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# The Value of Energy Storage and its Ability to Fight Climate Change

## By Catalina Delgado, Mariana Jimenez, and Montserrat Ramiro

October 2018

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## 1. Why Energy Storage?

According to the World Economic Forum's Global Risk Report 2018, extreme weather events are as big a threat to the global economy as weapons of mass destruction, albeit more likely to happen [1]. Last year's hurricanes, Harvey, Irma, and Maria, were tangible evidence of that.

Although weather is a complex phenomenon, there is substantial evidence that increasing levels of Greenhouse Gases (GHG) in the atmosphere will raise the Earth's temperature, disturbing normal climate patterns. Scientific consensus states that going 2°C above pre-industrial levels could lead to more frequent and stronger weather events, jeopardizing our livelihood [2]. Countries around the world are thus working to prevent this scenario through a set of climate mitigation and adaptation efforts defined in the Paris Agreement approved on the 21st Conference of the Parties (COP21) held in 2015, and ratified one year later by 176 countries [3].

Given that the energy sector accounts for almost two-thirds of the world's total anthropogenic GHG emissions [4], all mitigation strategies include at least one action aiming at the decarbonization of the electrical grid. Decarbonization efforts in the field of electricity rely on two pillars: energy efficiency and renewable energies.

While it was unthinkable decades ago, renewable energies are now the third-largest contributor to the world's power generation, amounting to 22.8 percent of the global power generation, just 0.1 percent below natural gas-based technologies. Hydropower is the most used renewable energy source; however, solar photovoltaic (PV) and wind are the fastest growing technologies with average annual rates of 45.5 percent and 24.0 percent, respectively, both in comparison with 1990 levels [5]. Although their net contribution to the global electricity matrix is quite low yet, dropping costs and favorable policies will likely increase their share in the near future.

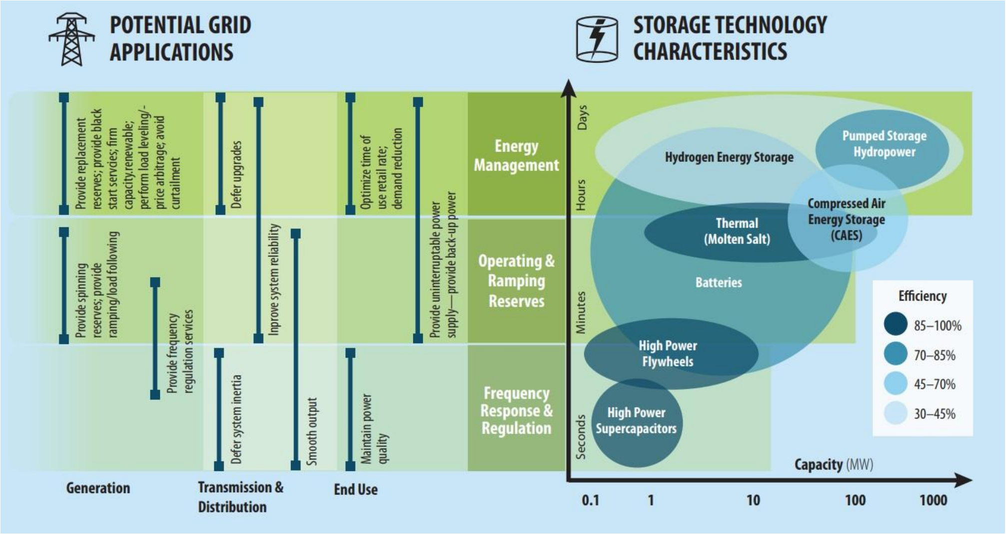
This is a desirable outcome for most countries, but there are compelling concerns on the potential impact of renewable integration on the reliability and security of electricity systems, as wind and solar are variable renewable energies (VRE) subject to natural forces, and therefore intermittent. Such characteristics pose additional challenges to grid operators, as they need to balance supply and demand in real time while operating the system at certain established parameters. Failing on this task can lead to variations in the quality of power supply, partial or total blackouts.

In traditional systems, grid operators change the output of conventional power plants to meet the variable –but highly predictable– fluctuations in demand. In liberalized markets, this task is supported by ancillary services, mostly provided by synchronous generation units. However, in a system with higher levels of VRE, more flexibility is required, increasing the need for more responsive ancillary services. Paradoxically, a larger share of VRE usually means that less conventional facilities will come online further reducing the supply of those services, given that wind and solar power plants are not able to supply them themselves (at least not to the same extent).

Greater flexibility is possible through a combination of different means, such as energy storage, demand-side programs, ramping of conventional generation, flexible dispatch of conventional generators, energy curtailment, and improvements in transmission [6]. Several studies have concluded that in systems with large shares of VRE –50 percent is the average tipping point [7]– affordable energy storage is a worthwhile solution that allows for more renewable energy deployments, without compromising the grid's safe operation. Even in systems with lower VRE participation, storage can add value to the energy sector value chain, for instance, by deferring investments in transmission and distribution infrastructure and empowering consumers to accommodate larger shares of VRE. These benefits will be discussed in the following sections.

This document considers 'storage' as the broad category of technologies that enables energy that is produced in one time period to be used at a later time period, and comprises a broad asset class that includes many subclasses, including gravitational, thermal, electro-chemical, and mechanical solutions (**Figure 1**). To date, the most popular and largest installed base of these technologies have been gravitational and thermal storage. More recently, in large part due expanding manufacturing capacity and resulting cost reductions from producing batteries for electric vehicles, grid connected electro-chemical batteries are now being deployed in the hundreds of megawatts scale.

***Figure 1. Potential grid applications per type of storage technology***



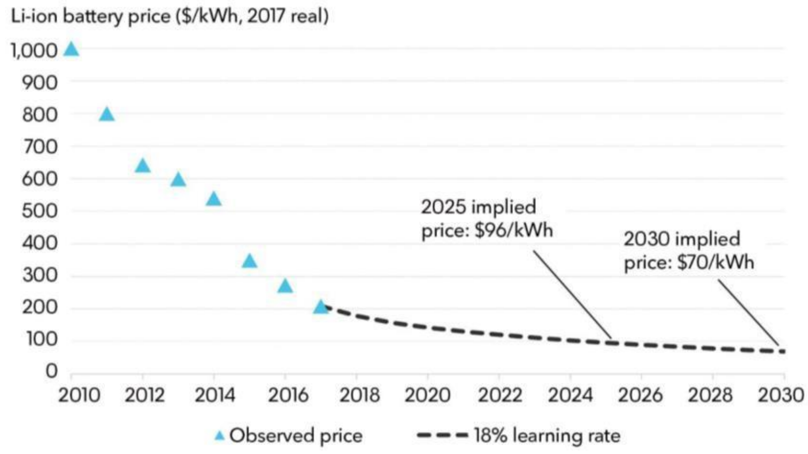
*Source: National Renewable Energy Laboratory, 2016* [7]

### 1.1 A commercially viable solution

We have known of storage's many benefits for a long time; however, until recently, its high capital requirements have been a barrier to its deployment. Current market trends show considerable cost reductions and efficiency improvements. For instance, the cost of Lithium-ion (Li-ion) batteries has fallen as much as 73 percent between 2010 and 2016 for transport applications, which is also driving a downward trend for stationary applications in countries like Germany, where small-scale Li-ion battery system's installation costs have dropped 60 percent between the end of 2014 to the first semester of 2017 [8].

The latest *New Energy Outlook*, by Bloomberg New Energy Finance, expects this trend to continue. A further deployment of electric vehicles will also drive down the price of batteries for stationary applications, so that they reach US$70/kWh by 2030; that is 67 percent down from today's costs (**Figure 2**). Cost competitive batteries will be a turning point for VRE, as renewable-plus-batteries configurations would expand their flexibility and make wind and solar dispatchable. This, in addition to further reduction in the costs of PV and wind components, make plausible that 50 percent of the world generation in 2050 could be supplied by wind and solar power plants [9].

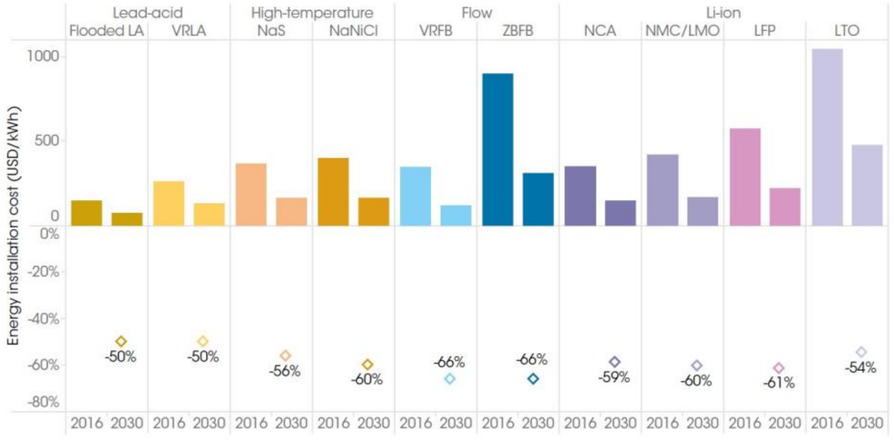
***Figure 2. Lithium-ion battery price, historical and forecast***



*Source: Bloomberg New Energy Finance, 2018* [9]

Other storage technologies also show signs of falling costs (**Figure 3**). The only exception is pumped hydro, a mature technology and currently the largest single source of electricity storage capacity, with 96 percent of the 4.67 TWh storage capacity installed worldwide [8]. Because of its long construction periods, geographic needs and scale, as well as its environmental and social impacts, there is little space for further reducing pumped hydro's costs. However, a number of startups are currently exploring modular purpose-built pumped hydro solutions with potential cost and siting advantages.

***Figure 3. Battery electricity storage system installed energy cost reduction potential, 2016-2030***



Note: LA = lead-acid; VRLA = valve-regulated lead-acid; NaS = sodium sulphur; NaNiCl = sodium nickel chloride; VRFB = vanadium redox flow battery; ZBFB = zinc bromine flow battery; NCA = nickel cobalt aluminium; NMC/LMO = nickel manganese cobalt oxide/lithium manganese oxide; LFP = lithium iron phosphate; LTO = lithium titanate.

*Source: International Renewable Energy Agency, 2017* [8]

Nevertheless, cost reduction alone is not enough to build the economic case for storage. At current costs, storage providing a single service –and accruing just one benefit stream– continues to be more expensive than the alternatives. Given that storage can provide various services, it can also generate several revenue streams. For example, energy storage can provide transmission congestion relief, and when the same asset is not providing this service, it can provide other market services such as capacity and ancillary services. Transmission congestion may only be needed a few times a year when peak demand exceeds capacity [10], if the asset were able to deliver other services to the grid it could maximize its value by adding different streams of revenue. Allowing this 'revenue stacking' is a common trait of markets where energy storage makes economic sense.

