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Coevolution between Institutions and Technologies: The Influence of Regulatory Rules on the Development of Battery Storage Systems in Electricity Industry

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Dissertação de Mestrado apresentada ao Programa de Pós-Graduação em Economia da Indústria e Tecnologia, Instituto de Economia, Universidade Federal do Rio de Janeiro, como requisito parcial à obtenção do título de Mestre em Economia.

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À minha âncora, Jesus.

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ABSTRACT

We studied the influence of regulatory rules of electricity industry on the technological development of Battery Storage System (BSS) with an institutional view of regulation. To that end, we first identified which aspects of BSS development can be affected by external factors that are exogenous to the BSS's providers, such as the decision of buy a BSS of the agents of electricity industry. After that, we studied how regulatory rules can influence affect such factors, and thus to influence the choice of which technological trajectories of BSS will be developed.

Differently of other new technologies in the electricity industry, BSSs have already a consolidated supply, since this technology is applied in other industries. Nevertheless, their application in electricity industry still requires their technological development. One of the main challenges in the development of this technology follows from the fact it can provide a big set of services for electricity systems. Those services require different technical characteristics. Thus, different technological trajectories can be developed. The choice of which trajectories will be developed depends on the expected demand of BSS, including the one in the electricity industry. However, the expected demand of BSS in the electricity industry is dramatically affected by the regulatory framework.

We classify the services provided by BSSs into i) Time Shift Services and ii) Location Shift Services. The first are services that postpone the electricity consumption or sale, while the second are services that avoid the electricity transportation between two points. That classification allows us to identify the effects of regulation on the demand for BSS: (i) the demand for Time Shift Services depends on the electricity market design; (ii) the demand for Locational Shift Services depends on network regulation (including tariff design).

Hence, to study the interplay between regulation and technological dynamics, we analyze different regulatory scenarios of electricity market design and network tariffs. We use information available in US Department of Energy (DOE) Energy Storage Database, websites of battery providers, scientific papers, and technical reports from research laboratories, regulatory agencies, government organizations and consultancies. From the five regulatory scenarios analyzed we conclude : (i) the greater the flexibility of the market design regarding the role of the end-customers within the electricity system, the greater the incentives for the battery providers to develop Time Shift Services; (ii) the investment in development of BSS capable to provide Locational Services is highly dependent on the tariff design (a volumetric tariff means the BSS' demand will ultimately be driven by electricity market results, while a two-part tariff means the BSS' demand will be driven by what the regulator establishes as fixed investment in network).

Keywords: Institutional Theory, Technological Dynamic, Electricity Industry, Regulatory Rules, Battery Storage Systems.

RESUMO

Neste trabalho é estudado a influência das regras regulatórias da indústria elétrica no desenvolvimento tecnológico dos “Battery Storage Systems” (BSS) com base numa pespectiva institucional da regulação setorial. Para esse fim, indentificou-se quais aspectos do BSS que podem ser afetados por fatores externos aos provedores de bateria, como a demanda por tal tecnologia. Em seguida, estudou-se como as regras regulatórias podem influenciar as trajetórias tecnológicas que os provedores de baterias desenvolverão.

Diferentemente de outras novas tecnologias na indústria elétrica, os BSS já possuem uma oferta consolidada, uma vez que são aplicados em outras indústrias. No entanto, sua aplicação na Indústria Elétrica ainda requer seu desenvolvimento tecnológico. Um dos principais desafios no desenvolvimento desta tecnologia decorre do fato de que ela pode fornecer um grande conjunto de serviços para sistemas elétricos. Esses serviços exigem características técnicas diferentes. Assim, diferentes trajetórias tecnológicas podem ser desenvolvidas. A escolha de quais trajetórias serão desenvolvidas depende da demanda esperada de BSS, incluindo a do setor elétrico. No entanto, a demanda esperada de BSS no setor elétrico é dramaticamente afetada pelo marco regulatório.

Os serviços prestados pelos BSS foram classificados em i) “Time Shift”, ou ii) “Locational Shift”. Os primeiros são os serviços que adiam o consumo ou a venda de eletricidade, enquanto o segundos evitam o transporte de eletricidade entre dois pontos. Essa classificação nos permite identificar os efeitos das regras regualtórias sobre a demanda dos BSS: i) a demanda por serviços Time Shift depende do market design adotado; ii) a demanda por serviços Locational Shift depende da regulação da rede (incluindo o design das tarifas).

Logo, a fim de estudar a interação entre regulação e dinâmica tecnológica, foram analisados diferentes cenários regulatórios de market design e regulação da rede. Foram utilizadas informações disponíveis no US Department of Energy (DOE) Energy Storage Database, sites dos provedores de baterias, artigos científicos e relatórios técnicos de laboratórios de pesquisa, agências reguladoras, organizações governamentais e consultorias. Dos cinco cenários regulatórios analisados, concluí-se que: (i) quanto maior a flexibilidade do market design em relação ao papel dos consumidores finais dentro do sistema elétrico, maiores são os incentivos para que os provedores de baterias desenvolvam os serviços Time Shift; (ii) o investimento no desenvolvimento de BSS capazes de fornecer serviços Locational Shift é altamente dependente do design da tarifa de rede (uma tarifa volumétrica significa que a demanda por BSS será guiada pelos resultados do mercados de eletricidade, enquanto uma tarifa “two-part” significa que a demanda será impulsionada pelo que o regulador entende como investimento fixo em rede).

Palavras Chave: Teoria Institucional, Dinâmica Tecnológica, Indústria Elétrica, Regras Regulatórias, Battery Storage System.

