1. Review of experiences and trends in electricity storage technologies in Mexico and globally

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This report is part of the study:
Technology Roadmap and Mitigation Potential of Utility-scale Electricity Storage in Mexico

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4. Stakeholders that provide technology assessment to the government or to private organizations like GIZ, the Danish Cooperation, etc.
5. Stakeholders involved in research, development and innovation related to electricity storage systems in Mexico.
6. Stakeholder that provides banking services and financial support at the international (WB, BID) and national level (NAFIN, BANOBRAS).
7. Private associations, think-tank's and non-governmental organizations supporting lobby activities or involved in the development of policy.

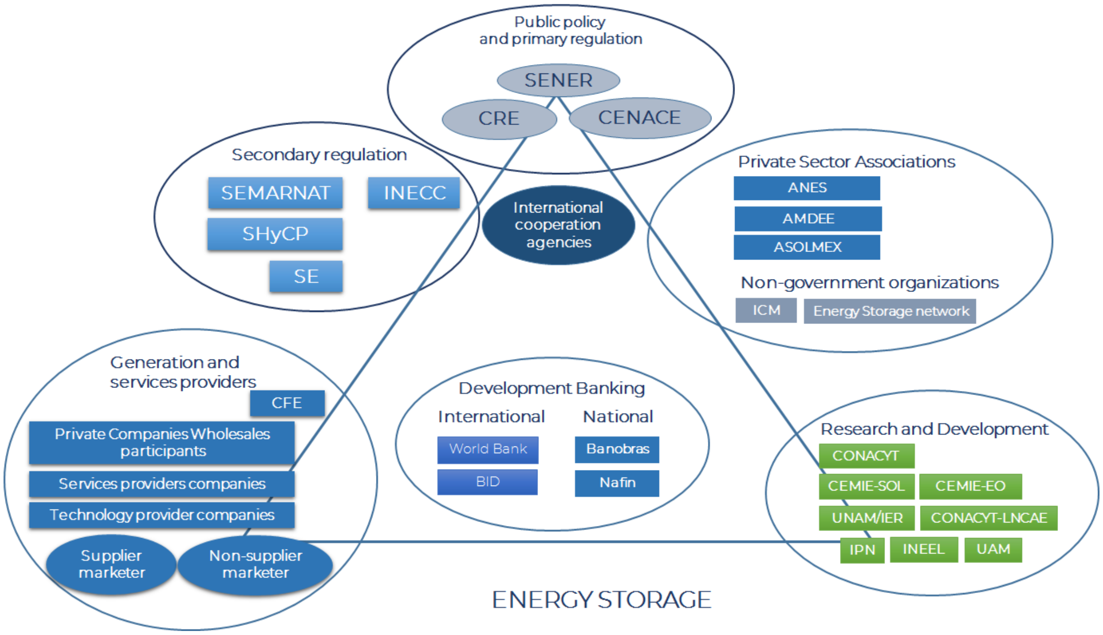

Figure 1. Stakeholders involved in the deployment of Energy Storage. Source: own elaboration.

Technology trends

The national electricity system (SEN) is organized into ten control regions. Seven regions in the continental massif are interconnected building the National Interconnected System (SIN), which connects most of Mexico and shares resources and reserves of capacity. The 3 remaining regions of Baja California, Baja California Sur and Mulegé are completely isolated from the rest of the national electricity grid.

The increasing penetration of intermittent or variable renewal generation in the SEN represents challenges on frequency regulation, frequency quality, reduction of inertia of the system, primary regulation, reserve margins and on the useful life of conventional power plants due to the need for more frequent and steeper ramps.

The operation of the SEN will increasingly be faced with the influence of the following trends: the country's renewable energy goals -35% by 2024 and 50% by 2050, the new renewable-energy based projects resulting from the long-term energy auctions (derived from the reform of electric system), the trend to more natural gas power plants that already change the generation matrix, as well the sustained growth on distributed generation and the future requirements of transport transition.

Electricity storage technologies might have a growing role to address some of these challenges in a cost-efficient way while promoting the decarbonisation of the Mexican power sector. Energy storage technologies can support energy security and climate change goals by providing valuable services such as: improvement of energy system resource use efficiency; integration of higher levels of variable renewable resources and end-use sector electrification; supporting greater production of energy where it is consumed; increasing energy access; and improving electricity grid stability, flexibility, reliability and resilience. Moreover, they can provide associated products and related services that can contribute with the components of efficiency, quality, reliability, continuity, safety and sustainability of the network to which they are connected.

On the global level information available shows that total installed storage power capacity is currently dominated by pumped hydro storage (PHS), with 96% of the total of 176 gigawatts (GW) installed globally in mid-2017. The other electricity storage technologies in significant use around the world include thermal storage, with 3.3 GW (1.9%); electro-chemical batteries, with 1.9 GW (1.1%) and other mechanical storage with 1.6 GW (0.9%). In 2019 the total installed operational storage power capacity of electro-chemical (mainly batteries) raised up to with 2.8 GW (1.6%), and the capacity from other mechanical storage was 1.3 GW (0.8%). In terms of the number of installations, the applications of Energy Storage Systems (ESS) with batteries are the ones that top the list according to the DOE data and other technologies, such as thermal storage or flywheels, have a relevant representation in applications below 10 MW capacity (Figure 1).

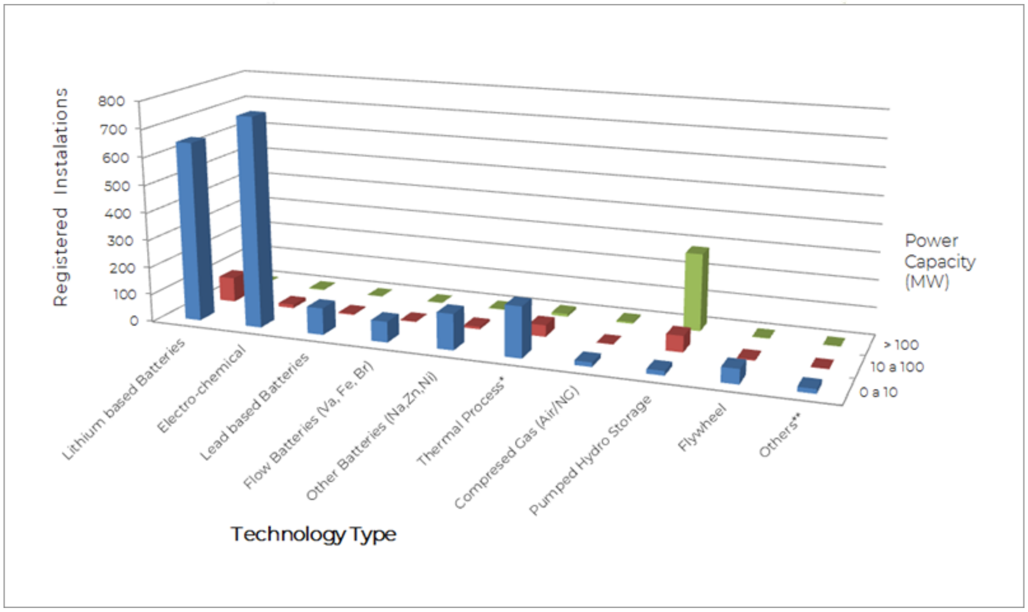

Figure 2. Global electricity storage number of projects by power capacity and technology. Source: own elaboration with data from (US-DOE (2019).

Despite the lower levels of deployment of electro-chemical, electro-mechanical and thermal storage, the main services provided by them are more diverse than those of PHS plants. Thermal energy storage applications currently are applied on concentrate solar power (CSP), allowing them to store energy, in order to provide the flexibility to dispatch electricity outside of peak sunshine hours, e.g. into the evening or around the clock (IRENA, 2016). Molten salt is the dominant commercial technology applied with 86% of the total capacity deployed of thermal storage used for electrical applications (2.6 GW) (US DOE., 2019).

Electro-mechanical storage deployment has had a relatively small number of projects with a total operational installed capacity of 1.3 GW. It is dominated by the flywheel technology, with 0.9 GW (69% of the total electro-mechanical capacity). The total deployment of CAES has reached 0.4 GW of power, although it is concentrated in in-ground natural gas combustion compressed air, and the deployment of other types of storage with compressed air is 0.5% (US DOE., 2019). Although the installed operational power of electro-chemical storage is still relatively small, it is one of the most rapidly growing market segments. During the last 20 years, deployment of global installations of electrochemical storage grew exponentially (Figure 2), as rapidly decreasing costs and performance improvements are stimulating investments (IRENA, 2017).

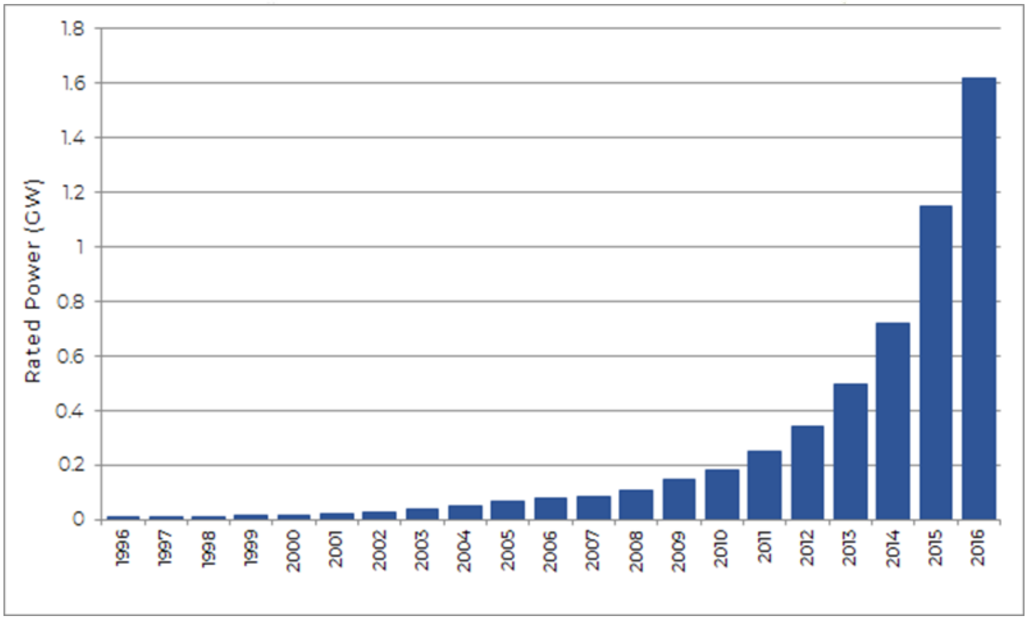

Figure 3. Global electro-chemical storage capacity for stationary purposes,1996-2016, Source: (IRENA, 2017).

In Mexico the Energy Regulatory Commission is beginning to recognize the value of storage and since 2018 has been working on developing a regulation for storage technologies. On January 2019, the CRE preliminarily defined the following products and services that energy storage may offer in Mexico: Energy; Capacity; Secondary reserves; Spinning reserves; Non-spinning reserves; Operating reserves; Supplemental reserves; Reactive reserves; Reactive capacity; Black start; Isolated operation; Services for the deferral of transmission and distribution investments. While energy storage in Mexico is not developed, some projects have been identified showing that there is a current interest on this area from the private and public sectors, as shown in the next Table 1.

Table 1. Current projects in Mexico. Source Own elaboration.

PROJECT	TECHNOLOGY	CAPACITY	LOCATION	PURPOSE	STATUS	NATURE
Aura Solar III	Lithium-ion batteries	10.5 MW/7.0 MWh	La Paz, Baja California Sur	Stabilization of the grid.	Constructed	Private
Arroyo Power Energy	Chemical batteries	12 MW/12 MWh	Monterrey, Nuevo León	Microgrid, Frequency Response, Spinning Reserve	Operating	Private
Mexico City	Flywheel	1,800 kVA	Mexico City	Back up	Operating	Private

PROJECT	TECHNOLOGY	CAPACITY	LOCATION	PURPOSE	STATUS	NATURE
Airport						
Toluca City Airport	Flywheel	600 kVA	Toluca, State of México	Back up	Operating	Private
San Juanico	Lead-acid	2,450 Ah	Comondú, Baja California Sur	Supply	--	Private
Zima-pán	Pumped Hydro	570 MW	Zimapán, Hidalgo	Ancillary services	Planned	Public-CFE

Also, a number of research projects related to energy storage have been launched in recent years financed by the CONACYT-SENER-Energy Sustainability Sector Fund through the National Council for Science and Technology (CONACYT) in various topics such as: hydrogen storage; material for efficiency improvement in capacitators; supercapacitors; regulatory, costs and economic energy storage feasibility studies; sodium-ion batteries; flow batteries; and fuel cells.

Regulatory trends

The reform of the Mexican electricity sector adopted numerous structural and regulatory elements form the California electricity market. Since California is more advanced than Mexico in terms of electricity storage regulations, the similarities between the two markets allows Mexico to adopt many of California's storage regulations with relative ease.

In 2002, California signed into law a Renewable Portfolio Standard (RPS) calling for 20% of electric retail sales to come from renewable sources by 2020. The RPS increased progressively over the years to reach the current objective of 60% of electricity from renewable sources by 2030 and all generation to be carbon free by 2040 (California Senate, 2018).

As its portion of renewable generation increased, California faced intermittency and ramping challenges associated with wind and solar generation. To address those challenges, California regulation obligated its main utility companies to procure energy storage.

Since the deployment of energy storage was driven by regulation, in order to integrate storage into the market, the California Energy Commission, California Independent System Operator and the California Public Utilities Commission created a "California Roadmap and the Energy Storage and Distributed Energy Resources Initiative" (CAISO, 2014). The Roadmap identified a number of actions necessary to promote grid-scale energy storage, and grouped them under five headings: planning, procurement, rate treatment, interconnection, and market participation.

The Roadmap was replaced by the "Energy Storage and Distributed Energy Resources Initiative" composed of four phases. The first phase "enhanced the ability of grid-connected storage and distribution-connected resources to participate in the ISO market" (CAISO, 2019A). The second phase, among other things, defined the treatment of energy used for operating storage vs. energy used to charge storage (CAISO, 2018), and the third phase still has not been completed at the time of writing of this section. The goal of the third phase is to identify additional means for grid-connected storage to participate in the market. The fourth phase is expected to address the state of charge and market power of storage resources, and streamlining interconnection agreements.

In addition to the regulations and policies promoting storage, there are various initiatives on the State and the Federal levels meant to facilitate electricity storage through research, tax incentives, and Federal regulations.

Despite numerous similarities between Mexican and Californian regulatory frameworks, there are some important differences. The most important difference is that in California a storage system can offer frequency control on the day-ahead and real time markets for ancillary services while Mexico has no market for frequency control.

While California deployed storage through regulation, the UK took a market approach.

Both the UK and Mexico had centralized state-owned electricity systems prior to their respective energy reforms. The Mexican electricity sector reform, which took place 24 years after the one in the UK, left a significant portion of the generation capacity as well as transmission and distribution systems under the control of government-owned enterprises. On the other hand, the UK privatized all aspects of electricity sector and adopted a market approach to energy storage.

The UK's drive to decarbonize the electricity system, propelled by the "Climate Change Act" of 2008 (UK Parliament, 2008) detonated renewable generation investments. The portion of electricity sales from renewable sources increased from 7.2% in 2010, to 25.1% in 2017 (DUKES, 2018). Also, the Feed-In Tariffs (FiT) program encouraged distributed generation on a small scale, and in 2017 the program reached the capacity of 6.1 GW. Whereas in Mexico distributed generation applies to installations up to 0.5 MW, in the UK FiT program applies to projects up to 5 MW (UK Parliament, 2008).

The increased participation of intermittent generation in the UK electricity system has sparked interest in optimal ways to integrate electricity storage into the network. In 2015, the UK introduced an Enhanced Frequency Response, an ancillary service with a response time of one second or less. This particular service clearly favored storage technologies such as batteries, flywheels, and supercapacitors with a very fast response time.

In 2016, Carbon Trust and the Imperial Collage London published a report entitled "Can Storage Help Reduce the Cost of a Future UK Electricity System?". The report finds that storage could significantly reduce the cost of the UK system, even without emphasis on decarbonization. The report stated that the key solutions to overcoming barriers to storage deployment are policy related. Examples of solutions included monetizing system benefits including externalities, reducing policy uncertainty and defining storage performance standards.

In both UK and California, the energy storage regulations and policies are not finalized and like Mexico are striving to successfully integrate storage into the system. There are three principal ways governments can promote deployment of storage: through a regulatory obligation similar to California; through subsidies, such as various international programs focused on distributed generation, or storage producers such as German government's subsidies for battery producers; and through regulations which create a market for storage products, similar to the UK.

- Regardless of the path taken, a successful deployment of grid-scale energy storage requires at least three factors:
- Clear rules, definitions and classifications of storage services.
- Non-discriminatory regulation, which recognize storage physical and operational characteristics
- Security of revenues, either through a tariff structure similarly to California, or market conditions conducive to storage contracts similarly to the UK.

1. Electricity Storage in Mexico

1.1 Background

In order to understand the state of electricity storage in Mexico, it is necessary to broadly understand the Mexican electricity sector and its transformation.

The Mexican constitution was amended in 2013 (*Reforma Energética - Resumen Ejecutivo*, 2014) to permit the participation of private companies in certain segments of the energy sector, which until August 2014 was composed principally of two vertically integrated national companies: the Mexican Oil State Company "Petróleos Mexicanos" (PEMEX) [1] and the Federal Electricity Commission "Comisión Federal de Eléctricidad" (CFE).

Hence, for nearly 54 years CFE had the full responsibility for the generation, transmission, distribution, and operation of the electricity system in Mexico, as well as the planning of the system.

CFE was created in 1937, with the objective of organizing and directing a national system of generation, transmission and distribution of electrical energy. At this time there were also other private participants in the market, mainly in the industrial sector. In 1960, President Adolfo López Mateos nationalized the electricity industry, in order to increase the level of electrification, since in that year it was only covering 44% of the Mexican population. At the beginning of the year 2000, CFE had a generation capacity of 35,385 MW, and electric service coverage of 94.7% nationwide (CFE, 2019). And it was not until 2009 that Mexico appointed CFE as the only parastatal company to provide electric service throughout the country, decreeing the extinction of the company "Luz y Fuerza del Centro" (LyFC), which supplied the electric power in the central region of the country until then.

Therefore, as of 2009, CFE participated in all the steps of electricity generation, i.e. planning, construction, operation, transmission and distribution of electricity. In this way, the Energy Ministry (SENER), together with the Energy Regulatory Commission (CRE) approved public policies, planning, regulation and rates for the services offered by CFE.