Revenue stacking is not a straightforward process, particularly in unbundled markets in which multipurpose storage usually does not fit neatly into existing regulatory frameworks, which were drafted long before modular energy storage was technologically possible. Most of these regulations and market rules were created for a world in which the technologies that provided value for generation, demand, transmission, and distribution were specific to each of these segments. This is why we generally define market players according to their activity: generator, load, utility, etc. Storage defies this sort of framework, as a singular asset can operate under one or several of these categories. Hence, its deployment depends on the proper development of a new regulatory framework that recognizes energy storage's multipurpose capabilities.

Building upon this idea, this paper reviews the most relevant energy storage applications and analyzes its potential for Mexico, given the recent creation of its energy markets and the promising role that VRE are expected to play in the future.

### 1. Why Energy Storage? – Section Recap

Meeting worldwide goals for GHG reduction requires innovative solutions. As the world's energy mix moves away from fossil fuels and towards a higher penetration of renewables, energy storage emerges as a promising tool to address the challenges of higher VRE shares.

Energy storage makes economic sense for some applications and in certain markets despite commonly held beliefs to the contrary. This is in part the result of falling costs. However, the economic case for storage requires a new regulatory framework that recognizes its multipurpose nature and that enables revenue stacking.

## 2. The Case for Energy Storage in Mexico

In December 2013, the Mexican government approved a constitutional reform that opened energy markets to competition. Prior to this, the Mexican electricity industry consisted of a single national vertically integrated state-owned utility, no functioning markets –energy nor capacity–, and minimal regulation. The fact that many of the regulations and market rules for the new competitive system are being drafted from scratch provides storage a unique opportunity to receive clean-slate treatment, as opposed to the more complex quilt-like approach that has been necessary in other more mature systems. This alone would be enough to analyze storage's potential in a recently created market of such dimension, but there are other reasons to do so.

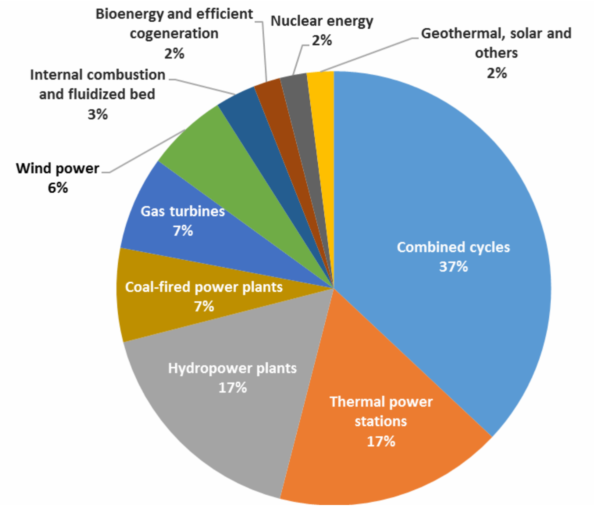
Mexico stands out for its privileged geographical position, with great potential for all renewable energy resources: solar, wind, geothermal, biomass, hydro, and marine energy. Solar potential is particularly notable as Mexico is one of the few countries whose entire territory is in the most favorable "sun belt."[1] These semi-arid regions are characterized by solar radiations over 1000 kWh/m$^2$-year, 90 percent of which comes in direct form due to the limited cloud coverage and rainfall, and over 3,000 hours of sunshine annually [11]. This is twice as much radiation as Germany, although this European country has around 200 times more solar PV power installed than Mexico (at the end of 2017, Germany had 43GW of nominal PV power installed [12]).

Indeed, Mexico's renewable energy potential remains untapped, as reasonable clean energy policies and new competitive market structures are driving its power generation matrix away from fossil fuels. In this context, storage's potential value grows with VRE penetration. Mexico's energy transition will be analyzed in the next section.

## 2.1 A renewable superpower in the making

By the end of 2017, Mexico had a total installed capacity of 75.7 GW, 70.5 percent of which was fossil-fueled generation (**Figure 4**). As in the rest of the world, renewable energy are the fastest growing technologies, but their overall contribution to power generation is still low. In 2017, renewable energy accounted for 25.7 percent of Mexico's total capacity, producing 49.2 TWh, or 15.4 percent, of the 319.4 TWh consumed that year in Mexico [13]. It is worth noting that the vast majority of Mexico's installed renewable capacity is concentrated in hydropower, with a share of 64.9 percent among all renewables.

***Figure 4. Installed capacity per type of technology (percentage) and type of renewable energy technologies (MW) in Mexico in 2017***



| Technology | Installed Capacity (MW) |
|---|---|
| **Total capacity:** | 75,685 |
| **Total renewable capacity:** | 19,462 |
| **Hydropower** | 12,642 |
| **Wind power** | 4,199 |
| **Geothermal** | 926 |
| **Solar energy** | 214 |
| **Bioenergy** | 1,007 |
| **Distributed Generation** | 434 |
| **FIRCO**[2] | 14 |

*Source: Ministry of Energy (SENER), 2018* [13]

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[1] The globe is divided in four broad sunbelts- according to the solar radiation intensity- for the sake of convenience and simplicity. The most favorable exists between 15°N and 35°N [52].

[2] FIRCO is the Spanish acronym for Shared Risk Trust, an initiative that operates programs for the rural sector development through the production of sustainable energy and the implementation of energy efficiency measures.

Mexico's 2015 Energy Transition Law sets binding targets to increase the share of clean energy in the country's electricity mix. This law builds upon the 2012 General Law on Climate Change and the country's international climate commitments. It establishes the obligation to generate at least 25 percent of the country's total power supply from clean energy sources by 2018, 30 percent by 2021 and 35 percent by 2024. The Transition Strategy to Promote the Use of Cleaner Technologies and Fuels, a policy tool derived from the Energy Transition Law, goes even further and establishes a minimum clean energy share of 50 percent by 2050.

In a context of a steadily growing demand for electricity –average annual growth is estimated between 2.4 percent and 3.6 percent up to 2031 [14]–, meeting clean energy targets will be challenging. Fortunately, Mexico's geography provides a privileged position in terms of renewable energy resources, as evidenced by record-setting low cost/MWh of renewable energy in Mexico's recent auctions (**Table 1**).

Although the country's renewable energy share has been dominated by large hydropower, wind and solar are growing faster than any other technology. According to a 2015 report from the International Renewable Energy Agency (IRENA), wind power alone has the potential to produce 92 TWh of electricity annually by 2030, while PV solar could contribute with 66 TWh over the same time horizon. This would represent 20 percent of the country's energy generation in 2030 and would require an average installation rate of 1.7 GW for wind and 1.5 GW for solar, per year [15].

There are reasons to believe that IRENA's projections will likely fall short. First, the interconnection of distributed systems below 0.5 MW has increased exponentially since 2014, and over 90 percent of systems installed are solar photovoltaic cells.[4] Large-scale projects from three long-term power auctions between 2015 and 2017 (**Table 1**) will add significant capacity of VRE to the national grid. According to SENER, 20 wind farms and 40 solar power plants will be built in the next three years as a result of these processes and will increase the total share of VRE from 4 percent to 11 percent once all projects are operating by 2021 [16].

***Table 1. Mexico's three long-term power auctions results for wind and solar***

| | First Auction | Second Auction | Third Auction |
|---|---|---|---|
| **Photovoltaic Solar** | | | |
| Capacity Awarded | **0** | **184MW-year** | **10MW-year** |
| Energy Awarded | **4.0TWh** | **4.8TWh** | **3.0TWh** |
| Average Price | **US$45.0/MWh** | **US$31.2/MWh** | **US$21.3/MWh** |
| **Wind Energy** | | | |
| Capacity Awarded | **0** | **128MW-year** | **83MW-year** |
| Energy Awarded | **1.4TWh** | **3,8TWh** | **2.5TWh** |
| Average Price | **US$55.3/MWh** | **US$33.3/MWh** | **US$18.5/MWh** |

*Source: own elaboration with data from the Ministry of Energy*

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[3] Under Mexican legislation, clean energy sources do not only include renewable energies but also nuclear power and efficient cogeneration, among other technologies described in the Article 3 of the Electricity Industry Law.

[4] Data from Mexico's Energy Regulatory Commission.

## 2.2 Challenges ahead

The integration of higher shares of VRE poses challenges for Mexico's existing grid. First, transmission and distribution network capacity needs to be expanded to eliminate bottlenecks and take advantage of low cost, remotely sited large-scale renewable power plants. Resource availability determines the plants' locations, which do not necessarily have to match demand's location or existing transmission capacity. Oaxaca's Isthmus of Tehuantepec is an illustrative example: the region offers excellent wind conditions all year round (power Class 5 and above[5]) but is far away from Mexico's central valley, where the highest demand is concentrated [17]. New transmission capacity is thus essential to exploit the isthmus' wind energy potential.

Operational challenges can also arise in places with large shares of VRE and an insufficient grid infrastructure. In this scenario, keeping the system's parameters between acceptable limits becomes harder, specially under unfavorable weather conditions. Experience has proven that high penetration of intermittent solar PV generation can have negative impacts on frequency regulation, frequency quality, system's inertia reduction, primary regulation, reserve margins, and on the lifespan of conventional power plants due to the need for steeper and more frequent ramping. This is already an issue in Baja California Sur (**Box 1**) and a similar scenario could take place in Yucatan, as four new PV power plants will come online as a result of the three long-term power auctions.

***Box 1. Challenges for the integration of VRE in Baja California Sur***

### Baja California Sur: an electrical island with attractive solar potential

Baja California Sur (BCS)'s electricity system consists of three transmission regions, La Paz, Los Cabos, and Constitucion, and is considered an 'electrical island' because it remains isolated from Mexico's National Interconnected System (SIN). In 2016, it served 1.4 million users, a demand of 2,689GWh [18].

Generation costs in BCS are among the highest in Mexico as most of its power plants run on diesel and fuel oil, shipped from mainland Mexico via the Sea of Cortes. Costly generation does not directly affect consumers because of onerous subsidies; however, environmental impacts are evident. As a result, the power generation sector has been identified as one of the region's main polluters, releasing significant levels of particulate matters and sulfur dioxide [19] –both dangerous to human health–, in addition to GHG emissions.

Moving to cleaner alternatives has been difficult, particularly because the grid's existing fossil fuel fleet has low flexibility, limiting its ability to integrate solar generation –a plentiful and low cost generation resource for BCS–. Being isolated, BCS does not have the response capacity needed to face sudden voltage or frequency variations, nor the operational reserves, start-up times or start-stop capacity. For these reasons, in 2014 CENACE, Mexico's Independent System Operator (ISO), declared a maximum integration capacity of 60 MW for large scale VRE and 10 MW of distributed VRE, to avoid putting the system at risk.

So far, only a 30 MW solar power plant –Aura Solar– is in operation, although three new facilities are already under construction and could add an extra 53MW by 2019 (23MW above the established limit [14]). In the case of distributed solar generation, BCS has already surpassed the established threshold,

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[5] According to the wind power classification of the US National Renewable Energy Laboratory, wind power Class 5 encompasses wind speeds between 7.5 m/s and 8.0m/s [54]

as 11MW small and medium-scale PV solar systems are already interconnected in its three transmission regions and the requests to interconnect further capacity continue to accumulate.