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LIST OF ACRONYMS

ARRA	American Recovery and Reinvestments Act
ASMP	Ancillary Service Marginal Price
ATRR	Annual Transmission Revenue Requirements
BSS	Battery Storage Systems
CAISO	California Independent System Operator
CEC	California Energy Commission
CES	Clean Energy Standard
CPUC	California Public Utilities Commission
DADRP	Day-Ahead Demand Response Program
DER	Distributed Energy Resource
DSASP	Demand-Side Ancillary Service Program
EDRP	Emergency Demand Response Program
ERO	Electric Reliability Organization
ESDER	Energy Storage and Distributed Energy Resources
ESR	Energy Storage Resource
EV	Electric Vehicle
FERC	Federal Energy Regulatory Commission
HEV	Hybrid Electric Vehicle
ICAP	Installed Capacity
ICT	Information and Communications Technology

IFM	Integrated Forward Market
ISO	Independent System Operator
LBPM	Locational Based Pricing Mechanism
LSE	Load Serving Entity
NERC	North American Electric Reliability Corporation
NGR	Non-Generation Resource
NOPR	Notice Proposed Rulemaking
NYISO	New York Independent System Operator
NYPSC	New York Public Service Commission
PG&E	Pacific Gas & Electric
PUC	Public Utilities Commission
PURPA	Public Utility Regulatory Policy
RA	Resource Adequacy
RDP	Demand Response Program
REM	Regulation Energy Management
REV	Reforming the Energy Vision
RFP	Request for Proposal
RTO	Regional Transmission Organization
RUC	Residual Unit Commitment
SB	Senate Bill
SCE	Southern California Edison

SCR	Special Case Resource
SDGE	San Diego Gas & Electric
T&D	Transmission & Distribution
TDRP	Targeted Demand Response Program

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INTRODUCTION

In the core of the change process that electricity industry has been facing in the last years is the emergency and diffusion of new technologies. Among the technologies pointed out as key for the industry future is the Energy Storage Systems, especially the Battery Storage Systems (BSS) (SCHMIDT & SEWERIN, 2017; CARBON TRUST & IMPERIAL COLLEGE LONDON, 2017; EASE, 2015; IRENA, 2015; MICHELL & WOODMAN, 2010).

In the last few years, BSS have been target of many policies as well as regulatory actions in some electricity system have been trying to promote their diffusion in applications in electricity markets and electricity networks. Although many works study how adapt the current regulatory frameworks to allow the full integration of those technologies, they little consider BSS still need to be technological developed for applications in electricity industry and that such development is in part conditioned by the context in which it occurs (HERMEIER & SPIEKERMANN, 2018; CHIN & JOONKI, 2018; HAGAN, RUEGER & FORBUSH, 2018; IRENA, 2017; AEMC, 2015).

The BSS full adoption still requires their technological development for applications in electricity industry though they are considered mature technology in applications in other industries. The battery has potential to provide a wide set of services for various agents within electricity systems which imply into two kinds of problems for battery innovation process. The first has a technical nature: different services require different technical characteristics and different battery technologies (lead-acid, lithium ion based, flow batteries) have different potential to improve their performance in each of those characteristics. The second has an economical nature: it is hard for electricity industry agents to calculate the battery economic benefits since they use it for many services in the same time and those services have different mechanisms of remuneration. The last problem means the battery diffusion faces some challenges related to external factors to battery industry. The factors related to the mechanisms of remuneration of the services in electricity industry have their origins in the way in which the industry is organized, especially, in the way that the industry has been regulated since its restructuring process (CARBON TRUST & IMPERIAL COLLEGE LONDON, 2016).

In view of that, we study the influence of regulatory rules of Electricity Industry on the technological development of Battery Storage Systems adopting an institutional perspective of Sectoral Regulation (HALLACK & VAZQUEZ, 2017; HESS & OSTROM, 2007; WILLIAMSON, 2002). Our problem is divided into two questions related to the two problems for battery innovation process identified above:

i. Which aspects of the technological development of BSS can external factors to the battery providers (including the choices of the agents who demands BSS) influence? In other words, are the regulatory rules (through their influence on the decisions of electricity industry agents) able to affect the decisions of battery providers regarding the choice of battery type (e.g. lead-acid, lithium ion based, sodium based or flow batteries) to be developed or only the battery providers' choices regarding the technical characteristics (e.g. duration, capacity, efficiency, density) to be develop?

ii. How do the regulatory rules of the electricity industry influence the development of BSS?

To answer those questions, we use information available in US Department of Energy (DOE) Energy Storage Database, websites of battery providers, scientific papers, and technical reports from research laboratories, agencies, government organizations and consultancies. From that information, we propose and analyze five different regulatory scenarios.

The work is divided as following. In the first chapter, we try to understand the role of regulator and its rules in an industry facing technological changes, as well as we describe some of applied regulatory concepts used later. The chapter 2 analyzes the batteries technical characteristics as well as how their supply and demand (within electricity systems) have been taking shape in recent years. In the third chapter, we study how the regulatory rules of electricity industry can influence the development of battery. Finally, it is presented the main conclusions of the work.

1. THE SECTORIAL REGULATION THEORY

1.1. INTRODUCTION

Before analyzing how the regulatory framework of electricity industry can influence the development of Battery Storage Systems, we need to understand first the theoretical fundamentals of sectoral regulation in technological change.

The regulation can be studied under different aspects: economic, environmental, social, or legal. The economic regulation of an industry is usually analyzed using the market failure approach or the institutional theory perspective. The market failure approach gave rise the normative turned positive regulation theory based on the idea that governments should correct the markets when they have failures. In opposition, the studies of sectorial regulation under institutional perspective did not result in a consolidated institutional regulation theory. Indeed, the applications of institutional concepts and ideas have different approaches according to the view of the authors and their object of study. In many cases, the institutional concepts and ideas have merged with concepts developed under market failure approach giving rise to reductionist institutional approaches. In other cases, the view of sectorial regulation has changed dramatically: the regulator came to be understood as an important agent to ensure a specific good (or service) will be produced when it is a common-good (such as electricity, telecommunications, gas, or others network industries), for example (VAZQUEZ & HALLACK, 2018; BALDWIN, CAVE & LODGE, 2010; HEIJDEN, 2008; PONDÉ, 2005).

In this chapter, we adopt the sectorial regulation theory under the institutional perspective. We use the theoretical developments of Oliver Williamson and Elinor Ostrom. We try to understand the role of regulator and its rules in an industry facing technological changes. Further, we aim to describe some of applied regulatory concepts that will be used later, that is, some regulatory tools used in network industries.

To that end, we use information available in Regulation Handbooks, scientific papers and reports of Public Agencies (e.g. OCDE and Regulatory Agencies). Our theoretical framework is based on the following works: Williamson (2002, 2000, 1985, 1979), Hess and Ostrom (2007), Ostrom (2011, 2010), Ostrom Gardner and Walker (1994), Dosi (1988, 1984, 1982), Freeman (2002), Freeman and Perez (1988), Hallack and Vazquez (2014), Vazquez and Hallack (2017), Di Castelnuovo and Vazquez (2018), and Kunneke (2008).