The 2013 reform unbundled CFE into various companies[2] centrally controlled by CFE corporate headquarters, with the intention of creating an open electricity market and making CFE one of the participating companies in this new arrangement, while maintaining the state-owned characteristic, such as a productive Company of the State, exclusive property of the Federal Government, with legal personality and own patrimony, that has technical, operative and management autonomy for business, economic, industrial and commercial activities in terms of its purpose, to generate economic value and profitability for the Mexican State. On the other hand, the responsibility for planning the electricity system was transferred to the Energy

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[1] *The 2013 reform transformed PEMEX into a state productive company for developing commercial and industrial activities for the whole productive chain in the oil industry (Ley de Petróleos Mexicanos, 2014).*

[2] Current CFE companies are: CFEnergía, CFE Internacional, Intermediación de Contratos Legados, Generación Nuclear, Generación (divided into six companies: from Generation 1 to Generation 6), Consumo Calificado, Suministro Básico, Transmisión, Distribución. From "Ley de la Comisión Federal de Electricidad" article 57 (Ley de la Industria Eléctrica, 2014)

Ministry (SENER). The implementation of the reform in the electricity sector completed these steps:

2013. Energy Reform. Constitution is amended to allow private sector participation in generation and commercialization of electricity, as well as to offer ancillary services. Both transmission and distribution remain under control of CFE, but contracts with private sector are permitted.
2014. The Electric Industry Law (LIE) (Ley de la Industria Eléctrica, 2014) is published, outlining the rights and responsibilities of the Energy Ministry (SENER), the Energy Regulatory Commission (CRE), the National Center for Energy Control (CENACE) as the Independent System Operator, and the rights and responsibilities of market participants.
2015. The Rules of the Electricity Market are published (Bases del Mercado, 2015).
2016. From 2016 onwards. Electricity Market manuals and pertinent regulation were (and still are) being published. The Majority of the regulatory infrastructure relevant to electricity storage has not been established yet.

Until 2014, CFE was the principal architect of the electric system planning, with contribution from SENER as well as the Ministry of Treasury and Finance (SHCP). The planned development of the electric grid and the associated infrastructure investments were periodically published by CFE in a comprehensive Electric Sector Investment and Construction Program, the so called “Programa de Obras e Inversiones del Sector Eléctrico” (POISE). The POISE served as a point of departure for all electric infrastructure projects in Mexico.

The last POISE was published by CFE for the 2014-2028 period (Comisión Federal de Electricidad, 2014). In this POISE, CFE argues that because electricity cannot be stored, establishing adequate reserve margins is very important to maintain the supply reliability of the national interconnected system (SIN). This implies that in order to maintain an acceptable reserve margin, it must be guaranteed that the generation capacity is greater than the maximum annual demand; but it must also have the necessary resources to handle the unavailability of the scheduled outputs or not of generating units for maintenance, degradation and other causes, increasing flexibility to face critical events or major contingencies such as deviations in the forecast of demand, losses contributions to hydroelectric plants, delay in the entry into operation of new units or transmission lines, long-term failures, unavailability of gas pipelines or natural disasters. In the methodology for calculating the reserve margin, three fundamental elements are recognized: Operating reserve (6% of the maximum demand), random failures of generating units, and critical events in the system (2% of the maximum demand) (Comisión Federal de Electricidad, 2014). However, CFE does mention within the margin of energy reserve, which must reach at the end of each year a minimum level of energy stored in large hydroelectric plants as an additional criterion of planning and operation, establishing this between 15 and 18 TWh. Also, the program shows the relationship between the volume (Mm^3) of water storage and the corresponding electricity that can be generated (GWh) for each regulated large hydroelectric power station in the system (Angostura, Chicoasén, Malpaso and Peñitas in Grijalva river; Caracol, Infiernillo and Villita in Balsas river; Temascal in the conjunction of Tonto and Santo Domingo Papaloapan rivers; El Cajón and Aguamilpa in Santiago river; and Zimapán in Moctezuma river) (Comisión Federal de Electricidad, 2014).

In 2014, in line with the Electricity Industry Law, SENER took the leading role in planning and developing the Mexican electricity system. In 2015 the first Development Program for the National Electricity System, the so called “Programa de Desarrollo de Sistema Eléctrico Nacional” (PRODESEN) was published by SENER. This report consisted of three complementary programs: the Indicative Program for Installing and decommissioning of Power Plants “Programa Indicativo para la instalación y Retiro de Centrales Eléctricas” (PIIRCE); the Expansion and Modernization Program of the National Transmission Network “Programa de Ampliación y Modernización de la Red Nacional de Transmisión (PAMRNT) 2018-2032; and the Expansion and Modernization Program of the General Distribution Grids “Programa de Expansión y Modernización de las Redes Generales de Distribución”. The main objectives were to: minimize the cost of satisfying the electricity demand; reduce the costs of transmission congestion; and encourage an efficient expansion of the generation capacity. The PRODESEN reports the general guidelines for developing the electricity system, presents generation, transmission and distribution projects for the short and medium term, with a 15-year time horizon (SENER, 2018).

The latest edition of the PRODESEN, “PRODESEN 2018-2032”(SENER, 2018), acknowledges the importance of electricity storage in the context of the development and modernization of the electricity distribution grid in a smart grid context, where it is expected to have a highly automated transmission and distribution infrastructure, as well as a complete asset management and a high operational flexibility of the network, foreseeing the increase in the incorporation of distributed generation systems and the optimal management of energy in the network,. While SENER does not mention specific storage projects in PRODESEN, it recognizes the concomitant role of electricity storage with renewable generation and identifies the development and integration of advance storage technologies as a goal for peak-shaving purposes, in line with the Special Energy Transition Program.

On 31st May 2017, SENER published the Special Energy Transition Program “Programa Especial de la Transición Energética” (PETE)(SENER, 2017), to promote the use of clean technologies and fuels. One of the four objectives of the Program was to expand and modernize the transmission infrastructure and to increase distributed generation and storage. SENER recognized the energy storage as a solution to the intermittency associated with renewable generation and identified the role that pumped hydro could play in the ancillary services market; the batteries and molten salt were also identified as a viable energy storage option. However, the Program also recognized the regulatory hurdles which currently prevent batteries from participating in the electricity market because the regulatory framework does not consider a figure or a special regime for the stored energy to be considered as electricity generation when it is supplied to the electricity market. A similar situation happens to allow the participation in the ancillary services market.

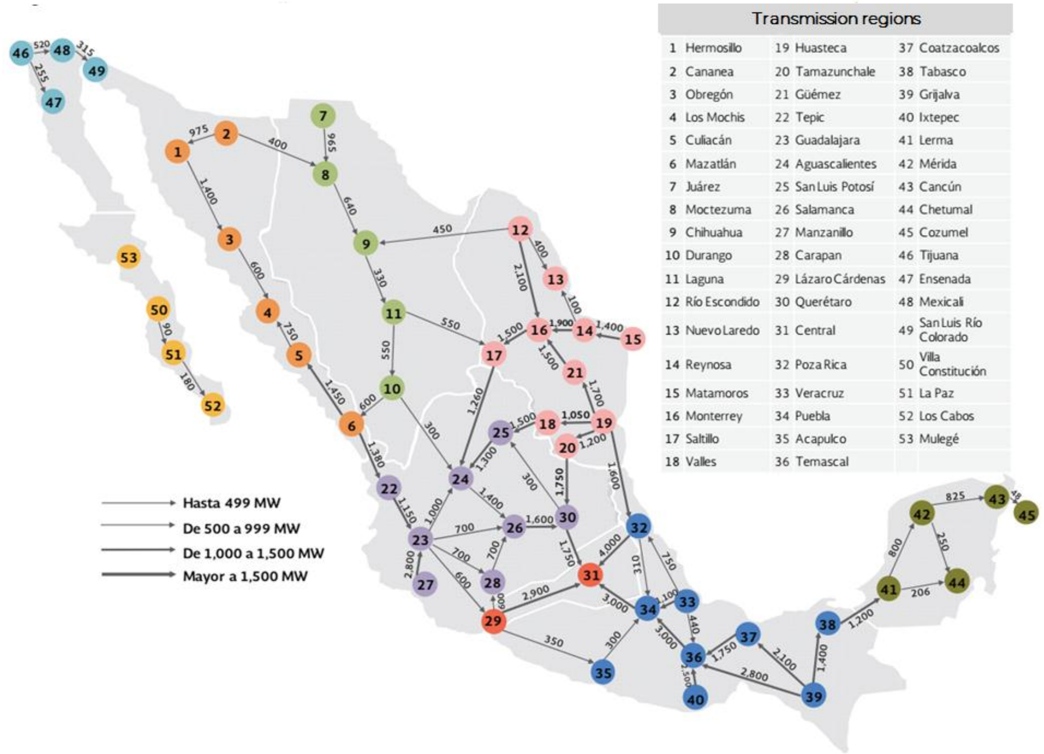
In addition to the synergy that storage offers for the integration of renewable and intermittent sources of energy, energy storage offers many other benefits for the Mexican electricity system, since the different services it can offer to the grid such as energy, power, operational and regulatory reserves, black start, decongestion of energy, peak-shaving, among others, would allow CENACE to have sufficient and adequate options to guarantee the safety, stability and quality of energy in the network. In addition, with proper regulation it will be possible to create a market around these services, which may be particularly beneficial for private companies but also for the CFE.

1.2 The Mexican Power System

The national electricity system (SEN) is organized into ten control regions, as shown in Figure 1.1. The operation of these regions is under the responsibility of 9 regional control centers. The seven regions of the continental massif (northwest, north, northeast, western, central, eastern, peninsular) are interconnected and form the National Interconnected System (SIN). It shares resources and reserves of capacity in the face of the diversity of demands and operational situations. This makes it possible to exchange energy to achieve a more economical and reliable operation as a whole. The 3 remaining regions of Baja California, Baja California Sur and Mulegé are completely isolated from the rest of the national electricity grid.

Figure 1.1. Control regions of the national electrical system. Source: “PRODESEN 2018-2032” (SENER, 2018).

Also, the SEN is composed of 53 transmission regions, whose link capacity during the year 2017 was 76, 697 MW (Figure 1.2), which represented a growth of 3.4% with respect to the previous year.



Transmission regions		
1 Hermosillo	19 Huasteca	37 Coatzacoalcos
2 Cananea	20 Tamazunchale	38 Tabasco
3 Obregón	21 Güémez	39 Grijalva
4 Los Mochis	22 Tepic	40 Ixtepec
5 Culiacán	23 Guadalajara	41 Lerma
6 Mazatlán	24 Aguascalientes	42 Mérida
7 Juárez	25 San Luis Potosí	43 Cancún
8 Moctezuma	26 Salamanca	44 Chetumal
9 Chihuahua	27 Manzanillo	45 Cozumel
10 Durango	28 Carapan	46 Tijuana
11 Laguna	29 Lázaro Cárdenas	47 Ensenada
12 Río Escondido	30 Querétaro	48 Mexicali
13 Nuevo Laredo	31 Central	49 San Luis Río Colorado
14 Reynosa	32 Poza Rica	50 Villa Constitución
15 Matamoros	33 Veracruz	51 La Paz
16 Monterrey	34 Puebla	52 Los Cabos
17 Saltillo	35 Acapulco	53 Mulegé
18 Valles	36 Temascal	

Figure 1.2. Capacity of links among the 53 regions of transmission of SEN 2017 (Megawatt). Source: "PRODESEN 2018-2032" (SENER, 2018).

At the end of 2017, Mexico had a total installed capacity of 75.7 GW, 70.5% of which was fossil fuel generation. While renewable energy accounted for 25.7% of Mexico's total capacity, producing 49.2 TWh, or 15.4%, of the 319.4 TWh consumed that year in Mexico (SENER, 2018). It is worth noting that the vast majority of renewable capacity installed in Mexico is concentrated in hydroelectric power, with a 64.9% share of all renewable energies.

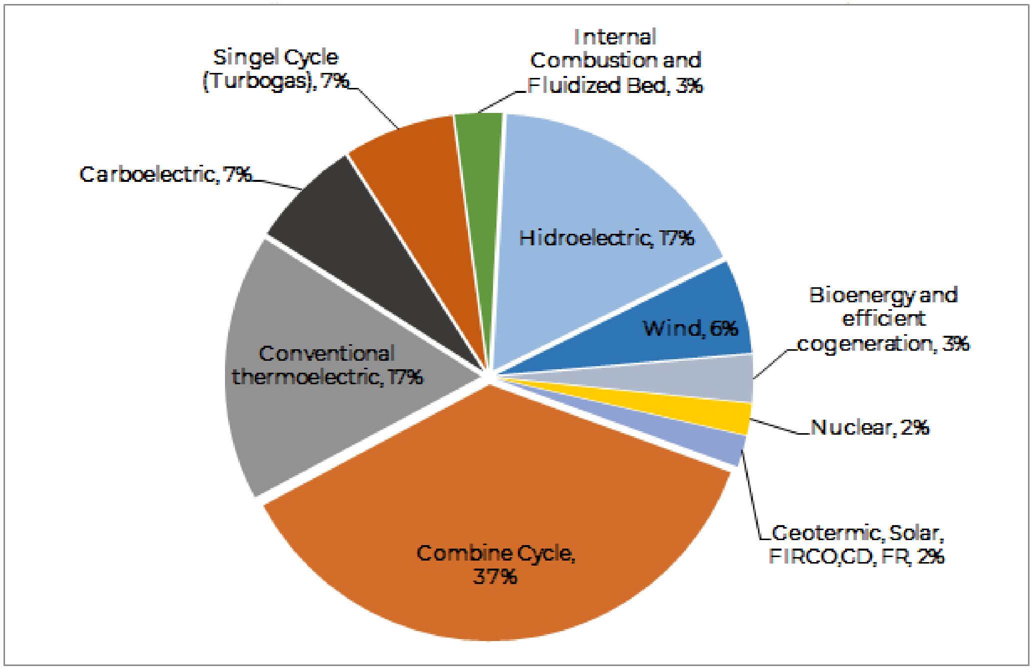


Figure 1.3. Capacity installed by type of technology 2017. Source: "PRODESEN 2018-2032" (SENER, 2018).

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

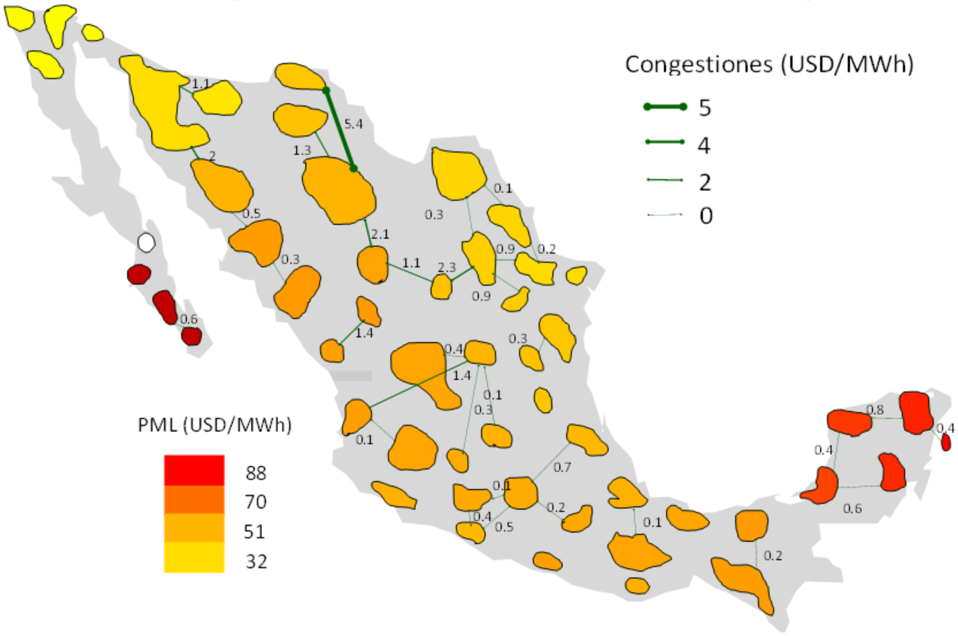


Figure 1.4. Average local marginal prices in each transmission region and bottleneck income in 2017.
Source: workshop SAE 2019

The integration of increasing shares of renewable power poses challenges for the existing network in Mexico. First, the capacity of the transmission and distribution network must be extended to eliminate bottlenecks, the operational challenges of maintaining system parameters between acceptable limits becomes more complex, especially in unfavourable weather conditions (Figure 1.4). The high penetration of intermittent generation represents challenges on frequency regulation, frequency quality, reduction of inertia of the system, primary regulation, reserve margins and on the useful life of conventional power plants due to the need for more frequent and steeper ramps.

Although Mexico has a substantial renewable potential, as aforementioned, the current penetration of renewable energies remains low. However, this situation is changing rapidly due to three factors: i) the country's renewable energy goals -35% by 2024 and 50% by 2050-; ii) the arrival of new projects resulting from three long-term energy auctions; and iii) the sustained growth of power plants in distributed generation.

The increase of renewable energies, the insufficient infrastructure of the transmission network and the congestion in the distribution networks, will put to the test the traditional operation of the network due to the intermittence of this type of sources. Electricity storage might have a growing role to address these challenges in a cost-efficient way while promoting the decarbonisation of the Mexican power sector.

1.3 Brief introduction to electricity storage

As it well known to decarbonize the energy matrix, it is necessary to deploy the use of different sources of renewable energy and increase energy efficiency, however, the penetration of renewable technologies has been hampered by their costs - which are improving - and their intermittency and variability, which reduces availability and induces grid instability. Therefore, overcoming these challenges its primordial if renewables are to account for more than just a negligible portion of the global energy portfolio.

As the IEA recognizes “Energy storage technologies can support energy security and climate change goals by providing valuable services in developed and developing energy systems.” and details that “Energy storage technologies can help to better integrate our electricity and heat systems and can play a crucial role in energy system decarbonisation by:

- improving energy system resource use efficiency
- helping to integrate higher levels of variable renewable resources and end-use sector electrification
- supporting greater production of energy where it is consumed
- increasing energy access
- improving electricity grid stability, flexibility, reliability and resilience“ (IEA, 2014)

According to the Deloitte audit and consulting firm “At present, the emerging consensus is that energy storage is the pivotal technology that will reshape the energy sector by enabling widespread adoption and grid-integration of solar and wind renewables” and mentioned that “The impact of energy storage is far-reaching, as not only does it address the issues that have limited renewable energy’s penetration, it fundamentally alters the longstanding relationship between utilities and their customers” (Deloitte, 2015). Energy Storage Systems (ESS) were conceived from the outset to consume surplus energy from the electricity grid. Evolving to the present, they now provide associated products and related services that can contribute with the components of efficiency, quality, reliability, continuity, safety and sustainability of the network to which they are connected, i.e. they can participate in the ordinary and emerging operation, collaborating in the stability of electrical systems.

The energy stored by the ESS may come from the grid or from an Associated Central, either due to surplus production, unavailability of the system to absorb energy, or market strategies (including energy arbitrage). In its simplest version, ESS behave as follows:

1. Conversion: Electricity is taken, either from the grid or from a power plant in a finite period, i.e. it acts as a load center and has the option of making purchase offers to convert the Electrification in another form of energy that can be stored.
2. Storage: this is the storage of energy *per se*, which can be done under different means. This phase is maintained in a finite period until the moment in which the release of energy is required.
3. Reconversion: the stored energy is released to deliver it back to the network in another finite period according to the needs of the electrical network or the requirements of the associated power plant. At this stage, the ESS behaves like an electric power plant with the option to make sales offers or according to the conditions established by the regulatory framework.

It is important to mention that for the three phases of storage there are energy losses due to the conversion, storage and reconversion process. Therefore, technologies that meet the highest efficiency may have a better technological penetration to store energy.

The storage of energy for the network is an area of incipient experience in Mexico, however, the transformation of the energy sector in Mexico is a reality. With changes in public policy, technological advances and economies of scale, a continuous process has been unleashed that encourages the competitiveness of renewable energy generation options and their penetration in the Mexican energy system. So while the work continues to adjust policies, regulations and market structures, to support the stable integration of the largest possible parts of power generation from renewable sources of energy; industry, investors and the government project and prepare by giving energy storage a crucial role in this transformation.