To cope with these issues, the Government of Mexico decided to request the construction of a High Voltage Direct Current (HVDC) transmission line to interconnect BCS and the SIN. Furthermore, the 2017 Development Program of the National Electricity System (PRODESEN) considered the installation of a 20MW battery bank as a potential short-term solution [14]. This project is currently on hold, while market rules clarify the role and scope of storage assets.

Working on these issues will become more pressing as Mexico moves toward a cleaner energy mix and increases VRE penetration. In fact, the Mexican government has already launched a fourth long-term power auction and, judging by the low prices offered by solar and wind power generators in the previous auctions, it is reasonable to expect that VRE projects will again win most of the new energy procurements.

Distributed VRE is also expected to continue to increase. The Energy Regulatory Commission estimates that, at the current installation rate, Mexico could reach 6.7 GW of installed distributed capacity by 2023. This would mean 22 times more distributed generation than today, most of which will come from PV solar systems. The massive adoption of distributed VRE can lead to grid congestion, especially at the distribution level. Grid reinforcement is a regular solution although it might be costly. According to a review conducted by South Africa's power utility, the additional costs to interconnect distributed generation –including network strengthening– can reach 2,000 €/kW [20]. Curtailment[6] is another way to deal with congestion, but it is generally avoided as it is suboptimal.

Energy storage can handle all these challenges while delivering other benefits too. The next section will further analyze storage's contribution to VRE integration, as well as the benefits from storage to users, to the system, and energy security in general.

### 2. The Case for Energy Storage in Mexico – Section Recap

Even though Mexico has a substantial renewable potential, current penetration of VRE remains low. However, this situation is rapidly changing due to three factors: i) the country's clean energy targets –30 percent by 2021 and 50 percent by 2050–; ii) the coming online of VRE projects from three successful long-term power auctions; and iii) the sustained growth of distributed VRE.

Increases in VRE will challenge traditional grid operation because of VRE intermittency, insufficient transmission grid infrastructure, and congestion in distribution networks. Storage is a viable solution to address these issues as Mexico moves forward on the path of energy transition.

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[6] An instruction to stop or reduce renewable generation due to physical constraints and not economic factors.

## 3. The Added Value of Storage

Due to its unique physical and operational characteristics, energy storage can provide a wide range of services along the energy value chain. In addition to increasing grid reliability, it promotes energy security by mitigating fuel dependency risks; improves generation efficiency and facilitates renewable integration; enhances grid operations and may reduce the need for costly transmission and distribution infrastructure upgrades; supports the electric grid by adding flexibility; and provides end users with additional means to manage their electric bill.

The benefits of storage may go beyond the electric system and spread to the overall society, via economic spillovers in its manufacturing and deployment, reduced emissions and a cleaner environment, and increased options and choice for increasing access to affordable electricity.

### 3.1 Variable renewable energies integration

Perhaps the most promising benefit of energy storage is its potential to support the energy transition towards cleaner generation technologies by accommodating increased penetration of VRE. This is possible because storage technologies are particularly well equipped to deal with VRE's distinctive characteristics, including its output variability –both short-term and long-term– and some of the undesirable effects that intermittent, variable resources may have on power service quality.

**Short-term arbitrage**. The ability to store energy at one moment and use it later is at the core of storage technologies' value proposition. This service, known as arbitrage or time shift, is highly valuable for VRE as they cannot be programmed to match demand and their outputs depend on external and uncontrollable factors, such as weather conditions.

During the summer, for example, peak demand in Mexico's central region takes place between 20:00 and 22:00, while lowest demand usually happens between 7:00 and 9:00. In this season, the sun usually rises around 6:00 and sets at 20:00. This means that PV solar systems installed in the central region produce more energy when it is least needed, a situation that could lead to curtailment of solar generation during off-peak demand periods. However, when storage is paired with solar PV power plants, this energy could be saved and injected back to the grid when it is most needed, providing a cleaner energy mix for consumers and higher economic value for the grid.

Additionally, sudden changes in weather conditions (e.g. passing clouds or stronger winds) can lead to rapid fluctuations of solar and wind generation output that have to be offset by other grid resources. Many types of energy storage are especially well suited to deal with these fast variations in output –called ramping–, as they can be programmed to quickly cancel out VRE's generation variability and can do so more efficiently than traditional fossil-fueled power plants.

**Long-term arbitrage**. Demand not only fluctuates in daily or weekly periods but also seasonally. So far, the only storage technology able to provide this service is pumped hydro, and potentially hydrogen storage. According to an IRENA report, 89 percent of the world's pumped hydro capacity is used for time shifting purposes. Other storage technologies have more diversified uses, although time shifting is at the top of the list (it accounts for 8.4 percent of the total usage given to these assets [8]).

Renewable generators can also use storage to maintain their production at a committed level during a specified period (i.e. ‘firming’ VRE output), enabling them to offer capacity-based products for a compensation. In the latest long-term power auction hosted by Mexico (**Table 1**), solar PV and wind projects were only able to get 1.7 percent and 13.9 percent of the available capacity, while gas turbines accounted for 84.4 percent of the capacity winning bids. Affordable storage technologies could make renewables as attractive for capacity-based markets as they are for energy. Thus, increasing the capacity value of renewable projects through energy storage could pave the way to greater portfolio diversification and reduced reliance on fossil-fueled generation for reliability purposes.

**Hybridizing existing fossil assets.** Energy storage can be integrated with existing fossil-fueled generators, an application known as ‘hybridization’. In this case, the storage device is the first responder to deal with short-term fluctuations in demand, allowing the underlying generator to be ‘always on’ and to operate at its peak efficiency. This, in turn, optimizes fuel consumption and minimizes emissions and water usage, while simultaneously extending the asset´s lifespan. Southern California Edison, a utility in California claims that this application of energy storage has been the most cost effective application deployed to date. (CITE SCE’s filing for approval).

**Service quality**. Energy storage can also be used to improve the power service quality, regardless of the generation mix. As mentioned, higher levels of VRE entail more output variability, but renewable projects paired with storage might have the opposite effect, enhancing the system’s overall reliability. This is particularly true in systems already experiencing reliability issues such as India, where power outages are the rule and not the exception. Despite India’s recent efforts to increase its generation capacity, it faces structural power shortages that affect households during peak demand times. Customers that can afford to invest in diesel generators or batteries and inverters as backup. The latter are used to save energy from the grid when it is available, so households can use their power appliances during the frequent outages [21]. Distributed renewable energy with storage can provide this service while relieving the grid and freeing available power for other consumers.

## 3.2 System advantages

One of the most relevant benefits of storage is its ability to provide flexibility to the overall system. Flexibility is the capacity to maintain a continuous service despite sudden fluctuations in supply and demand, a challenge that proves ever more pressing as the share of VRE increases. On the one hand, VRE sources displace conventional generators that provide flexibility; on the other, they increase the need for additional flexibility due to their intermittent nature, creating a “flexibility gap” that has to be bridged by new options [22].

Because of their ability to shift supply and demand in time and their unique technical features, energy storage systems can provide a wide variety of services that –either on their own or combined– represent valuable alternatives for flexibility. Some ways in which storage can contribute to system flexibility are discussed below.

**Time-shift**. Perhaps the most basic advantage of storage is that it allows for energy time-shift, that is, storing energy during periods of low demand and low prices, in order to use it –or sell it– during peak demand periods, when energy is more expensive. Time-shifting also reduces the need for ‘peaker’ plants that are generally more expensive and polluting.

These benefits, in the form of reduced energy costs and a reduced need for generation equipment may accrue to electric utilities, system operators, and virtually any participant in a wholesale electricity market who can profit from energy price differentials. However, it is worth noting that revenues from this sort of price arbitrage alone are not enough to cover current storage costs.

**Capacity**. Storage can improve the reliability of energy supply as it can effectively supply capacity, a task that has usually been done by expensive, inefficient, and polluting fossil fuel plants. Hence, storage reduces the need to install new generation equipment, as well as the need to keep operating and maintaining obsolete power plants just for capacity purposes

This application of storage may generate important savings from avoided and reduced costs from generation capacity. It also provides important opportunities for utilities seeking to cut capacity-related costs, and to merchant storage owners participating in capacity markets, or capacity long-term auctions.

**Ancillary services**. A stable, reliable and efficient electric grid requires a variety of services that support the transmission of electric power from generation facilities to loads, while maintaining a reliable system operation. Some key ancillary services are frequency regulation, load following, spinning and non-spinning reserves, voltage support and black start.

Different storage technologies are capable of providing most ancillary services more efficiently than traditional fossil-fuel plants. This advantage stems from the fact that storage is a more easily dispatchable resource since it has a much faster response time than most existing generators. In fact, some storage technologies can react in a fraction of a second, whereas a fast-start combined cycle plant takes no less than 10 minutes (conventional thermal units take around 20 minutes to start up). This fast response also means a more accurate response to system needs, resulting in reduced need for ancillary services procurement as compared to supplying the same need with slower, less accurate fossil resources.

An additional advantage over conventional plants is that storage can operate both as a power generation resource and as load. Hence, it can provide ancillary services either by modifying its delivery of power (discharging mode) or by changing its demand patterns (charging mode), and it can do so quite quickly. Additionally, this unique feature of energy storage means that its flexible capacity is actually twice its rated capacity as a storage device can both charge and fully discharge its full rated capacity.

Relying on storage for ancillary services has multiple benefits, apart from the aforementioned efficiency gains from its superior service provision. Storage use allows for savings on operating costs and diminishes fuel use and emissions, given that it decreases the need for conventional generation capacity. In addition, ancillary services from storage can simplify and facilitate system operators' planning and operation processes.

**Transmission and distribution support**. Energy storage systems can also add value to transmission and distribution (T&D) networks in a number of ways. First, storage can reinforce power lines, substations, transformers and other T&D infrastructure, so that the same equipment –plus storage– is able to handle larger amounts of energy. In addition, its energy time-shifting ability allows storage to alleviate the stress on overloaded T&D equipment, diminishing its wear, allowing for safer operational conditions, and extending its life cycle.

Secondly, storage can relieve transmission congestion when installed downstream from a congested section of the grid. In such a case, energy would be stored when there is no congestion (that is, at nighttime or weekends), to be released later during periods of peak demand. As a result, utilities and ultimately end users will be able to avoid transmission congestion charges, that is, market-based location or time specific pricing for congested transmission capacity [23].

A third benefit arises from improved cost-effectiveness of T&D systems, since grid-integrated storage can lead to increased asset utilization. When large amounts of energy are transmitted during off-peak periods for storage purposes total energy transmission increases; that means more energy transported (kWh) for the same T&D capacity (kVA). Higher asset utilization, in turn, may lead to lower T&D tariffs for the benefit of ratepayers.

By temporarily addressing network congestion, mitigating equipment overload and extending the life of existing T&D equipment, storage helps defer –and potentially even avoid– capital-intensive upgrades and expansions of the grid. This fourth benefit –in the form of avoided investments– could be quite substantial given that sometimes, a relatively small amount of modular strategically sited energy storage can be used to defer (or entirely avoid) a rather large, expensive incremental transmission investment, that could take years to study, permit and install. This application of storage has already proved successful in the Australian state of Queensland, where batteries were used to support the existing distribution grid and maintain a reliable energy supply (**Box 2**).

