isolated grid in Mexico (Google Maps)

6.1.1 Goal and scope of the LTAs

As per the LTA Manual, the LTAs have the following aims and objectives:

i Allow Basic Service Suppliers (BSS) to celebrate and enter into contracts, in a competitive manner, to satisfy their needs in terms of Firm Capacity, Energy and CELs,

ii Provide Generators with a stable source of income in order to contribute to secure the required financing to build new power plants or to re-power existing ones.

All technologies may participate, however, with a few restrictions: i) CELs are only awarded to Clean Energy[21] technologies and thus no non-clean energy technologies may offer to sell this product; ii) Energy may only be offered to sell by power plants that are eligible to receive CELs, and thus only Clean Energy technologies can sell Energy.

As being generally technology-agnostic, the use of Electrical Energy Storage Systems (EESS) within the long-term power auctions was neither explicitly encouraged nor discouraged. This analysis assumes that the EESS, more specifically the BESS, would be part of a solar PV plant.

6.1.2 History of the auctions

As of February 2019, three auction rounds have successfully taken place. These auction rounds were carried out in 2015, 2016 and 2017. In this document, the auctions will be named according to the year they were started in, i.e. 2015 auction, 2016 auction and 2017 auction. The regulator CRE will take over the development of all future LTAs, with the ISO (CENACE) still being the entity responsible of evaluating all bids (selling and buying).

All three auctions have been dominated by wind and PV due to their low overall generation cost under the local Mexican conditions.

6.1.3 Roles in the auctions

The main roles in the auctions are:

- Independent system operator CENACE: Carries out the auctions as well as evaluating all bids from all participants.
- Ministry of Energy (SENER): drafted, authorized the Call for Auctions and the Bidding Bases for the first three auctions. Furthermore, SENER oversaw calculating and estimating the Expected Differences as well as the Hourly Adjustment Factors.
- Regulator CRE: Will take over SENER's role from the fourth auction onwards.
- Bidders: Offer quantities and prices for each of the three products.
- Buyers: Qualified users and the former single buyer CFE may bid to buy each of the three products.

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[21] Specific legal definition as can be found in Article 3, section 22 of the Electric Industry Act of 2014.

6.2 Analysis of revenues and losses through EESS use

During the operation of the Electrical Energy Storage System (EESS) in combination with a photovoltaic (PV) plant under the LTAs, possibilities exist to generate revenues that would come in addition to the revenues from the PV plant only:

- Energy can be sold at times where higher prices are paid.
- If the PV plant fails to deliver the capacity it has been awarded, the EESS can be used to deliver this capacity instead of having to purchase it on the capacity market.

However, the usage of the EESS also generates additional costs:

- Capital Expenditure and associated costs, if owned by the PV owner, or cost for the operational lease if the EESS is owned by a third party.
- Reduction of total yearly energy that can be sold, due to losses and auxiliary consumption of the EESS, compared to a scenario where no EESS is used.
- Reduction of total yearly clean energy certificates than can be sold, due to EESS losses.

The method to quantify and evaluate the effect of these losses on the economic operation of the PV plant and the EESS are described in this section.

6.2.1 Energy component

The first source of revenue for suppliers is the 15-year contract to supply energy.

Market design

The price for the energy product in each hour consists of:

- the general energy price as bid by the seller (Generator), and
- an Hourly Adjustment Factor applied to the energy for each hour of injection into the grid.

Energy base price

The general energy price paid to the supplier for this energy is based on the bids each vendor places during the auction, i.e. it is a pay-as-bid scheme. As this base component is fixed over the 15-year lifetime of the PV system, there is no possibility to generate an additional revenue from the usage of an EESS. The total quantity of energy to be sold is indeed determined by the production of the PV plant, and passing though the EESS system would only add EESS losses and additional cost from the so called Levelized Cost of Storage (LCOS)[22].

Hourly adjustment factor

However, additional to the base component, an hourly adjustment factor is applied. Through this adjustment factor, CENACE seeks to incentivize generators to preferably generate electricity during hours of high demand and to inject less energy during hours of low demand.

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[22] See section 3.5 on page for a more detailed description of the LCOS and how they are considered in this study

The hourly adjustment factors are calculated, and published at the beginning of each auction, for every hour in each month for the 15-year operation of the PV plant in each of the 53 price zones[23]. These adjustment factors are expressed in USD/MWh and only apply to variable renewable energy technologies (wind and solar PV) that adhere to each auction. In other words, the hourly adjustment factors published during the first auction process will only be valid to winning offers of said auction, whereas winners of the second auction will adhere to the hourly adjustment factors published during the second auction. A sample table for the La Paz price zone in the 2016 auction is shown in Table 17 below.

Adjustment Factores for Price Zone: La Paz

Hours							2016 - 51 LA PAZ
	January	February	March	April	May	June	Julio
0	-6.25	-6.25	-6.19	0.02	4.07	4.96	4.96
1	-6.25	-6.25	-6.25	-3.54	2.11	4.96	4.96
2	-6.25	-6.25	-6.25	-6.25	1.53	4.96	4.96
3	-6.25	-6.25	-6.25	-6.25	0.15	4.96	4.79
4	-6.57	-6.25	-6.25	-6.25	-0.22	3.85	4.69
5	-6.57	-6.25	-6.25	-6.25	-2.23	3.52	3.59
6	-6.25	-6.25	-6.25	-6.25	-1.91	3.52	3.11
7	-6.25	-6.25	-6.25	-6.25	-2.27	2.82	1.14
8	-6.25	-6.25	-6.25	-6.25	-6.25	2.17	-0.71
9	-6.25	-6.25	-6.25	-6.25	-2.14	4.29	0.52
10	-6.25	-6.25	-6.25	-3.45	1.10	4.29	2.58
11	-6.25	-6.25	-3.88	-2.51	1.48	4.29	3.64
12	-6.25	-4.45	-2.75	-2.10	2.64	4.96	3.69
13	-3.21	-6.25	-2.38	-1.15	3.76	4.96	3.79
14	-3.58	-4.09	-0.92	0.91	3.76	4.96	4.76
15	-6.25	-6.25	-1.51	1.62	4.16	4.96	4.73
16	-3.93	-3.04	-0.67	3.24	4.55	4.96	4.96
17	-3.54	-2.24	0.68	3.67	4.52	4.96	4.96
18	-2.64	0.22	2.86	4.10	4.52	4.96	4.96
19	4.10	4.07	4.96	4.10	4.53	4.96	4.96
20	4.53	4.52	4.96	4.10	4.56	4.96	4.96
21	4.10	4.52	4.96	4.52	4.96	4.96	4.96
22	0.16	3.17	4.96	4.52	4.96	4.96	4.96
23	-3.76	-1.68	0.42	4.07	4.96	4.96	4.96

Table 17: Sample table of the hourly adjustment factors for the La Paz node in the 2016 long-term power auctions

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[23] The hourly adjustment factors are published for 17 years total per auction

The average and maximum hourly adjustment factor difference in each day, i.e. the difference between maximum and minimum price of that day, for the La Paz price zone from the auctions in the years 2015, 2016 and 2017 is shown in 18 below. The hourly adjustment factor data covers the entire timespan of the expected operation of the clean energy producer under the long-term power auctions. As an example, the data of 2016 includes the hourly adjustment factors for the years 2016 to 2033.

Auction Year	Avg. daily adjustment factor difference of total operating time	Max. daily adjustment factor difference of total operating time
2015	37.67 USD/MWh	73.37 USD/MWh
2016	37.84 USD/MWh	117.17 USD/MWh
2017	1.29 USD/MWh	2.60 USD/MWh

Table 18: Average and maximum daily price differences in hourly adjustment factor

The table illustrates that while the hourly adjustment factor has remained relatively stable between the 2015 auction to the 2016 auction, the factor for the generators bidding in the 2017 auctions are heavily reduced by 97% compared to the 2015 auctions and 96% compared to the 2016 auctions.

Electrical Energy Storage System use case strategy

The main energy storage use case in the energy auctions would be to charge the EESS during hours where the hourly adjustment factor is low or negative and to discharge the EESS during hours where the factor is positive and high. The flowcharts for this operational strategy are shown in Figure 19 and 20 below.

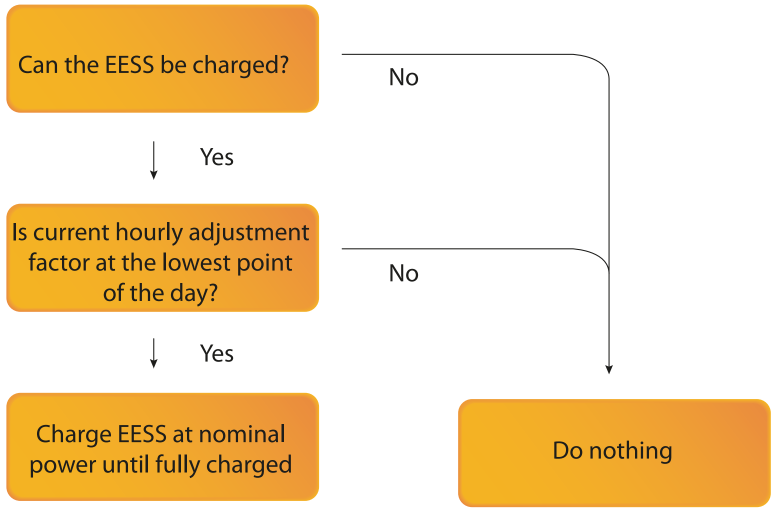

Figure 21: EESS energy shifting use case strategy: Charging

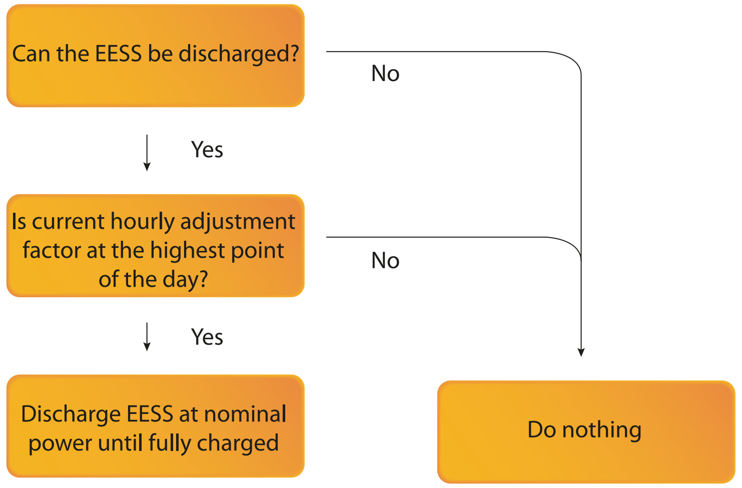

Figure 22: EESS energy shifting use case strategy: Discharging

Evaluation of strategy feasibility

Through this strategy, the revenue generated by each MWh sold is maximized. Since the hourly adjustment factor is published "ex ante" before the actual auction and operation, it is easy to optimize this strategy to achieve the maximum price difference in each day.