The Energy Regulatory Commission (CRE) are beginning to recognize the value of storage and are creating policies that further improve the business case for adoption, it has been working on developing a regulation for storage technologies since 2018. On January 2019, they preliminarily defined the following products and services that energy storage may offer in Mexico:

a) Energy
b) Capacity
c) Secondary reserves
d) Spinning reserves
e) Non-spinning reserves
f) Operating reserves
g) Supplemental reserves
h) Reactive reserves
i) Reactive capacity
j) Black start
k) Isolated operation
l) Services for the deferral of transmission and distribution investments

With a proper regulation it will be possible to create a prosperous market around these services, which may be given the opportunity of beneficial for private companies but also for the CFE itself. Derived from the energy reform, the CFE has certain conditions that must be explored as opportunities, before viewed like barriers i.e. the management of the ramping and the intermittency of the generation from renewable sources are borne by CFE, so an adequate regulation will allow to obtain income for these services, or in its case it would allow the company to offer better prices for this type of generation. Another is the hydroelectric plants would allow it to optimize revenues through the pumped hydro storage as long as possible. Because most of the hydroelectric plants are in legacy contracts, it will be necessary to analyse in a particular way the possibility of using that additional capacity outside the legacy contracts.

1.4 Existing and Planned Projects of electricity storage

As previously mentioned, despite acknowledging its importance, PRODESEN does not present specific electricity storage projects; however, the PETE contains various action lines related to energy storage within the objective 2 “Expand and modernize infrastructure and increase Distributed Generation and Storage”:

2.1.2 Identify and evaluate viable pilot projects for pumped hydro and battery storage and manage variable renewable sources.

2.5.1 Analyze the potential of related services for large-scale storage.

2.5.2 Develop a Roadmap for the deployment of energy storage systems.

2.5.3 Support, through funds from the sector, the development of studies, research projects, technological development and innovation in energy storage.

2.5.4 Promote national and international collaboration in research, development and innovation in storage technologies.

2.5.5 Strengthen the regulatory framework for the recognition and participation of storage systems in the electricity market.

Nevertheless, this action lines, such as pilot projects, establishment of regulatory framework, and others, are a general guideline and no represents an specific projects or link to a quantifiable target.

Table 1.1. Energy storage projects identified in Mexico. Source: Own elaboration.

NAME	TECHNOLOGY	CAPACITY	LOCATION	PURPOSE	STATUS	SOURCE
Aura Solar III	Lithium-ion batteries	10.5 MW/7.0 MWh	La Paz, Baja California Sur	Stabilization of the grid.	Constructed	(Gauss Energía, 2018)
Arroyo Power Energy	Chemical batteries	12 MW/12 MWh	Monterrey, Nuevo León	Microgrid, Frequency Response, Spinning Reserve	Operating	(Teslas only, 2018)
Mexico City Airport	Flywheel	1,800 kVA	Mexico City	Back up	Operating	(Active Power, 2018)
Toluca City Airport	Flywheel	600 kVA	Toluca, State of México	Back up	Operating	(Active Power, 2018)
San Juanico	Lead-acid	2,450 Ah	Comondú, Baja California Sur	Supply	--	(Corbus, Newcomb, & Zke, 2004)
Zimapán	Pumped Hydro	570 MW	Zimapán, Hidalgo	Ancillary services	Planned	---

The first utility-scale electricity storage project in Mexico was built in La Paz, in Baja California Sur, as part of the 39 MW Aura solar power plant which includes a 11 MW Li-ion batteries storage system(Gauss Energía, 2018). A more recent development is the 32 MW Aura III solar park also by the Gauss Energía company (Gauss Energía, 2018). The storage consists of lithium-ion batteries with 10.5 MW of charge/discharge capacity and 7 MWh of stored energy. It is important to note that the state of Baja California Sur (BCS) is not connected to the mainland National Interconnected Grid, it is an isolated system with no natural gas supply, Also, the local marginal prices in BCS are generally higher than in mainland (see table A1 and A2 Annex) , with higher volatility and bigger daily minimum and maximum spreads

According to tools such as the national clean energy inventory (INEL), the national atlas of areas with high clean energy potential (AZEL) and the Geographical Information System for Renewable Energy in Mexico (SIGER)(see figure A1 Annex), the state of BCS has one of Mexico's highest solar radiation, whose main supply of electricity is expensive diesel, and given recent decreases in solar PV costs, solar parks might become increasingly attractive. Considering, possible solar curtailment and arbitrage opportunities due to price differentials, energy storage also seems like a prominent option. Gauss Energy company has commissioned a study (Gauss Energy-GIZ 2019) on the economic viability of battery storage in Baja California Sur. The study concludes that an economic operation of a Battery Energy Storage System with the existing PV plant could be possible based on the use cases energy trading with mixed revenue and maximized pricing.

A third grid-scale battery storage system is the Arroyo Power energy back-up power battery bank. In October 2018 Arroyo Power installed a 12MW/12MWh batteries system for an auto manufacturer in Monterrey, but the batteries are not connected to the grid and serve as an insurance against power failures (Teslas only, 2018).

Another storage projects are the flywheel systems in the in Mexico City and Toluca airports, which installed a 1,800 kVA and one 600 kVa kinetic energy storage flywheel systems, respectively, from Active Power to use as back up for runway lightning and other critical navigation systems (Active Power, 2018).

On a much smaller scale, the tiny village of San Juanico in Baja California, which is isolated from the national transmission grid, installed a hybrid electricity project in 1999. The system is comprised of 17kW photovoltaic cells, ten wind turbines with a total capacity of 70 kW, and an 80kW diesel generator. The hybrid system includes flooded lead-acid battery bank with a nominal capacity of 2,450 Ah (Corbus, Newcomb, & Zke, 2004).

As described above, the experience on utility-scale electricity storage based on "new" strategies such as batteries or flywheels in Mexico is not large. Nevertheless, CFE has accumulated a vast experience in simple hydro storage, i.e. accumulating water In large dams to generate electricity following a controlled and dispatched-at-will scheme. On the other hand, the possibility of utilizing the current hydroelectric infrastructure for pumped hydro storage is very recent, even so, it can be expected a rapid deployment of this electricity storage alternative.

In 2017, CFE conducted a study and identified at least 169 possible sites for developing pumped hydro energy storage (PHES) projects utilizing its main dams. CFE observed the following criteria in order to identify the potential sites: minimum reservoir size equal to one million cubic meters, minimum power to be installed equal to 1 MW, and minimum usable water load of 150 m. CFE identified at least 169 possible sites on its main dams which could potentially install pumped storage. This analysis was based on the methodology for site identification that was developed by the European Union, but the CFE developed its own algorithm based on the publication: "Pumped-hydro energy storage: potential for transformation from single dams". In this way, a Geographic Information System (GIS map) is created, which analyzes the topographic and water availability characteristics, as well as the distance between reservoirs, minimum hydraulic load and minimum reservoir size, defining in this way a theoretical potential; Subsequently, in a second stage physical restrictions are assigned as natural protected areas, uninhabited sites, transport infrastructure, etc., and electrical infrastructure as the location of the lines and transmission capacity, thus limiting a country-level potential, resulting in a more real identification or with greater probability of reaching its viability.

In the case of Mexico, the same methodology is used, considering in the first phase all the artificial water bodies, that is, they only took the location of the PHES on the dams of the CFE. It would be sought that in the second phase the algorithm proposes the identification of sites in all the water bodies of the country that meet the minimum characteristics for a PHES with greater viability.

One of the PHES project with the most advanced feasibility study is the Zimapán dam whose main data are shown in **Table 1.2**. The PHES Zimapán project could operate with a capacity greater than 500 MW. The site is located in the limits of the states of Hidalgo and Querétaro and operates by taking advantage of the runoff and spills of the "Fernando Hiriart Balderama" hydroelectric plant. This project has the advantage of being located in an area with a large amount of energy demand (see **figure A.2 Annex**), according to the latest PRODESEN 2018-2032.

Table 1.2. Data of the Zimapán PHES project. Source: (CFE, 2019b)

Parameter	Interval	Units
Lower reservoir Capacity	1.2 - 2.3	hm^3
Reversible turbines (2)	199.5 - 370.5	MW
Pressure pipe (diameter)	3.22 - 5.98	m
Pressure pipe (length)	682.5 - 1267.5	m
Upper reservoir Capacity	1.232 - 2.288	hm^3
Filling time	3.5 - 6.5	hrs
Turbidity time	2.8 - 5.2	hrs
Usable load	361.2 - 670.8	m
Power to install	399 - 741	MW

The Research School of Electrical Engineering, Energy and Materials of the National University of Australia The Electrical Research, Energy and Materials tool of the National University of Australia analyzes different bodies of water that do not have to be rivers, this identification is done by algorithms with maps of GIS information and uses the results of the search in the geospatial maps with storage ranging from 2 GWh for 6 hours to 150 GWh for 18 hours. Within its analysis it is considered that in Central America there is a probable potential of 4,200 TWh of storage, and Mexico is within this identification. This identification takes into account a load / discharge cycle analysis per day, a value of USD 1.15 / Service and storage cost of USD 55 / MWh.

In 2017, the company Quanta Technology elaborated a study (Quanta Technology, 2017) where it mentions that the growth of demand and storage needs in Mexico will amount to 2,300 MW of power and 3,800 MWh of energy stored in the next ten years.

1.5 Research projects

Research projects related to energy storage have been launched in recent years. These projects have been financed by the CONACYT-SENER-Energy Sustainability Sector Fund through the National Council for Science and Technology (CONACYT, 2020). Table 1.3 shows the projects and objectives list.

Table 1.3. Research projects in Mexico, 2013 – 2018. Source: (CONACYT, 2020).

Project	General Goal
Research on Reactive Hydride Mixtures: Nanomaterials for Hydrogen Storage as an Energy Vector 2013-05 - 215362 Instituto de Investigaciones en Materiales UNAM	Produce and characterize new reactive hydride mixtures with high hydrogen storage capacity.
Characterization and evaluation of the Zn deposition process in terminal contact to improve the energy efficiency of MPP capacitors 2013-05 - 272272 Instituto de Energías Renovables UNAM	Design and evaluate a prototype on Zn evaporation deposition process to know its scope in the manufacture of end connections of metallized polypropylene capacitors (MPP) in order to improve the efficiency of these capacitors.
Renewable Energy and Energy Storage Systems 2013-05 - 262880 Instituto Politécnico Nacional	Investigate the economic feasibility of incorporating energy storage systems by pumping into the national electricity network through a "production cost" computer program.
Energy storage system based on the unconventional purification and compression of hydrogen (electrochemistry). 2014-01 - 246079 Centro de Investigación y Desarrollo Tecnológico en Electroquímica SC	Develop, characterize and evaluate a coupled system for the purification and compression of hydrogen from reformed tributaries using high-efficiency electrochemical methods based on PEM technology.
Synthesis and application of carbon nanostructures in obtaining supercapacitors with high density 2014-02 - 245225 Instituto Nacional de Investigaciones Nucleares	Synthesis of NEC and its subsequent use in the elaboration of electrodes, from which its characteristics as electrical energy storage systems will be studied to determine its viability as supercapacitors.
Generation and storage of chemical energy with new materials and polymeric fuel cells, with applications in electric vehicle transport	Design, build and put into operation a three-seater electric transport with its own technology to produce high purity hydrogen based on a technology of fermentative metabolism of enteric bacteria resulting from the

Project	General Goal
2014-02 - 245920 Centro de Investigación y de Estudios Avanzados, Instituto Politécnico Nacional	decomposition of substrates from residues of fruits and vegetables rich in carbohydrates. and nopal for microbial fermentation and hydrogen storage based on containers containing compounds of Alanates.
Renewable energy based on the recovery, purification and storage of hydrogen from chlor-alkali production plants 2015-03 - 269546 Centro de Investigación y Desarrollo Tecnológico en Electroquímica SC	To develop a prototype system of energy purification and storage based on electrochemical compression of hydrogen with high efficiency, to be coupled in an electrolytic cell producing chlorine-soda on a pilot scale.
Development of advanced Sn, Sb and C based electrodes as anodes for low cost sodium ion batteries 2015-07 - 274314 Dr. Jassiel Rolando Rodríguez Barreras (1)	Promote scientific and technological knowledge on the development of nanostructured materials of Sn, Sb and C to obtain anode electrodes that allow a high intercalation and mobility of sodium ions in anode electrodes of rechargeable sodium ion batteries, with application in rechargeable batteries of sodium ion for high energy storage, stability and life.
Manufacture and application of nanostructured hexaborides for power generation and gas storage as fuel cells 2015-07 - 279090 Dr. Oscar Eugenio Jaime Acuña (1)	Study of the scalable manufacture of boron nanomaterials using hexaborides as model systems to measure behavior in electronic transport processes, as well as understand and improve their potential in the storage of ions and hydrogen. A class of materials with unique and potentially transformative power generation capacity will be obtained, which can be directed to the development of future functional devices.
"Development of Low-Cost Energy Storage Technologies: Flow Batteries and Alkaline Fuel Cells" 2017-03 - 292862 Instituto Nacional de Electricidad y Energías Limpias	Establish in Mexico a multidisciplinary R&D program of long-lasting electrochemical energy storage systems with the goal of developing and testing prototypes (connected to the grid).
CEMIE Networks: "Technical, economic and regulatory analysis of Energy Storage Systems in Mexico" 2018-01 - B-S-50730 PE-A-13 Instituto Nacional de Electricidad y Energías Limpias	Identify potential areas in which Energy Storage Systems can give flexibility and solve problems to the electrical system in the short and medium term, considering its technical and economic feasibility regarding using other types of equipment or technologies to solve these problems, and with the purpose of having technical support in the process to propose regulatory mechanisms.

Note (1): postdoctoral projects.

A brief description of 3 projects is presented below.

Project 2013-05 - 262880 called "Renewable Energy and Energy Storage Systems". In consortium, the IPN and the CFE are interested in the development of computational models to evaluate the economic impact of using the Río Grijalva hydroelectric complex as a compensator for the production variations derived from the wind development of the Isthmus of Tehuantepec, as well as its use as "Synchronous capacitor" to maintain the security of the national system backbone. Additionally, it is desired to develop models to quantify the economic value of inserting pumping hydroelectric plants to enhance the value of renewable (intermittent) energy and low-cost thermoelectric energy in the National Electric System. Finally, it is desired to investigate the state of the art in energy storage in order to boost the production of renewable energy at different scales, from domestic applications to industrial scale such as hydroelectric pumping plants (CONACYT, 2020).

Project 2017-03 – 292862 called "Development of Low-Cost Energy Storage Technologies: Flow Batteries and Alkaline Fuel Cells". Establish in Mexico a multidisciplinary R&D program of long-lasting electrochemical energy storage systems with the goal of developing and testing prototypes (connected to the grid). The results of this project will provide Mexico with a better use of its renewable energy resources. Additionally, it will allow the Mexican energy storage industry to position itself as an important participant in this emerging global market. In order to achieve these purposes, the project will focus on developing and testing two novel low-cost energy storage technologies in a power grid environment: electrodialysis-based flow batteries and aniconic exchange membrane fuel cells. In addition, this project will focus on exploring the feasibility of using organic reducing materials for low cost flow batteries. The objective of taking these developments to the prototype tests is to generate a technological package that serves as a stepping stone for their commercialization (CONACYT, 2020).

Project 2018-01 - B-S-50730 PE-A-13 CEMIE Networks: "Technical, economic and regulatory analysis of Energy Storage Systems in Mexico". The project seeks to be the main ally in technological development and innovation in the field of Intelligent Electrical Networks and Microgrids for the participants of the national and international electrical industry, contributing through applied research, modeling, simulation and laboratory and field tests in technological areas. , priority policies and regulations for the efficient and reliable operation and expansion of the National Electric System. In addition, seek to be an applied research center that operates transversally in priority areas for Intelligent Electric Networks and Microgrids, by creating synergies in innovation and technological development, which will be focused on providing solutions to make the operation more efficient, strengthen regulation, security, reliability, availability and interoperability of the intelligent technologies adopted in the National Electric System, through the training and development of specialized human resources in Intelligent Electric Networks and Microgrids for the sector (CONACYT, 2020).

2. Mapping of relevant stakeholders

The following criteria was considered for the identification and selection of the stakeholders:

- Organizations in the public sector, the academy or the private sector related to the development and implementation of storage technologies in Mexico within three main areas of expertise: technical-operational, regulatory and economic.
- For the private sector was considered as selection criteria: the active participation or experience in renewal energy projects,
- Associations of the private sector.
- For the public sector was considered institutions with direct influence on the regulation or operation processes and the role and legal attributions of the stakeholders around the energy storage.
- Institutions performing activities within a secondary level influence on the decision-making process related to the energy storage development in Mexico such as:
  - Environmental government institutions with "indirect regulation attributions on the energy sector "; such as SEMARNAT;
  - Mexican development bank institutions such as BANOBRAS
- International development organization like:
  - Development bank institutions acting in Latin America as the Interamerican Development Bank or the World Bank;
  - International cooperation agencies as the German Agency for Cooperation (GIZ) or the Danish Energy Agency (DEA).
- Finally, non-governmental organizations.

This project aims to identified relevant stakeholders from three main axes:

1. Stakeholders who have a role in the development of public policy and regulation, with certain influence in the decision-making process that might affect the deployment of the electricity storage technologies.
2. Stakeholders that provided electricity or other services in the Mexican power system, and who might have an interest in the development of electricity storage systems or in the impact electricity storage systems could have in their operation.
3. Stakeholders that conduct research, development and innovation related to electricity storage systems in Mexico.

Furthermore, other stakeholders might not have a direct impact in the development of the technology itself, but might have certain influence in the decision-making process and might impact the successful deployment of the technology, such as finance institutions, international donors, private sector associations and non-governmental associations. On this basis, Figure 1.5 shows a scheme of the main stakeholders.

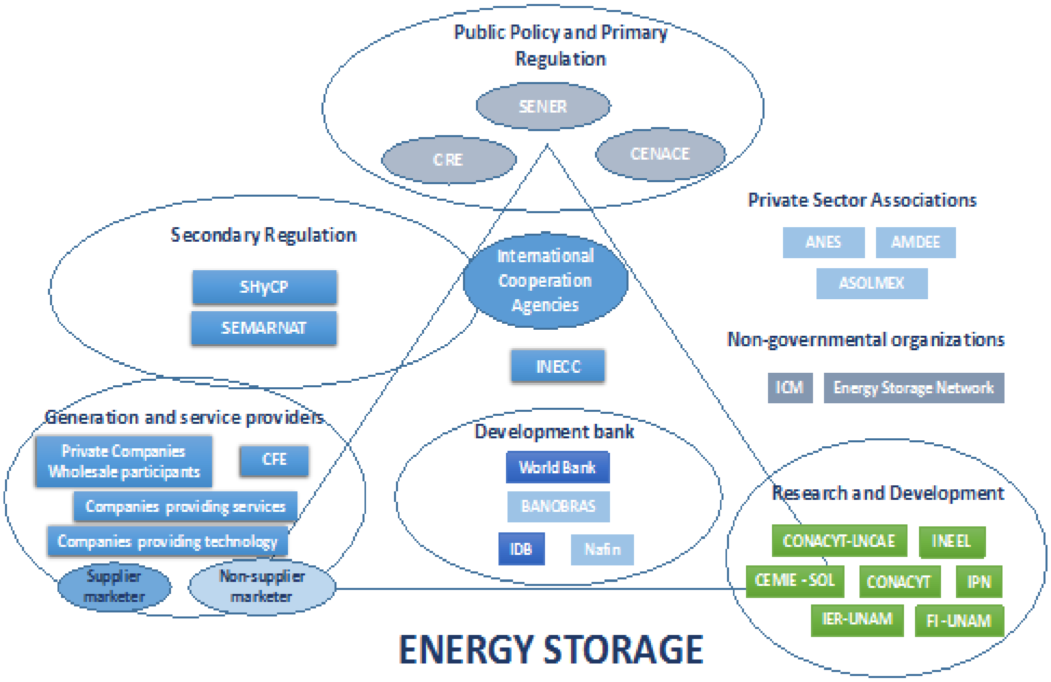


Figure 2.1. Institutions related with Energy Storage. Source: own elaboration.