Apart from the avoided investments, T&D asset optimization circumvents other challenges of further expanding T&D infrastructure, such as dealing with local communities, rights of way and other permitting processes (red tape), the time to develop projects and the rising costs of building new infrastructure in urban and remote rural areas.

**Box 2. An investment deferral application for distribution infrastructure in Queensland, Australia** *[24] [25]*

### Australia's pioneering grid scale battery trial

With more than 164,000 km in Australia's northeastern state of Queensland, Ergon Energy manages one of the largest energy distribution systems in the world. The network, a single wire high voltage distribution, was deployed in the late 70s and 80s. Since then, energy requirements significantly increased yet population has remained sparse and located mainly in remote, rural areas.

One alternative to address increasing energy demand was to replace the single wire network with a three-phase network. However, that was neither cost-effective nor realistic. Ergon Energy needed innovative solutions to reduce peak loads and maintain a reliable and safe energy supply to its relatively few clients.

That is where storage came in: Ergon deployed 20 Grid Utility Support System (GUSS) units, each consisting of 56 lithium-ion batteries with a 100 kWh rating. Their purpose is to minimize peak load by charging the batteries late at night, when energy use is low, and discharging them (if necessary) during peak electricity use. It is worth mentioning that, unlike poles and wires, GUSS units are relatively easy to move and can be redeployed in accordance to shifts in energy demand.

GUSS deployment is expected to reduce the grid operator's costs, particularly network maintenance and upgrade costs. This, in turn, will contribute to reduce overall electricity costs for end-users.

Queensland has a small share of renewable energy (only 8% in 2017, according to the Clean Energy Australia 2018 report [26]) but the state has adopted a 50% clean energy target by 2030. The deployment of GUSS batteries in Queensland's rural areas aimed mainly at deferring necessary investments in distribution infrastructure for reaching a disperse population with growing energy needs.

## 3.3 Advantages for end-users

Storage has the potential to empower consumers and gives them a more active role in their consumption and generation decisions. Businesses or households, all types of end-users can benefit from adopting behind-the-meter storage solutions.

Behind-the-meter systems chiefly contribute to reduce costs and enhance power resiliency for commercial, industrial and residential consumers. End-users profit by means of cutting electricity expenses and avoiding financial losses from electric service irregularities.

Moreover, the added value of behind-the-meter energy storage does not only accrue to end-users, but also to local utilities or grid operators. These systems are capable of automatically responding to grid signals to adjust voltage, frequency, and reactive power, contributing to grid stability [27].

Below we discuss the main ways in which end users can profit from behind-the-meter storage. Though many of these benefits are yet to be monetized (some are not well priced, some may not be measurable, while others may not even be fully understood), they do represent potential financial benefits to end-users and, as with in-front-of the-meter energy storage systems, many of them are stackable.

**Back-up power**. One of storage's major selling points is its ability to improve the resilience of power supply, for example, by providing power during outages caused by natural disasters or grid failures. This application of storage is particularly important for commercial and industrial customers, who suffer monetary losses from sudden halts in their activities caused by electric service disruptions. In case of a brief outage, storage ensures operability while the electric service is restored. If the outage outruns the unit's charge, storage allows for an orderly shutdown of processes.

Furthermore, commercial and industrial users are the most likely to invest in costly and –most likely– polluting backup infrastructure (e.g. diesel fueled power plants). Storage may provide them opportunities to upgrade their back-up equipment, while saving money with other storage applications, like the ones discussed below.

In addition, in the event of a power outage storage can facilitate the operation of critical loads under an islanded microgrid, powered by multiple generation sources including local renewable energy.

**Power quality**. Similar to the back-up power application, storage helps avoid costs and losses caused by poor quality of the power delivered by the grid. Power quality problems are usually short-lived, but they tend to be more frequent. Some of the most common quality issues are voltage variations and electrical interference, caused by lighting or other equipment connected to the grid.

Storage improves power quality. It can protect sensitive equipment from variations in power and it helps avoid the disturbances and costs resulting from interrupted processes due to deficient power quality.

**Distributed energy resources**. Storage contributes to renewable energy penetration; this is also true for behind-the-meter storage as it allows generating consumers to retain energy surpluses within their own installations. Distributed energy resources integrating onsite storage solutions –solar PV in particular– are able to store excess energy generated throughout the day, for its later consumption, reducing electricity expenses. Germany, for example, already has more than 280 MW installed capacity of residential storage, spreading across 85,000 installations, that are used primarily for time-shifting and solar self-consumption [28].

This type of consumer optimization adds value to solar PV distributed resources and has the potential to increase their cost-effectiveness, as the percentage of self-consumption increases. Some studies argue that residential storage could boost this proportion from 30% to 65-75% [29]. As follows, behind-the-meter storage may ease barriers and objections to advancing the deployment of distributed renewables.

In addition, using storage to maximize consumption of onsite generation also contributes to grid stability, given that most distribution networks are not able to deal with considerable back feeding of electricity.

There are some caveats to this application of storage. If a growing number of users turn to storage and become energy self-sufficient, then load defection –or even grid defection– pose a serious threat to the revenue models of network operators and traditional power generators. In consequence, users that remain connected to the grid are likely to face increasing costs, since there would be fewer customers to distribute the costs of existing infrastructure.

**Bill management**. Storage provides end-users at least two possibilities for optimizing their demand and reduce their electric expenses. On the one hand, there is an opportunity from demand-charge reduction for customers on demand-based rates. This opportunity arises from the fact that utilities generally apply demand charges to industrial and commercial customers based on that customer's maximum electricity demand during specified periods. The time-shifting capability of storage allows customers to respond automatically to a building load spike, adjust their demand accordingly, and cut their electric bill.

On the other hand, there is an opportunity to manage time-of-use energy costs, for customers who pay time-specific energy tariffs. This storage application is similar to time-shifting capability, though savings come from differences in retail prices, whereas time-shifting benefits rely on variations of the prevailing wholesale electricity price.

Electricity bill management may be the primary function of energy storage for industrial and commercial end-users. Utility rate structures are determinant factors when it comes to assessing the economic viability of storage in a given market: lofty or extremely unstable electricity rates for business help build a stronger business case for storage.

**Demand response participation**. Another way to reduce electricity expenses is via consumer engagement in demand response, programs designed to compensate consumers for performing load curtailment or shifting in order to reduce grid stress. Energy storage facilitates the participation of commercial and industrial facilities in these programs as it enables them to cut their grid energy needs during peak usage, without affecting business processes. By providing back-up power and reacting to energy price signals, storage systems can generate financial revenues while contributing to overall grid reliability.

### 3.4 Energy security

Given the world economy's large dependence on fossil fuels, their supply has become a geopolitical issue in many countries. Some hydrocarbon rich nations have used fossil fuel supply as strategic lever in international negotiations by increasing prices or restricting supply. This was the case when Gazprom, Russia's national gas company, increased its gas prices to Ukraine from EUR$268.5 to EUR$485.0 per thousand cubic meters, in March 2014. Gazprom justified the sudden increase claiming Ukraine's unpaid gas debts (the outstanding debt went back to 2009 [30]), but in the end, supplying a more expensive gas was a clear signal to European countries following Russia's invasion of Crimea.

In addition to geopolitical risks, operational difficulties are also a threat to systems with limited energy supply sources. This is the case for Yucatan Peninsula, where a single pipeline supplies natural gas to both power plants and industrial users in this partially disconnected region (**Box 3**).

**Box 3. Heavy dependence on natural gas is a risk to electricity supply in the Yucatan Peninsula** *[31]*

#### Gas supply shortages compromise power reliability in Yucatan

Since 1999, the Yucatan Peninsula receives natural gas through a single 780 km pipeline that connects it to Mexico's natural gas integrated system as well as from occasional shipments of liquefied natural gas. Regardless of this, the region's electricity demand depends heavily on gas-based power plants, thus threatening the region's energy security.

For instance, on Friday May 11, 2018 at 12:00 hours, the natural gas pipeline experienced a sudden pressure drop, forcing operators to shut down Merida Potencia and Valladolid Tres, two combined-cycle power plants. These facilities accounted for 400MW of the 950 MW available generation at that time, so CENACE had to import energy from other areas of Mexico and cut exports to Belize to manage the system and keep the lights on.

Moreover, the Peninsula faces transmission constraints due to its isolated nature, which also heightens the risk of congestion. To avoid a grid overload, CENACE had to apply rotating 30-minute blackouts across the entire Peninsula from 14:20 to 18:17 hours. Load behavior during the evening forced more programmed outages at 19:24 PM, reaching a maximum affectation of 96MW. Supply under normal conditions was not reestablished until 00:04 AM on Saturday 12.

Either for geopolitical or operational reasons, a system's energy security[7] very much depends on its ability to diversify its energy mix, so that it is less dependent on hydrocarbons. Energy storage can become a sensible ally in this endeavor, as it has already proved to be in California after the Aliso Canyon incident (**Box 4**).

**Box 4. Energy storage's role in maintaining California's grid reliability following the Alison Canyon incident** *[32]*

**Demand response and batteries support California during gas supply shortcuts**

Following the discovery of methane leakages in October 2015, California's largest underground gas storage facility, Aliso Canyon, underwent extensive testing and corrective actions that diminished its operational capacity. This event had a major impact on California's power sector, as 18 power plants –70% of total capacity in the Los Angeles basin– depended on Aliso Canyon's gas for fuel.

To cope with the supply constraints, California decided to promote flexibility measures such as demand response, energy storage and energy efficiency to increase the grid's reliability and alleviate market supply issues. For instance, California Independent System Operator (CAISO) implemented Flex Alerts, a demand response program that encourages households to decrease electricity consumption in the evening up to 21:00, the peak demand period. Over the summer of 2016, CAISO issued three Flex Alerts, which resulted in demand reductions of around 500MW.

The Aliso Canyon incident also accelerated the procurement of energy storage capacity and, by late 2017, approximately 100 MW of four-hour utility-scale battery systems were installed in Los Angeles, San Bernardino and Orange counties. The combination of these measures was so successful that a study commissioned by Los Angeles County in early 2017 concluded that Alison Canyon was no longer necessary for power reliability in the area.

Natural gas is the dominant power generation fuel in Mexico. In fact, combined-cycle power plants served 50% of Mexico's load in 2017 [13]. However, since 2009 domestic production has steadily declined and the country now relies on imports (equivalent to 55% of current natural gas demand), mainly from the United States (87.2% of imports come in from the north border via pipeline [33]). Recent changes in the United States' commercial agenda have increased concerns for Mexico's energy security.

Hence, another benefit of energy storage is that, by allowing further renewable integration, it may contribute to reducing the country's dependency on imported American natural gas, enhancing energy security and independence.