After this introduction, in the next section we expose the theoretical framework of Williamson (2000) and Hess and Ostrom (2007) that explains the institutional levels to identify where the regulation fits. We explain with more detail the governance level using Williamson (1985, 2002) in third section. After that, we discuss the main functions of the regulation in a network industry as well as we present some applied regulatory concepts used in chapter 3 (fourth section). In sections 1.5 and 1.6, we study how institutions and technology evolves for then we briefly discussed the role of the regulator in a context of technological change in sixth section. Finally, we present the main conclusions in section 1.8.

1.2. THE INSTITUTIONAL THEORY

The concept of institution has many definitions. Those definitions identify in somehow institutions as a regularity of behavior or as a type of structure that generates this regularity. This regularity standardizes or coordinates the interactions of agents within a socioeconomic context. Those agents in turn have their own beliefs and expectations of how the other agents behave and how the context in which they interact works. In this way, institutions can be understood as constraints created by human that structure their economic, social, and political interactions. In other words, institutions are rules established by different agents of a socioeconomic context that shape the interaction process of those agents (PONDÉ, 2005; NORTH, 1995; LANGLOIS, 1986).

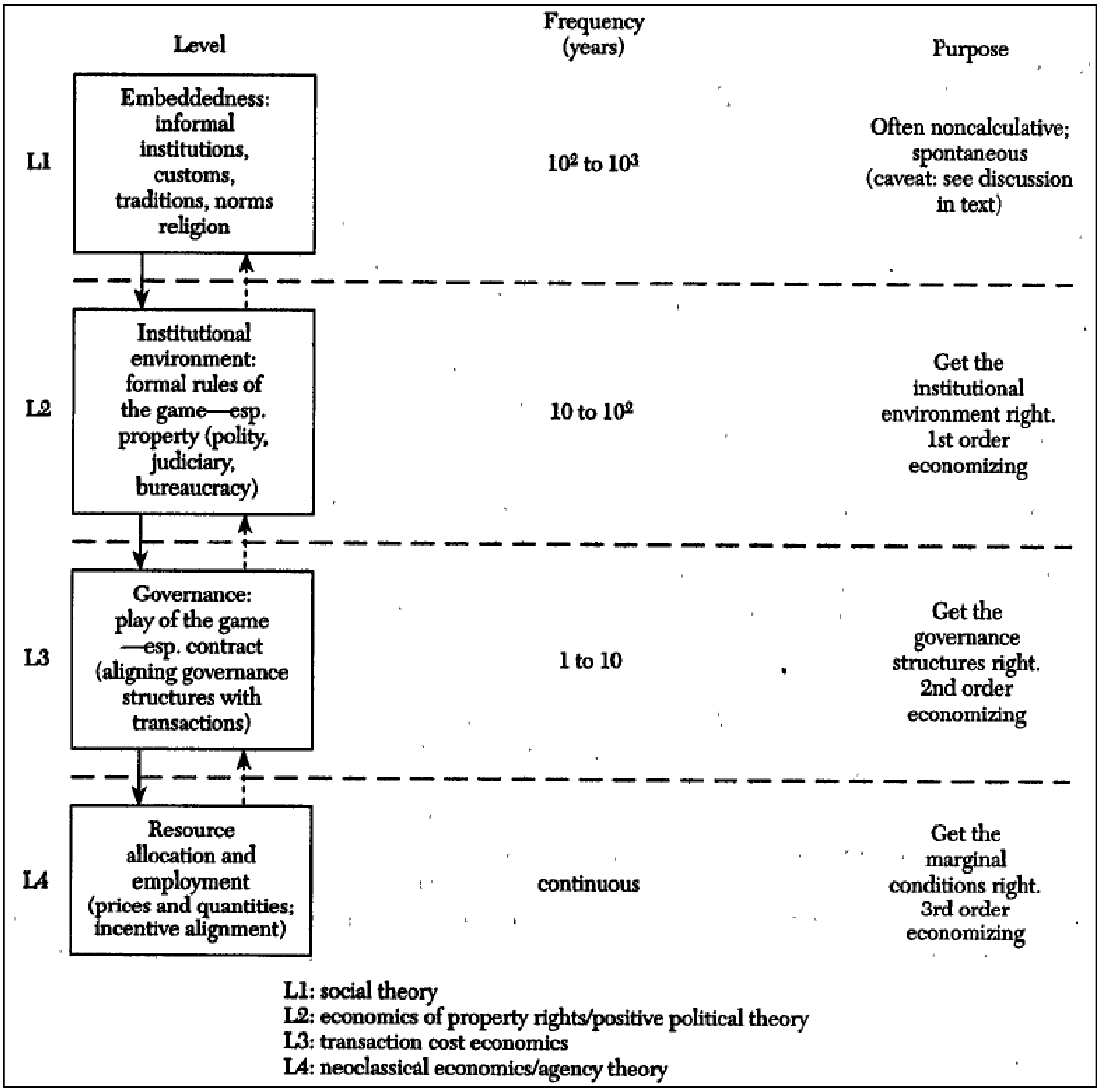
Hess and Ostrom (2007) define rules as the prescriptions of what players can and cannot do, what they must or mustn’t do, and the penalties in the case of the rules are broken. Each interaction among two or more players or between an agent and a physical aspect follows a set of rules. That set of rules can be small or big having rules that can be universal for all agents or specific to a set of agents in a specific situation.

From that, Hess and Ostrom (2007) and Williamson (2000) argue the rules can be studied from different analytical levels. Hess and Ostrom (2007) identify three different levels:

i. Operational Level: the agents make their daily decisions basing on the interactions between them and the physical aspects of the relevant world.
ii. Collective Choice Level: the interaction process occurs to establish rules for a specific operational level.
iii. Constitutional Level: the agent or the set of agents that can (or should) participate in the choices of collective choices is defined.

Williamson (2000) in turn works with four levels (as figure 1 shows):

Figure 1: Institutional Analytical Levels



Fonte: Williamson (2000)

shows):

i. “Embeddedness”: level that represents the constitutional level being composed by informal rules (sanctions, taboos, customs, traditions and codes of conduct). They have pervasive influence on the economic behavior of societies. They generally emerge spontaneously and are consolidated over centuries and millenniums. Their change process is slow taking centuries and millenniums.

ii. “Institutional Environment”: it is also equivalent to constitutional level in Hess and Ostrom (2007) classification, but is formed only by formal rules (constitutions, laws, property rights). The formal rules restrict the interactions at the levels below, defining functions of governments and the distribution of property rights and power among the agents of a society. The process of change of formal rules is faster than the previous level taking decades or centuries.

iii. “Governance”: it is equivalent to the Collective Choices Level. Its change process take years or decades.

iv. “Resource Allocation”: level equivalent to the Operational Level. It is the level where the best allocation of the resources is made. The process of change at this level is fast changing with the process of continuous interaction between the agents and between the agents and the environment.