2.1 Institutions with direct influence in the regulatory process

The institutions with the direct political or regulatory attributions on the electricity sector are:

- The Ministry of Energy, (SENER for its acronym in Spanish), is the institution responsible for the legal framework and the energy policy in Mexico;
- The Federal Energy Regulatory Commission, (CRE), in charge of the market regulations making.

2.2 Institution that operates the electrical system and with influence in the technical regulatory process

The National Energy Control Center, (CENACE for its acronym in Spanish), the Independent System Operator (ISO) that's controls the operations in the electricity system and wholesales market but is also in charge of the elaboration of technical guidelines and rules;

2.3 Institutions with secondary influence in the regulatory process

The Environmental and Natural Resources Ministry (SEMARNAT for its acronym in Spanish) is the institution in charge to perform the Environmental Impact Assessment on the basis of the public and private applications and is also the institution that's regulates the emissions of the power sector.

2.4 State owned company and private sector (participants in the wholesales market)

The power and service providers include as well the private companies and the Federal Electricity Commission, (CFE), all of them are considered participants in the wholesales market. The state-owned electricity company (CFE) hat a relevant role in the market, due to the capacities for generation, and the operation of the transmission, distribution and commercialization systems. The private companies will be represented mainly through two private business associations The Mexican Solar Association (ASOLMEX) and The Mexican Wind Energy association (AMDEE). The National Solar Association (ANES) includes both researchers and companies as well. The identified private companies where: TETRA TECH; AES México; ENEL GREEN POWER; ESTA International; SIEMENS México; FLUENCE/AES/; Invenergy; THERMION ENERGY; Robert Bosch México, S.A. de C.V.

2.5 Institutions from the academic sector

On the side of R&D the National Council for Science and Technology (CONACYT) by its acronym in Spanish, is a public institution created to provide advisory for the articulation of the public policies to the government and to promote the scientific research, the technological development and innovation to encourage the technological modernization in Mexico (2014c). Attending its mandates, the CONACYT has promoted the creation of research and innovation centers and laboratories; in the field of renewable energies and energy storage, the CONACYT supports for example: the Mexican Center for Solar Energy Innovation (CONACYT-CeMIESol) which is a consortium of Mexican Universities grouped to link the academy and the private sector to strengthen the solar industry in Mexico, including energy storage technologies; and the National Laboratory for the Storage and Conversion of Energy (CONACYT-LNCAE). Stakeholders form the Mexican Universities with education and research activities on electricity, renewable energies and energy storage were identified. They are in part integrated in the Energy Storage Network or are part of public research centers and institutes like the National Institute for Clean Energy and Electricity (INEEL) or the Renewal Energy institute (IER).

2.6 International institutions

The Development Bank institutions play a very important role as they can provide the necessary financing for developing the energy storage projects. In Mexico, the Inter-American Development Bank IDB and the World Bank are the main private Development banking institutions while from the public side, the institutions are the National Public Works Bank (BANOBRAS) and the National Financial (NAFIN).

2.7 Non-governmental organizations

While from the NGOs side, the Mexico Climate Initiative, the Mexican Center of Energy Innovation are the most relevant organizations that perform various activities related to energy and electricity.

2.8 Legal attributions

The main legal instruments that describe the legal attributions of the public stakeholders in the electricity sector are:

- Electric Industry Act (Cámara de Diputados, 2014a),
- Coordinated Regulatory Bodies in Energy Matter Act (Camara de diputados, 2014b);
- Federal Electricity Commission Act (Cámara de Diputados, 2014c);
- The Energy Transition Act (Cámara de Diputados, 2015),
- Decree by which the National Energy Control Center is created (DOF, 2014a)
- Internal Regulation of the Ministry of Energy (DOF, 2014b)
- Internal Regulation of the Energy Regulatory Commission (DOF, 2017),
- Organic Statute of the National Center for Energy Control (DOF, 2018)
- Modification to the Internal Regulation of the Energy Regulatory Commission (DOF, 2019)

2.8.1 SENER

According to the Energy Transition Act, Article 14, the Energy Ministry (SENER) has, amongst others, the fallowing mandates on the development on Renewal energies:

> "IV. To promote the accomplishment of the international commitments acquired by Mexico in relation with generation and use of Clean Energies and the sustainable use of energy, observing the economic viability and protecting the competitiveness";
>
> "V. To promote the accomplishment of all Mexico's goals by the development and application of the corresponding instruments of public policy, …";
>
> "XVI. To promote the sustainable construction of electricity infrastructure to beneficiate the electricity system and to facilitate the interconnection of Clean Energies to the National Interconnected System";
>
> "XX. To coordinate the funds and trusts integrated by the Federal Government to support the sustainable use of energy"; and
>
> "XXIII. To identify the best international practices regarding programs and projects for energy transition and to promote, when considered pertinent, its implementation in the national territory".

According to the Electric Industry Act, Article 11 (Cámara de Diputados, 2014b), SENER has amongst others the following mandates of:

> "I. Establish, conduct and coordinate the country's energy policy regarding electricity;"
>
> "II. Formulate sectoral programs for the development of the electricity industry in accordance with the National Development Plan;"
>
> "III. Direct the planning process and the development of the National Electric System Development Program;"
>
> "IV. Prepare and publish annually a detailed report that allows to know the performance and trends of the national electricity industry;"
>
> "V. Ensure coordination with the regulatory bodies in the field of the electrical industry, the other relevant authorities for the electrical industry, CENACE and the National Center for Natural Gas Control;"
>
> "IX. Establish the requirements for the acquisition of Clean Energy Certificates;"
>
> "X. Establish the criteria for the granting of Clean Energy Certificates;"
>
> "XII. Develop the indicative programs for the installation and removal of Power Plants tending to meet the needs of the country, incorporating the requirements referred to in section IX of this article;"
>
> "XIV Issue opinion on the Market Rules;"
>
> "XV. Issue an opinion on the operation of the Wholesale Electricity Market;"
>
> "XVI. With the opinion of the CRE, establish the mechanisms, terms, deadlines, criteria, bases and methodologies under which the Basic Service Providers will

> have the option to enter into Electricity Coverage Contracts based on the costs of the Legacy Power Plants and the contracts of Legacy External Centrals;”
>
> “XX. Authorize the expansion and modernization programs of the National Transmission Network and of the General Distribution Networks that are submitted by CENACE or by the Distributors and request changes to them, listening to the opinion that, where appropriate, the CRE issues;”

The legal attributions of SENER are completely described in the Interior Internal Regulation of the Ministry of Energy (DOF, 2014b).

2.8.2 CRE

The Electric Industry Act, Article 12 (Cámara de Diputados, 2014a), the Coordinated Regulatory Bodies in Energy Matter Act Article 41 (Camara de Diputados, 2014b) and the Energy Transition Act article 15 (Cámara de Diputados, 2015) points out the legal attributions of the Federal Energy Regulatory Commission (CRE). As by SENER the description of the legal attributions are listed in the Internal Regulation of the Energy Regulatory Commission (DOF, 2017) and the last Modification to the Internal Regulation of the Energy Regulatory Commission (DOF, 2019).

The CRE is the regulatory authority for all the activities related to the wholesale market and market rules of the electricity system, the wholesale market include: generation, transmission, distribution and ancillary services.

> I. Grant the permits referred to in this Law and decide on its modification, revocation, assignment, extension or termination;
>
> II. Determine the calculation methodologies, criteria and bases to determine and update the consideration applicable to Exempt Generators and Users of Basic Supply with Controllable Demand when they sell their production or demand reduction to a Basic Service Provider;
>
> III. Establish the general conditions for the provision of the Public Electricity Transmission and Distribution Service, as well as the general conditions for the provision of the Electric Supply, and resolve on its modification;
>
> IV. Issue and apply the tariff regulation to which the transmission, distribution, operation of the Basic Service Providers, the operation of CENACE and Related Services not included in the Wholesale Electricity Market will be subject, as well as the final rates of the Basic Supply in terms of the provisions of article 138 and 139 of this Law;
>
> V. Issue and apply the methodologies to determine and adjust the maximum rates of the Last Resource Providers and the maximum prices of the Last Resource Supply, and determine the other conditions for said Supply;
>
> VII. Establish the accounting guidelines that will be observed in the activities of transmission, distribution, Basic Supply and Supply of Last Resource, as well as in the operation of CENACE, for purposes of tariff regulation;
>
> VIII. Issue the Bases of the Electricity Market;

IX. Establish the mechanisms for the authorization, revision, adjustment and updating of the Market Operating Provisions;

X. Define the terms for offers based on costs and monitor compliance with the obligations established in Article 104 of this Law and the Market Rules;

XI Monitor the operation of the Wholesale Electricity Market and the CENACE determinations in order to ensure the efficient operation of the Wholesale Electricity Market and compliance with the Market Rules;

XVI. Grant the Clean Energy Certificates;

XVII Issue regulations to validate ownership of Clean Energy Certificates;

XVIII. Verify compliance with the requirements related to Clean Energy Certificates;

XIX. Issue the efficiency criteria used in the definition of Clean Energies;

XX. Issue the norms, directives, methodologies and other administrative provisions that regulate and promote the generation of electric energy from Clean Energies, in accordance with the provisions of this Law, in accordance with the energy policy established by the Secretariat;

XXII. Authorize CENACE to carry out auctions in order to acquire power when deemed necessary to ensure the Reliability of the National Electric System, determine the allocation of costs resulting from said auctions and issue protocols for CENACE to manage the contracting of power in cases of emergency;

2.8.3 CENASE

The legal attributions of CENASE were mentioned out in LIE f. e. articles 14, 15, 16; the LTE article 16, the Decree by which the National Energy Control Center is created (DOF, 2014), article 4 and the Organic Statute of the National Center for Energy Control (DOF, 2018), all these legal instruments points out the legal attributions and purpose of the National Energy Control Center (CENASE).

The CENACE is the Independent System Operator (ISO) and therefore responsible for the control of the operation of the electricity system, the operation of the Wholesale Electricity Market and guarantee open and not unduly discriminatory access to the National Transmission Network and the General Distribution Networks, and propose the expansion and modernization of the National Transmission Network and the elements of the General Distribution Networks that correspond to the Wholesale Electricity Market

The CENACE has the attributions of: deciding which elements of the grid and of the operations in the grid correspond to the electricity market; operating the electricity market; calculate de tariffs for the electricity market; issuing the operative rules for the electricity market; conducting auctions for contracts for electricity generation and demand; stablishing the contracts with the market participants; coordinating the billing processes for the electricity market; coordinating the electricity system's operations to ensure the safety of dispatch, reliability, quality and continuity in the system, through instructions for operating power plants, programming of maintenance services, decommissioning of powerplants, control of demand, import/export of electricity and provision of conex services; programing maintenance services of the transmission and distribution grids; coordinating the operation of the transmission and distribution grids; proposing expansion and modernization programs for the transmission and distribution grids; define the technical specifications required for connecting new power plants and demand centers, and interconnecting grids, amongst others (Cámara de Diputados, 2014b).

Article 15 and 16 of LIE describes the mandates of CENASE that's includes to determine the elements of the National Transmission Network and the General Distribution Networks and their operations that correspond to the Wholesale Electricity Market; The other operations of these networks may be carried out by the Carriers or Distributors, subject to the coordination of CENACE. CENACE will determine the assignment of responsibilities and coordination procedures with the Transporters and Distributors in order to exercise the Operational Control of the National Electric System.

For the best fulfillment of its purpose, CENACE may form associations or enter into contracts with individuals to provide auxiliary services to the operation of the Wholesale Electricity Market. The respective associations and contracts must be subject to the following conditions:

> I. The individuals with whom CENACE contracts will be jointly and severally liable for the provision of the corresponding services, within the scope of their participation, and
>
> II. In the constitution of encumbrances on the rights derived from the associations and contracts, it will be noted that, under no circumstances, may the assets of the public domain subject to them be guaranteed.
>
> The instructions issued by CENACE in the exercise of the Operational Control of the National Electric System are mandatory for all members of the electrical industry.

2.8.4 Federal Electricity Commission (CFE)

The legal attributions of the Federal Electricity Commission (CFE) are mentioned in the articles 4 to 9 of the Federal Electricity Commission Act (Camara de Diputados, 2014c) has the objective of performing activities of generation, transmission, distribution and commercialization of electricity. Amongst other attributions CFE can: develop and execute engineering projects, supervisions, geological, geophysical and general research related to its general objective; perform research, development and implementation of technologies for the use of renewable energies (Cámara de Diputados, 2014a).

2.8.5 Other public institutions

The Clime Change General Act, article 7 (Cámara de Diputados, 2018), points out the legal attributions of the Environment and Natural Resources Ministry (SEMARNAT) and those of the National Institute for Clime Change and Ecology (INECC).

Regards the clime consequences of the activities of the energy sector the Ministry is responsible for: the regulation of the emissions in the electricity system; conduct and support to public institutions in the elaboration of environmental impact assessments of electricity generation projects on areas with high clean energies potential; elaborate the greenhouse gases mitigation line for the electricity industry to achieve the mitigation goals internationally adopted by Mexico also, SEMARNAT has the attribution of elaborating and establishing the goals, strategies and actions to face de climate change, including targets for the electricity system.

The article 31 of the Federal Public Administration Organic Act (Cámara de Diputados, 2019) points out in the legal attributions of the Finance and Public Credit Ministry (SHCP). The Ministry has the attributions of evaluating and stablishing incentive policies to promote the investment in emission reduction, energy efficiency and distributed electricity generation

> I. Project and coordinate the national development planning and develop, with the participation of the social groups concerned, the corresponding National Plan;
>
> II. Project and calculate the income of the Federation and the parastatal entities, considering the needs of federal public spending, the reasonable use of public credit and the financial health of the Federal Public Administration;
>
> IX.- Determine the global criteria and amounts of the fiscal stimuli, listening for it to the responsible units of the corresponding sectors and administer their application in the cases in which it competes with another Secretariat;
>
> XXV Plan, establish and conduct the general policy regarding public procurement regulated by the Law on Procurement, Leases and Services of the Public Sector and the Law on Public Works and Services Related thereto, promoting the best contracting conditions in accordance with the principles of efficiency, effectiveness, economy, transparency, impartiality and honesty; issue and interpret the standards, guidelines, manuals, procedures and other similar instruments required in such matters; as well as to promote the homologation of policies, norms and criteria regarding public contracts.

2.8.6 Research and Development Institutions

The Energy Transition Act also establishes (articles 75, 76 and 77) attributions of scientific and technological research to assist the public policies for the Electricity and Clean Energies National Institute, INEEL by its acronym in Spanish. This public research institute has the mandates of: conducting and coordinating scientific and technological research studies on energy, electric energy, clean energy, renewable energies, energy efficiency, emissions in the electric industry, sustainability, transmission, distribution and energy storage, and operating systems associated to the electric industry; providing technical and scientific support to SENER and to the energy-related public institutions for the development of the public policies; participating in the accomplishment of the clean energies and energy efficiency goals; conducting prospective analysis and collaborating in the elaboration of analysis, plans, strategies, and actions related to electricity, clean energies, energy efficiency and reduction of pollutants emissions; promoting with the assistance of the National Council for Science and Technology (CONACyT) the applied research and the development of technology for increasing the clean-energies based electricity generation, amongst others. The legal attribution of CONACyT are included in National Council for Science and Technology organic Act (Cámara de Diputados, 2014d).

3. Global and Regional Trends on Grid-Scale Electricity Storage

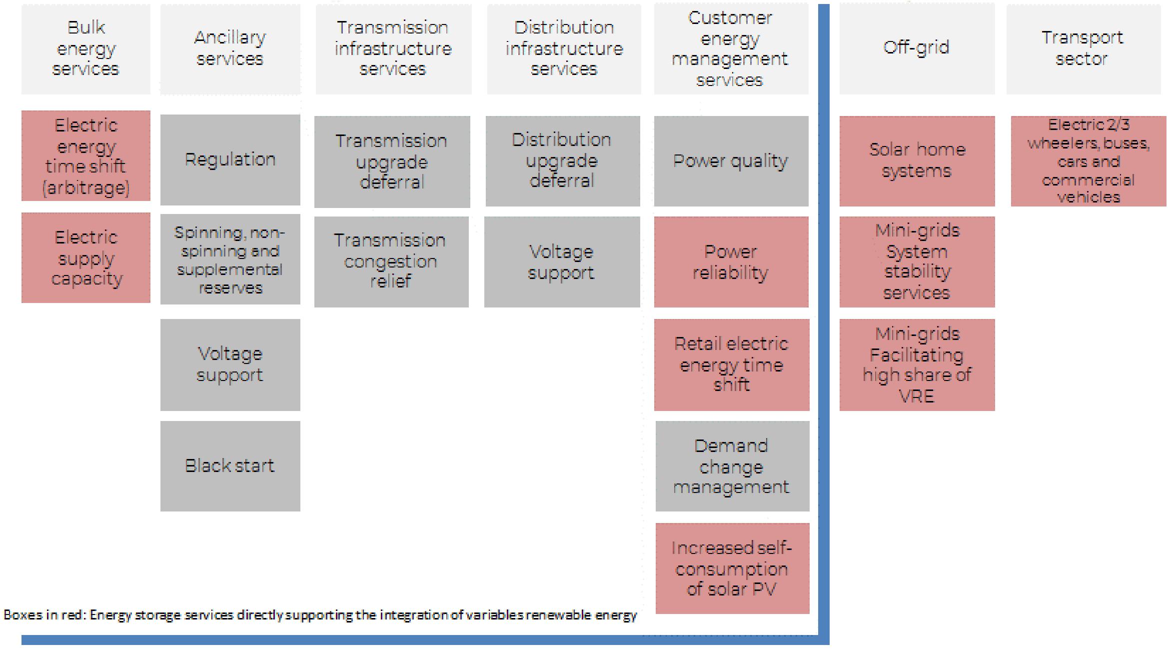
Climate change threatens the health, livelihood, food security, water supply, human security and economic growth. Therefore, a strong and decisive action towards climate change mitigation is required. In order to stay "well below 2°C", as agreed in the Paris Agreement on December 2015, greenhouse gas emissions must peak and start declining within the next ten years, according to the Special Report on Global Warming of 1.5°C. This challenge calls for a coordinated effort that should build upon energy efficiency, renewable energy, demand electrification, a decrease in fugitive and agricultural emissions, and an increase in carbon sinks.

The International Renewable Energy Agency (IRENA), analyzing the effects of the energy transition until 2050 in a study for the G20, found that over 80% of the world's electricity could derive from renewable sources by that date. Solar photovoltaic (PV) and wind power would at that point account for 52% of total electricity generation (IRENA, 2015). In the Special Report on Global Warming of 1.5°C, the scenario that stays within 1.5°C has around 70-85% renewable energy for primary energy consumption by 2050, and because the electricity sector is relatively easy to decarbonize compared to other sectors, such as the heavy transport sector or high process heat demand for industries, the share of renewable energy for electricity generation might rise up to 97% by 2050. However, because sustainable biomass resources are limited due to land constraints as well as the construction of large hydropower dams rise sustainability concerns, the share of variable renewable energy in the system is predicted to be very high, up to 60% at a global level in some scenarios by 2050.