In order to be able to use this strategy, it is necessary that the low or negative hourly adjustment factor occurs during a time when the EESS can be charged from the PV plant, i.e. optimally between 10 AM and 2 PM. The typical daily course of the hourly adjustment factor in each month is shown in the example of the La Paz node in the year 2016 according to the 2016 auction in Figure 23 below.

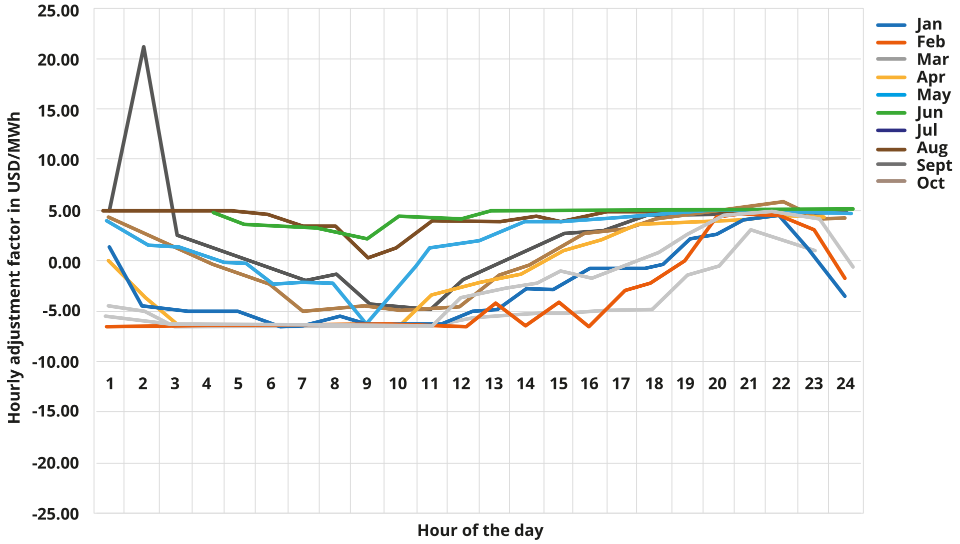

Figure 23: Hourly adjustment factor in La Paz node 2016, 2016 LTA

It is evident that indeed the negative and lower hourly adjustment factor occur during the noon hours. This behavior is also logical and consistent with market data from the current short-term electricity market in Mexico, where electricity prices are lower during daytime and higher in the evening and during the night. Furthermore, it is consistent with the future development path of the Mexican energy system, where PV will play an increased role. Typically, in systems with high PV penetration, market prices are lowest during the noon hours when the PV plants produce more and will always try to sell any energy due to their negligible marginal costs.

Assumptions to calculate revenue

To calculate the possible revenue, it is assumed that the EESS will carry out one cycle per day where it will be charged during the hour of the lowest adjustment factor and discharged during the hour of the highest hourly adjustment factor. Thereby, the specific additional revenue per MWh is equal to the difference of the hourly adjustment factor in these hours. For a generalized calculation for each of the three auctions, the average factor given in Table 18.

To achieve these additional revenues, energy will be charged into and discharged from the EESS. This process will lead to storage losses as well as an auxiliary power consumption in the EESS. Due to these losses, less total energy can be sold from the PV plant than without an EESS. The commercial loss caused by this decreased production is described in section 6.2.4.

6.2.2 Clean energy certificate component

The second of the three sources of revenue from the LTAs are the selling of clean energy certificates. As every Load Serving Entity must purchase these clean energy certificates, there is a strong incentive to buy them from clean generators that are eligible to receive them. This product within the LTA has a contract duration of 20 years, i.e. the time of remuneration exceeds the clean energy and capacity component by five years.

Market design

Clean energy certificates are awarded per MWh of clean energy production. The clean energy certificate balance is settled for the grid users on a yearly basis. Therefore, there is no component that makes the certificates more expensive or cheaper during any hour, day or month of each given year.

Electrical Energy Storage System use cases

As there is no time-dependent component in the clean energy certificates sold through the LTAs, there is no possibility to earn additional revenue using an EESS. However, the use of an EESS in any other use case associated to the auctions will lead to reduced clean energy certificates that can be sold due to storage losses and auxiliary power consumption of the EESS. These commercial losses are addressed in section 6.2.4.

6.2.3 Capacity component

The third of the three components in the LTAs is firm capacity. Just as the energy product, this component is auctioned for a period of 15 years.

Market design

Clean energy providers such as a PV plant may choose to sell capacity. At the end of the year, the 100 critical hours of the year will be determined, whilst evaluating whether each vendor has supplied the quantity of capacity that was offered during these hours. If this is not the case, the vendor must purchase the lacking capacity from other generators directly or through the Capacity Balancing Market.

Distribution of 100 critical hours

As such, the capacity component is a part of the auction whose payment is determined ex post after the operation. As such, the generators cannot know beforehand during which days and hours the power should be fed into the grid. However, CENACE provides the calculation method and an overview over the 100 critical hours for the years 2014 – 2016 [1][2][24]. The distribution of these hours over the months is shown in Figure 24 below while the distribution over the hours of the day is shown in Figure 25 below.

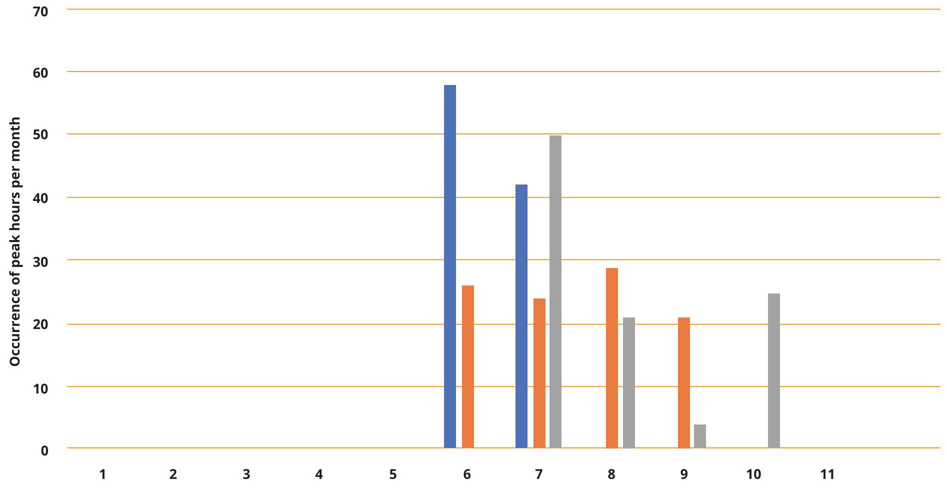

Figure 24: Distribution of 100 critical hours by month of each year

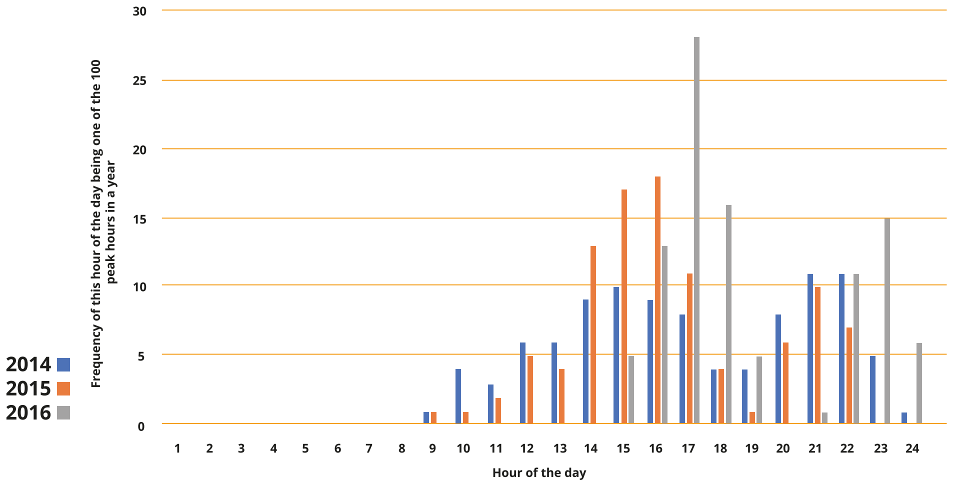

Figure 25: Distribution of 100 critical hours by daily hour

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[24] The calculation method is due to change in 2018, see [3]

From these graphs, it is visible that there is a certain pattern in the critical hours for each year, but that this pattern is not accurate enough to reliably predict the critical hours beforehand.

2015, 2016 and 2017 auction results

In the 2015 auction, no successful offers were awarded with capacity by clean providers. In the 2016 and 2017 auctions, various clean energy providers included offers for capacity in their bids and were successfully awarded. These bids included PV plants, wind power plants and geothermal generators.

Electrical Energy Storage System use cases

An Electrical Energy Storage System use case for the capacity component only exists if a capacity component was awarded in the auctions. Therefore, no revenue can be generated from the results of the 2015 auctions due to a lack of awarded capacity bids.

However, capacity is a possible source of revenue from the 2016 and 2017 auctions. As the capacities were already awarded, it is not possible to increment the sold capacity afterwards. However, the EESS could be used to hedge the risk of not fulfilling the capacity requirement in a fraction of the 100 critical hours instead of having to buy the capacity from the Capacity Balancing Market. Table 19 shows prices for 2016.

Region	Price
National interconnected system (SIN)	67,073 USD/MW-y
Baja California (BCA)	139,303 USD/MW-y
Baja California Sur (BCS)	68,897 USD/MW-y

Table 19: 2016 general capacity market prices

As discussed before and shown in Figure 25, there is a high likelihood that the 100 critical hours will occur in the evening or night hours. Therefore, it is likely that the PV plant will not be able to fulfill the contracted capacity in a significant fraction of the 100 critical hours and that a hedging of the lack of capacity will be needed. The suitable EESS strategy to hedge this risk is discussed in the following.

As explained, the PV is likely to fail to deliver a significant fraction of the contracted capacity. An EESS could be suitable to provide the capacity in this case instead of the PV operator having to purchase it ex post in the yearly capacity settlement. Therefore, the average value of each avoided critical hour is equal to 1h/100h or 1% of the values shown in Table 20.