Each of those levels has its own development trajectory and this trajectory is influenced by other levels. The four levels interact among them in both directions: the Resource Allocation to Embeddedness and Embeddedness to Resource Allocation.

In view of that, public policies can act in more than one level. Regulator operates in two different levels. The regulator interacts with other agents at Resource Allocation Level (or Operational Level) characterized as an uncertain environment under the influence of rules established at the above levels. At superior level, the Regulator is also responsible for establishing rules that will define the transactions in the regulated industry being an agent at the Governance Level (VAZQUEZ & HALLACK, 2018).

Many works of regulation try to establish an ideal regulation from the institutional theoretical developments at Governance Level since the problems of contract definition and enforcement, and of conflict resolution mechanisms are discussed at this level of analysis.

Considering that, we describe in more detail the Governance Level for after that to expose the discussion of sectorial regulation.

1.3. THE GOVERNANCE LEVEL

The studies of Governance Level are known as being the object of study of the Transaction Costs Theory. The Transaction Costs Theory has as unit of analysis the transactions. A transaction is the event that occurs when economics agents transfer a good (or service) through a technologically separable interface. The transactions can be study as a contractual relation that involves an interactive process and inter-temporal behaviors between two or more agents. These agents are characterized by having bounded rationality and opportunistic behavior, while the environment of interaction between the agents is characterized by uncertainty (WILLIAMSON, 1985).

Bounded rationality is defined as bounded cognitive capacity of decision-maker agents due to their inability to know all information and the occurrence probability of the events, and to calculate all consequences of their decisions. In this way, the agents' decisions are not only determined by their rational cognitive processes, but also by their experiences, the characteristics of the environment, the behavior of other agents, and their perception and expectation of the characteristics of the environment and behaviors of other agents (KANNEMAN, 2003; SIMON, 1979). The presence of bounded rationality means the contracts are always incomplete and the coordination of the economic actives cannot be made ex-ante (WILLIAMSON, 1985).

Opportunistic behavior is defined as the behavior that agents may have to cover up or distort relevant information misleading, disturbing or confusing the other agents during the interaction process. It may imply in difficulties to some transactions occur due to the possibility of gain of one part at expenses of another involved in the contract when a situation which the contract does not cover happens (especially, when the bargaining power between the parties is unequal) (WILLIAMSON, 1985).

Uncertainty is analyzed differently by the authors. Dequech (2001) argues there are two main kinds of uncertainty: the procedural uncertainty that arises from the complexity of the environment regarding the cognitive capabilities of the agents; and the substantive uncertainty that arises from insufficient quantity or quality of information that would be necessary to agents make their decisions with certain outcomes. The substantive uncertainty can be divided in probabilistic terms into weak and strong uncertainty. The first is characterized by the absence of unique, additive and fully reliable probability distribution, and the second by the absence of a distribution. The substantive strong uncertainty is in turn divided in ambiguity or fundamental uncertainty. Ambiguity is the uncertainty about probability due to missing information that could be known, while the fundamental uncertainty is the possibility of non-predetermined changes occurs.

The characteristics of the transactions between the agents determine the way they will interact or will be coordinated, that is, the characteristics of the transactions determine the governance structure. The governance structure is defined as a matrix of rules in which the transactions are negotiated and executed. Markets and hierarchies are two examples of "pure governance structures". Between them there is a large set of intermediate structures that can be more or less complex. Their characteristics are reflections of the characteristics of transactions that they coordinate. In this sense, the main idea of the transaction costs studies is the most economical governance infrastructure will be defined for each description of a transaction.

Considering that, Williamson (1979, 2002) identifies three essential attributes of transactions to define the governance structure: frequency, uncertainty and assets specificity. The frequency at which the transaction occurs determines the degree of complexity of the contractual relation: a transaction which occurs many times justifies the creation of a more complex and specialized structure.

In the same way, the degree of uncertainty will determine the efforts of the agents to establish contractual relations that allow ex-post adjustments and renegotiations (WILLIAMSON, 1979; 2002).

Finally, the greater the specificity of the transacted assets, the greater will be the complexity and specificity of the contracts relations. The asset specificity is a fundamental concept in this theoretical framework. An asset is considered specific when they cannot be used for another purpose without a significant loss of its productive and/or economic value when contracts have to be interrupted or prematurely shut down. They take various forms (physical, human, site, dedicated, brand name, among others) and can emerge from four situations:

i. Acquisitions of dedicated equipment to offer (or consume) the transitioned goods (or services).
ii. Expansion of production capacity to meet the specifics needs of one part.
iii. Need for geographical proximity between the parties combined with costs of transferring the production units if there is a change in the demand or offer.
iv. Existence of different forms of learning.

Specific assets is a measure of bilateral dependency of a transaction since the interactions between the agents became personal and non-instantaneous increasing their coordination costs (WILLIAMSON, 1979).

In the last decades, the concepts developed by transaction costs theory have been applied empirically. One of the most prominent areas of application is the study of public policies, especially antitrust and regulation (WILLIAMSON, 2000).

Additionally, Hallack and Vazquez (2014) and Vazquez and Hallack (2016) argue the study of regulation of network industries (our object of study) must consider the concept of common resource developed by Ostrom (2010) and Ostrom, Gardner and Walker (1994). It is explained by the fact that the network infrastructures (e.g. electricity, telecommunication, gas and water networks) can be classified as specific assets of common use (HALLACK & VAZQUEZ, 2014).

The network is a common resource. Common resources are defined as resources with high subtractability and low exclusivity. Subtractability (also known as rivalrousness) occurs when the consumption of a resource by one person reduces of other agents' consumption. The excludability in turn refers to the possibility of exclude the consumption of some agents (OSTROM, GARDNER & WALKER, 1994).

The transactions that occur around a common resource often create the possibility of occurrence of the problem of tragedy of the commons. This problem is defined as a situation in which a common-pool resource is exhausted as resulted of the maximizing of individual utilities rather than the maximizing of community utility due to the difficulty and/or high cost of exclusion of potential users from resource use that yields positive benefits (HALLACK & VAZQUEZ, 2014; OSTROM, GARDNER & WALKER, 1994).