## 3.5 Cybersecurity: a new concern for smart grids

Digitalization has transformed the world in many ways and the energy sector is not an exemption. A modern grid is synonymous with the accompanying information and communication technologies (ICT) that enable data analytics and further connectivity across different segments. Energy systems incorporating ICTs and other advanced resources, such as energy storage or the Internet of Things,

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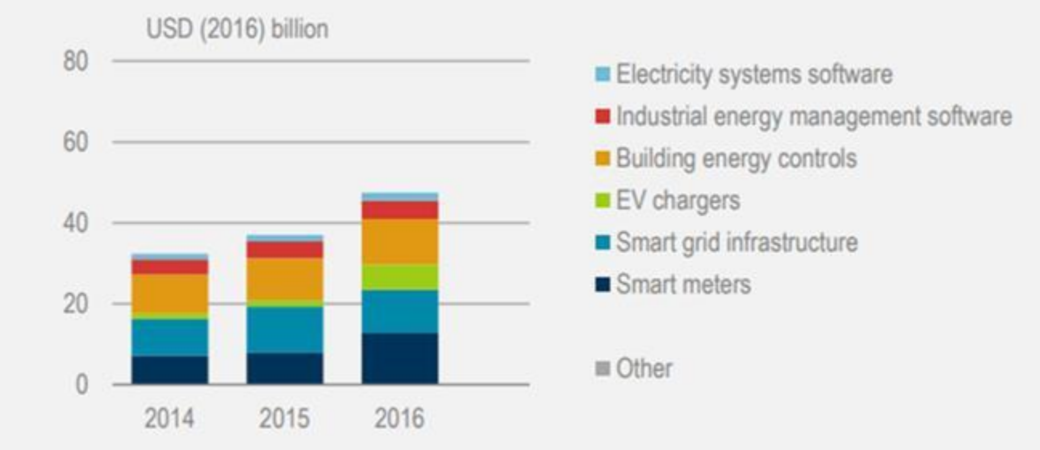
[7] According to the International Energy Agency (IEA), energy security is defined as the uninterrupted availability of energy sources at an affordable price.

are known as ‘smart grids’, a buzzword that is becoming widespread as the pace of digitalization in energy increases. This is evident just by looking at the global statistics of investments in digital electricity infrastructure and software, which has grown over 20% annually, between 2014 and 2016. There is more money now flowing globally into digital electricity infrastructure and software than into gas-fired power generation [34].

The logic behind those billionaire investments is sound. Digitalization has proven to be useful to increase safety, efficiency, productivity, accessibility and sustainability of energy systems through a broad range of applications. For instance, smart meters are becoming ever more popular, mainly to support hourly tariffs and demand response programs, measures that increases the grid’s reliability and operability.

**Figure 5. Global investments in digital electricity infrastructure and software**



*Source: International Energy Agency, 2017* [34]

System operators are becoming increasingly concerned about cyber security (enhancing resilience to sophisticated attacks from professional or amateur hackers, fraudsters, and even military units). As any other digital system, energy networks are vulnerable to ransomware, malware, and botnets, among other malicious applications that can be used during cyberattacks, thus proper precautions must be taken to avoid these and any other potential hazards.

In the undesirable scenario of a massive outage, storage devices can provide power to critical applications, such as medical or military equipment, or help restore power supply after the attack is neutralized (black start), thus improving the system’s security.

**Box 5. A technical defect led to major power outages in the US Northeast region in 2003** *[35]*

### Potential impact of technical failures: the 2003 US Northeast blackout

The 2003 blackout was the largest power outage in the history for the North American power grid. It affected around 50 million customers and more than 70 GW of electrical load in diverse regions of Ohio, Michigan, New York, Pennsylvania, New Jersey, Connecticut, Massachusetts, Vermont and the Canadian provinces of Ontario and Quebec. Most regions got power supply back in a few hours, but in some parts of the United States it took up to two days to restore normal supply, while Ontario experienced rotating blackouts for up to two weeks.

An investigation conducted by the North American Electric Reliability Corporation (NERC), revealed that the main causes of the blackout were:

a) The regional electric utility, FirstEnergy, lost functionality of critical monitoring tools. It lacked situational awareness of line outages, which resulted in degraded transmission system conditions.
b) FirstEnergy did not adequately manage tree growth in its transmission rights-of-way (as a matter of fact, an outgrown tree caused the line outage).
c) The Midwest Independent System Operator (MISO) reliability coordinator did not provide the right diagnostic support.
d) Coordination between MISO and Pennsylvania-Jersey-Maryland (PJM) reliability coordinators was ineffective.

A failure in one of FirstEnergy's hardware detonated the problem. The utility's alarm processor did not work adequately. This remained unnoticed by the computer support staff for about 40 minutes when a second Energy Management System also failed. Furthermore, it took over 90 minutes for the grid operator to realize the alarm processor was lost and respond to it, originating a cascade of events that lead to the massive outage. If the operator had acted during the first alarm loss, it would have had enough time to detect the Chamberlin-Harding line outage, recognize worsening conditions on the system, thus minimizing the impact.

Simple events such as an overgrown tree can have widespread effects if information technology tools are not properly managed and monitored.

### 3.6 Economic and overall spillovers

On top of the gains that energy storage can bring about to the overall system and its stakeholders, there are additional economic, environmental and social benefits.

The ways in which society as a whole can benefit from storage usage are examined below.

**Economic benefits**. By 2030 the global energy storage market is expected to double six times, increasing to 125 GW of capacity and 305 GWh, with future investments in storage technologies adding up USD$103 billion [36]. Other projections are equally optimistic and put the global energy storage market at 8.6 GW and 21.6 GWh by 2022 [37]. These forecasts point to the huge economic potential of a nascent market and highlight the need to capture the associated manufacturing opportunities, particularly in the battery segment.

Even though the battery industry is currently concentrated in the US, and to a lesser degree in Germany, there may be attractive opportunities for other countries with competitive component industries such as Mexico to engage in the storage manufacturing value chain.

Other ways in which energy storage can promote economic growth include:

- Development of new industrial structures
- Job creation in manufacturing, installation and operation of storage systems

- Export opportunities, from storage and component industries
- Research and development –and resulting innovation– to achieve industry competitiveness
- Reliable supply of electricity, an essential input for virtually all economic activities
- Spillovers to other industries directly linked to storage, such as transportation (electric vehicles), software (storage system operation), telecommunications (send and receive data and control signals, to and from storage equipment) and finance (project funding).

**Environmental benefits**. Storage plays a major role in renewable integration; it can balance out their intermittency and address the time mismatch between energy generation and consumption. The adoption of storage solutions across the grid, as well as behind the meter, will unavoidably result in a redistribution of the energy mix away from fossil fuels, increasing renewable participation. GHG emissions associated with fossil-powered electric generation are bound to reduce as storage becomes more widespread.

It is important to bear in mind that energy storage systems have no direct emissions and there is no impact on air quality related to their location. Furthermore, generation will be GHG-free when paired with a solar PV facility.

Because of its versatility, energy storage can also contribute to reduced emissions by optimizing fossil fuel generation and reducing emissions. Just in the same way in which a hybrid car uses storage to enhance efficiency and cut fuel use, a traditional power plant integrated with an energy storage system can lead to considerable savings on fuel consumption.

In conclusion, energy storage is a powerful tool to complement the ongoing efforts to fight climate change and to successfully achieving global clean energy goals.

**Social benefits**. Energy is essential for human and economic development. In spite of recent progress, there are still 1.1 billion people worldwide without access to electricity according to the IEA [38]. Renewable energy, as well as off-grid and mini-grid systems can prove crucial to give access to electricity to people in remote rural areas. Energy storage is crucial for mini-grid operation, as the 'balancing resource' efficiently matching supply and demand.

Currently, the most common solution to electrify remote areas is through mini-grids relying on small diesel generators that in many cases have significant impacts on local air quality. As renewables costs go down, solar PV and distributed wind are becoming relevant alternatives to displace costly and polluting diesel. Such a substitution calls for energy storage solutions to deal with output variability and properly address the time decoupling between generation and consumption. In addition, storage systems can also deliver services to remote power systems similar to the ones they provide to conventional grids (e.g. resource integration, bulk energy services and basic ancillary services). And, even if diesel generation continues to power the mini-grid, adding flexible, load following energy storage may have a rapid payback due to the improved efficiency of the diesel generator.

Access to electricity in Mexico is relatively high: 98.5% of the country's population has access to this service [18]. However, nearly 1.8 million people[8] could benefit from renewables plus storage solutions, to decarbonize smaller, isolated systems and to reach the universal access goal.

Building the business case for storage in remote power systems may be a difficult task if only considering the economic dimension. Other alternatives, such as fossil fuel generators, may have lower upfront costs and may prove less costly than expanding the T&D network. Given that these systems are small in scale, this segment is not attractive to electric service providers, developers and investors. It is from an energy fairness perspective that these projects are justified and that they should be developed.

3. The added value of storage – Section recap

After reviewing the benefits energy storage systems can bring about it is important to acknowledge that, while some of them are already recognized and can be properly quantified (mainly in the form of a larger VRE share, and avoided costs to the system and its users), others are more difficult to conceptualize- for instance, social benefits- and require further assessment.

As storage deployment becomes more widespread and all stakeholders gain additional experience with it, this valuation task will become easier and more informed.

## 4. What needs to be done in Mexico

Following the Energy Reform of December 2013, Mexico has worked in record time to open its energy markets to competition. Essential laws and a significant amount of regulations were drafted and approved in the next two years, although there is still a good number of regulatory instruments in the process.

One of these missing regulatory pieces are the rules for energy storage. Small steps have been taken on the subject. For instance, the Energy Transition Law states that CENACE, Mexico's ISO, must elaborate a Smart Grid Program every three years that must consider the integration of advanced technologies for electricity storage. The first of these programs was published in 2016, and it deems storage as a privileged technology due to its potential for reducing energy costs and voltage variation, further renewable integration and its capability to prevent outages. This has driven CENACE and the transmission and distribution operators (CFE Transmision and CFE Distribucion, respectively) to consider storage to comply with their missions. Moreover, the Ministry of Energy included a 20 MW storage project for the Baja California Peninsula in its network planning exercise, PRODESEN 2017-2031 (**Box 1**).

Specific regulations that define and provide certainty regarding storage's role are needed to realize its full potential. Even the 2017 Energy Transition Special Program, a planning instrument derived

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[8] Considering a total population of 119,938,473 people as reported by the National Institute of Statistics and Geography (INEGI) in 2015 [53].

from the Energy Transition Law and published by the Ministry of Energy, recognizes that the existent regulatory framework does not provide the conditions for the grid to benefit from storage.

A number of investors have communicated to Energy Regulatory Commission (CRE, for its Spanish acronym) their interest in Mexico's storage market potential, but also their concern regarding business environment risks and uncertainty given the lack of clear storage rules. Defining the asset's role in the market, enabling it to provide, as many services as it is technically capable of, and outlining the applicable remuneration schemes would eliminate regulatory barriers that prevent storage investors and developers to enter the Mexican market.

## 4.1 It all starts with a definition

So far, Mexican regulation has no proper definition for energy storage, nor a specific legal figure for it as a market participant. The closest attempt are the indications provided in the Electricity Market Rules (base 3.3.21) published by the Ministry of Energy in 2015, in which storage assets are required to observe the following:

- Register as a Power Plant and be represented by a Generator
- Sell all their output as any other Power Plant
- Purchase all the same products as a Load, assuming the same responsibilities as other load-serving entities ('*Entidades Responsables de Carga'*)
- If the storage asset is part of the National Transmission Network or the General Distribution Grids, the Generator that represents it in the market and the T&D companies must observe strict legal separation measures and they will be subject to tariff regulation by the CRE.