EESS dispatch strategy

The main difficulty for an EESS dispatch strategy is that it is unknown at what exact day and hour the critical hours will occur. However, when comparing 23 and Figure 25, it is evident that the operation of the EESS driven by the hourly adjustment factor is likely to coincide with the 100 critical hours. Therefore, it will be assumed in the calculation that the EESS with the energy-based strategy described in section 6.2.1 can replace some of the capacity that would otherwise have been purchased on the general capacity market ex post.

The effectivity of this strategy was tested against the 2016 data of the hourly adjustment factor and proved to be successful to improve the provision of capacity in 6.89% of the 100 critical hours.

6.2.4 *Lost revenue due to storage losses*

To calculate the value of the EESS losses, an EESS efficiency of 85% is assumed. This efficiency is a typical current value for state-of-the-art Battery Energy Storage Systems (BESS). It accounts for the losses in the transformers, power conversions systems (inverters) and batteries as well as the auxiliary consumption of control systems, cooling etc.

The USD/MWh value of this lost energy is assumed to be equal to the average value of the energy plus of the clean energy certificate from the auctions results, as shown in Table 20.

Auction Year	Avg. package price for energy and CEL
2015	48.00 USD/MWh+CEL
2016	33.50 USD/MWh+CEL
2017	20.57 USD/MWh+CEL

Table 20: Combined prices of clean energy auction and clean energy certificates used to account for specific commercial loss through EESS losses

6.2.5 *Storage cost*

The Levelized Cost of Energy (LCOE) of one MWh injected by the EESS, for a typical stand-alone 10 MW / 10 MWh Battery Energy Storage System (BESS) operated in the current Mexican market conditions, has been determined in a financial model[25]. In that case the LCOS is equal to the LCOE since the considered system added to the PV plant is composed of only a BESS.

Other costs parameters such as CAPEX, OPEX and financial inputs are identical to the ones used for the LMO AC BESS case. The resulting LCOS is used to calculate the yearly cost of the BESS during the intended operation period.

6.3 Economic analysis

6.3.1 *Based on 2015 auction*

The results of the BESS operation based on the conditions given by the 2015 LTA is shown in Table 21.

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[25] A detailed overview of the financial modeling results can be found in section 6.3 on page.

2015 LTA results	Value	Unit
BESS revenue from hourly adjustment factor	**137, 495.50**	**USD p.a.**
BESS revenue from capacity	**0.00**	**USD p.a.**
BESS losses from non-sold CELs + Energy	**-35,040.00**	**USD p.a.**
BESS yearly cost	**-1,548,128.63**	**USD p.a.**
Total profit from BESS operation	**-1,445,673.13**	**USD p.a.**

Table 21: Economic analysis results based on 2015 auction results

As no capacity bids were awarded, and as the BESS would not add revenue but losses in the energy and clean energy certificate components, additional revenue could only have been obtained from the hourly adjustment factor. The additional revenues generated yearly are far below the yearly cost of the BESS, unfortunately showing that there is no viable business case for a BESS under the 2015 auction condition.

6.3.2 Based on 2016 auction

The results of the economic analysis based on the 2016 auction is shown in Table 22.

2016 LTA results	Value	Unit
BESS revenue from hourly adjustment factor	**138,108.78**	**USD p.a.**
BESS revenue from capacity	**47,470.03**	**USD p.a.**
BESS losses from non-sold CELs + Energy	**-24,455.00**	**USD p.a.**
BESS yearly cost	**-1,548,128.63**	**USD p.a.**
Total profit from BESS operation	**-1,387,004.81**	**USD p.a.**

Table 22: Economic analysis results based on 2016 auction results

The revenue from taking advantage of the hourly adjustment factor is slightly reduced in comparison with the 2015 auctions. This is due to the overall reduced average difference between the daily lowest and highest hourly adjustment factor (see Table 18 for comparison).

However, as there were capacity bids awarded in the 2016 auctions, a revenue can be generated from avoiding having to buy capacity from the ex post market if the PV plant cannot deliver the contracted capacity. As the results table show, this strategy could result in a considerable revenue.

In total, this additional revenue improves the business case, but the BESS lease cost is still much higher than both revenues combined.

6.3.3 Based on 2017 auction

The economic results based on the 2017 auction are shown in Table 23.

2017 LTA results	Value	Unit
BESS revenue from hourly adjustment factor	**4,708.50**	**USD p.a.**
BESS revenue from capacity	**47,470.03**	**USD p.a.**
BESS losses from non-sold CELs + Energy	**-15,016.10**	**USD p.a.**
BESS yearly cost	**-1,548,128.63**	**USD p.a.**
Total profit from BESS operation	**-1,510,966.20**	**USD p.a.**

Table 23: Economic analysis results based on 2017 auction results

The economic losses caused by BESS storage losses leading to CELs and energy that cannot be sold are lower as the specific costs for these products is lower compared to the 2015 and 2016 auctions. However, the revenue from arbitrage through the price difference in the hourly adjustment factor is significantly reduced as well because of the high drop in the average daily difference.

As a result, the overall yearly profit from the BESS operation within the 2017 auction framework is the lowest of all three cases that have been analyzed.

6.4 Conclusions

An analysis was carried out to verify if it would be commercially feasible to operate a Battery Energy Storage System (BESS) to complement the operation of a PV plant in the Mexican market. This PV plant would generate a revenue through the contracting via the 2015, 2016 or 2017 LTAs in Mexico.
Under this market framework, the BESS could generate additional revenue through:

- Increasing the revenue from the energy component: shifting the PV production into the evening or night hours, where a higher remuneration for the feed-in is paid than in the daytime in accordance with the hourly adjustment factors
- Taking part in the capacity component of the auction by feeding in active power during the 100 critical hours in the grid while the PV plant cannot deliver said power (only 2016 and 2017 auctions)

Both revenue components showed to be feasible; however, the associated yearly cost of a BESS to fulfill these services would considerably exceed the possible revenues. Therefore, it currently seems unfeasible to operate a BESS under these conditions. However, it is worth mentioning that under the current operational regime, the BESS would only be in use for two hours each day.

In the remaining 22 hours, the BESS would be available for other use cases such as ancillary services. Usually, this availability would be asymmetric:

- The BESS is available for ancillary services concerning the import of active power in the morning hours
- The BESS is available for ancillary services concerning the export of active power in the afternoon hours. However, any ancillary that is exclusively used for the export of active power would result in a reduced availability of energy for the energy trading and capacity use case discharge in the evening or night

Therefore, it is recommended to analyze whether the EESS could be commercially viable through this strategy of a further value stacking.

III. REGULATORY INFLUENCES ON EESS MARKET DEVELOPMENT

7 TECHNICAL CHALLENGES and solutions

Before explaining the possibilities for governmental influence on EESS deployment in ancillary services, some general technical characteristics and their influence on deployment are given in this section. Afterwards, the benefits of EESS for the grid stability in normal grid operation and in contingency handling are explained.

7.1 EESS benefits in contingency handling

The most common contingency in grid operation is the loss of a large generator unit. The typical response of the grid frequency to a reference loss of generation in a grid is shown in Figure 26[26]. The term “reference loss of generation” describes the sizing of the biggest contingency the electricity grid is designed to withstand without affecting the stability and availability. It is often chosen according to statistical concerns, e.g. less than one reference event every 50 years, or according to deterministic concerns, e.g. the grid must be able to remain stable upon the loss of the two biggest generators in the grid.

After a grid contingency, which commonly consists of the loss of a large generation unit, the generation power is lower than the consumption by the load. Therefore, the rotational energy of the generators is drawn and the grid frequency drops. The rate (gradient) at which the grid frequency drops is called Rate of Change of Frequency (“RoCoF”). When the frequency drops, certain loads consume less power and generators feed in more active power into the grid. If effective, this behavior stops the frequency drop at the lowest frequency, which should be higher than the lower permissible frequency boundary of the grid. This lowest point that the frequency reaches is sometimes referred to as the frequency nadir. The permissible frequency nadir is usually set by the grid code and is the design criterion for the required amount and configuration of Ancillary Services designated for frequency containment. Typical permissible frequency deviations are 200 mHz for large interconnected grids (e.g. the interconnected European entso-e grid), 500 mHz for medium sized grids (e.g. UK) and 1 or 2 Hz for small islanded grids.

After this frequency nadir point, the grid operator coordinates the frequency restoration to return the grid frequency back to its nominal value. Typically, if the frequency containment is not successful and the permissible frequency nadir is exceeded, a load shedding scheme is initiated as the last resort. This is typically carried out by protection devices in the grid that automatically disconnect large users or grid section upon reaching a certain frequency threshold.

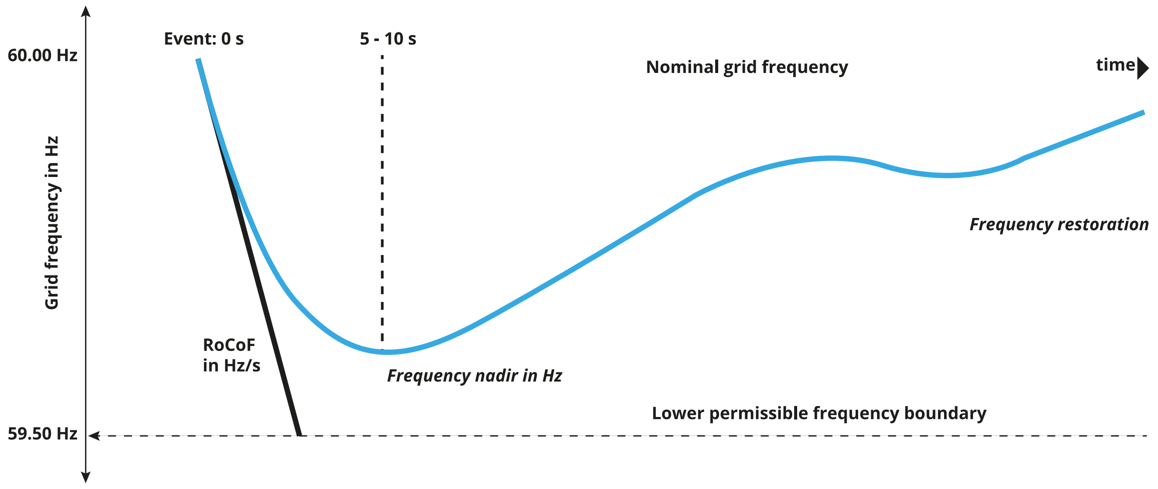

Figure 26: Typical behavior of a frequency excursion after a grid contingency

EESS in general and Battery Energy Storage Systems in particular, are commercially used in the contingency handling in the short-term range. Their added value for each of the parameters after a grid contingency is explained below.