In 2017, the electricity storage capacity was approximately 4.7 TWh (this number remains highly uncertain given the lack of comprehensive statistics for renewable energy storage capacity in energy rather than in capacity terms). The total installed capacity of electricity storage in energy terms might grow to 11.9-15.7 TWh by 2030 (i.e. 155- 227% higher than in 2017); especially, if the share of renewable energy in the energy system is to be doubled (IRENA, 2017). Therefore, there is the need to consider the role that electricity storage technologies could play in facilitating the cost-effective integration of high shares of variable renewable energy in the power system.

It is worth noting that storage in EVs is not covered in these data, At the end of 2016, the global electric vehicle fleet reached a total size of 2 million vehicles (including battery EVs and plugin hybrid vehicles), with an estimated total battery capacity of 40-60 gigawatt-hours (GWh) (OECD/IEA, 2017; IRENA analysis).

Furthermore, electricity systems already require a range of ancillary services to ensure smooth and reliable operation, and certain degree of flexibility, which allow grid operators to react to unexpected changes in demand or to the loss of large periods of supply. Hence, electricity storage systems might play even nowadays a role in facilitating the transition towards decarbonized energy systems, by providing a wide range of services, as depicted in Figure 1.6.



Bulk energy services	Ancillary services	Transmission infrastructure services	Distribution infrastructure services	Customer energy management services	Off-grid	Transport sector
Electric energy time shift (arbitrage)	Regulation	Transmission upgrade deferral	Distribution upgrade deferral	Power quality	Solar home systems	Electric 2/3 wheelers, buses, cars and commercial vehicles
Electric supply capacity	Spinning, non-spinning and supplemental reserves	Transmission congestion relief	Voltage support	Power reliability	Mini-grids System stability services	
	Voltage support			Retail electric energy time shift	Mini-grids Facilitating high share of VRE	
	Black start			Demand change management		
				Increased self-consumption of solar PV		

Boxes in red: Energy storage services directly supporting the integration of variables renewable energy

Figure 3.1. Services that can be provided by electricity storage. Source: (IRENA, 2017).

The different services electricity storage can supply have implications in terms of which electricity storage technologies are most suitable to provide a specific array of services. Therefore, the decision to invest on some specific storage technologies would depend upon the service/s required as well as the economic and social benefits it could provide.

The following section briefly summarizes the global trends regarding electricity storage and describes the main services they are provided. Afterwards, two specific cases, California and United Kingdom, are presented in more detail.

4. Global trends

4.1 Global status of electricity storage systems

Total installed storage power capacity is currently dominated by pumped hydro storage (PHS), with 96% of the total of 176 gigawatts (GW) installed globally in mid-2017. The other electricity storage technologies in significant use around the world include thermal storage, with 3.3 GW (1.9%); electro-chemical batteries, with 1.9 GW (1.1%) and other mechanical storage with 1.6 GW (0.9%) as shown in Figure 1.7 (IRENA, 2017)

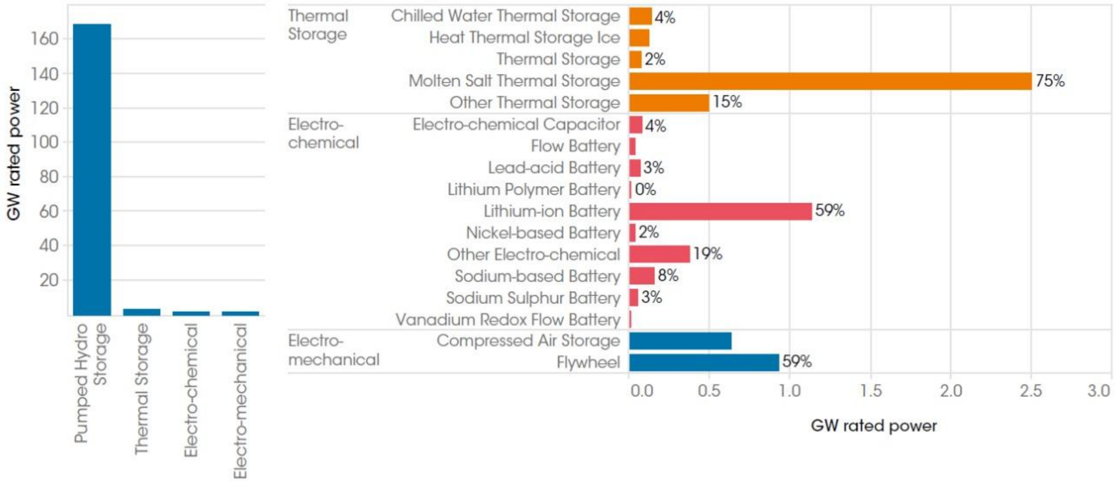


Figure 4.1. Global operational electricity storage capacity by technology. Source: (IRENA, 2017).

For 2019 this distribution is maintained in accordance with the data, as registered in January 2019, from the Department of Energy (DOE) of the United States of America (US DOE., 2019). The total installed operational storage power capacity of electro-chemical (mainly batteries) raised up to with 2.8 GW (1.6%), and the capacity from other mechanical storage was 1.3 GW (0.8%) (Figure 1.8.).

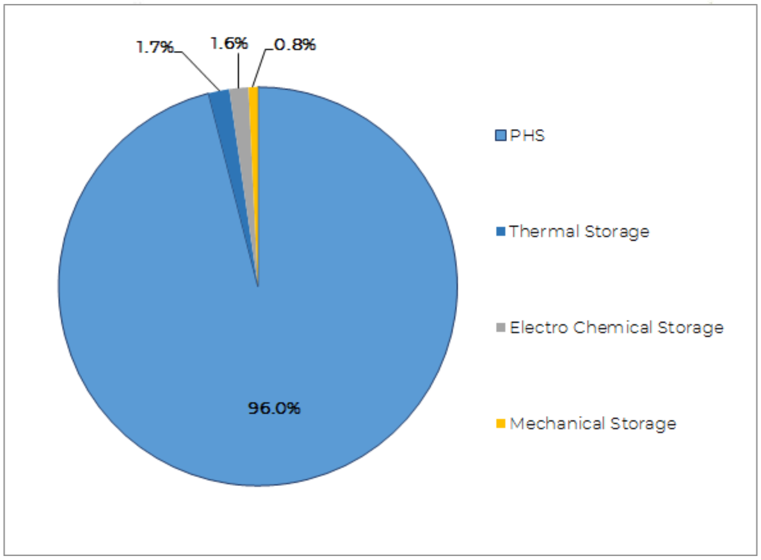


Figure 4.2. Global electricity storage power capacity installed and operating (GW) by classification of technology in 2019. Source: own elaboration with data from (US-DOE, 2019).

Conceptually, there are many different types of energy storage system, as shown in Figure 1.9, with different sizes and discharge times, determined by its technological characteristics, such as round-trip efficiency, self-discharge, etc. and economies of scale or modular technologies that could be scaled down to very small sizes (IRENA, 2017). Some of them operate over short time periods – nanoseconds to seconds and minutes at a relatively small power rating (lower left corner). At the opposite side, there are large-scale energy storage systems, which might provide storage of hundreds of minutes to hours, such as pumped-hydro (Victor, et al., 2019).

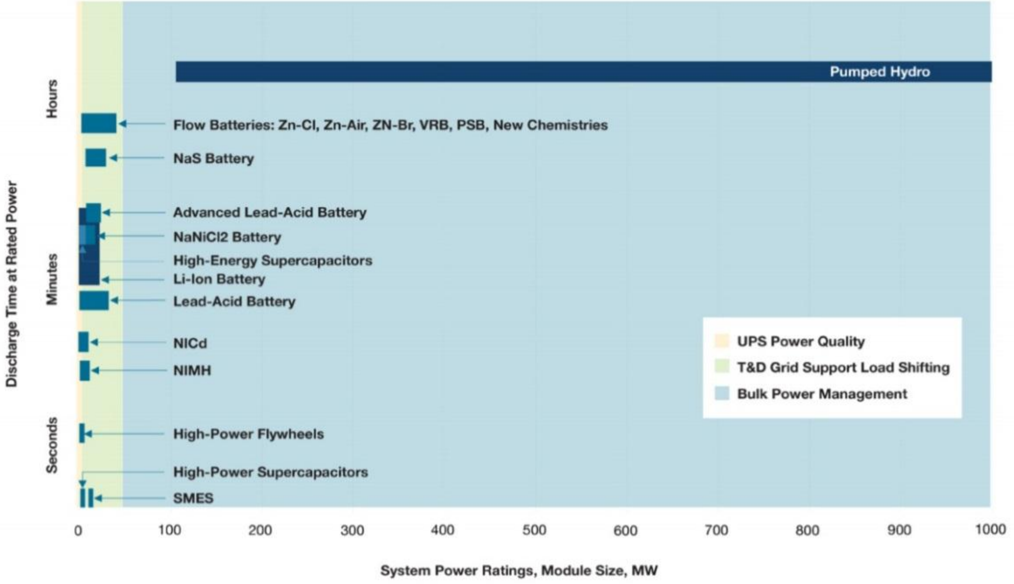


Figure 4.3. A snapshot of the different types of energy storage typical module sizes, discharge time and services (SME: Superconducting magnetic energy storage). Source: (Victor, et al., 2019).

In terms of the number of installations, the applications of Energy Storage Systems (ESS) with batteries are the ones that top the list according to the DOE data and other technologies, such as thermal storage or flywheels, have a relevant representation in applications below 10 MW capacity (Figure 1.10).

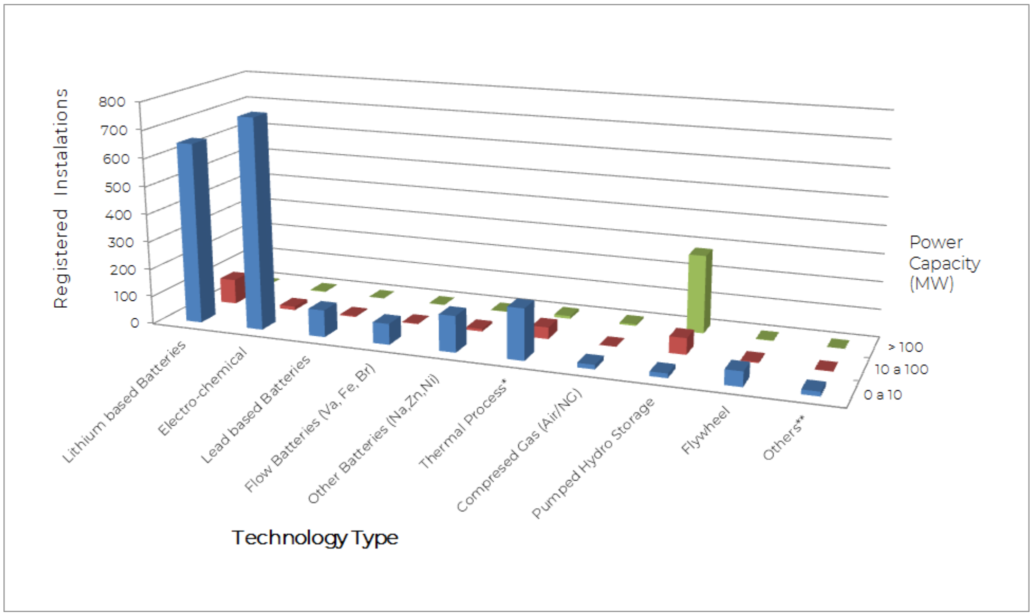


Figure 4.4. Global electricity storage number of projects by power capacity and technology. Source: own elaboration with data from (US-DOE (2019).

Implications in terms of which electricity storage technologies are most suited to provide different array of services, vary depending on the application requirements, performance characteristics of electricity storage systems, and the economic, practical or environmental considerations that need to be taken into account when matching a storage technology to a specific application.

Despite the lower levels of deployment of electro-chemical, electro-mechanical and thermal storage, the main services provided by them are more diverse than those of PHS plants. Thermal energy storage applications currently are applied on concentrate solar power (CSP), allowing them to store energy, in order to provide the flexibility to dispatch electricity outside of peak sunshine hours, e.g. into the evening or around the clock (IRENA, 2016). Molten salt is the dominant commercial technology applied with 86% of the total capacity deployed of thermal storage used for electrical applications (2.6 GW) (US DOE., 2019).

Electro-mechanical storage deployment has had a relatively small number of projects with a total operational installed capacity of 1.3 GW. It is dominated by the flywheel technology, with 0.9 GW (69% of the total electro-mechanical capacity). The total deployment of CAES has reached 0.4 GW of power, although it is concentrated in in-ground natural gas combustion compressed air, and the deployment of other types of storage with compressed air is 0.5% (US DOE., 2019).

Although the installed operational power of electro-chemical storage is still relatively small, it is one of the most rapidly growing market segments. During the last 20 years, deployment of global installations of electrochemical storage grew exponentially (Figure 1.11), as rapidly decreasing costs and performance improvements are stimulating investments (IRENA, 2017).

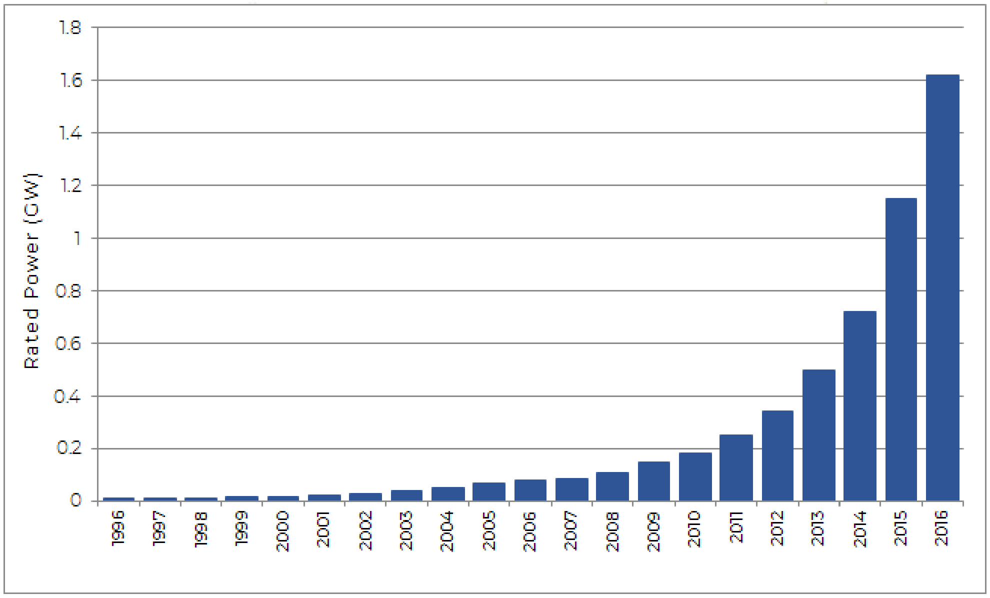


Figure 4.5. Global electro-chemical storage capacity for stationary purposes,1996-2016, Source: (IRENA, 2017).

Lithium based batteries are likely to dominate the market in the short-term with an identified capacity installed of 2,133 MW, i.e. two thirds of the total installed capacity of electro-chemical storage (US DOE., 2019). Other types of electro-chemical storages are flow batteries (including redox flow batteries, 2.83%), lead-acid batteries (2.17%), electro-chemical capacitors (2.74%) and sodium-base batteries (11.31%), which their specific market niches, although they are still small (US DOE., 2019).

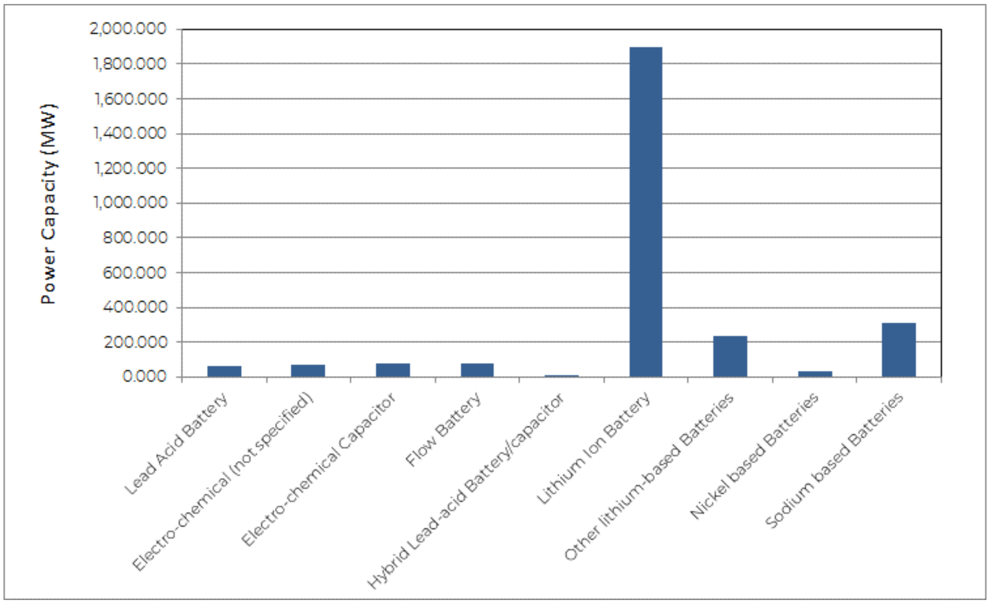


Figure 4.6. Operating Electro-chemical power capacity (MW) and technology. Source: own elaboration with data from (US-DOE, 2019).

It should be noted that the data described were only covering stationary applications, and e.g. batteries for mobile applications, such as for electric vehicles, were not included. However, the deployment of the electric vehicle sector might trigger the availability of cheaper batteries. For instance, the projected annual capacity of Tesla's Gigafactory (a Li-ion battery factory under construction in Nevada, United States) for 2020 is 35 GWh of cells, as well a 50 GWh of battery packs. In mid-2018, battery production at Gigafactory 1 reached an annualized rate of roughly 20 GWh, making it the highest-volume battery plant in the world. A production of 500,000 cars per year would require today's entire worldwide supply of lithium-ion batteries (TESLA, 2019).

4.2 Regional deployment of electricity storage systems

Over three-quarters of all energy storage was installed in only 11 countries , while only 3 – China (32.1 GW), Japan (28.5 GW) and the United States (24.2 GW) – accounted for almost half (47.5%) of global energy storage capacity (Figure 1.13).

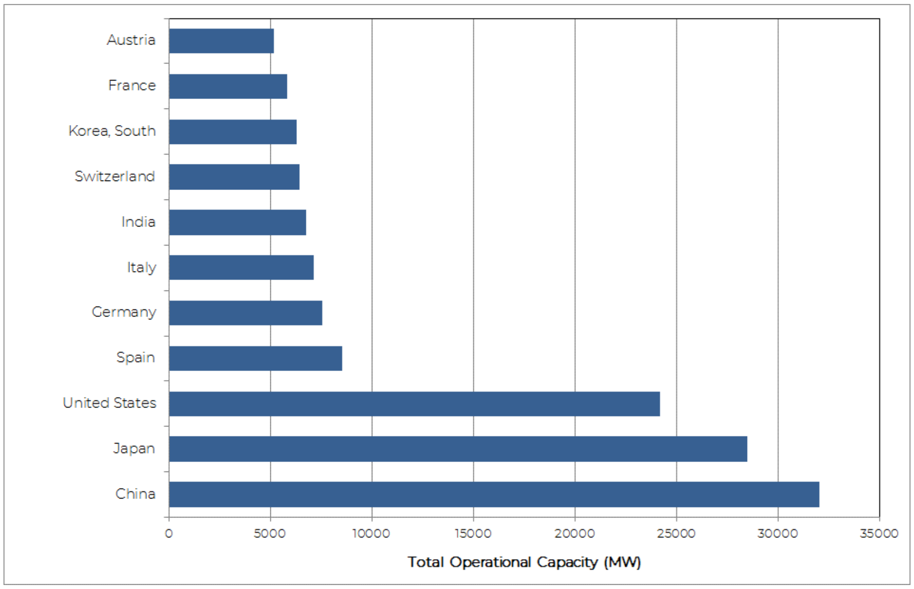


Figure 4.7. Installed operational capacity (MW) of energy storage systems (ESS) by country (first eleven of the world ranking). Source: own elaboration with data from the (US-DOE, 2019).