The above concepts recognize –to a certain extent– storage's multipurpose nature. However, it fences storage in categories that may not be applicable, relevant, or favorable to its inherent flexibility. Concepts like Power Plant, Load or Generator impose unnecessary barriers to storage's revenue potential. There are concerns on overlapping transmission charges as, under current rules, there are two different tariffs for Generators and Loads. In addition, there is no clarity on how these different figures will coexist, particularly in the case of T&D services, making revenue stacking uncertain.

Given the novelty of energy storage as a commercially viable solution, these barriers also occur in other markets. In the UK, storage is classified as a generation asset, which is broadly defined in the Electricity Order 2001 as a technology that "generates or is capable of generating electricity" [39]. This definition hinders storage deployment, as it does not recognize its multipurpose nature or differentiates it from generation facilities.

CRE must consider all these issues, modify the Electricity Market Rules accordingly, and develop specific regulation for energy storage that allows it to provide as many services as it is technically capable of.

In this endeavor, CRE would largely benefit from studying success stories such as California's. The energy storage market developed greatly in this state after the passage of Assembly Bill 2514 in 2010. This legislation required the California Public Utilities Commission (CPUC) to open a new proceeding to analyze storage's applications, benefits and commercial viability, and if found to be viable and cost effective, to determine appropriate targets for energy storage procurement by 2013 [40]. In response to this legislation, the CPUC eventually adopted a 1,325 MW procurement target for electricity storage by 2020. This target comprehends transmission connected, distribution level and customer-sited storage and considers a broad range of eligible technologies (pumped hydro storage above 50 MW are nonetheless excluded) [41].

According to CPUC regulation, mandated utilities must hold continuous competitive solicitations – at least once every two years, starting December 2014 and ending by 2020 (all assets must be operational by 2024). This process selects the best performing and most cost-effective storage, although the CPUC must approve each procurement decision prior to construction. By 2017, California had procured 488 MW of energy storage through this mechanism, the first of its kind worldwide [41]. More importantly, it has created a dynamic market that is driving storage costs down globally and has prompted additional research and development on the matter, including an innovative and constantly evolving regulatory framework.

Assembly Bill 2514 marked another turning point for energy storage by establishing a comprehensive definition for it, as explained in **Box 6**. In terms of market participation, the California Independent System Operator (CAISO) considers two specific figures that provide opportunities for storage technologies to participate in the wholesale ancillary services and energy markets: pumped storage and non-generator resource [42].

CAISO defines non-generator resources as resources that "*have the capability to serve as both generation and load and can be dispatched to any operating level within their entire capacity range* [42]." This figure includes energy storage resources such as batteries, flywheels and electric vehicles, among others. Having an exclusive figure permits optimize storage performance, considering constraints on capacity, ramping and state of charge –all of which differ greatly between generation and storage assets–.

**Box 6. Extract from the State of California Assembly Bill No. 2514, Chapter 469 approved in 2010** *[40]*

### Definition of energy storage systems in California

(1) "Energy storage system" means commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatch the energy. An "energy storage system" may have any of the characteristics in paragraph (2), shall accomplish one of the purposes in paragraph (3), and shall meet at least one of the characteristics in paragraph (4).

(2) An "energy storage system" may have any of the following characteristics:
  a) Be either centralized or distributed.
  b) Be either owned by a load-serving entity or local publicly owned electric utility, a customer of a load-serving entity or local publicly owned electric utility, or a third party, or is jointly owned by two or more of the above.

(3) An "energy storage system" shall be cost effective and either reduce emissions of greenhouse gases, reduce demand for peak electrical generation, defer or substitute for an investment in generation, transmission, or distribution assets, or improve the reliable operation of the electrical transmission or distribution grid.

(4) An “energy storage system” shall do one or more of the following:
  a) Use mechanical, chemical, or thermal processes to store energy that was generated at one time for use at a later time.
  b) Store thermal energy for direct use for heating or cooling at a later time in a manner that avoids the need to use electricity at that later time.
  c) Use mechanical, chemical, or thermal processes to store energy generated from renewable resources for use at a later time.
  d) Use mechanical, chemical, or thermal processes to store energy generated from mechanical processes that would otherwise be wasted for delivery at a later time.

Following California’s example, the United States Federal Energy Regulatory Commission (FERC) Order 841, issued in February 2018, mandates all Regional Transmission Organizations (RTOs) and ISOs in the country to develop a participation model (market figure) recognizing the physical and operational characteristics of electric storage resources to facilitate their participation in the market. Moreover, the Order states that such participation model must ensure storage assets are eligible to provide all capacity, energy and ancillary services that they are technically capable of [43].

FERC’s Order 841 stresses the need for regional markets to develop a specific definition for energy storage that clarifies their eligibility to participate in different market segments. Although not explicitly mentioned, FERC Order 841 promotes technological neutrality, not mentioning a specific technology and referring to storage resources in general. Neutrality in this matter is key as new storage technologies could prove valuable in the near or distant future. Regulation must consider this if the objective is to develop storage to its full potential.

## 4.2 Regulating for multipurpose assets

Storage’s multipurpose nature requires more than a definition to be operational. The regulator must develop a set of rules, and contractual frameworks so different services can coexist efficiently. Otherwise, problems in the operation might arise. For instance, if two services from the same asset are required at the same time, which one has priority? Who should decide? The asset owner or the system operator? Having clear guidelines for these decisions is essential to stakeholders and the system as a whole.

During the first months of 2018, CPUC decided to change its market rules so storage could stack more than one service and realize full economic value. It then outlined a set of rules on how utilities could promote storage’s ability to provide multiple services to the power system (**Box *7***). In addition to the eleven rules for the evaluation of storage’s multiple-use applications, CPUC defined service domains, reliability services and non-reliability services (**Table 2**). This classification determines the type of services that storage assets can provide, depending on the grid level in which they are connected. CPUC’s ruling is a turning point for energy storage: It is the first effort to change regulation in a sizeable market in order to accommodate storage’s multipurpose capabilities in a meaningful way.

In addition to the eleven rules for the evaluation of storage’s multiple-use applications, CPUC defined service domains, reliability services and non-reliability services (**Table 2**). This classification

determines the type of services that storage assets can provide, depending on the grid level in which they are connected.

**Box 7. Extract from CPUC's decision on multiple-use application issues** *[44]*

### California's eleven rules for multiple-use application issues

**Rule 1.** Resources interconnected in the customer domain may provide services in any domain.

**Rule 2.** Resources interconnected in the distribution domain may provide services in all domains except the customer domain, with the possible exception of community storage resources.

**Rule 3.** Resources interconnected in the transmission domain may provide services in all domains except the customer or distribution domains.

**Rule 4.** Resources interconnected in any grid domain may provide resource adequacy, transmission and wholesale market services.

**Rule 5.** If one of the services provided by a storage resource is a reliability service, then that service must have priority.

**Rule 6.** Priority means that a single storage resource must not enter into two or more reliability service obligation(s) such that the performance of one obligation renders the resource from being unable to perform the other obligation(s). New agreements for such obligations, including contracts and tariffs, must specify terms to ensure resource availability, which may include, but should not be limited to, financial penalties.

**Rule 7.** If using different portions of capacity to perform services, storage providers must clearly demonstrate, when contracting for services, the total capacity of the resource, with a guarantee that a certain, distinct capacity be dedicated and available to the capacity-differentiated reliability services.

**Rule 8.** For each service, the program rules, contract or tariff relevant to the domain in which the service is provided, must specify enforcement of these rules, including any penalties for non-performance.

**Rule 9.** In response to a utility request for offer, the storage provider is required to list any additional services it currently provides outside of the solicitation. In the event that a storage resource is enlisted to provide additional services at a later date, the storage provider is required to provide an updated list of all services provided by that resource to the entities that receive service from that resource. The intent of this Rule is to provide transparency in the energy storage market.

**Rule 10**. For all services, the storage resource must comply with availability and performance requirements specified in its contract with the relevant authority.

**Rule 11.** In paying for performance of services, compensation and credit may only be permitted for those services which are incremental or distinct. Services provided must be measurable, and the same service only counted and compensated once to avoid double compensation.

The definitions for domain, reliability and non-reliability services used along these rules are detailed in **Table 2**.

The classification of reliability and non-reliability services creates a hierarchy of products that can be offered simultaneously; in fact, according to Rule 5, reliability services will always come first. The rules also forbid storage assets from offering two reliability services that cannot be provided simultaneously, avoiding conflicting decisions on which service to provide first that could risk the grid's optimal performance.

It is worth noting that Rule 11 establishes guidelines to avoid double compensation, a common concern when discussing service stacking: only measurable services that are distinct or incremental should be paid for. Relying on a sound compensation methodology for each of these services is another critical regulatory decision that will be discussed later on.

Although these rules are too recent to claim their success, they were built on California's years-long experience with energy storage and are certainly worth analyzing by other markets. In particular, service differentiation and hierarchization are two important issues that Mexico could learn from.

**Table 2. CPUC's classification of reliability and non-reliability services per domain**

| Domain | Reliability Services | Non-Reliability Services |
|---|---|---|
| **Customer** | None | Time-of-use bill management, Demand charge management, Increased self-consumption of on-site generation; Back-up power; Supporting customers participation in Demand Response programs |
| **Distribution** | Distribution capacity deferral; Reliability (back-tie) services; Voltage Support; Resiliency/Microgrid/islanding | None |
| **Transmission** | Transmission deferral; Inertia*; Primary frequency response*; Voltage support*, Black start | None |
| **Wholesale Market** | Frequency regulation; Spinning reserves; Non-spinning reserves; Flexible ramping product | Energy |
| **Resource Adequacy** | Local capacity; Flexible capacity; System capacity | None |

**Voltage support, inertia and primary frequency response have traditionally been obtained as inherent characteristics of conventional generator, and are not today procured as distinct services. CPUC include them here as placeholders for services that could be defined and procured in the future by the CAISO.*

*Source: California Public Utilities Commission, 2018* [44]

### 4.3 Consistency with other market instruments

Most existing market instruments were not designed to easily fit modern energy storage, as it was not a viable technology when they were written. Therefore, in addition to drafting specific rules for energy storage, it is necessary to conduct a thorough review of the existing regulations, mechanisms, and definitions that could be inconsistent with new storage regulation. This is the case for Mexico and other markets working to adopt energy storage. In the United States, for instance, FERC Order 841 requires RTOs and ISOs to revise their tariff schemes to accommodate storage resources.

An important limitation for storage already appears in the Manual for the Balancing Capacity Market: all assets looking to participate in the firm capacity market are required to provide at least six hours of full capacity continuous operation (including storage). Devices unable to comply with this requirement are treated as intermittent non-dispatchable sources, limiting their revenue opportunities. Although such requirement is considered excessive (CAISO, for instance, requires storage devices to provide at least 60 minutes of continuous operation to certify their suitability for regulation, spinning, non-spinning and maximum capacity services), it is unlikely the grid operator will be willing to change it in the near future, even though it creates a technology-specific barrier, potentially limiting the deployment of particular forms of storage solutions that offer short-term advantages.