- Rate of Change of Frequency: EESS with a fast reaction time can almost immediately react to a change in frequency and export power to the grid to reduce the Rate of Change of Frequency. Thereby, the Rate of Change of Frequency (RoCoF), i.e. the gradient or steepness of the frequency change, can be limited. An example of this application is the Enhanced Frequency Response market in the UK explained in section 9.5.2.
- Frequency nadir: EESS can be equipped with a linear droop static that configures them to react to a change in the local grid frequency with an export or import of active power. This behavior reduces the excursion of the frequency. The associated service is often referred to as Primary Frequency Response. An example of EESS in this ancillary service in the Primary Frequency Response market in Germany.

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[26] A detailed overview of the financial modeling results can be found in section 6.3 on page.

- Frequency restoration: A lot of conventional generators used in the Primary Frequency Response have an energy reservoir that is limited, e.g. the steam tank in a coal power plant. After this energy reservoir is depleted, their increase in active power output is stopped and other units must take over the lack of active power. The dispatch of this reserve is usually called Frequency restoration, Secondary Frequency Response or Automatic Generation Control. An example of EESS in these ancillary services is the Automatic Generation Control in the US markets as described in section 9.4.
- Blackstart: In the case that the Rate of Change of Frequency or the frequency nadir exceed the safe limit of operation of the generators, the generators shut down to protect themselves, resulting in a blackout of the grid. In two pilot projects in the US and Germany, Battery Energy Storage Systems have been successfully used to black-start other, larger power plants. Though still in pilot stage, this is an attractive secondary application for these units as the supply of this ancillary service is not in conflict with any other ancillary service.

7.2 EESS benefits in normal grid operation

EESS are also able to economically provide ancillary services required for normal (i.e. non-contingency) grid operation. These services cover:

- Congestion management: EESS are used for the relief of line and transformer connections, especially in load centers. These services can be attractive in regions where an extension of the grid is currently not feasible. Reasons for this may be large distances to cover (e.g. in remote rural areas) or difficulties in installing new lines and equipment (e.g. in densely populated urban areas).
- Ramp rate control: EESS are used to limit the active power ramps both in generators and loads. These ramps usually occur within minutes to hours because steep increase in load or drops in generation. The ramp rate control is either coordinated centrally from the grid operator or certain units such as PV plants are obligated to limit their ramp rates autonomously.
- Energy based EESS services: EESS can also be used for energy-based services such as energy time shift for price arbitrage. However, as this report focuses on ancillary services, these energy-based services are not covered herein.
- Generator- and load-connected EESS services: EESS can also be used for services that provide advantages to generators and loads. Examples of these services are peak shifting and increasing local energy autonomy. However, since this report is focused on grid operator use cases, these EESS use cases are not relevant in the scope.

8 GOVERNMENTAL INFLUENCES

on EESS deployment

Governmental influence can have a positive and negative impact on the deployment of EESS within a grid. Furthermore, a third category considered misguided incentives exists. In this category of governmental measures, the introduction of EESS is promoted, but the behavior of the EESS is likely not to benefit the grid.

The major categories of governmental tools that are currently in action are shown in Figure 27 below and further described in this section.

Remark: EESS also provide commercial and technical advantages that can make them feasible even without storage-focused incentives, e.g. the reduction of payments for peak power from the grid through EESS peak shaving or the shifting of day-time PV generation to the evening hours. These advantages and business cases are not in the scope of this document.

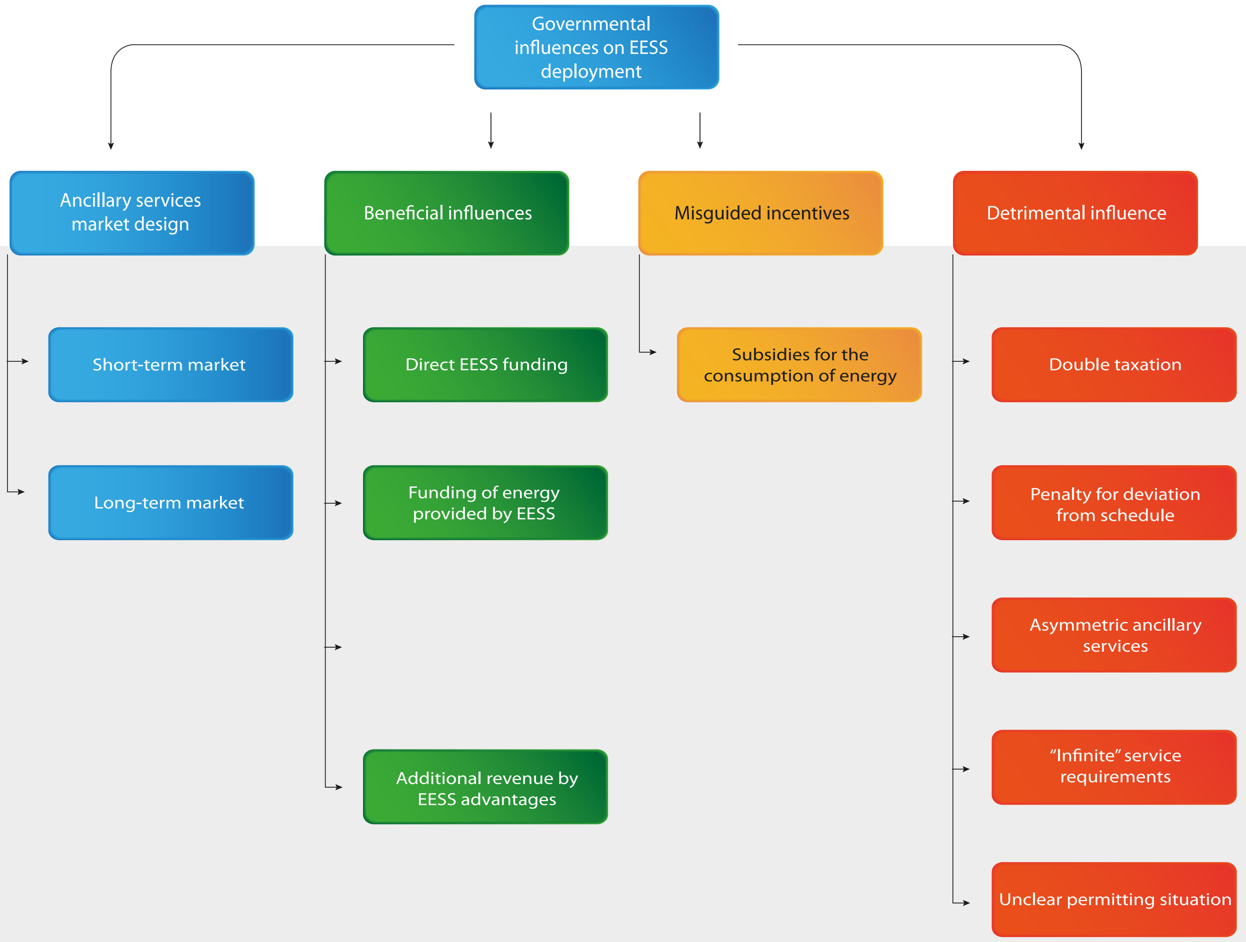

Figure 27: Overview over governmental influences on EESS technologies in electricity grids

8.1 Ancillary services market design

For the organization of a market for ancillary services, two market designs exist: i) short-term; and, ii) long-term.

8.1.1 Short-term market

In these markets, the ancillary service is usually publicly tendered for a timespan that is much shorter than the investment period of the EESS, e.g. an hour or a week. The main advantage of short-term markets is that they quickly allow to adjust the kind and amount of ancillary services that is procured. Furthermore, they allow for a competitive pricing in markets with a high liquidity, i.e. where enough market participants are active.

Due to the liquidity requirement, short-term ancillary service markets are only common in larger deregulated market grids with peak demands of 10 GW or more. Prominent examples are:

- US markets, i.e. CAISO, PJM, NYISO and MISO (see section 9.4)
- Continental European markets, e.g. Germany, Austria and Switzerland
- The United Kingdom ancillary services market (see section 9.5, except the UK Enhanced Frequency Response market)

8.1.2 Long-term market

In these markets, long term contracts are given to the ancillary service providers. The contract duration is in the same dimension of the EESS lifetime, i.e. usually between one and ten years. These markets can either be organized through public tenders or through bilateral contracts.

The main advantage of these long-term markets is that they reduce the market risk for the EESS owner. This is a key incentive since all ancillary service markets are a single buyer market. If the market framework changes in short-term markets, this leaves a considerable risk for a stranded investment since the EESS owner cannot sell the EESS service to any other customer. In long-term markets, the owner has more time to adjust to that change.

The main disadvantage is the lack of technical and commercial competition after the contracts have been awarded. In this framework, the ancillary service single buyer cannot benefit from lower cost of newer units that may enter the market.

Prominent examples of long-term markets are:

- The Ireland and North Ireland grid (see section 9.6)
- Most smaller island grids (e.g. the Hawaiian Islands – see section 9.3 - and Greek islands)
- The Enhanced Frequency Response market in the UK (see section 9.5)

8.2 Beneficial influence for EESS deployment

8.2.1 Direct funding

The most basic incentive for EESS within a grid is a direct funding of the costs for installing and operating the EESS. This funding can either be a complete funding or a partial funding of the EESS investment cost.

Complete funding

The first option for this funding is a 100% complete funding. This is commonly found in EESS for research purposes, e.g. in universities. These EESS are commonly very small (i.e. 1 MW / 1 MWh or smaller) and do not contribute to the grid they are installed in, but rather to general research. As they provide no incentive for follow-up installations, their impact is very limited.

Partial funding

The second option for this funding is a partial funding. In this case, the government grants a fund for a fraction of the EESS installation and operation cost. This can make EESS viable in markets where the break-even point has not yet been reached or where private investors are hesitant because of technical or market risks. An example of this funding is the 20% government grant for the 5 MW / 5 MWh BESS in Schwerin, Germany. This first-mover grant enabled the first commercial multi-MW EESS in the European grid and has since led to multiple commercial follow-up projects.

8.2.2 Funding of energy provided by EESS

Another incentive for funding EESS is to provide a funding for any energy that is fed from the EESS to the grid. An example of this funding is the increased feed-in tariff for hybrid power systems (HPS) on the island of Crete in Greece[27].

This funding can help lower the entry barrier for new technologies into a market and therefore has a considerable leverage. Caution must be taken to limit the total amount of EESS operated under such a scheme. If there is no upper limit or the runtime of the funding is very long, considerable fixed costs can cause high fixed cost for the funding governmental entity.

8.2.3 Defining stricter minimum technical requirements for generators

Another beneficial influence for the introduction of EESS into grids is to define minimum technical requirements that favor characteristics of an EESS. Examples of these are the requirement towards PV generators to provide a guaranteed ramp rate control or to participate in ancillary services such as Primary Frequency Response.