As mentioned above, more than 95% of the operational storage capacity registered in the database corresponds to PumpHydro, which is also reflected in general in the main countries. China, for example, has an operating capacity of 32,067 GW, of which 99.7% corresponds to hydraulic pumping. Japan with 28,475 operational GW owns 99.1%, and the United States with 24,197 GW of operational capacity has 93.1% of these in PumpHydro. The following countries in the top 10 operating capacity for energy storage follow the same trend as can be assumed: Spain with 86.5%, Germany 86.5%, Italy 99.1%, India 99.7%, Switzerland 99.9%, South Korea 90.7% and France 99.5%.

In the meantime of the remaining percentage of storage technologies, it is the United States that presents a more important variety of application of different technologies, the most important being electro-chemical for the most widespread use of batteries with an operating capacity of 796.45 MW which represents 48% of the total of the different technologies to hydraulic pumping, while the thermal storage linked mainly to the storage of molten salts the CSP plants is also important with 673.26 which represents 41%, and the remaining 11% (178.78 MW) corresponds to mechanical storage.

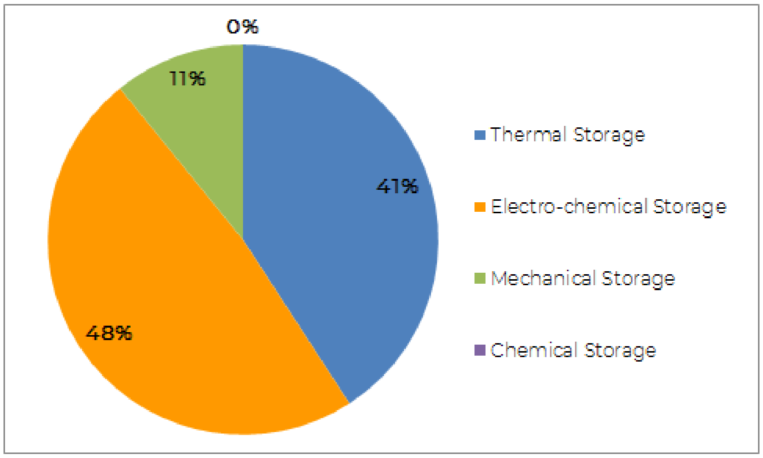


Figure 4.8. Percentage of type of installed energy storage technology excluding Pumped-Hydro in the United States. Source: own elaboration with data from (US-DOE 2019).

In the case of China, the country with the highest operational capacity, exists an application of storage technologies where electrochemical storage predominates with 82%.

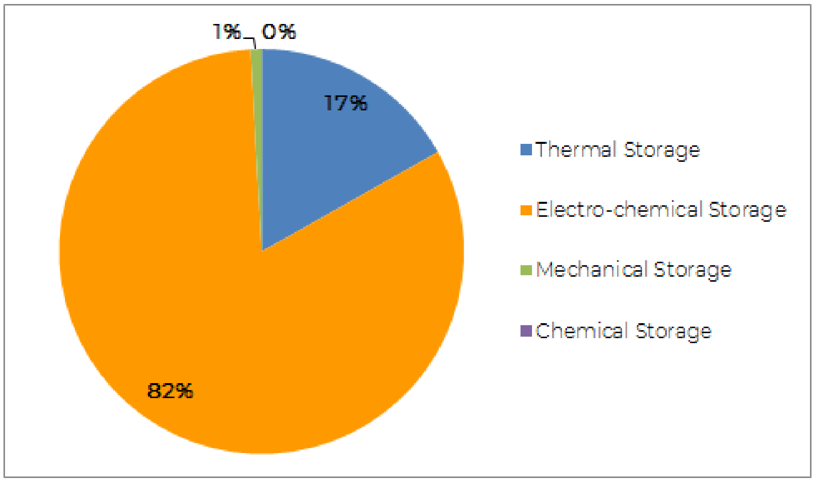


Figure 4.9. Percentage of type of installed energy storage technology excluding Pumped-Hydro in China. Source: own elaboration with data from (US-DOE 2019).

While Japan, which barely has a percentage of 0.9% of storage different of PumpHydro, corresponds entirely to electrochemical storage (253.43 MW), notable cases such as Spain and Germany, have an operative storage capacity applied mainly in thermal storage and mechanical storage technologies respectively, mainly linked to the application of molten salts for CSP in Spain (1100MW) and to Flywheel (387 MW) and CAES (290 MW) in Germany.

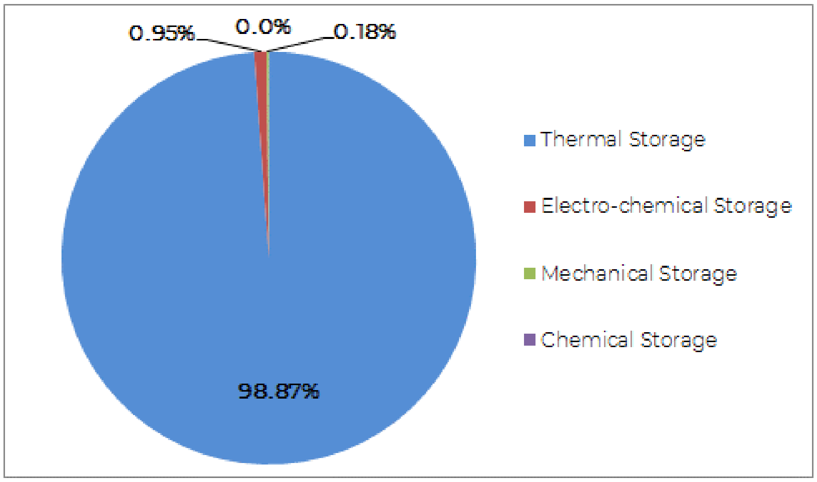


Figure 4.10. Percentage of type of installed energy storage technology excluding Pumped-Hydro in Spain. Source: own elaboration with data from (US-DOE 2019).

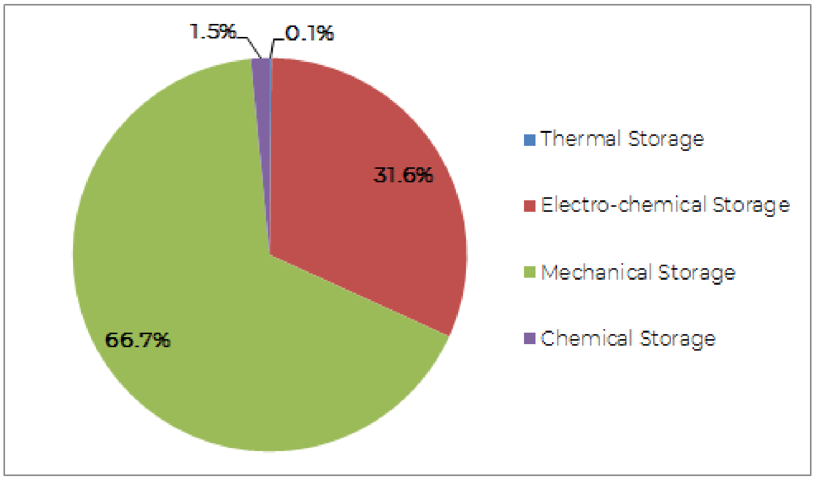


Figure 4.11. Percentage of type of installed energy storage technology excluding Pumped-Hydro in Germany. Source: own elaboration with data from (US-DOE 2019).

For instance, with some financial support for battery storage, approximately 40% of small-scale solar PV systems in Germany have been installed with battery systems in the last few years. In Australia, with no financial support in place, approximately 7 000 small-scale battery systems were installed in 2016. (IRENA, 2017).

On a utility scale, competitive projects are becoming increasingly common. To name just a few examples: the recent UK capacity auction saw winning bids from 225 megawatts (MW) of electricity storage; Tesla will establish a 100 MW battery system in South Australia; and grid-scale projects are increasing in Germany (IRENA, 2017).

4.3 Services provided by electricity storage systems

Pumped hydro storage has historically been implemented to shift the electricity supply from times of low demand to times of high demand to reduce generation costs, as shown in Figure 1.18. Currently, the economics of providing grid services is more challenging for batteries and other mechanical and thermal storage systems that provide electricity storage. Relatively high costs and often low-cost alternative flexibility options mean that current economics are very much market-specific. Nevertheless, as technology costs fall and performance improves, they might play a more important role in the power system.

Therefore, future energy systems will rely on a large array of services based on effective, economical electricity storage. It is expected that storage based on rapidly improving batteries and other technologies will permit greater system flexibility, making possible an increase of variable renewable electricity, a transport sector dominated by electric vehicles (EVs), 24-hour off-grid systems and support to 100% renewable mini-grids. Therefore, technologies will find different market segments where they can be more competitive on performance and cost.

As mentioned, pumping hydro storage (PHS) is the most widely deployed technology and since the main application in 90% of PHS facilities is the energy time shifting service, it also means that stationary energy storage facilities are overwhelmingly used primarily for time shifting of electric power with an installed capacity of 155 GW of the total of 178 GW, i.e. 86.6%.

It is worth noting that this does not imply that the use of facilities is exclusive to this application, since stationary energy storage systems (ESS) generally provide several types of services depending on their response characteristics. Other significant applications include black start capability (3.5%); renewables capacity firming (3.3%); electric supply capacity (2.8%); as well as electric supply capacity spinning (1%) and frequency regulation (1%).

In addition to electricity time shifting, PHS provides significant levels of installed capacity for other services (as a main service), mainly black start (5.9 GW), electric supply capacity (4.9 GW); renewables capacity firming (1.9 GW) and electric supply reserve capacity-spinning (1.9 GW) (Figure 1.18). These four cases represent almost the entire remaining 10% of the services different to electric energy time shifting with regard to PHS technology.

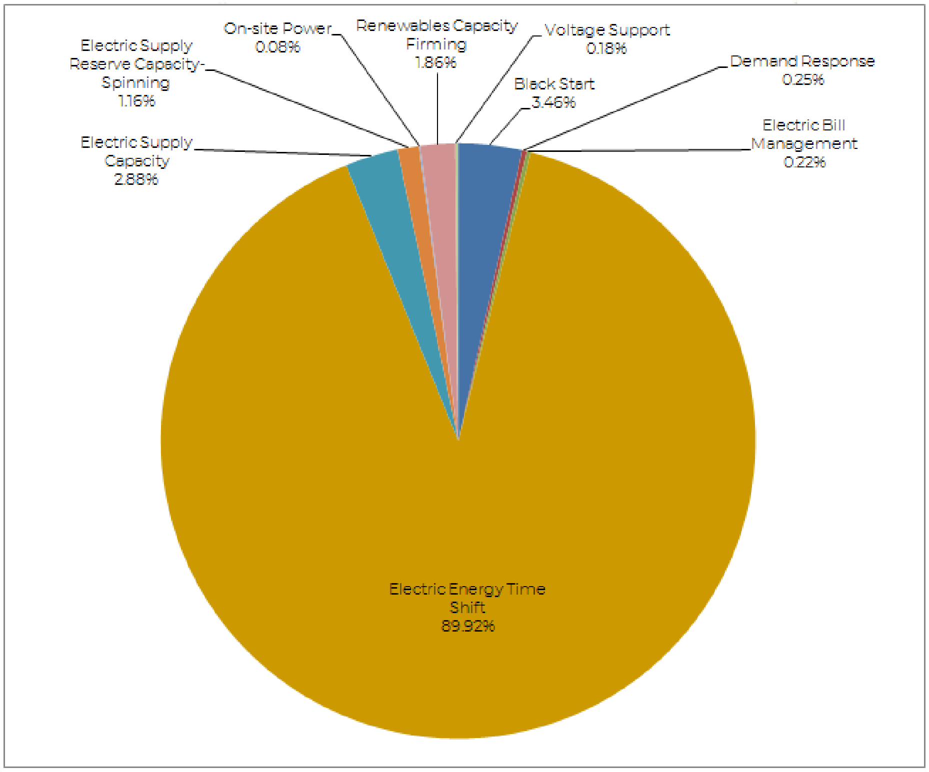


Figure 4.12. Distribution of provided services by Operating PHS power capacity. Source: adapted from (US-DOE, 2019).

Electro-chemical, electro-mechanical and thermal ESSs still have a much lower level of deployment than PHS; however, the main services provided are more diverse. Slightly more than half of the operational installed capacity of electro-chemical systems provide frequency regulation services (51.5%), followed by electric energy time shift (13.1%), electric bill management (10.3%), spinning reserve capacity (4.6%), renewables capacity firming (4.39%), and black start (3.9%), as shown in **¡Error! No se encuentra el origen de la referencia.** (US DOE, 2019).

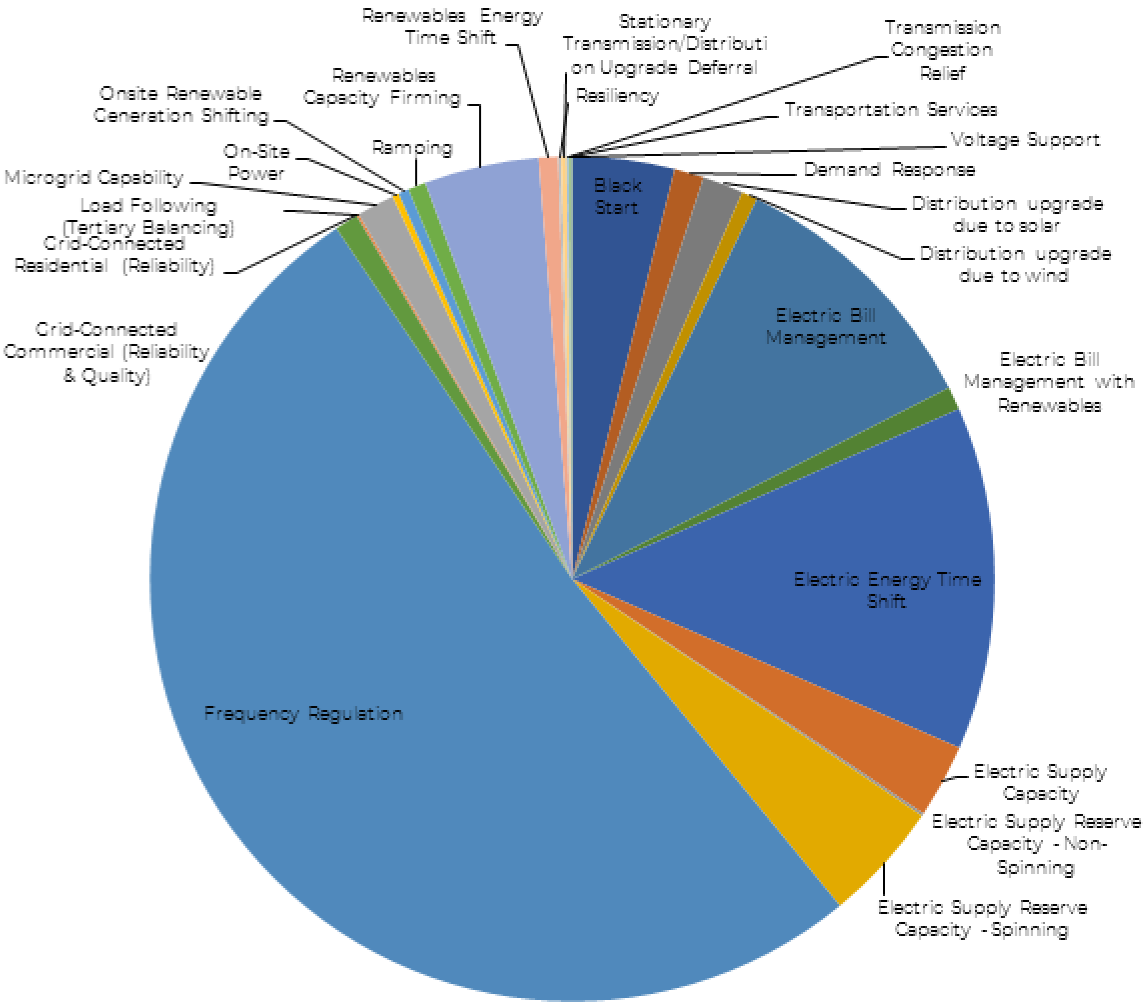


Figure 4.13. Distribution of provided services by electro-chemical storage power capacity. Source: own elaboration with data from (US-DOE, 2019).

Around 34% of the operating capacity of registered electro-mechanical storage systems is used mainly for on-site power; while 33.4% is for frequency regulation; 21.6% provides black start, and 8.3% is mostly used for electricity time shifting, as shown in Figure 1.20.

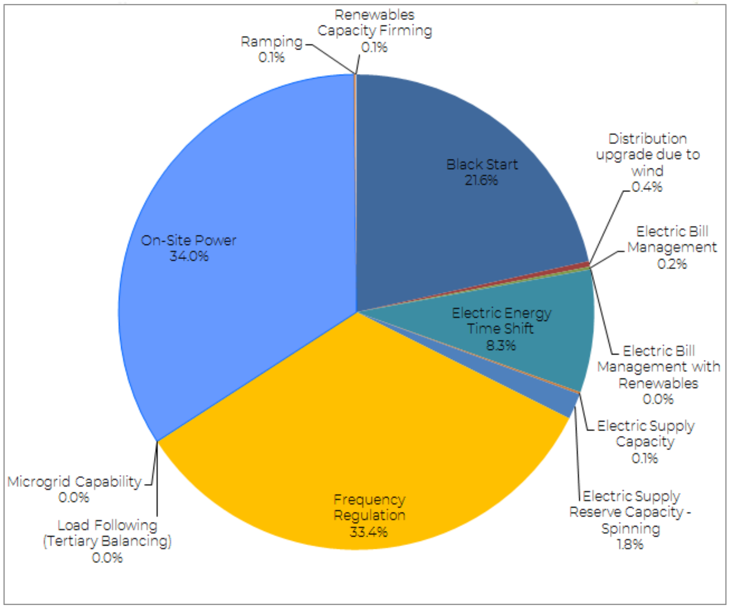


Figure 4.14. Distribution of provided services by electro-mechanical storage power capacity. Source: own elaboration with data from (US-DOE,2019).

In the case of thermal energy storage, global deployment is currently dominated by storage through molten salts due to its application in parabolic solar concentration plants. Therefore, 85% of the operating capacity is currently mostly used for renewable capacity firming, although it could be arguable if this application can be considered as electricity time shift (Figure 1.21).