The need to establish rules for the utilization of a common infrastructure to avoid that problem originated theoretical developments about Sectorial Regulation in network industries (HALLACK & VAZQUEZ, 2014).

1.4. THE THEORY OF SECTORIAL REGULATION

From the previous sections, we identify that regulation has the legal responsibility of determining the governance structure that define and coordinate a set of important transactions between the agents of the industry.

In this perspective, a regulatory regime can be understood as an institutional regulatory structure and assignment of responsibilities for carrying out regulatory action. The institutional regulatory structure comprises a set of rules that prescribe expected behaviors or outcomes, standards, mechanisms for determining the regulatory compliance, and sanctions for failures to comply with the established rules. It as other governance structures is specific to each industry and to the geographic, political, social and economic context in which it acts (HEIJDEN, 2008; MAY, 2007).

The developments of regulation theory based on institutional concepts and in the experiences of network industries (specifically, electricity industry) have been concentrated into main problems: the definition of market designs and regulation of the infrastructure owners (through of the definition of tariff design). The next two subsections study with more details some regulatory developments that emerge from the application of institutional concepts on those problems (DI CASTELNUOVO & VAZQUEZ, 2018; WILLIAMSON, 2002).

1.4.1. The Market Design

One fundamental aspect of regulation theory is the definition of the market design. The market design is nothing more than the governance structure that coordinates the process of trading of goods and/or services by a set of socioeconomic agents. According to what was seen in the last section, for each transaction there is an efficient governance structure defined as a function of the characteristics of it. In this sense, we can conclude that given the characteristics of the transactions that happen in an industry, there would be an efficient regulatory market design (or a set of efficient regulatory market designs).

As well as the definition of the governance structures occurs naturally with the interaction processes of the agents, the definition of the market design in many industries occurs naturally during its consolidation process over the time. Nevertheless, in the case of network industries, the definition of one particular governance structure is not a "natural result" of the process of consolidation of the industries. Indeed, the choice of the market design is imposed on regulated agents.

In view of this, the regulation theory tries to identify the best market designs (and tariff design) given the characteristics of network industries. Two theoretical models of market design are described below.

1.4.1.1. Centralized Trading (or Auctions)

In this market design, the trading is organized around a uniform-price auction that occurs some time in advance of the physical delivery of the product. The idea is the bidders send bids specifying the price required for selling its product (or products); then the auction's runner will determine the product price and the bidders who will provide the product according to pre-established criterion. There are four types of auctions: the ascending-bid auction (in which the price raises until only one bidder remains); the descending-bid auction (that works in the opposite way of the first), the first-price sealed-bid auction (in which each bidder submits a single bid without knowing the others' bids, the product is sold to the bidders who makes the highest bid); and the second-price sealed-bid auction (is like the first-price sealed-bid auction but the product is sold for the bidder with the second highest bid) (OCDE, 2001; BOWER & BUNN, 2000; KLEMPERER, 1999).

The characteristics of the auctions vary in function of the product being marketed and the context in which they occur. For example, the basic idea of auction mechanisms in electricity systems is to select the cheapest bid offered by the sellers defining the commodity prices (OCDE, 2001; BOWER & BUNN, 2000).

The auctions can be described as multi-unit (in electricity auctions, many megawatts are purchased in each moment of the time in each auction) and as multi-product (the amount of electricity services needed to meet the demand are purchased in the same time in each auction) (DI CASTELNUOVO & VAZQUEZ, 2018).

Considering that, we summarize three auction models:

i. Simple Auctions: they disregard the multi-product feature. There is one auction for each hour where the bidders send bids specifying a price for selling any possible quantity. The price and the product provider will be selected independently for each hour.

ii. Sequential Auctions: they regard the multi-product feature. In those actions, for each product, the bidders send bids specifying its price for selling a determined quantity.

iii. Complex Auctions: the bidders send bids that specify the price for amount of each product as well as a set of other conditions (for example, technical constraints or start-up fees that are designed to reimburse the fixed start-up costs of the generation plants) (KATEHAKIS & PURANAM, 2012; BALTADOUNIS, 2007; KLEMPERER, 1999).

In electricity centralized trading the role of System Operator (or Transmission System Operator) are fundamental. They are independent entities founded as objective to manage the auctions and the network constraints to allow the well operation of the electricity markets (as will be described in chapter 3). They are responsible for the allocation electricity services determining the dispatches based on merit order of bids or costs (OCDE, 2001).

1.4.1.2. Decentralized Trading (Bilateral Trading or Continuous Auctions)

In the Decentralized Trading, the commodity trade occurs through contracts between the commodity buyer and seller. For each bilateral contract, it is established the conditions of the commodity provision according to the needs of the buyers. The contracts specify the amount and price of the product and when the trade will take place. Since the prices are negotiated, in bilateral model there is less price volatile than in auction model. Moreover, this model has more flexibility than the centralized trading model since the parts can consider their specifics needs in the negotiation process.

One of the main differences between bilateral and centralized trading models in electricity industry is the role of System Operator. The decentralized trading model relies on the self-dispatching of the agents which makes it not compatible with a centralized optimization of dispatch. The system operator is constrained in scheduling by the negotiated contract price and volumes between the agents. On the other hand, the technical constraints of the moment of network use cannot be known in advantage. Thus, these constraints are not included in the contracts which imply in the need for the system operators or transmission operators to manage the network use (DI CASTELNUOVO & VAZQUEZ, 2018; BOWER & BUNN, 2000).

Further, we stress the bilateral and centralized trading models can coexist and even compete, though not always the prices determined bilaterally have influence on spot prices (OCDE, 2001).

1.4.2. Network Regulation

The study of network regulation can have as focus various aspects including the quality of the services provides and tariffs. In electricity industry, the quality is directly related to the system reliability. The Regulator here can establish the minimum technical requirements necessary for the systems to operate with a certain level of reliability that must be met by both network owners and users (OCDE, 2001).

The tariff design is considered the most fundamental aspect of network regulation. Due to the characteristics of network investments, the main tool to coordinate incentives for the provision of network services is the long terms contracts. These contracts establish the commitment among the infrastructure investors and users. Nonetheless, once the investment in network has high fixed costs, normally, the network investors are monopolists having bigger bargaining power than the users. It is the principal challenge faced by network regulation.