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[27] It must be noted that there is yet no provider that has successfully commissioned a plant using this scheme in Greece

Option 1: Power and energy requirements

The first option to implement these requirements can either be expressed in technical requirements towards the EESS, e.g. the EESS active power or energy content. An example of this would be a grid code that requires PV generators to install an EESS that has half the active power of the PV generator and must be able to be discharged for half an hour.

The disadvantage in this method is that no guarantee over the actual performance of the EESS can be given. It is difficult to externally evaluate if the EESS is operating at its full capacity or if the operator limits the operation, e.g. to reduce wear and tear on the components.

Option 2: Fulfillment requirements

The second option is to express a requirement towards the performance and fulfillment ratio of the grid service. An example of this could be that any PV plant must guarantee a maximum ramp of 10% of nominal power per minute and that this requirement must be met during 99.9% of the time.

The advantage of this method is that it is technology-agnostic and that it incentivizes the EESS owner to design and operate the EESS in the most economic manner. Furthermore, the control of fulfillment (e.g. by the Distribution System Operator or Transmission System Operator) is very easy. Care must be given to define a fulfillment requirement that is usually below 100%. Since it is not economical to design the EESS for any and all eventualities, a 100% fulfillment requirement usually leads to an extreme oversizing of the EESS which renders the business case for the generator unattractive.

8.2.4 Additional revenue by EESS advantages

The fourth option is to allow additional revenue for EESS technologies due to their inherent technical advantages compared to other flexibilization technologies. These advantages are:

- Speed: Typical ramp rates for Battery Energy Storage Systems (BESS) reaction can be as low as 100 ms from zero to nominal power, which is magnitudes faster that thermal generators
- Accuracy: The typical deviation of a Battery Energy Storage System's active and reactive power delivery is ±2 – 3% after 5 seconds of the set point change, which is much more accurate than thermal generators. I.e., 5 seconds after having received a command for 1 MW of active power delivery, the actual active power output of that BESS will usually be between 0.97 MW and 1.03 MW
- Availability: Common technical units of a large-scale Battery Energy Storage System have a nominal power of 500 kW – 2 MW. Due to this, the failure of the largest unit commonly has a lower impact compared to conventional generation, where larger generator sizes are often preferred due to lower specific cost. This increased availability can either be:
  - paid preferentially through comparing the expected output of the BESS with the actual output (where a reduced availability of some units would affect the output in peak times). Examples of this are the US CAISO and PJM markets, where the performance of the BESS is solely rated on the comparison of delivered vs. required power at any given time.
  - or paid by comparing the number of online BESS units with the required minimum (which would reduce the payment even if the outage of some BESS units wouldn't have impacted the Ancillary Service). In this scheme, the BESS operator must submit the availability of all units to the buyer of the Ancillary Service. If insufficient power is available, the BESS operator is penalized even if the non-availability has not led to an under fulfillment at that time because not all units were called. An example is the penalization in the German Primary Frequency Response market: Even if the nominal power was not required at the time of insufficient power, the BESS operator is penalized if the available power is lower than what was sold to the Ancillary Service buyer.
- No must-run capacity and low standby losses: Battery Energy Storage Systems can stay in standby at very low losses and auxiliary consumption. A typical Battery Energy Storage Systems in standby only consumes between 0.5 – 2% of its nominal power (e.g., a BESS with a nominal power of 1 MW would have an average auxiliary power consumption of 5 kW - 20 kW) and can be started from the "cold" offline state to the "hot" running state within 5 seconds or less

All these advantages make EESS in general and BESS in particular very attractive for applications where there is a requirement to stay in standby in case of need. The best example for this is the Primary Frequency Response ancillary service. In this service, the technical unit offering the ancillary service stays in standby and monitors the grid frequency. If the grid frequency is dropping, this is an indicator for a lack of generation in this grid. In this case, the EESS automatically starts injecting active power into the grid to quickly compensate for the lack of active power. As this is a process that is seldom requested at full power, but that must be fulfilled within 10 seconds when requested, EESS are very suitable for that application.

These advantages of EESS can be facilitated by either:

- Introducing special services that offer an increased payment for a faster and more accurate service (such as the UK EFR service explained in section 9.5 and the PJM RegD market)
- Introducing a performance-based payment for existing services, i.e. evaluating the speed and accuracy that a technical unit is providing in an ancillary service and rewarding a better performance (such as the CAISO AGC performance evaluation)

8.3 Misguided incentives for EESS deployment

In some markets, market mechanisms commercially incentivize the use of EESS in a way that is not beneficial for the grid. These mechanisms are explained in this section.

8.3.1 Subsidies for the consumption of energy

In some energy markets, subsidies for the consumption of electricity exist. These subsidies may extend to certain customers, load sizes or areas. If the subsidies are very high, the price of the electricity for consumers may be lower than the price the governmental single energy buyer pays to the generators for the feed in. If this is the case, there is a theoretical business case for energy storage systems to buy electricity at a subsidized price and re-sell it to the governmental single energy buyer. This influence only affects stand-alone EESS as the energy of generator- and load-coupled EESS is not fed through the grid again via a meter after being released.

As this market mechanism was usually not designed with the possibility of EESS in mind, the operation of EESS under this scheme is usually not advantageous for the grid. It is therefore recommended to eliminate the possibility for EESS to benefit from this scheme. Two possible options for this are either to completely exclude EESS from these subsidies or to only allow subsidies for the energy that has been charged into the EESS and later not released back into the grid.

The first mechanism is easier to implement, while the second mechanism allows to use EESS in use cases that can be beneficial for the grid, e.g. in load peak shaving operation.

8.4 Detrimental influences for EESS deployment

There are cases of governmental action that can be detrimental to the introduction of EESS into the electricity grid. Usually, these detrimental influences are not intentionally set by government entities. More often than not, they exist because of governmental regulations and actions that were designed with conventional generation such as combustion plants, nuclear power plants or hydro plants in mind. The most common of these detrimental legacy requirements are explained below.

8.4.1 Double taxation

In many electricity markets, loads must pay taxes and levies depending on their grid connection size and energy consumption. As an EESS consecutively operates as a load and a generator, taxes and levies apply in the times of EESS operation. In traditional markets, there is no consideration for the fact that most of the energy charged into the EESS during operation as a load is later released again. Only the EESS losses and auxiliary power consumption are not fed into the grid again.

This influence only affects stand-alone EESS as the energy of generator- and load-coupled EESS is not fed through the grid again via a meter after being released. If there is no consideration for this fact, the EESS units often must pay a substantial extra that makes their operation non-economic.

The common solution is to exempt energy storage systems from such levies since they are not final consumers of the energy. A refinement of that method is to only apply the taxes and levies on the energy that is not discharged again, i.e. the losses and auxiliary consumption. This refinement incentivizes the EESS owner to choose an efficient EESS technology and operation strategy.

8.4.2 Penalty for deviation from schedule

In many common electricity markets, generators and loads must submit hourly or 15-minute schedules for their interaction with the grid. Deviations from these schedules are later penalized since they cause the requirement for compensation.

Units providing ancillary services often also need to follow this regulation. However, since most ancillary services such as Primary Frequency Response and Secondary Frequency Response deviate from their standard schedule by definition, this causes additional cost for schedule deviation to the EESS operator. This is even though the EESS operation actually benefits the grid.

Common effective countermeasures include:

- Exempt EESS that provide ancillary services from these penalties
- Design a bidirectional penalty-benefit mechanism that also includes benefits if the deviation from the schedule benefits the grid
- Adjust the penalties and/or ancillary service payment so that the overall profit for the EESS operator is still attractive

8.4.3 Asymmetric ancillary services

Ancillary services can either be organized symmetrically, i.e. designed to require import and export of energy to the grid, or organized asymmetrically, i.e. separating the tendering of ancillary services between energy import (negative) and export (positive).

Asymmetrical tendering makes the market more accessible for unidirectional ancillary negative and positive power service providers. Negative power services are those where the power output is reduced below the scheduled power, as possible in wind power and PV. Positive power services are the services where the power output is increased above scheduled, e.g. flexible thermal generation, or where the power consumption is reduced below the schedule, e.g. demand side management. In theory, those providers could also provide symmetric services, but this is often not economical, e.g. because positive service provision by PV can only be achieved by constantly operating below the possible power which curtails clean electricity of a marginal price near zero from the grid.

Symmetric tendering makes the market more accessible for BESS since they would run full or empty in asymmetric markets.

8.4.4 *"Infinite" service requirements*

As conventional power plants usually store large amounts of carbon or nuclear fuel, they do not face a limited energy reservoir on a timescale of days to weeks. Due to this fact, most requirements for ancillary services in grid codes were written without a limitation of service delivery.

An example of this is the requirement for the Primary Frequency Response requirement in the German grid codes until 2013. In this grid code, the Primary Frequency Response provider was required to be able to provide the ancillary service over an entire week. However, in practical grid operation the PFR is replaced by the Secondary Frequency Response within 15 minutes, rendering the infinite duration requirement obsolete. For conventional plants, this requirement was never an issue due to the large energy reservoir. However, for a BESS it is a decisive factor if energy capacity – being the most expensive component in a BESS – needs to be installed with a 15-minute reserve or with a 7-day reserve.

The common countermeasure against this incentive is to define an upper limit required for each ancillary service.

8.4.5 *Unclear permitting situation*

Major project risks for any EESS developer are time and cost risks associated to unclear permitting. This situation is commonly caused by the fact that either no regulations for energy storage permitting is available or that the permitting only includes legacy technologies such as lead-acid battery installations. Common permitting issues EESS face are:

- Lack of definitions of technical criteria to fulfill in order to be qualified to deliver certain ancillary services
- Unclear situation regarding the situation for public permitting regarding the building code including the handling of fire hazards and chemical hazards
- Unclear situation regarding the requirements for the grid code compliance when connecting energy storage systems. As most energy storage systems are coupled through inverters, most best practices from PV and wind power plants can be re-used. Care has to be taken since EESS differ from PV and wind power plants since they do not only export energy, but import energy as well. This can lead to a situation where EESS must fulfill the requirements for generators and loads, leading to an additional risk for the EESS developer
- Unclear situation regarding the regulations and possibilities for the recycling of batteries

The most effective countermeasure is to publish guidebooks on best practice for storage design and permitting. References for best practice can be taken from existing standards. If international standards such as the IEC 62485 series are used, the entry barrier for foreign technology providers can be significantly reduced.