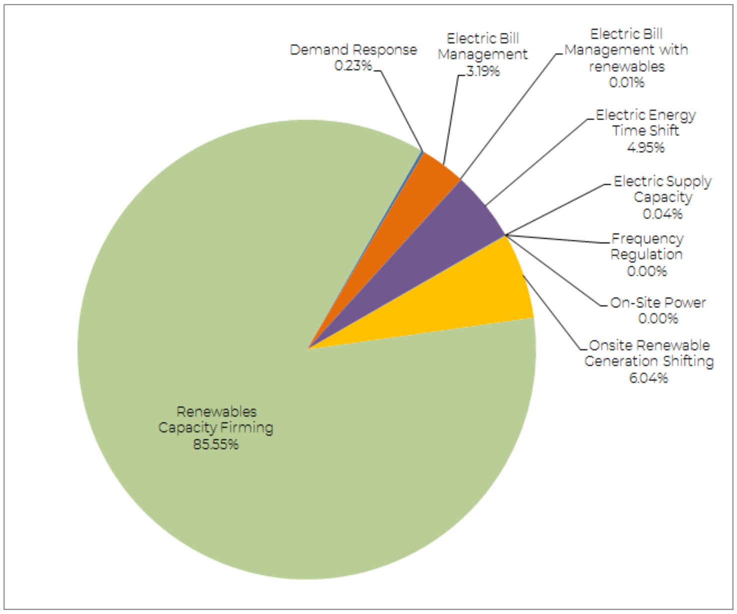


Figure 4.15. Distribution of provided services by thermal storage power capacity. Source: own elaboration with data from (US-DOE, 2019).

Smaller applications are growing, particularly for battery storage systems and including residential and commercial systems. These applications are a market of vertiginous growth and are also used in isolated systems; micro-networks (e.g. important fractions of solar use allow the replacement of diesel generators); isolated domestic electrification and electric vehicles. This market could be underestimated in the "Global Energy Storage Database" due to the potential high number of small projects not reported. However, this study targets the utility-scale level; therefore, in spite of the fact that the previous description might omit use of storage systems at a distribution level it is not considered to affect significantly the discussion.

4.4 California

The Mexican electricity reform described in the previous section produced a market very similar to principal electricity markets in the United States[3] based on nodal pricing, day-ahead and real time markets, capacity markets, transmission revenue rights, etc. Those structural similarities mean that laws and regulations pertaining to storage in those markets could be adapted in the Mexican market with relative ease. The California Market, usually referred to as CAISO, since it's operated by the California Independent System Operator, is at the forefront of integrating electricity storage into its system. Consequently, because of the structural similarities between the Mexican and the CAISO markets, in it makes sense to review how California has dealt with challenges associated with incorporating electricity storage into the grid and see which practices could be adopted in Mexico.

4.4.1 Regulatory Background

Long before the signature to the Paris Agreement in 2016, many governments around the world have promoted generation of electricity from renewable sources and reduction in emission of greenhouse gases. As early as 2002, California has signed into law a Senate Bill No. 1078 or SB1078 (California Senate, 2002) which established California Renewables Portfolio Standard (RPS) (CPUC, 2019a). The RPS required that by 2017, 20% of electricity retail sales come from renewable sources. In 2006, under SB107, the RPS program was accelerated obliging the 20% goal to be met by 2010. The Senate Bill No. 2 (California Senate, 2011) signed in April of 2011 increased the RPS requirement to 33% by 2020, and in 2015 the RPS mandate was raised once again via the Senate Bill No. 350 (California Senate, 2015) to 50% by December 31, 2030. The SB 350 also required that 65% of renewable energy be procured through long-term contracts of at least 10 years. Finally, in the fall of 2018, a Senate Bill No. 100 (California Senate, 2018) was signed into law, which increased the RPS to 60% by 2030 and established a requirement that all of California's electricity come from carbon-free sources by 2040. As of

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[3] California Independent System Operator (CAISO), Electric Reliability Council of Texas (ERCOT), Pennsylvania-New Jersey-Maryland (PJM)

2017, California retail sales have met the RPS and California's three[4] large Investor Owned Utilities (IOUs) have collectively served 36% of retail sales from renewable power (CPUC, 2019).

The ever-increasing participation of renewables in California's generation stack has highlighted two principal problems associated with "green energy", especially wind and solar power: intermittence and ramping.

> **Intermittence refers to the fact that the source of energy to be converted into electricity is not continuously available, and its availability might be hard to predict.** In other words, wind and solar generation can only happen when wind is blowing, and sun is shining. Moreover, the most windy or sunny periods might not correspond to peak demand.
>
> **Ramping refers to change in generator's power output.** The power supply must meet power demand at any point in time, and the demand might change rapidly. When wind and solar generation cannot increase its ramp rates to meet rising demand, then the ramp rates required of other resources increase. Put differently, renewable generation has an inherent problem with frequency response.

The grid-scale energy storage can mitigate not only challenges associated with intermittency and ramping but can also offer an array of ancillary services among other benefits. The California Energy Commission Chair, Robert B. Weisenmiller, stated in a press release: "As [California] aims to further reduce greenhouse gas emissions by 2030 and get 50 percent of our electricity from renewable sources, flexible resources such as energy storage, will be important to balance the power grid".

In 2010, the Governor of California approved the Assembly Bill No. 2514 (California Assembly, 2010), which directed the California Public Utilities Commission (CPUC) to establish an Energy Storage Program and a corresponding storage target to help integrate renewable energy into the system. The CPUC established a cumulative target for the three largest California IOUs of 1,325 MW by 2020.

In September of 2016, the Governor of California approved the Assembly Bill No. 2868 (California Assembly, 2016) meant to accelerate widespread deployment of distributed energy storage systems, effectively elevating energy storage goals for the California IOUs to 1,825 MW by 2020.

4.4.2 Key Players in California Electricity & Energy Storage

To understand the factors that foster or hinder grid-scale electricity storage in California, it is important to understand the relevant regulatory and market context. The structure of the California electricity sector bares many similarities to the one in Mexico. The table below identifies the key players in California electricity sector and identifies corresponding Mexican entities.

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[4] Pacific Gas & Electric, Southern California Edison and San Diego Gas & Electric

Table 4.1. Stakeholder and market comparison of California vs. Mexico. Source: own elaboration.

Electricity Sector Function	California	Mexico
Policy and Planning	California Energy Commission (CEC)	Secretaría de Energía (SENER)
Regulator	Public Utilities Commission (PUC)	Comisión Reguladora de Energía (CRE)
System Operator	California Independent System Operator (CAISO)	Centro Nacional de Control de Energía (CENACE)
Generation	Public Sector and Private Sector plants	Public Sector (CFE) and private Sector plants
Transmission	Private Sector and Public Sector Companies [8][5]	CFE Transmisión, Comisión Federal de Electricidad (CFE), a state-owned company.
Distribución	Investor Owned and Publicly owned Utility Companies	CFE Distribución, Comisión Federal de Electricidad (CFE), a state-owned company
Ancillary Services (not included in the wholesale market)[6]	Market Driven	CFE Generación, Comisión Federal de Electricidad (CFE), state-owned.
Capacity Market	Opaque (principally bilateral) market for Resource Adequacy (115% of peak demand)	Price of Capacity determined ex-post by CENACE based on 100 system peak hours
Sales	Investor Owned and Publicly owned Utility Companies	For small-size consumers it's CFE, for larger size consumers it can be the wholesale market, CFE, or a private sector supplier

4.4.3 California Roadmap and the Energy Storage and Distributed Energy Resources Initiative

The development of grid-scale energy storage in California was principally driven by policy and regulation, not by creating commercial incentives that would create a marketplace for energy storage resources.

In terms of energy, for example, the California electricity market is composed of a Day-Ahead market where most of transactions take place, as well as real time market which is virtually used for balancing demand and supply differences. Since by design both day-ahead and real time markets are short term, they do not promote the development of commercial energy storage due to the uncertainty of recuperating energy storage investment over a long term.

The California Energy Commission (CEC), the California Independent System Operator (CAISO), and the California Public Utilities Commission (CPUC) recognized the need to create a marketplace for energy storage, and have worked with energy storage developers, utilities,

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[5] California Energy Commission lists electric transmission lines, their owners, and provides a map (reference 8)

[6] Ancillary services not included in the Mexican wholesale electricity market are: black start and the connection to the grid, voltage control, and isolated operation.

generators, environmental groups, and other stakeholders to identify key challenges and actions necessary to overcome them. The result of that work was a document published in December of 2014, entitled "Advancing and Maximizing the Value of Energy Storage Technology: A California Roadmap (CAISO, 2014)".

The purpose of the document is to promote grid-scale energy storage by identifying and prioritizing actions that respond to three principal issues identified by energy storage stakeholders:

- Ability to realize the full revenue opportunities consistent with the value energy storage can provide.
- Need to reduce cost of interconnecting to the grid and ongoing operations.
- Streamlining and spelling out policies to increase certainty regarding processes and timelines.

The actions to address the three challenges above were grouped into five topic areas: planning, procurement, rate treatment, interconnection, and market participation. The highest priority actions were identified within each group, and ipso facto provide guidelines for how to construct a template for Mexican Energy Storage Roadmap.

The California Roadmap was a precursor to the Energy Storage and Distributed Energy Resources initiative (CAISO, 2019a). The initiative focuses on facilitating the participation of electricity storage and distributed generation resources connected to the grid operated by CAISO, in the electricity market. These resources encompass rooftop solar, energy storage, plug-in electric vehicles, and demand response. The initiative is composed of four phases:

Phase 1 was implemented in the fall of 2016, and "*enhanced the ability of grid-connected storage and distribution-connected resources to participate in the ISO market. Improvements included the ability for submitting the state of charge* (of electricity storage resource) *as a daily bid parameter in the day-ahead market, as well as an option to not provide state of charge limits or not have the ISO co-optimize non-generator resources based on state of charge* (CAISO, 2019a)." Since energy storage has a limited amount of energy available, knowing the state of charge of a storage resource helps CAISO optimize dispatch optimization. Prior to Phase 1 implementation, CAISO assumed resource state of charge to be 50%.

Phase 2 was implemented in November of 2018. It clarified the difference in treatment of retail power used for generation plant's needs (power for own use, or so called Station Power) such as operating of storage asset, office lights, etc., and wholesale power used to refill electricity storage; increased number of methodologies to evaluate demand resource performance from two to five and clarified various definitions relevant to demand response; and added natural gas indices into the net benefits test to evaluate the benefit of decreased demand. The test, which is ongoing, checks whether the benefit of electricity price decrease associated with the dispatch of demand response resources is greater than the cost of using those resources (CAISO, 2018).

Phase 3 still has not been completed, but it will "*continue to identify and evaluate opportunities for increased participation of transmission grid-connected energy storage and distribution-connected resources in the ISO market* (CAISO, 2019a)." More specifically, the issues that are being considered deal with electric vehicle participation in the market, modeling demand response limitations, and creating a peak-shaving demand response market product (CAISO, 2018).

Phase 4 is under development. The issues that it plans to address include:

- Adding a state of charge parameter for storage resources[7] in the non-generator resource model.
- Applying market power mitigation to energy storage resources.
- Streamlining interconnection agreements for non-generator resource participants.
- Establishing parameters to better reflect demand response resource operational characteristics.
- Vetting qualification and operational processes for variable-output demand response resources.
- Discussing the non-24x7 settlement implications of behind the meter resources within the non-generator resource model (CAISO, 2019b).

4.4.4 Energy Storage Incentives

While regulations and policies regarding energy storage in California are still evolving, it is important to mention that there are several incentives, both at the state and at the federal level, meant to promote energy storage:

- The CEC funds research into effectiveness of energy storage as a grid resource through the Electric Program Investment Charge (EPIC) (CPUC, 2011).
- The CPUC provides funding for programs such as Permanent Load Shifting and the Self Generation Incentive Program to incentivize adoption of customer-side energy storage (CPUC, 2019b).[8]
- The Federal Energy Regulatory Commission Order No. 792 defined electricity storage as generating facilities to facilitate interconnection procedures (FERC, 2013).
- Federal Business Energy Investment Tax Credit and the US Department of Agriculture High Energy Cost Grant Program provide support for energy storage (DOE, 2009).
- The US Department of Energy funds research into new storage technologies through Advanced Research Projects Agency – Energy and Energy Efficiency and Renewable Energy offices (ARPA, 2007).

4.4.5 California, Mexico, and Electricity Storage

Transmission and Distribution

Some of the principal differences between Mexico and California, in terms of electricity sector set-up relevant to energy storage, deal with the role of the system operator. Whereas both in California and Mexico the system operator oversees the wholesale electricity market and the operation of the grid, in California CAISO also operates transmission lines.

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[7] It is a measure of the short-term capability of the energy storage system. It reflects the amount of energy left in the storage system, compared to the rated capacity.

[8] CPUC decision on permanent load shifting, D 12-04-045, implemented through resolution E-4586, see CPUC 2019b.

Currently, CFE Transmission tariff is set up to recuperate operational and infrastructure costs with a fair rate of return determined by the CRE. Energy storage has a potential of delaying CFE's transmission (or distribution) infrastructure investments, and therefore could challenge CFE's earning potential. It could be socially and economically beneficial for CFE Transmission to invest in storage instead of transmission infrastructure and earn a fair rate of return on that investment, while mitigating congestion, providing voltage and frequency control. However, under current regulation which requires strict separation of duties, CFE Transmission cannot own electricity storage because it is classified as generation.

Similarly, distribution in Mexico is run by the state electricity company, CFE, where as in California distribution is operated by publicly-, and privately-held utility companies.

The Cost of Storage

One important similarity between California and Mexico is that both the California Public Utilities Commission (CPUC) and the CRE are responsible for setting relevant tariffs based on cost of service – this includes tariffs related to electricity storage. In California the IOU's are required to procure electricity storage, and are compensated for the cost of storage through their regulated tariffs. Since the cost of storage is ultimately paid for by consumers, the PUC gets involved in the storage procurement process to ensure that end users get the best deal possible (CPUC, 2014) .

Storage is typically procured on tolling contract basis, which is akin to a long-term rental of storage infrastructure where a utility company would pay for capex, opex, and a negotiated rate of return.

4.4.6 Ancillary Services

Another important difference between Mexico and California is procurement of ancillary services. In Mexico, ancillary services are divided into those procured in the wholesale electricity market (MEM), such as operating reserves, and those that are not included in the MAM, such as voltage control, black start-up and connection to the grid, and operating in an "island mode" (SENER, 2014). It is important to note that legally speaking, private sector companies could provide ancillary services not included in the MEM, which are currently provided by CFE generation companies.

In California, there is a market (day ahead and real time) for four ancillary services: Regulation-up, Regulation-down (frequency control, active energy in matter of seconds), Spinning Reserves and Non-Spinning Reserves (active energy, respond within 10 minutes)(CAISO, 2019c, FERC 2016). The voltage control (synchronous condenser) and black start are also acquired by CAISO, but not through a market mechanism, but on contractual basis, in locations identified by CAISO as adequate (CAISO, 2013). There is no such service as "island mode" in California.

The California market's short time horizon, and the lack of long-term contracts for those services does not incentivize energy storage investment in and of itself – ancillary services need to be considered as one piece of the revenue generating puzzle. The California Roadmap and the Energy Storage and Distributed Energy Resources Initiative focus on finding optimum ways for energy storage to participate in ancillary services market, such as Non-Generating Resource (NGR) market model, discussed below.

For example, as recently as February of 2019, the CEC approved the installation of Lithium-ion batteries to provide a black start capability to the Russel City Energy Center (ENERKNOL, 2019).

4.4.7 Wholesale Market

As mentioned in the previous section, the Mexican energy storage experience and its interaction with the electricity market is very limited. California, on the other hand, is experimenting with various market participation models to integrate flexible energy sources, such as distributed generation and energy storage into mainstream operations. This program of integration has three elements: Proxy Demand Response (PDR), Distributed Energy Resource Provider (DERP), and Non-Generating Resource (NGR) [24].

The PDR permits third parties to bid directly (i.e. not through a utility), into the CAISO load curtailment and ancillary services markets.

The DERP refers to a distributed generation aggregator that can act as a resource, if it meets the minimum capacity requirements.

Both PDR and DERP are considered a non-resource participation model and do not deal with energy storage.

The Non-Generating Resource (NGR) on the other hand refers to energy storage (which includes energy storage: batteries, flywheels, pumped hydro and electric cars), and is considered a resource. The NGR refers to a positive (discharging) and negative (charging) range of energy storage resources that can be provided. Energy storage can participate through PDR and DERP market models, or it may bid directly under NGR market model.

There are three NGR subtypes (CAISO, 2019d):

1. **Limited Energy Storage Resources (LESRs)**: offer positive and negative energy products constrained by their State of Charge (SOC). Both Batteries and flywheels qualify as LESRs.
2. **Dispatchable Demand Response (DDR)**: offer negative products only (i.e. demand response) and are constrained by the curtailable energy limit.
3. **Generic NGRs**: are like LESR without the SOC constraint but can only offer Regulation Energy Management (REM), i.e. Regulation up, Regulation Down.

In summary:

Table 4.2. Non-Generating Resource (NGR) and offered products. Source: own elaboration.

Market Product Offered	LESR	DDR	Generic NGR
Day-Ahead (**DA**) & Real Time (**RT**) Energy	✓	✓	
DA & RT Spinning and Non-Spinning Reserves	✓	✓	
DA & RT Regulation Up and Regulation Down	✓	✓	✓

The minimum storage capacity requirements to participate in the market are 500kW. A Non-REM resource is obliged to meet 60 min. continuous energy while REM resource must meet a 15 min. continuous energy requirement.

The NGRs are modelled with no start-up time or start-up costs, and energy losses are considered during the charging process, not discharging.

The day-ahead market (DAM) and the real-time market (RTM) observe state of charge (SOC) limitations in the energy and ancillary service optimization for DDRs and LESRs. Specifically, DAM calculates SOC based on previous day's history, if SOC is not included in the DA bid. For Generic NGRs, CAISO manages SOC.

4.4.8 The Capacity Market

The Mexican annual capacity market prices are determined by CENACE every February, following the end of the year for which prices are being calculated. For example, the capacity prices for 2018 were determined in February of 2019, based on the 100 most critical hours in the Mexican power system (SENER, 2015). The critical hours are defined as the hours with the smallest gap between the maximum demand and the system's available capacity.

The California market has a mandatory 15% reserve margin (CPUC, 2019c). Consequently, Public Owned Utilities (POU) and Investor Owned Utilities (IOU) are required to purchase 115% of their peak demand capacity. In California, capacity is referred to as resource adequacy (RA). The extra 15% that is required is not associated with a specific capacity type, such as storage, combined cycle, etc.

That said, the energy storage that can provide power at full capacity for three hours can offer RA capacity on the market. This can pose a challenge for some of storage technologies which were not designed to discharge over a prolonged period of time, such as supercapacitors for example.

Energy storage, among other resources, such as demand response, is referred to as Effective Flexible Capacity (FEC) on the capacity market. The FEC resources are divided into categories depending on availability (CPUC, 2019d).

The FEC RA Capacity market is composed of three different types:

- Base Ramping,
- Peak Ramping,
- Super-Peak Ramping

"A resource qualifies to provide Flexible RA Capacity in each Flexible Capacity Category for which it meets the qualifications set forth in CAISO Tariff Sections 40.10.3.2, 40.10.3.3, and 40.10.3.4, (CISO, 2019e)[9]"

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[9] This document explains in more detail the EFC Categories

4.5 The United Kingdom (UK)

Approximating numerous countries that have had centralized, state-owned electricity systems, Mexico and the UK were comparable prior to their respective electricity market reforms. The CFE (Comisión Federal de Electricidad) in Mexico and the CEGB (Central Electricity Generation Board) in the UK were publicly owned companies that controlled generation, transmission and distribution of electricity in their corresponding markets.