## 4.4 Design an ancillary services market with storage in mind

As mentioned, storage can supply ancillary services in a more efficient manner than traditional generators. One of its most attractive features is the speed of its response to frequency variations (which tend to be more frequent as VRE shares increase). Some storage assets can provide frequency regulation services in less than a second, whereas traditional generation assets may take up to 20 minutes. Recognizing this speed advantage in the value of the service may generate necessary incentives for storage deployment, while market so operators benefit from faster response times.

Mexico's ancillary services catalogue contains both regulated and market-based products (**Table 3**). The market-based products are traded in the short-term markets (day-ahead and real-time) and their price is set by CENACE. The operator calculates the demand based on the likelihood of power plant variations, unplanned transmission outages and the variability and errors in the supply and demand forecasts. It then receives market participants' offers and decides which one to use through an economic dispatch model. This methodology also provides marginal prices for each reserve area and sets prices according to established restrictions [45]. It is important to mention that the economic dispatch consists on a co-optimization model that evaluates offers for energy and ancillary services at the same time; the objective is to minimize total cost to the system [46].

Although no document explicitly forbids storage to participate in these markets, the current design was conceptualized for traditional generators. For instance, storage is required to register as a Power Plant and will be considered as such in CENACE's dispatch model whenever it presents an offer. Given that the model co-optimizes both energy and ancillary services offers, it is not clear how storage's double nature as a generator and a load will be evaluated. Under the current regulation, demand response is considered a resource capable of providing ancillary services but, so far, there are no such resources participating in the market, in part because demand response-specific regulation is also under development.

Another shortcoming is that primary regulation (the fastest response to frequency variation) is not currently considered as a market product, but as a mandatory service to be provided by all Power Plants interconnected to the national electric system. Primary regulation is probably where storage could be more valuable because of the required speed of response (less than four seconds); not being remunerated for this service –even when it would represent a systemic benefit– prevents storage deployment and hinders incentives for third-party and merchant procurement.

Changing the current scheme to pay for market-based ancillary services would require coordination among the regulator, the Ministry of Energy and CENACE, plus an extensive consultation process to modify existing manuals. However, it is worth the effort as it would not only benefit storage, but other assets that can provide primary regulation, incentivizing a more efficient operation and enhancing the system's reliability and power quality.

**Table 3. Classification of ancillary services in the Mexican market according to current Market Rules**

| Market-based services | Regulated services |
|---|---|
| 1) Secondary reserves (frequency regulation) | 1) Black start |
| 2) Spinning reserves (10 minutes) | 2) Emergency operation |
| 3) Non-spinning reserves (10 minutes) | 3) Islanding operation |
| 4) Spinning supplemental reserves (30 minutes) | 4) Voltage regulation and reactive power |
| 5) Non-spinning supplemental reserves (30 minutes) | |

*Source: own elaboration with information from Mexican legislation*

Regarding regulated ancillary services, CRE is currently working on rate methodologies for them; a good opportunity to align regulatory instruments so that they work properly for non-traditional resources such as storage. Services such as voltage regulation, black start and emergency operation are also attractive niches for most types of storage. Setting clear prices on these services would contribute to storage revenue stacking.

### 4.5 Define how to recognize T&D value

Different stakeholders, including regulators, system operators and T&D companies, recognize storage's potential value as a T&D asset. In fact, there are already some experiences with storage as a transmission asset, perceiving a regulated tariff as any other transmission device. However, the possibility to combine a regulated activity with market-based services is not as clear, particularly when discussing how to separate, prioritize and remunerate both activities, avoiding double payments for the same service, operational hurdles and reducing risk for ratepayers

Mexico wants to break ground in this regard and allow storage participation in both types of activities from the start. Given storage's multipurpose nature, this is the best way to fully realize its potential, for the benefit of both the overall system and end users. The idea is to not only allow merchant projects providing exclusively market services, others solely working as T&D assets on a cost-of-service basis but to allow projects that can provide both kinds of services as is the case in California (**Table 4**). Defining a fair cost recovery mechanism for the latter is not as simple. Even California authorities, perhaps the most experienced on the matter, have not yet decided on which is the best methodology; CAISO is currently working on a final proposal to be delivered by November 2018 [47].

A review of California's developments will be given in sections 0 and 4.5.24.5.2 emphasizing the issues that Mexico will need to work on to design a successful regulation that recognizes storage's value to T&D network, without imposing unnecessary barriers to accessing other markets. We will not discuss storage projects as a pure market resource (**Table 4**), as the focus of this section is the economic recognition of storage's value as T&D assets.

**Table 4. Storage participation models in the Californian market**

| Model | Market Resource | Network Asset | Hybrid |
|---|---|---|---|
| **Description** | Storage built to provide services in the wholesale markets for electric energy, capacity and ancillary services. | Storage designed and built to solve transmission or distribution specific needs. | Storage that is primarily providing transmission and distribution services but can also participate in wholesale markets. |
| **Origin** | Approved through a public utility or other local regulatory authority procurement process; or developed by a private company at its own risk. | Approved through the ISO transmission planning process, under the methodology for non-transmission alternatives (end-use efficiency, generation, demand response and energy storage). | *Proposal*: Approved through the ISO transmission planning process. Market revenues considered part of the project value proposition during the economic evaluation of different alternatives.<br>Participation in wholesale markets subject to predictability of network needs (decided by ISO and is not fixed). |
| **Compensation scheme** | • Bilateral contracts<br>• Market revenues<br>• Both | • Cost-of-service rates established on a regulated revenue requirement. | • *Proposal A:* Full cost-of-service based cost recovery with energy market crediting.<br>• *Proposal B:* Partial cost-of-service cost recovery with no energy market crediting. |

*Source: own elaboration with information from California Independent System Operator, 2018* [47]

### 4.5.1 Storage as a T&D asset: heavily linked to the network planning processes

FERC, following its response to Western Grid Development LLC (Western Grid)'s proposal in 2010, recognized storage projects could be treated as wholesale transmission facilities –including access to guaranteed revenues through regulated tariffs– [48]. In this decision, FERC limited the use of storage as a transmission asset mostly to the provision of thermal loading and voltage support services, without considering the possibility to offer market-based services. Nevertheless, the Western Grid case was a turning point for storage projects, particularly in California, as it prompted CAISO to include them on a regular basis in its transmission planning process (**Box 8**).

**Box 8. The Western Grid case and its impact on storage's participation in transmission services** *[47]*

### Western Grid's proposal opened the door for storage participation in transmission services

Western Grid filed a petition in 2009 requesting FERC to consider its sodium sulfur batteries project as a wholesale transmission facility eligible for cost-of-service rates. The company argued that the storage project would limit its operation to provide voltage support and thermal overload protection, abstaining from arbitrage wholesale energy market prices. Western Grid also suggested it would manage the batteries' charging and discharging to avoid conflicts with the ISO's independence and that it would credit any market revenues derived from this operation toward its transmission rates.

One year later, FERC stated that Western Grid's project operated as a transmission facility and was therefore eligible to access regulated tariffs as long as they were approved in CAISO's transmission planning process and no other alternative existed. Western Grid's project did not materialize as CAISO never needed it, but it opened new possibilities for storage to be evaluated in the operator's transmission planning process and eventually be compensated as a traditional transmission asset.

After Wester Grid's first proposal, CAISO has studied other 27 battery storage projects and one pumped hydro storage proposal as potential transmission assets. Only two of these projects have materialized so far, both in the 2017-2018 Transmission Plan. The case also motivated FERC to evaluate storage's value further, leading to technical conferences on the subject and the recent decision to allow storage to participate in both regulated and market-based services.

Evaluating storage solutions in the transmission planning process is a mandatory requirement to access regulated tariffs, just as it is the case for traditional network assets. Through this process, the system operator must demonstrate energy storage is the best alternative –based on a cost-benefit analysis– to address an actual need. According to CAISO, California's transmission planning process consists of three phases [47]:

- **Phase 1:** Developing and completing the annual unified planning assumptions, information and study plan for Phase 2. It is a coordinated effort between CPUC, California's Energy Commission (CEC) and CAISO.
- **Phase 2:** Performing all necessary technical studies, conducting a series of stakeholder meetings and developing the transmission plan for the ISO's controlled grid. The plan must specify the transmission solutions (traditional and non-traditional) required to meet the reliability, public policy and economic needs of the grid. ISO's board approves the final version of this plan.
- **Phase 3:** Transmission facilities identified in Phase 2 and others eligible for competitive solicitation participate in Phase 3. For example, if CAISO identifies a new transmission line and a new storage facility as plausible solutions to a specific transmission need, then developers can present offers for either option, and the ISO selects the best one based on the tariff selection criteria and compliance with technical requirements.

In 2013, CAISO developed a new methodology to evaluate non-transmission alternatives in Phase 2 of its transmission planning process, in part driven by California's energy policy that encourages the use of preferred resources (energy efficiency, demand response, renewable generating resources and energy storage) [49]. Before, it already considered such resources but on a case-by-case basis, as was the case with storage following Western Grid case (**Box 8**).

In Mexico, the Program for the Modernization and Expansion of Transmission and Distribution Networks (PAM, for its Spanish acronym)[9] is the equivalent to CAISO's transmission planning process. Considering that up until recently there was one national, State-owned, vertically integrated utility,[10] T&D solutions identified in PAM are not yet as sophisticated as those in its Californian counterpart. In its 2018-2027 edition, PAM considered only two alternatives to each need identified and the best one was chosen through an economic analysis performed by the grid operator.

PRODESEN, published annually by the Ministry of Energy, uses PAM's findings as an input. In their latest 2017-2031 edition, both programs consider the use of batteries to solve a congestion problem in Baja California (**Box 1**). However, CENACE does not have a defined methodology for evaluating non-traditional transmission alternatives in its planning processes in a systematic way. This complicates identifying the cases in which storage could be the superior alternative. Not all projects in PRODESEN will materialize, but only those included in this planning process are eligible to be instructed for construction. Therefore, the absence of a clear methodology to evaluate storage and other non-traditional solutions represents a huge barrier for their economic viability and access to regulated tariffs.

Additionally, there is also the unresolved issue of asset ownership. CENACE has shown interest in developing and operating storage projects to facilitate voltage control and congestion management, among other issues. It is not clear how this will influence the operator's independence. Prior to the Western Grid case, FERC rejected a pumped hydro storage project that filed a similar petition because the project developer –Nevada Hydro Company– proposed that the ISO had operational control over it. FERC and the own ISO were concerned this would compromise its independence [47]. If third-party ownership were defined as the way to circumvent this issue, CENACE and CRE would have to define the contractual relationship between the ISO and the storage project owner.