That challenges imply in two different problems that must be managed by network regulation. The first is a long-term issue regarding to how provide incentives to network investments. It is treated by revenue regulation. The second is how allocate the costs of a network investments when there is scarce capacity among different customers. It is a short term issue that leads to a price-setting discussion (DI CASTELNUOVO & VAZQUEZ, 2018; OCDE, 2001).

The revenue regulation is also known as revenue cap regulation. The traditional revenue regulation consists in the Regulator setting the level of revenue that the firms are allowed to collect. The main idea is the level of revenue allowed would be equal to the aggregation of the all firm’s costs. In their costs are included the operational costs, the cost of capital invested to provide the services (considering a “fair” return rate of the investments made), and a depreciation allowance that represents the repayments to investors of their loans and investments.

The revenue regulation is usually adopted with a decoupling approach. Decoupling is a tool used to ensure the allowed level of recovery of the firm's cost will not be a function of its sales volumes. In other words, it intends to eliminate the incentives of the firms to increase their profit through the increase of their sales.

When the regulator determines the tariffs for the services provides, they have to first compute the total cost of the services (or the revenue requirement) to then determine the necessary rate (tariff) that will be charge to network users to collect a determined revenue level (RAP, 2011).

The definition of network tariffs provides incentives for network users. The main issue faced by regulator is how to allocate among different customers the network costs. In presence of congestion, the organization of the allocation of network capacity can affect negatively the utilization of the network by others agents of the industry. Three main aspects are considered in the process of definition of network tariffs:

i. Capacity: definition of how the capacity which actually is used will be charge.
ii. Location: definition of how locational aspects will be charge.
iii. Flexibility: definition of how the capacity used with flexibility will be charge (DI CASTELNUOVO & VAZQUEZ, 2018).

Considering those dimensions, many pricing methods have been developed in the lasts decades. Indeed, in each region, the Regulator can determine a tariff with a specific structure of network prices to deal with the particularities of the regulated network.

A tariff can be composed by fixed connection charges, capacity charges and volumetric charge. The first is a determined fixed value. It is charge to recover the costs of connection of the user with the network infrastructure. The capacity charge is also fixed value that recovers the costs of providing sufficient capacity to meet demand. It is usually based on the user consumption pattern: for example, the electricity capacity charge is determined by the level of electric capacity (in Kilowatt) that the customers usually need to be delivered per month. Finally, the volumetric charge is a value charged by the consumed units of the good (or service) that recovers the operational costs of providing the good (or service). An electricity volumetric tariff is determined by amount of energy in kilowatt-hours (kWh) transported. The combination of the second and third charges creates two-part tariff that are composed by a fixed charge plus a charge per unit. Furthermore, each of those charges can be determined separately for each location or type of user (KARP, 2017; OCDE, 2001).

There are two main approaches to determine the price of network services according to locational dimensions (OCDE, 2001).

The first is to determine non-transaction based tariffs (or point tariffs) that are independent of commercial transactions that originated the need to use the infrastructure of transport. They are designed to reflect the costs of using the infrastructure. They are function only of the amount of good injected or taken from the network in each local. It makes them more capable to manage congestion. Nodal tariffs, zonal tariffs and postage stamp are example of point tariffs. The nodal tariffs determine the price for each nodal (or point) of the system. Often, they are completed with fixed charge. They reflect the relative scarcity of network capacity at each node, then the charge paid by network users are relatively more expense at the nodes in which there are not enough capacity available. It provides incentive for network investors to increase capacity in those nodes. Zonal tariff is a version of nodal tariff. The system is divided into zones being each zone composed by a set of nodes. The tariffs are determined as the average of the congestion costs of the nodes that compose each zone. Postage Stamp tariff is a flat rate. It is set over pre-specified time periods. The users can use different nodes of the system to inject and taken their product. It implies non-price methods have to be applied to manage congestion whenever it arises.

The second is to define transaction based tariffs (or point-to-point tariffs) that are set by each individual transaction. The common forms of this type of tariff are the Contracts Path Pricing in which the prices are set for each network of the system (e.g. each electric transmission or distribution line); and Distance-Related Pricing in which the prices are determined on amount of kilometers used of the network (OCDE, 2001).

In the process tariff design, the definition of incentive pricing mechanisms can be adopted to increase the cost efficiency of regulated firms. As example of this king of mechanism, there are the "price cap", sliding scale regulation, and the yardstick and benchmark pricing. The "price cap" is set to cover the past costs of the firms plus a return rate on the investment made minus a factor X of the costs. If the firm reduces its costs more than X, the firm will be allowed to retain all the additional profits. In the sliding scale, the regulator determines a price cap but the firms are allowed to retain only a fraction of the profits obtained. The yardstick and benchmark pricing mechanism is to establish the price equal the estimated cost of providing the same services by other firms (OCDE, 2001; ALEXANDER & IRWIN, 1996).

Summarizing, considering the concepts of rules of Hess and Ostrom (2007) and the institutional levels defined by Williamson (2000), we have seen the Sectorial Regulator operates at two different institutional levels: the regulator interacts with the industry agents which result in some decisions (Level of Allocation); and determines the industry regulatory framework, that is, the set of rules that agents must follow that coordinate the agents transactions (Governance Level). The theory of regulation tries to identify the governance structures are more appropriate given the characteristics of the agents, the regulated industry, and of the characteristics of the transaction between the agents and the characteristics of industry. In the case of network industries (our object of study), regulation theory discusses governance structures regarding two main aspects: market design that coordinates the way agents trade, and network regulation or tariff design that coordinates the common resource use and investment.

Among the characteristics considered in the process of definition of that regulatory framework is the technological attributes of the industry. However, technology is by nature dynamic: it transforms itself over the time as well as the context in which it is inserted. In other words, the process of technological change occurs together with the change of industry rules.

Before we discuss the dynamic interaction between rules and technology, we need to understand better the process of change over the time of institutions and technology. We use the Institutional Analysis and Development Framework developed by Ostrom (2011; 2010) to study the process of change of institutions and the concept of technology developed by Dosi (1988, 1984, 1982).

1.5. THE INSTITUTIONAL DYNAMIC

Institutions can be considered rules that restrict and prescribe the human interactions. Thus, studying the process of emergence and transformation of the rules is the same that study the institutional change. Hess and Ostrom (2007) and Ostrom (2011; 2010) propose a framework capable to identify the elements of the change process of the rules in a dynamic environment. Figure 2 presents this framework called Institutional Analysis and Development (IAD) Framework. The IAD Framework is divided into three types of structural variable.