The UK's energy sector reform began with the Electricity Act of 1989 (UK Parliament, 1989), 24 years before Mexico. Although currently both countries face similar challenges associated with the growing participation of renewable energy generation and inclusion of energy storage technologies within their individual electricity sectors, the UK has faced those challenges for a longer period. Mexico can benefit from UK's experience and observe which practices have hindered or fostered the grid-scale deployment of electricity storage. What makes the UK case unique is that as early as 2012, the government identified energy storage as one of the "Eight Great Technologies" (DBIS, 2013), which played a role in the national industrial strategy.

4.5.1 The UK Electricity Market

The UK has taken a market approach to electricity sector, including energy storage, as it will be shown in the following subsections. After liberalization and privatization of the electricity sector in the UK, all services have been delegated to the private sector.

Generation

The CEGB was initially broken up into four companies: three generation companies and a transmission operator. The generation companies were National Power, PowerGen, and Nuclear Electric, which included all nuclear plants (IEA, 2005). Initially, Nuclear Electric was under public control, but afterwards, all nuclear power plants were privatized, and are currently operated by the French company EDF Energy (DUKES, 2018).

Transmission

The UK transmission network is owned and maintained by three transmission companies: National Grid Electricity Transmission (England and Wales), Scottish Power Transmission Limited (southern Scotland) and Scottish Hydro Electric Transmission (northern Scotland and the Scottish island groups). The entire system is operated by National Grid Electricity Transmission, a multinational electricity and gas utility company listed on both the London and New York Stock Exchanges (OFGEM, 2019a).

Distribution

The distribution networks are privatized in the UK. There are 14 distribution networks owned by six different companies (OFGEM, 2019b).

4.5.2 Key Players in the UK Electricity Sector

The private sector takes the front and center stage in UK's electricity system. The public sector is principally focused on policy, regulation, grid planning and development.

The Department of Business, Energy & Industrial Strategy (DBEIS) formulates the energy policy and proposes bills to be presented in the parliament. The department is similar to the Mexican Secretaría de Energía (SENER), with the exception that SENER is also responsible for the planning and development of the electric system.

The Office of Gas and Electricity Market (OFGEM) is the UK regulator. One of the responsibilities of the regulator is planning of the electricity sector infrastructure. The regulator is independent, similarly to the CRE in Mexico, in that it does not respond to DBEIS. Also like CRE, it is responsible for the implementation of the government energy policy.

It is important to highlight that unlike California, the UK does not have electricity storage obligations. Consequently, the success or failure of grid-scale energy storage depends on the existence of an adequate regulatory framework and the market conditions. With regard to the market conditions, the success depends not only on the competitiveness of storage in terms of prices, but on the structure of the market itself that might, or might not, reward all the benefits that storage offers.

4.5.3 The UK Energy Policy

The electricity sector trends, in general, and electricity storage trends, in particular, are largely shaped by national energy policies. The development of the UK energy policy reviewed below provides the context for the discussion of grid-scale electricity storage in the UK.

In 2008, the UK parliament passed a "Climate Change Act 2008" (UK Parliament, 2008), which created a legal obligation to reduce the national greenhouse gas emissions by 80% compared to 1990 baseline, for the year 2050. Shortly afterwards, in the spring of the following year, the European Union (EU) published the "Renewable Energy Directive 2009/28/EC" (EP, 2009), which dictated that 20% of the energy consumed in the EU must come from renewable sources by the year 2020. While the 20% referred to the total energy, the renewable generation targets varied among member states, and the UK target was established at 15%.

These two regulations have accelerated the drive to decarbonize the UK electricity system and promote renewable generation. Considering that in 2011, coal and gas together accounted for 64% (DECC, 2012) of the generation mix, promoting renewable generation meant a significant transformation of the Electricity market. To that end, in 2012 the Department of Energy and Climate Change (DECC) presented to the Parliament the Energy Bill and Electricity Market Reform, a broad name for a series of reforms aimed at transforming the UK electricity market, that was approved in 2013 (UK Parliament, 2013). The stated purpose of the bill was to ensure low-carbon, secure and affordable electricity supply.

4.5.4 Trends in UK's Electricity Sector

The government policy had a very strong impact on growth of renewable generation. In 2010, all renewable electricity accounted for 6.9% of total UK electricity generation. In 2017, that percentage increased to 29.3%. Measured as a percentage of UK electricity sales, electricity derived from renewable sources increased from 7.2% in 2010, to 25.1% in 2017. Independently of the measurement method, renewable generation more than tripled since 2010. In 2017, wind (onshore and offshore) and solar photovoltaic comprised 48.9% and 31.5% of the total renewable generation capacity, respectively (DUKES, 2018).

The Feed-In Tariffs (FiTs) were perhaps one of the more effective policy mechanisms designed to support investment in renewable generation on a small scale. The FiTs program was introduced in April of 2010 and was accepting new applications until the end of March 2019[10]. Households or small businesses that installed qualifying technology would receive a payment for generated electricity, as well as a payment for electricity sent back to the grid. The program is analogues to the Distributed Generation in Mexico. The main difference is the scale: Distributed Generation applies to installations up to 0.5 MW, whereas the FiTs program applies to generation projects up to 5 MW. At the end of May 2017, installations in the Fit program reached the capacity of 6.1 GW (UK Parliament, 2008).

Another important policy was the increase of Carbon Price Floor, which showed an increasing price of carbon emissions over a long-term time horizon.

Therefore, the overarching trend in the UK electric system is a shift towards renewable generation, on both large and distributed generation scales. One of the implications of that shift is a decline in traditional thermal generation. In 2017 the generation from coal and gas fell by 27% and 5%, respectively (DUKES, 2018). Another implication is that energy storage has a potentially large role to play in a market with increasingly larger share of intermittent energy.

4.5.5 Ancillary Services

The UK, like most other liberalized electricity systems, has developed a market for ancillary services, which are provided by the private sector (IEA, 2005). The National Grid, the system operator, is responsible for procuring the ancillary or "Balancing" services. There are 15 services in total (NG, 2019):

- Black start.
- Balancing Mechanism (BM) start up.
- Demand side response (DSR).
- Demand turn up, encourages large energy users to either increase demand or reduce generation at times of high renewable output and low demand.
- Enhanced frequency response (EFR), which provides frequency response in one second or less.
- Enhanced reactive power service (ERPS), voltage support that exceeds the obligatory levels.

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[10] https://www.gov.uk/feed-in-tariffs

- Fast reserve, active power of either increased generation or decreased consumption.
- Firm frequency response (FFR), minimum 1MW of response energy.
- Inter-trips, typically operates in less than 0.1 seconds to resolve transmission thermal and stability issues.
- Mandatory response services, mandatory frequency response within statutory limits.
- Obligatory reactive power service, provision of varying reactive power output.
- Short-term operating reserve, additional active power or demand reduction.
- Super SEL, ability to reduce the minimum generation level in times of low demand (SEL: Stable Export Limit).
- System operator to system operator, this trading determines the direction of electricity flow through interconnectors.
- Transmission constraint, required during high congestion.

4.5.6 Capacity Market

The Capacity Market (CM) was introduced to the UK in 2014 as a part of the Electricity Market Reform. As a countermeasure to decommissioning of coal power plants to comply with decarbonization commitments and as a remedy to an increasing portion of renewable generation that provides intermittent energy, the goal of the Capacity Market is to ensure security of electricity supply. The CM is also meant to support the development of demand management and encourage investments in new generation by offering revenue security over a certain time horizon (DBEI, 2015).

4.5.7 The UK electricity Storage Trends

Similarly to other countries undergoing fundamental changes in their electricity systems associated with renewable generation, smart metering, decarbonization, and energy storage, the UK is looking for optimal ways of integrating storage into their electricity network. It is an ongoing process that started with identification of energy storage as one of the “eight great technologies” where the UK believed it could be a world leader due to its science and business strengths. In 2012 the government announced the support for those eight technologies as part of the national industrial strategy and committed public funding to support their development (DBIS, 2013).

The aforementioned Electricity Market Reform recognized the potential of energy storage. In November of 2012, the Department of Energy & Climate Change (DECC) published the “Electricity Market Reform: Policy Overview” (DECC, 2012), where it recognized the importance of storage, specifically in the context of load shifting and capacity market.

Nevertheless, the first capacity auction in 2014 failed to recognize differences between storage and traditional generation (DECC, 2012b). By leaving the duration of service to be provided open-ended, it created significant participation barriers for most storage technologies.

On the other hand, in 2015 the Enhanced Frequency Response (EFR), one of the ancillary services previously mentioned, was introduced on the market (OFGEM, 2014). The response time for EFR is one second or less, clearly favoring a number of energy storage technologies.

Even though initially, the EFR was initally expected to run from April 2015 until March 2018, it is now one of the ancillary services procured by the National Grid.

Also in 2015, forecasting trends of the UK electricity system, the National Grid produced an annual report entitled Future Energy Scenarios (NG, 2015), whose scenarios served as basis for a report published in March of 2016, entitled "Can Storage Help Reduce the Cost of a Future UK Electricity System?" (CT&ICL, 2016). The report was published by Carbon Trust in conjunction with the Imperial Collage London, and was sponsored by the Department of Energy and Climate Change, the Scottish Government, and three major utilities: Scottish Power, E.ON, and SSE.

The report set out to answer three questions, summarized as follows:

1. Can electricity storage benefit consumers?
2. What prevents investment in storage?
3. What can be done to overcome investment barriers?

The study modelled the UK electric system and found that deploying electricity storage (the study was storage technology neutral) could significantly reduce the cost of the system. Using National Grid's "Go Green" future energy scenario, with high "prosperity" (read strong economic growth) and high "green ambition" (decarbonization is a priority), the savings from deploying electricity storage reached £2.4 billion (2016 £) per year in 2030. In an opposite scenario labeled "No Progression", where both prosperity and green ambition were low, deploying electricity storage was still beneficial.

The study also identified the barriers that prevent the deployment of storage:

- Policy risk – uncertainty about the future policies and laws that define storage revenues.
- Failure to recognize externality benefits to society – not recognizing the full benefit storage provides in the price of storage leads to underinvestment.
- Revenue cannibalization risk – fear that oversupply of storage services drives the marginal prices below the marginal cost.
- Distorted market price signals – uncertainty associated with the disagreement among the stakeholders (regulator, system operator, service providers, etc.), as to the value of storage.
- Disintegrated market structures – inability of a single storage asset to provide multiple services.
- Multiple stakeholders, multiple benefits – diverse stakeholders derive different benefits from storage. To capture overall benefit of storage, collaboration among stakeholders is necessary, but it is not easily facilitated.

The principal solutions to the identified barriers are mostly policy related:

- Align incentives – introduce dynamic electricity pricing to reflect true cost of electricity at any given time and remove barriers that prevent a storage asset from providing stacked services.
- Monetize system benefits – evaluate the value of externalities associated with storage and include them in the price of storage services.
- Reduce policy uncertainty – adopt long-term predictable regulation.
- Engage stakeholders – despite overall positive effect of storage, adoption of storage technologies will affect organizations beyond storage industry.

- Demonstrate the cost and performance of storage – performance characteristics and costs associated with storage should be disseminated to promote informed discussion.
- Define performance and operating standards for storage – build confidence with system operators to facilitate efficient integration with the network.

Following up on the report's findings, the DECC and OFGEM released a call for evidence in November of 2016, soliciting input from energy industry participants and consumer groups on how to make the energy system smarter and more flexible. In July of 2017, OFGEM published the results of a survey (DBEIS & OFGEM, 2017), where respondents addressed six questions related to storage.

The first question dealt with policy and regulatory barriers to the development of storage. The stakeholders stated that the market does not reward the full benefit of storage because the complexity of regulations for different services and short contract lengths for those services make it difficult to build a business model based on stacking of ancillary services, capacity market, and load shifting. They also stressed the need for regulatory clarity for storage.

The second question dealt with network connection for storage. The stakeholders agreed that more clarity is required on the storage connections process, information on where to connect, and the treatment of storage connection which is added to existing generation. Also, the delay in connecting in storage in favor of generation was identified as a problem, especially in cases where storage can relieve congestion.

The third question dealt with the fees faced by the storage providers. The stakeholders agreed that storage can benefit the system and should be compensated accordingly. There was no agreement as to whether storage should pay import-export fees, and various stakeholders asked for consistency in charging methodologies for transmission and distribution. The stakeholders asked for clarification as to whether storage is considered non–intermittent.

The fourth question enquired about the usefulness of storage for network operators, whether the regulatory framework permits the development of competitive storage market, and whether the network companies should own storage.

All stakeholders agreed that the use of storage by network operators is cost-effective. Majority of respondents also agreed that separation of duties should apply to storage, but many acknowledged that distribution networks might own storage under special circumstances.

The answers to the fifth question, which enquired about regulatory approaches to provide greater clarity for storage, were combined with the answers to the sixth question which asked whether storage is correctly defined. Here, the stakeholder answer was not clear as to whether storage should be considered as a new asset class, or whether it should remain classified as generation.

4.6 Conclusions

- The energy storage regulations and policies are still not finalized even in advanced markets like California or the UK.
- The success of integrating energy storage into their electric system operations would require:
    - Both regulatory and commercial incentives. The development of energy storage driven by regulation alone or market alone is not optimum.

  - Coordination between CENACE, CRE, SENER, the private sector as well as other stakeholders in identifying and eliminating barriers to deployment of energy storage.
  - Quantification of benefits energy storage can provide at an energy storage developer level, as well as at a social level (i.e. quantification of externalities).
  - Definition of storage and of the products that energy storage can provide to the grid, and a methodology that would permit valuating those products.
  - Predictable and transparent regulatory framework.
- Facilitation of interconnecting energy storage to the grid.

5. Success criteria and drivers that enabled the deployment of utility-scale electricity storage projects

5.1 Background

The principal non-regulatory driver behind the growing deployment of utility-scale storage is the constantly increasing share of renewable energy, which has created a business opportunity for services that energy storage can provide. The flexibility of energy storage is in many ways the answer to the inflexibility associated with renewable generation. Specifically, storage can address challenges such as intermittency and ramping, while offering ancillary services, capacity, and frequency control.

The declining capital cost of electricity storage, especially batteries, is another very important non-regulatory factor behind the growth of storage projects. However, starting from the assumption that, ceteris paribus, the private sector does not need encouragement to capitalize on profitable business ventures, the review of elements which are necessary in successfully enabling utility-scale electricity storage will focus on regulations that promote storage integration into an electrical system.

There are three ways governments have mostly been promoting energy storage: deployment by legal obligation, deployment by subsidies, and the development of a consistent regulatory framework.

5.2 Deployment by legal obligation

An example is the California Assembly Bill 2514 which resulted in an energy storage target for the three largest California utilities. The principal advantage of creating legal storage targets is timing. The law indicates who must have energy storage installed and by when, potentially making implementation of energy storage fast.

The main disadvantage of promoting storage through a regulatory requirement is that it is most likely to be considered a pass-through cost of doing business to be forwarded to consumers, and which should be fulfilled to meet minimum legal requirements - no more.

5.3 Deployment by subsidies

The residential energy storage subsidies are often attached to distributed generation initiatives. For example, the previously mentioned self-generation incentive program (SGIP) in California, which subsidizes the “behind the meter” energy storage was extended in September of 2018 until 2026[11]. In Australia energy storage, when combined with solar power generation, receives national subsidy through Solar Credits[12].

There are also subsidy programs related to storage on a much larger scale. At the beginning of 2019, Germany announced a subsidy program for battery cell production[13], and the European Commission dedicated funds to battery research drive, which will be led by InnoEnergy, along with European Energy Research Alliance and the European Association for Storage of Energy[14].

Subsidizing energy storage is socioeconomically feasible up to the value of positive externalities that energy storage provides. Positive externalities refer to positive effects or consequences of storage that are not reflected in the cost of the service, such as greenhouse gas emission mitigation due to decreased fossil fuel consumption. Examples of other positive externalities for Mexico might include a decreased reliance on imports of natural gas, postponement or alleviation of transmission and/or distribution infrastructure investments.

5.4 Regulatory framework

The third way of promoting energy storage consists of a regulatory framework – as opposed to a regulatory requirement – that promotes the development of a market for services offered by storage technologies. The advantage of a market, any competitive market, is that it promotes competition on quality of service, costs, and encourages research, development, and innovation.

Arguably, the regulatory framework is the most important factor behind the deployment of electricity storage, because it defines the role storage plays within the system and determines whether the market regulations make that role commercially viable. Consequently, the section below will focus on general guidelines that a regulatory framework must contain to ensure successful deployment and integration of electricity storage into the system.

A government can choose to promote energy storage through any combination of the three approaches described above, since they are not mutually exclusive.

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[11] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB700

[12] https://www.energymatters.com.au/rebates-incentives/solar-credits-australia/

[13] https://www.electrive.com/2019/02/23/german-government-to-subsidise-battery-production/

[14] https://renews.biz/51360/eu-launches-battery-research-drive/

6. Factors that Enable Utility-Scale Electric Storage

Integrating electricity storage into an electrical system is work in progress, not just in Mexico but around the world. The California market is possibly the most advanced in facilitating the participation of the energy storage in the CAISO market, but the final phases of the California Energy Storage and Distributed Energy Resources Initiative are still being negotiated between the regulator, the private sector participants, the system operator, and the energy commission which determines energy policies in the state.

Although there are no time-proven regulatory methods that enable storage, there are certain components that regulatory framework should contain to make deployment and integration of utility-scale energy storage projects a success. This section will discuss those components in general, while Section 3 will discuss them in more detail in Mexican context.

6.1 Clear Rules, Definitions, and Classifications

Although it seems obvious, it's a point that is often overlooked. Since storage alternates between depositing energy (as a load) and releasing it (as a generator), it is critical to define fair tariff treatment in terms of transmission, carbon credits, etc., which will avoid double charging storage providers. Also, having clearly defined services that storage can provide, and operation and market rules on how it can provide them goes a long way in defining investment incentives.

6.2 Non-Discriminatory Regulation

In February of 2018, Federal Energy Regulatory Committee (FERC) in United States issued an Order 841 to all Independent System Operators (ISO) and Regional Transmission Organizations (RTO) which obliges them to create non-discriminatory market rules for energy storage participation in electric markets. The order aims at "(…) removing barriers to the participation of electric storage resources in the capacity energy, and ancillary service markets (…)[15]" operated by ISO and TRO. Specifically, it directs ISOs and RTOs to create rules that not only recognize the physical and operational characteristics of storage resources, but that ensure that those resources are eligible to provide all services (capacity, energy, ancillary services) in the electricity market.

The FERC Order 841 fosters creation of participation models for energy storage in all US electric markets. One of the factors which can obstruct the participation of electricity storage in

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[15] https://www.ferc.gov/whats-new/comm-meet/2018/021518/E-1.pdf

electric markets is de-facto discrimination which consists of not recognizing the characteristics of electricity storage. For example, an open-ended delivery obligation in the UK's capacity market does not define a time limit for the service provided, effectively barring storage participation in that market[16]. In short, regulation that recognizes physical and operational characteristics of storage fosters storage deployment.

6.3 Security of Revenues

Electricity storage is characterized by large fixed costs. Consequently, a regulatory framework that means to encourage electricity storage needs to create conditions where services provided under the storage contract can be contracted over longer time periods to ensure stability/security of income.

The security of income need not come from one service that storage can provide. Regulatory framework that allows storage owners to capitalize on all services storage can provide is one of the success criteria behind the deployment of storage.

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[16] https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/RESTLESS-brief-Regulatory-barriers-to-energy-storage-deployment-July-2016.pdf

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