Once these barriers are sorted out, the compensation scheme will be straightforward. Storage would receive a regulated tariff as traditional T&D facilities. The picture gets more complicated when dealing with multi-use projects as explored in the next section, particularly as fears of double compensation appear. This possibility also requires a more complex contractual framework that includes service hierarchization based on a system such as that described in Section 4.2

### 4.5.2 Multi-use projects challenge even mature markets

In January 2017, FERC issued a policy statement to clarify its view on storage participation in regulated and market-based services, following the precedents of Nevada Hydro Company and Western Grid. In this statement, FERC recognized the benefits of allowing storage to serve both types of services, but also provided guidance to guarantee market fairness. Particularly, FERC stressed the need to prevent adverse market impacts, avoid double payments and protect ISO's

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[9] *Programa de Modernización y Ampliación de la Red Nacional de Transmisión y Redes Generales de Distribución del Mercado Eléctrico Mayorista.*

[10] Prior to the Energy Reform of 2013, private participation in generation was allowed under very restrictive figures, that required that all energy had to be sold through the former State monopoly (CFE).

independence. It also highlighted that storage resources must demonstrate cost competitiveness with transmission [50].

Motivated by FERC's statement, CAISO started a consultation process in early 2018 to develop a proposal for storage to access market revenues, while receiving regulated rates. So far, a straw proposal is available for stakeholder's comments, which gives an indication on CAISO's ideas to address the aforementioned FERC concerns.

CAISO's proposal requires that all storage resources go through the transmission planning process discussed before –even if they also plan to participate in wholesale markets– in order to access regulated rates. Storage's role as transmission facilities is prioritized and, as storage resources resulting from the planning process are sized according to the need they address, any excess capacity will not receive regulated rates [47].

An important issue addressed in CAISO's document is when to allow storage to participate in other markets, without compromising their network services. Its proposal is to base that decision on the degree of predictability of transmission needs: Storage resources operating in unpredictable contexts will not have access to market revenues (CAISO would need them ready to respond to any transmission need practically all the time); resources in predictable environments could access market revenues, although CAISO reserves the right to analyze such conditions on a case by cases basis, and adjust the time windows in which a resource could provide market services [47].

The second major issue is how to compensate those resources participating in both markets avoiding double cost recovery. CAISO has proposed two mechanisms to reconcile other revenue streams with a regulated rate [47]:

a) Full cost-of-service based cost recovery with energy market crediting: market-based revenues are offset from the regulated rate, reducing the revenues otherwise required through transmission tariffs.
b) Partial cost-of-service based cost recovery with no energy market crediting: Only a portion of the cost recovery is guaranteed through a rate base, the rest must be recovered from market services at the owners' risk.

The first mechanism has the advantage of ensuring full cost recovery and facilitating storage evaluation against other transmission assets. However, it provides little or null incentive for a resource to participate in wholesale markets. The second mechanism does solve this issue as storage resources will have the incentive to earn market revenues to ensure cost recovery and, potentially, extra earnings; but also creates the risk of not recovering the asset's costs [47].

In both cases, CAISO also identifies the need to draft a new contractual framework for storage as transmission assets accessing market revenues. So far, the operator considers that having "*visibility in real-time operations, including a complete and encumbered path to the operation of the storage device in real-time*" is a requirement for considering storage as a transmission asset [47]. It is therefore imperative that the contract specifies under which circumstances will ISO operate the device and when the operator could freely charge and discharge to participate in wholesale markets (as it is believed that ISO could not do this to avoid compromising its independence).

Mexico is a new market thinking on how to work on these issues. The idea is to benefit from the current lack of regulation for storage and draft a framework that allows for all participation models from the start. The concerns raised by FERC and CAISO are also relevant to their Mexican counterparts, particularly those regarding the existence of double payments at the expense of ratepayers, as well as the contractual frameworks to ensure a smooth coordination between the ISO and the storage operator. It is important to stress the need to include storage evaluation in CENACE's planning process; resources outside this process are not candidates to receive regulated rates.

Mexican storage regulation is in its initial phase, but it is already clear that a strong coordination among the regulator, the system operator and the Ministry of Energy will be key to ensure a successful outcome. Engaging industry and academic stakeholders could also add important value as it has been the case in California.

## 4.6 Culture and education are key

Storage's multipurpose nature requires coordinated efforts from different actors to operate properly and realize its full potential. An area that demands such coordination is the process to be considered as a T&D asset with regulated rates. This process not only needs clear and effective regulations, but also the ISO's decision to include it in its planning process and its instruction as a network asset by the Ministry of Energy. Moreover, it requires companies that are knowledgeable enough to present offers and participate in competitive processes. Clear communication with all stakeholders is essential to be able to capture the benefits that storage can provide to the system. With this in mind, a series of recommendations to address the most important stakeholders are provided next.

**Ministry of Energy.** Provide information to all areas and policymakers on storage's potential in different areas, particularly those aligned with their energy policy. Mexico has ambitious targets for clean energy production that storage can contribute to materialize more easily. There are also concerns about the country's strong dependence on imported hydrocarbons that could be mitigated by promoting a more diversified power generation matrix. Communicating such ideas to all authorities is necessary to put storage on their radar. Additionally, future decisions should consider storage's falling costs in order to achieve optimal outcomes.

Mexico's Ministry of Energy signaled its interest in promoting energy storage; with the new administration coming in December 2018, raising awareness and educating decision makers will become crucial again. Experiences like California, where a storage-friendly policy is in place, demonstrate the importance of coordinating efforts with policymakers. Case studies and success stories from mature markets are helpful tools to showcase storage cost-effectiveness, efficiencies and benefits to the system.

**Energy Regulatory Commission.** Collaborate closely with the country's ISO and the Ministry of Energy. The regulator must consider holding extensive consultation processes, similar to that conducted by CAISO for all of its storage-specific regulations [47]. Technical conferences on energy storage, inviting relevant stakeholders, could contribute to reveal storage project's needs while collecting the views of market participants, the grid operator, policy makers, academics, and other interested actors.

**CENACE.** Open communication channels with the ISO are essential for success as they will eventually coordinate with storage operators and manage part of its services. It is also imperative that the operator acknowledges storage's value as a T&D asset so it can systematically consider it in its planning process. The grid operator must see storage as its ally, which is why the regulator must tirelessly stress storage's benefits and the safeguards to avoid double payments and interference between regulated and market-based services.

The operator's opinion is very important and must be heard. It knows the grid's needs and market behavior. The regulator could even consider asking CENACE for a technical proposal for an energy storage pilot to help solve some of the challenges identified in the operation of storage in both regulated and market-based environments.

**Market participants.** The regulator should also listen to the experiences and ideas of different market participants, not only developers but generators, T&D companies, suppliers and end users. Will they benefit from storage? In which way? Do they think storage should be valued as a network asset? Why? Understanding their points of view will enrich storage's regulation and direct it towards an open conversation on the future of Mexico's storage.

T&D companies' participation is highly encouraged. In the case of Mexico, this is the duty of two large companies, which were previously part of the vertically integrated monopoly. Their input is essential to the network planning process; they control all existing T&D assets so storage operators will eventually have to collaborate with them. Listening to renewable generators is also recommended. Whom better than them to explain the issues that VRE can pose on the Mexican network and the best ways to address them.

**Others.** Consider involving academy and non-energy industry representatives such as trade organizations. Experts, regulators and government representatives from markets where storage is already a reality would be a valuable addition.

It is important to keep in mind that failing in this communication effort might prompt opposition from critical actors, leading to insufficient agreements and compromising storage participation in all the activities where it can add value.

### 4. What needs to be done in Mexico – Section recap

After recently opening its energy markets, Mexico is in a privileged position to create a sensible and comprehensive regulatory framework that recognizes storage's multi-purpose nature and enables revenue stacking.

There is a long list of tasks ahead for Mexican authorities undertaking this endeavor: coming up with a broad enough definition for storage, creating rules and contractual frameworks so that different storage provided services can coexist efficiently, recognizing its T&D value and designing attractive and transparent remuneration schemes, are just some examples to begin with.

## 5. Conclusions

The decarbonization of the power sector is an unstoppable trend as evidenced by the Paris Climate Agreement and the actions taken by a large number of countries. Energy efficiency and renewable energy are the pillars for most of these decarbonization strategies, particularly in countries with a sizeable renewable potential, such as Mexico. Encouraged by its great solar, wind, biomass and hydro resources, Mexico has set ambitious goals to generate more of its power from clean energy sources. Wind and solar power plants are growing faster than any other technology. This is great news for Mexico's clean energy goals, but it also poses some concerns over the grid's reliability and operability.

Fortunately, storage technologies costs are dropping, making it an affordable solution to ease the management of voltage and frequency variations caused by variable energy resources such as wind and solar. Moreover, storage is valuable for other purposes apart from supporting renewables integration. Storage can contribute to a country's energy security by diversifying its energy matrix away from fossil fuels. Storage also offers attractive services for end users, including the possibility to save energy when it is cheaper –or not needed– to use it later. It also allows consumers to manage their electric bill, as well improve power service quality. Thus, storage is good for promoting the use of distributed energy as well.

Storage is a valuable source of ancillary services. In particular, storage is highly efficient in providing frequency regulation, load following, spinning and non-spinning reserves, voltage support and black start. Its best quality is its response speed, much faster than traditional generators. Storage's potential use as a network asset is probably a less known application but not least important. This technology can reinforce existent T&D infrastructure, prevent stress and thermal loading, and avoid transmission congestion. In this way, storage might defer investments in new T&D infrastructure, saving costs to the system and end users.

Developing a comprehensive regulation that allows realizing storage potential is not easy, particularly when combining participation in T&D activities (regulated) and wholesale markets. California is one of the most advanced markets in this regard, having solved many of the challenges surrounding storage deployment. Nonetheless, rules for storage resources as transmission assets providing market services remains an unresolved matter, although CAISO has taken serious steps in this direction.

Mexico should take advantage of the early stages of its market to design a regulatory framework for storage that includes all best practices from the beginning. This means it needs to work out most of the things that mature markets like California have already solved. Perhaps the most pressing issues are the following:

- Change the current definition of energy storage to recognize storage's multipurpose nature. This new definition must avoid arbitrarily placing storage into existing categories such as Power Plant or Generator. Energy storage is a completely different resource that must be considered as its own legal and regulatory figure.
- Expand its existing ancillary services market to consider storage participation without constraints from the Power Plant figure. Consider the inclusion of ancillary services that give economic value to the speed of response (including pricing primary frequency regulation).
- Coordinate efforts with CENACE and the Ministry of Energy to include storage in the current T&D planning process, using a standardized methodology that evaluates storage's technical and economic feasibility. This is the first step for storage to access regulated rates as traditional network assets.
- Develop a methodology to identify the times in which storage is the best T&D alternative, when it can participate in wholesale markets without compromising its T&D operation, and how to compensate it (avoiding double cost recovery).
- Categorize the different services that storage can provide and establish a hierarchical order that will help to develop rules for the storage operator and the ISO to work together.
- Review other market instruments to ensure consistency.

To succeed in these tasks, it is essential that storage's potential benefits are crystal clear to relevant stakeholders. The Ministry of Energy, the Energy Regulatory Commission, CENACE and market participants –such as T&D companies and renewable generators– are identified as critical stakeholders for the implementation of a successful storage regulation.

Energy storage is a game changer for the electricity sector and virtually all of its stakeholders. Its falling costs –particularly Li-ion batteries'– make it a commercially viable solution for renewable integration at a massive scale. Renewable energy plus storage will be key for energy transition, and materialize a future in which most power –or even all of it– comes from abundant, local renewable sources.

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