9 REFERENCE CASES

In this section, an international overview over market mechanisms for ancillary services is given. These market mechanisms cover:

- Ancillary services that were specifically designed to benefit the usage of EESS
- Ancillary services that were designed for other technologies, but in which EESS have proven successful commercial operation

9.1 International overview

An international overview over the situation in various grids is given in Figure 3 on page below. The diagram shows the size of the respective electricity grid on the x-Axis (logarithmic scale) and the yearly energy share of variable renewable energies (i.e. PV and wind) on the y-Axis. The following symbols are used:

- Grids with a vertically integrated generation are marked with an "x". In these grids, the grid operator is allowed to own the assets that provide ancillary services
- Grids with a long-term energy market that requires generators to supply ancillary services as an included "free" service with the Power Purchase Agreement are marked with an "o"
- Grids with an ancillary services market separated from the energy market are marked with a ".". These may be short-term or long-term ancillary service markets
- Grids with an unclear market mechanism are marked with a "◆"

The focus on variable renewable energies instead of all renewable energies (also including biofuels, hydro and geothermal) is on purpose as the main current challenge in Baja California Sur is the operation of variable renewable energies, especially PV, which pose special challenges to operation of the grid.

Through this comparison, cases with grids facing comparable challenges as the Baja California Sur grid can be identified to verify their approaches to integrate a higher share of variable renewable energies.

It is to be noted that the diagram shows the peak demand and variable renewable energy share of the selected grids, not of the countries where they are located. This is on purpose because focusing on regions or countries can be misleading from a technical perspective. As an example, the electrical grid in the South Australia region operated by ElectraNet claims a very high variable renewable energy share of 53%. However, this grid is synchronously coupled to other grids. Therefore, grid issues are shared between the grid. In the interconnected grid the ElectraNet grid is operated in, the total variable renewable share is only 8.5% and therefore comparatively low.

9.1.1 Conclusions

As a conclusion, the following grids are an interesting example for the Baja California Sur grid:

- US Hawaiian Islands, e.g. Kauai and Maui: Comparable size, very high share of variable renewable energies
- US California grid (CAISO): Very high share of variable renewable energies, market mechanisms very similar to Baja California Sur
- Ireland and Northern Ireland: Very high share of variable renewable energies
- United Kingdom main grid: High share of variable renewable energies, long-term tendering of some ancillary services

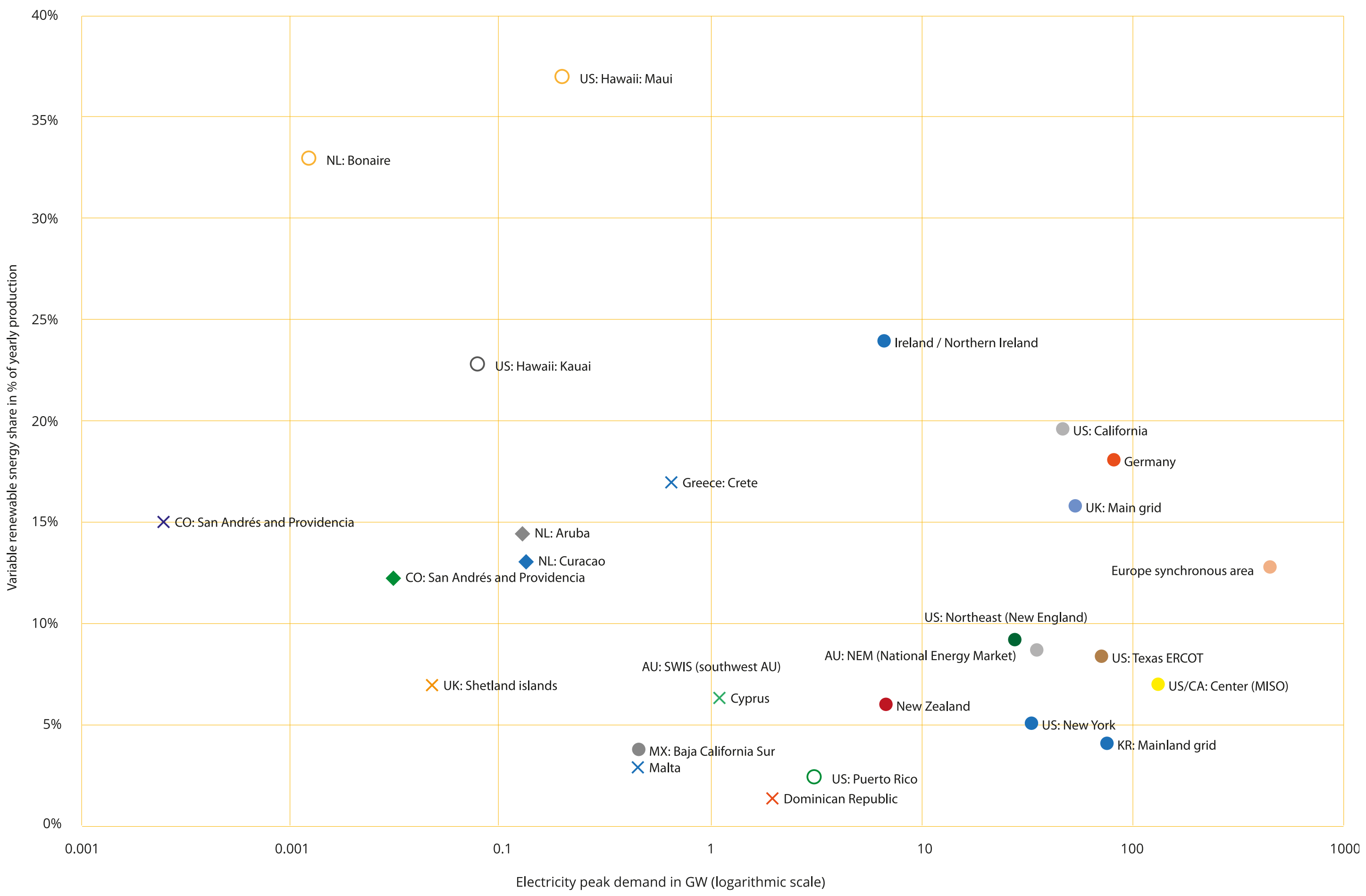

Figure 28: Comparison of peak demand and variable renewable energy share in various grids

9.2 Reference case: Baja California Sur (Mexico)

As Baja California Sur is the reference case, the conditions will be described for a comparison with other grids.

The peak demand in Baja California Sur is approximately 450 MW. Currently, 30 MW of large-scale PV and approximately 4 MW of small-scale PV is in operation. In the recent years, these PV generation capabilities have not been in operation throughout the entire year. However, by the size of the generation capacities it is expected that the Baja California Sur grid can achieve a moderate yearly variable renewable energy share of 4 – 5%.

9.2.1 Battery Energy Storage System deployment situation

Currently, there are no grid-connected EESS operated in Baja California Sur.

9.2.2 Ancillary service market situation

In Baja California Sur, there is an energy market called the Precio Marginal Local (abbreviated PML) in operation. There is also a separate Ancillary Services Market that contains the following products:

- Secondary regulation
- Spinning reserve
- Non-spinning reserve
- Supplementary reserve

However, due to the small size of the grid, the total volume of the ancillary service market is very small at a combined size of less than 150 MW for all four services combined[28].

9.2.3 Findings

Baja California Sur was by far the smallest grid (by peak demand) that was found to have a short-term ancillary service market in operation. Within the analyzed grids, the next smallest grid operating a short-term ancillary service market is the New Zealand grid. However, the peak demand in the New Zealand grid is approximately 15 times higher than that of the Baja California Sur grid.

9.3 Hawaii: Kauai and Maui

With grid sizes of up to 1.14 GW, the size range of the Hawaiian Islands grids is very comparable to the Baja California Sur grid in Mexico. In recent years, these grids have achieved some of the highest yearly variable renewable energy shares worldwide: 22.8% on the island of Kauai and 36.9% on the island of Maui.

9.3.1 Battery Energy Storage System deployment situation

Surprisingly, Hawaii has not needed a high penetration of EESS for this share so far. As shown in Figure 29, only a few EESS – most of them for research purposes – have been installed so far. One of the major current EESS units is the 10 MW *BESS* on Maui that is allocated to a wind farm and provides multiple *Ancillary Services*. However, there is currently a strong push to install more EESS on the islands. Examples are the 13 MW / 52 MWh Tesla BESS associated to a new 15MWp PV plant[29] and the *AES 20 MW / 100 MWh BESS* associated to a 28 MWp PV plant[30]. Therefore, it seems likely that the variable renewable energy share mentioned above is the current limit without EESS.

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[28] As retrieved from “Requerimientos de Servicios Conexos” from http://www.cenace.gob.mx/SIM/VISTA/REPORTES/ServConexosSisMEM.aspx

[29] http://fortune.com/tesla-solarcity-battery-solar-farm/

[30] https://www.greentechmedia.com/articles/read/aes-puts-energy-heavy-battery-behind-new-kauai-solar-peaker

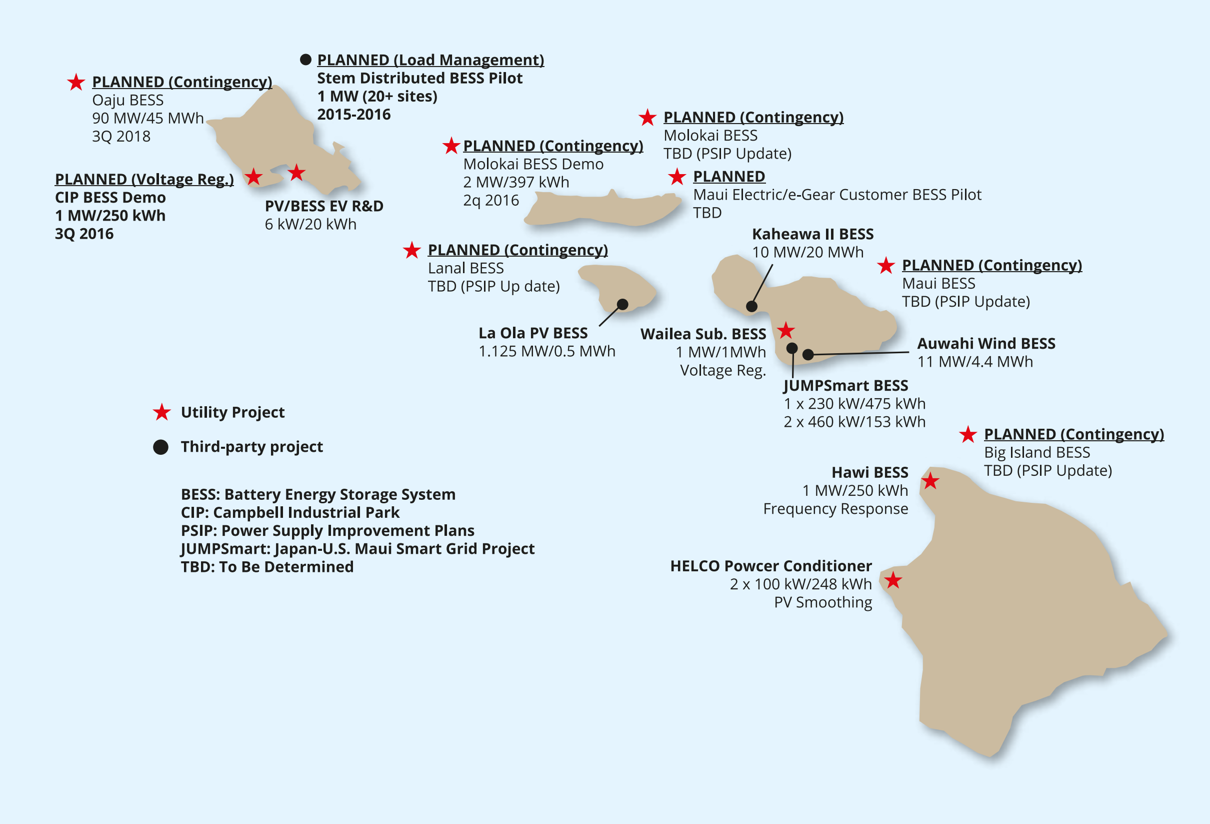

Figure 29: Locations of EESS in the Hawaiian Islands. Image: Maui Electric

9.3.2 *Ancillary service market situation*

The Hawaiian Islands feature a long-term single buyer market for the energy. The requirement to deliver ancillary services is included in the purchase contract for said energy. There is no separate market for ancillary services.