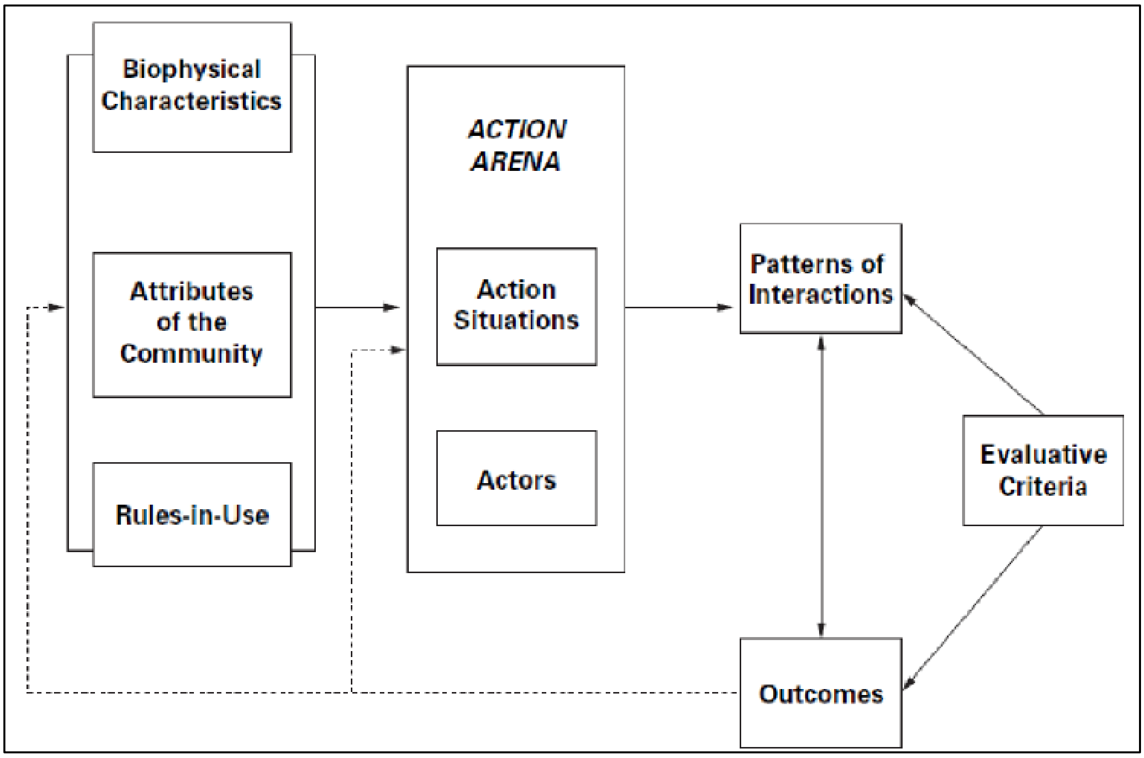
i. The characteristics of the resources: biophysical characteristics, attributes of the agents involved, and rules already established.

ii. The arena of action in which occurs the interaction between the agents and the characteristics of the resources.
iii. The interaction patterns between the agents and the observed results.

The authors argue that it is possible to analyze systematically different situations and problems as well as the implementation of public policies from the description of those structural variables, the process of interaction between them, and form the outcomes of the interaction process.

The main idea is the characteristics of the resources (that are given initially) interact in an action situation. The action situations are the social spaces where the agents can interact and with the physical attributes, trading good and services, solving problems, among other actions. Some patterns of interaction that lead to specific outcomes emerge from this interaction process. Those outcomes in turn can lead to changes in the characteristics of the resources which become endogenous to the system.

Figure 2: Institutional Analysis and Development Framework



Source: Hess and Ostrom (2007).

Applying this framework in the study of change of the rules, we see it is a result of complex process of interaction. The interaction of those rules with the biophysical attributes of the resources and characteristics of the agents lead to their own change process, that is, the outcomes obtained in this interaction may lead to changes in the same rules that generated them. Further, the change of rules can be seen reactive to changes in the context they are acting (that is, changes of biophysical characteristics or the attributes of the agents involved in the transactions). On the other hand, the changes of the rules can be seen as factors of changes of this context.

The last aspect is particularly important when we are considering technological dynamic, that is, changes in physical characteristics. As pointed out by Williamson (2000), North (1995; 1991; 1990) and Kunneke (2008), the interaction among technology and institutions are a fundamental aspect to comprehend the institutional change in the current economies. In the next section, we study with more detail the definition of technology and the technological innovation.

1.6. THE TECHNOLOGICAL DYNAMIC

The neoschumpeterian theory has been building based on idea that the emergence and diffusion of new technologies are responsible for the process of transformation of capitalist economies. In that theory, the technology is understood as a set of knowledge (practical and theoretical), methods and procedures, experiences (of successes and failures) and physical equipment and devices. The technologies are created with the purpose of solving a specific problem that may be of different natures (technical and scientific, social, political or institutional) (FREEMAN & PEREZ, 1988; DOSI, 1982).

From this, Dosi (1988; 1982) define the idea of Technological Paradigm. It is a model of solution of specific techno economic problems based on principles derived from the natural sciences. This model is composed by technical-economic trade-offs. Those trade-offs define the possible directions of the technological development of one technology. Technological trajectories are the innovation actives that occur within the trade-off defined by a paradigm, that is, they are the different ways one technology can develop technically.

The technological trajectory defines what firms need to do to develop their technologies. In other words, the routines of the firms are partly defined by the conditions of the technology and its development potentials (KUNNEKE, 2008).

In a neoschumpeterian theory, firms are the main agents responsible for the development of new technologies (LUNDVALL, 2005). Firms' decisions are made according to their routines. The routines are defined as patterns of behavior that are the result of an interactive process among agents with different cognitive abilities, social structures and administrative pressures inside the firm’s walls. They can be considered a set of rules that define how the day-to-day operation and management of production and development of technologies will be carried out.

On the other hand, the occurrence of day-to-day operation and management of production and development of technologies redefines the firm's routines. The routines in turn selects partially the technological trajectories will be developed (KUNNEKE, 2008).

In this sense, Dosi (1988; 1984) argues the choice (or emergence) of a specific trajectory over others is the result of two selection processes. The first is an ex post process: the market selects the trajectories will be developed. The second process of selection is ex-ante. In the process of searching for new technologies, firms decide which characteristics of the technology have to be developed and how they will do that based on: (i) their core of competencies and experiences, (ii) the set of available information, and (iii) the attributes of technology in respect to existence of technological opportunities, and degree of cumulativity and appropriability.