Instead of establishing an ancillary services market or funding EESS first, the Hawaiian utilities have decided to implement various operational measures to allow for a high renewable penetration. These measures include voluntary load shedding schemes that are also offered to private and small commercial customers.

9.3.3 *Findings for the Baja California Sur case*

The US traditionally has been in favor of deregulating the *Ancillary Services* market. In contrast to that general strategy, the decision for the Hawaiian Islands has been to create no such market. The reason for this is that the small size of the grids does not allow for a competitive environment between the possible providers for ancillary services. This can be an example for Mexico, where an ancillary service market may work in the interconnected grid due to the amount of ancillary service providers. In contrast to this, *Ancillary Services* could be integrated into the requirements for generators or remunerated through a tariff-based scheme in the much smaller Baja California Sur grid because the small grid size does not allow a competition that would be possible in larger grids.

Furthermore, the Hawaiian Islands are a good example that it is possible to reach high variable renewable energy shares without the need for large EESS, i.e. that EESS are one option for flexibilization, but not the only one. Operational methods and other flexibilization technologies such as flexible generation and demand side management can be used to mitigate the impact of variable renewable generation, up to a ratio of 25% to 35%.

Finally, the Hawaiian Islands serve as a kind of prototype for the integration of high renewable energy shares. A lot of studies have been carried out on these grids and most of these studies are publicly available.

9.4 US mainland markets

Of all *Independent System Operators (ISO)* in the US mainland, the Californian *ISO* named *CAISO* is the only one with a yearly variable renewable share of more than 10% in its grid. In 2016, 19.62% of the energy in the *CAISO* grid was delivered by wind and PV.

9.4.1 *Battery Energy Storage System deployment situation*

Currently, around 700 MW of *Battery Energy Storage Systems* with a total capacity of about 1.25 GWh are installed in the US.

9.4.2 *Ancillary services market situation*

The ancillary service markets of the major grids in the US (e.g. *CAISO, PJM, MISO NYISO)* are short-term tendered markets. Even though the composition of most of the markets is very similar, it can be seen in Figure 30 below that the market prices vary highly between the regions and that prices are generally volatile.

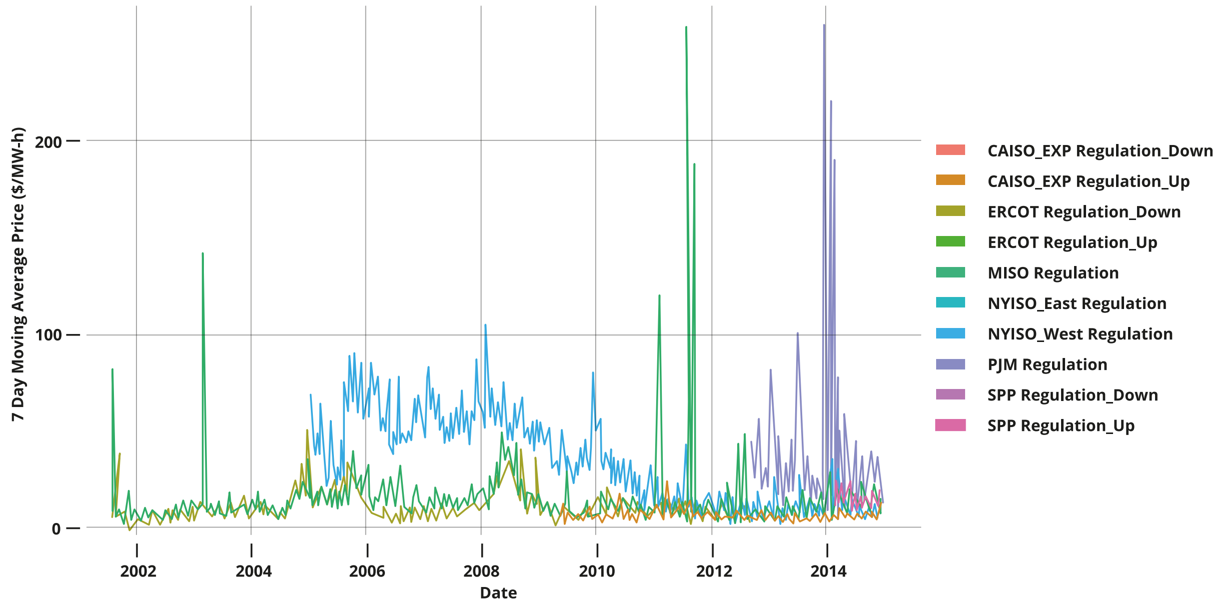

Figure 30: Ancillary service market price comparison in various US markets

Specialized markets for EESS

All *Independent System Operators (ISO)* in the US have developed market mechanisms to encourage the introduction for EESS operated by third parties into their grid. Even though every *ISO* uses a different mechanism, the common traits of these ancillary service markets are:

- There is a higher payment for a higher speed and accuracy of fulfilling a service
- Special markets offer opportunities for EESS with a limited energy reservoir. This is either implemented through short-term markets of one hour or through ancillary services that do not require an infinite energy reservoir, e.g. by averaging the control signal to the EESS to zero over a certain period or by allowing the EESS to recharge during operation

Beyond these common services, *CAISO* having the highest variable renewable energy share has also implemented a *ramp rate control*[31] product to limit the steep gradient that is caused by the increase of consumption in the evening together with the decrease of PV production at the same time.

EESS ownership models

Currently, all EESS in the US mainland markets are operated in a third-party ownership model, i.e. the Independent System Operator may contract the ancillary services an EESS *offers, but he is not allowed to own the EESS by himself. This is due to the fact that in deregulated markets, the grid operators are not allowed to own means of generation. As EESS have traditionally been associated to their functions in the wholesale energy market only, grid operators were not allowed to own these units.*

A current discussion in the US grids is the question if the Independent System Operators should be allowed to own and operate EESS themselves for ancillary services. This especially focuses on ancillary services that cannot be procured independent of the location of the EESS, such as line congestion management. In the rationale of this discussion, the EESS is not an *"Energy"* Storage system for the storage of energy itself, but rather an ancillary service provider comparable to other assets like *STATCOMs* used for reactive power provision,[32] which has classically been an asset which grid operators in deregulated markets are allowed to own. However, it must be noted that the result of this discussion is still pending[33].

9.4.3 *Findings for Baja California Sur grid*

The major findings of the US markets for the Baja California Sur grid are:

- An efficient market design plays a key role in the price for ancillary services. Introducing EESS as a new technology alone does not necessarily lead to lower prices for ancillary services. An example of this problem is visible in the PJM price peaks Figure 30 - this market contains a high share of BESS and still has exhibited Frequency Regulation cost that is even higher than typical marginal costs for conventional peak generation.
- Short-term ancillary service markets can lead to highly volatile prices, especially when few parties offer in said market
- *Ramp rate control* can be procured and delivered efficiently through a centralized market
- Legalizing EESS ownership by the grid operator can be considered if the EESS is only limited to ancillary services

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[31] *CAISO* calls *the ramp rate control product Flexible Ramping*
[32] https://en.wikipedia.org/wiki/Static_synchronous_compensator
[33] https://www.ferc.gov/whats-new/comm-meet/2017/011917/E-2.pdf

9.5 United Kingdom

The UK main grid features a peak demand of approximately 52.7 GW, which is approximately 100 times bigger than the Baja California Sur grid. However, as it is an islanded grid that has a high share of variable renewable generation of 15.79% mainly consisting of wind power plants, it faces similar challenges to other islanded grids with high renewable shares.

9.5.1 *Battery Energy Storage System deployment situation*

Currently, around 25 MW of Battery Energy Storage Systems with a capacity of about 25 MWh are installed in the UK. However, due to the Enhanced Frequency Response tendering described in the section below, this number is expected to increase by 200 MW soon.

It should be noted that even though the UK grid is not synchronously connected to any other grid, there are HVDC connections to Continental Europe and Ireland that help in the procurement of ancillary services.

9.5.2 *Ancillary services market situation*

The UK can serve as a reference for Baja California Sur because it is very progressive in the deregulation of ancillary service markets and because it has recently invested high amounts in the practical research and implementation on the usage of energy storage systems for ancillary services.

Research funding for energy storage

The most prominent research project is the UKPN Smarter Network Storage (SNS) featuring a lithium-ion Battery Energy Storage System of 6 MW and 10 MWh. This project also featured an analysis on the commercial viability of the EESS operation and the project documentation[34] provides a deep insight on the results.

Enhanced Frequency Response

On the implementation level, a new ancillary service called *Enhanced Frequency Response* has recently been introduced. While the fastest frequency response service to handle grid contingencies before had to fully react within 10 seconds, the *Enhanced Frequency Response* service has to fully react within 0.5 seconds. This significantly reduced the maximum Rate of *Change of Frequency*. This ancillary service was not exclusively aimed at *Battery Energy Storage Systems*, but all winning bidders offered this technology. To incentivize bidders for this ancillary service, the service was tendered over a long-term period of four years. This long-term tendering resulted in surprisingly low prices. These prices are now even lower than the common prices for *Primary Frequency*

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[34] http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/

Response in the UK even though the requirements are stricter for the *Enhanced Frequency Response*.

9.5.3 Findings for the Baja California Sur case

The tendering of the new *Enhanced Frequency Response* market in the UK is a response to the reduction of spinning inertia in the UK grid. This is a situation that is feasible in the future for the Baja California Sur grid too. Therefore, the definition of this service could be used as a reference for ancillary service definitions in the Baja California Sur grid.

Furthermore, the switch from short-term hourly tendering to a long-term four-year tendering for the new *EFR* service is a good example to incentivize the installation of EESS technologies. This mechanism reduces the market risk for ancillary service providers and thereby has resulted in favorably low prices for the provision of this new ancillary service. A possible conclusion for the Baja California Sur case is that short-term tendering of ancillary services as it is currently practiced does not necessarily result in a better market design.

9.6 Ireland and Northern Ireland

The interconnected electricity grid of Ireland and Northern Ireland features a peak demand of 6.57 GW. The yearly variable renewable energy share is currently 24% and mainly consists of wind energy.

The current main challenge of the grid operation in Ireland is the high Rate of Change of Frequency that is caused by the reduced inertia due to the high percentage of wind feed-in in peak periods. This high *Rate of Change of Frequency* poses these two threats to the grid:

- Accidental disconnection due to islanding detection: in the past, so called RoCoF-relays have been used to detect a separation of grid sections from the main grid. If this so-called islanding had happened, the generators in this island grid were supposed to shut down. As the Rate of Change of Frequency is commonly higher in smaller grids, it was used as a shut-down criterion. However, high rates are now also seen in the larger grids such as the Irish network. However, this issue can be mitigated through a change in the protection concept
- Disconnection of generators due to generator self-protection: Conventional generators can only tolerate a limited Rate of Change of Frequency between 1 Hz/s and 2 Hz/s. Once this limit is exceeded, the generator disconnects itself to avoid mechanical damage. This issue cannot be mitigated easily and the *Rate of Change of Frequency* needs to be limited to avoid a serial shutdown resulting in a total blackout

9.6.1 Battery Energy Storage System deployment situation

Unlike UK, Ireland has focused on operational measures instead of EESS to cope with the challenges variable renewable generation has introduced in the grid. Therefore, less than 1 MW of grid-connected EESS are currently operational in Ireland. However, Ireland is currently tendering the installation of operation of EESS so it is likely that this situation will change in the near future.

It should be noted that even though the Ireland grid is not synchronously connected to any other grid, there are two HVDC connections to UK that can be used for the procurement of some ancillary services.

9.6.2 Ancillary services market situation

Most ancillary services are procured through a separate market in the grid for a period of 12 months. The unique feature of this market is that there is a tendering to provide inertia to the grid. Just as the UK Enhanced Frequency Market, this ancillary service aims to limit the Rate of Change of Frequency, but instead of an actual service, the physical inertia of rotating masses is tendered. The service even considers the physical property of the inertia and reflects this in the tariff pricing. The current procurement prices are shown in Table 24 below.

Service Name	Unit of Payment	Proposed Rate €
Synchronous Inertial Response (SIR)	**MWs^{2}h**	**0.0048**
Primary Operating Reserve (POR)	**MWh**	**3.09**
Secondary Operating Reserve (SOR)	**MWh**	**1.87**
Tertiary Operating Reserve (TOR1)	**MWh**	**1.48**
Tertiary Operating Reserve (TOR2)	**MWh**	**1.18**
Replacement Reserve - Synchronised (RRS)	**MWh**	**0.24**
Replacement Reserve - Desynchronised (RRD)	**MWh**	**0.53**
Ramping Margin 1 (RM1)	**MWh**	**0.11**
Ramping Margin 3 (RM8)	**MWh**	**0.17**
Ramping Margin 8 (RM8)	**MWh**	**0.15**
Steady State Reactive Power (SSRP)	**MVarh**	**0.22**

Table 24: Current ancillary service tariffs in the Ireland / Northern Ireland grid

9.6.3 Findings for Baja California sur case

The three main findings applicable to the Baja California Sur grid are:

- From a market perspective, long-term ancillary service procurement can be advantageous to attract ancillary services
- Ancillary service procurement can also be obtained at fixed prices in smaller grids
- At high penetrations of variable renewable energies, the Rate of Change of Frequency becomes an issue that may require the introduction of new ancillary service products or requirements

10 CALCULATING THE COST
of Energy Storage in BCS

To get a better understanding about what payments would have to be expected for a third-party owned Battery Energy Storage System in Baja California Sur, a sample financial modeling has been carried out for this case. The modeling was carried out under the following assumptions:

- Using a 10 MW / 10 MWh state-of the art Battery Energy Storage System with common 2017 market prices
- Ancillary services require an energy throughput of ca. 10 MWh/day
- Generic financial assumptions for regions comparable to Mexico
- Profitability assumptions that make the project attractive for a private investor
- Stand-alone operation of the Battery Energy Storage System for ancillary services, i.e. no direct coupling to any generation or load

The power-to-energy ratio of 1:1 is very common for systems used for ancillary services and is usually sufficient for use cases such as *ramp rate control, Primary Frequency Response and short-term Automatic Generation Control (Secondary Frequency Response).*

10.1 Results

Under the assumptions for the situation in Baja California Sur, the grid operator would need to pay between 40 and 50 million MXN per year for the service of a 10 MW / 10 MWh Battery Energy Storage System. If this price is paid, the installation and operation of the system is commercially attractive for a private third-party investor.

This value is in line with typical market conditions worldwide, where the contracted operation of such services is typically between 150,000 USD and 400,000 USD (3 to 8 million MXN) per MW and year. The broad range is caused by different expectations for the Internal Rate of Return, wear and tear determined by the operation and perceived market risk.

If it would be feasible to have the grid operator himself own and operate a Battery Energy Storage System, the associated cost would likely be lower as this structure would reduce the added cost by the high Internal Rate of Return expectation and a high market risk of a private owner.

11 CONCLUSIONS
and Recommendations

Based on the reference cases and experience from the introduction of energy storage systems in other grids, general, technical and market recommendations to incentivize the use of Battery Energy Storage Systems in Baja California Sur can be given. These recommendations are listed in this section.

General recommendations

- Publish technical requirements and procedures in English language as well, to reduce the entry barrier for foreign investors and technology suppliers
- Energy Storage Systems are one possible path for the delivery of ancillary services that are for example used in the United Kingdom an in the mainland US. However, other regions such as Ireland and the Hawaiian Islands have proven that other flexibilization technologies are also feasible to provide these ancillary services even at very high variable renewable energy penetrations
- If a funding for Energy Storage Systems is considered, partial funding instead of full funding provides an incentive to implement economic systems and thereby reduce the risk of misguided funding

Recommendations for technical conditions

- Clarify the technical procedures and conditions to connect Energy Storage Systems to the grid
- Require EESS to fulfill a certain service level such as a certain availability period or a certain accuracy instead of requiring technical parameters such as EESS power or energy
- Implement ancillary services that have a finite fulfillment timespan before being replaced by slower units. This timespan should not be greater than 30 minutes for symmetrical services (e.g. positive and negative primary frequency response) or 60 minutes for asymmetrical services (e.g. the injection of energy into the grid upon command)

Recommendations for market conditions

- It may not be economical to require variable renewable energy generators to fulfill the same ancillary services as conventional generation. Instead, a centralized procurement allows each supplier to decide for himself if the participation in the ancillary service market is attractive for him. Thereby, the most cost-efficient technology will be used to cover the requirements of each ancillary service
- EESS ownership: Consider if the grid operator may be permitted to own and operate Energy Storage Systems for certain ancillary service cases that do not relate to the wholesale electricity market
- Consider a long-term tendering mechanism for ancillary services instead of the current short-term tendering. Short-term tendering in small market poses a high market risk for investors in new technologies
- If third-party ownership of the Energy Storage Systems is desired, expect a cost of ca. 4 – 5 million MXN per MW and year for the fulfillment of typical ancillary services under the 30 / 60-minute fulfillment timespan under the current market conditions for private investors in Mexico

ABBREVIATIONS AND DEFINITIONS

Abbr.	Term	Definition
AC	Alternating current	
BESS	Battery Energy Storage System	Limited to battery storage systems
BMS	Battery Management System	
BOL	Begin Of Life	Start of operation of the ESS where no aging has occurred yet (see EOL)
BOS	Balance of system	All components of a BESS except the batteries themselves, e.g.: ◦ Power Conversion System (PCS) / Inverters ◦ Enclosures ◦ Transformers ◦ Control System (SCADA)
CapEx	Capital Expenditure	Expenditures required for the planning, procurement and installation of the EESS. Major contributors for BESS include: ◦ Land lease ◦ Batteries including accessories ◦ Civil works ◦ Balance of system (see above) ◦ Project development, planning, permitting
C-rate	C-rate	See 2.2.1
Cycle	Cycle	Charging an ESS from a certain state of charge to a target state of charge and later discharging it to the initial state of charge
DC	Direct Current	
DOD	Depth of Discharge	Ratio between energy content that is discharged within a cycle vs. total potential energy content of the ESS
EESS	Electrical Energy Storage System	Only includes ESS that are being charged with electrical energy as well as providing electrical energy for discharge. Excludes storage systems where the release of the energy (discharge) is not in form of electricity
EOL	End Of Life	Aging state of the ESS where the desired service performance cannot be fulfilled anymore (see BOL)
ESS	Energy Storage System	Includes all energy storage systems
-	Energy content	Amount of energy that can be discharged from an ESS under the technology-specific discharging conditions such as discharge power and depth of discharge. Usual units: Ws (J), kWh, MWh
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit	
IRR	Internal Rate of Return	
ISO	Independent System Operator	In Mexico: CENACE
LFP	Lithium-Iron-Phosphate	A lithium-ion cell chemistry
LMO	Lithium-Manganese-Oxide	A lithium-ion cell chemistry
MXN	Mexican Peso	
NCA	Nickel-Cobalt-Aluminum	A lithium-ion cell chemistry
NMC	Nickel-Manganese-Cobalt	A lithium-ion cell chemistry
NPV	Net present value	
OpEx	Operational Expenditure	All expenses that occur during the operation period of the EESS, e.g.:Power ◦ Energy purchases ◦ Operation personnel ◦ Taxes and levies ◦ Maintenance and repair ◦ Insurances and warranties
PML	Precio Marginal Local	Locational Marginal Price (LMP) in other markets
PPA	Power Purchase Agreement	
RE	Renewable Energies	
SOC	State of Charge	Ratio between present energy content of the ESS vs. maximum possible energy content of the ESS
SOH	State of Health	Ratio of the maximum possible energy content of the aged ESS vs. the maximum possible energy content of the factory new ESS

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ID	Author	*Title* and Remark
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