Therefore, routines are rules that work as a mechanism of selection (ex-antes) of technological trajectories within firm walls. Once a technological trajectory has been chosen, the final characteristics of a primitive version of the technology that will compete with others technologies in the market are defined (DOSI, 1988).

In view of that, Kunneke (2008) proposes that the technological practice[1] can be classified according to its frequency of change and analysis level, just as the institutional levels. The operation and management level has a high frequency of change. The routines have a lower frequency of change than them, but they change faster than the technological trajectory. The technological trajectory in turn has a faster speed than a technological paradigm.

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[1] The technological practice is define by Kunneke (2008) as the way in which technological artifacts are planned and operated in order to meet human needs.

Further, it is also necessary to point out that technology interact with other elements in the socioeconomic system. This interaction influences the firms' routines and their decisions regarding the development of new technologies as well as the institutional development (LUNDVALL, 2005; FREEMAN, 2002; NELSON 1992; NELSON & NELSON, 2002). Freeman and Perez (1988), and Freeman and Soete (1997), classify technological change into four types according with their effects on the institutional environment:

i. Incremental Innovations or continuous improvements that are usually associated with lower production costs.

ii. Radical Innovation is associated to the emergence of new technological paradigms, that is, they are discontinuous leaps in terms of technological development.

iii. New Technological System that is a set of new disruptive technologies whose diffusion process affects an industry or a limited set of industries (replacing or creating industries).

iv. New Paradigm or Techno-Economic Paradigm that is changes in the technological base of the economies, that is, a new set of key technologies with high pervasiveness emerges and diffuses creating new paradigms and establishing new development trajectories for decades.

As Freeman (2002) and Nelson and Nelson (2002) point out, the technological development is only possible if it is accomplished by institutional changes. In this way, the more disruptive the technology is, the greater is the need for transformation of the current rules for its development within the system may occur. Thus, internal and external rules matter for development of a new technology.

1.7. THE COEVOLUTION BETWEEN INSTITUTIONS AND TECHNOLOGY: WHAT IS THE ROLE OF REGULATOR IN A CONTEXT OF TECHNOLOGICAL CHANGE?

From the previous sections, two facts can be highlighted. First, the institutions and technologies can be analyzed according to levels of pervasiveness and frequency of change. It means the study of the transformation of rules and technologies over the time must consider not only the characteristics of change of their levels, but also the influences of which happens in the lower and higher levels. Indeed, as point out by Vazquez and Hallack (2018), these levels are crucial to understand how institutions and technologies evolve. The change process of both rules and institutions are explained by micro and macro transformations movements: the big set of transformations (institutional or technological) that often occur at lower levels of analysis influences the slow changes at higher levels, and vice versa.

In this sense, Pondé (2005) argues that just as technological change, the institutional change can be understood from a process of evolutionary competition. Applying Ostrom’s concepts to that idea, it means the different changes at lower levels create an almost infinite set of microeconomic patterns of interactions and outcomes that are restricted by rules in use (or technological practices in the case of technologies) at higher levels. The “allowed” outcomes in turn lead to the continuation of the change process of initial rules (or technologies) in the lower levels. In the same time, these outcomes in their consolidation as the expected pattern create need to adapt or create new rules of higher levels (or create patterns of development of the technological paradigm or even lead to the emergence of new paradigms).

Second, if on one hand, the change of rules can only be understood as result of a continuous process of interaction between the rules and the attributes of resources (including the technological aspects). On the other hand, technology is in constant transformation and among the determinants of this transformation process are institutional factors.

1.7.1. Coevolution between Institutions and Technologies

From these two facts, we conclude the process of institutional and technological coevolution is the process in which the rules and technologies (a physical aspect of the resources) interact continuously resulting in their transformation over the time. In that process, there is not a defined and unilateral relation of causality: changes in rules lead to changes in technology while changes in technologies lead to changes in rules (FREEMAN, 2002).

The process of change of the rules is understood as a result of the interactions with the characteristics of the agents that provide and consume the technology, and the characteristics of the technology itself. The characteristics of the technology change over the time as result of the dynamic of accumulation of scientific knowledge (and its applications in a specific problem), and of the decisions of firms. The decisions of firms regarding their routines and operations of development of new technologies in turn are determined based on its technical competences and experiences; the characteristics of the technologies in development, and their interactions with resources attributes, characteristics of agents outside the firms' wall (as the technology consumers) and the rules in use.

However, the change process of these rules as well as of the technological practice has its own velocity of change. Therefore, the velocity of change of rules considering that the coevolution between institutions and technologies is determined by: (i) their interactions with the physical attributes of the technology and the characteristics of technological providers and consumers; (ii) the process of change of rules and technological practices in other institutional levels.

1.7.2. What is the Role of Regulator in a Context of Technological Change?

Considering that, Vazquez and Hallack (2018) and Kunneke (2008) argue that there is coherence between the institutions levels and technological practice levels (Table 1). Taking into account this coherence is fundamental to comprehend the change process of network industries whose regulation has an important role due the technical specificities related to the use and management of network infrastructures.

Table 1: Relationship between Action Situations and Institutional and Technological Levels

Action Situation Types	Institutional Levels	Frequency of Change	Pervasiveness Degree	Technological Practice
Constitutional Level Situations	Embeddedness	+	+ + + +	Technological Paradigm
	Institutional Environment	+ +	+ + +	Technological Trajectory
Collective Choice Situations	Governance	+ + +	+ +	Routines
Operational-Level Situations	Resource Allocation	+ + + +	+	Operation and Management

Source: Elaboration based on Vazquez and Hallack (2018) and Kunneke (2008).

From now on, we restrict our study to the third level institutional (Collective Choice or Governance) to try to answer what is the role of regulator in a context of technological change. The Governance Level is the level where the governance structures are established which in practical terms means that the Sectorial Regulation determines the market design and the rules of network use and operation.

In the next subsections, we study the relation between the regulatory rules and changes in the four technological practice levels. Considering what was exposed so far in this section, we assume in our analysis:

i. Different levels of technological practice influence the emergence and consolidation process of regulatory rules (regarding the market design and network regulation);

ii. The process of emergence and transformation of regulatory rules is the result of interactions between them and the technology characteristics, that is, the regulatory rules interact with the technological aspects creating specific results, the regulator then based on these results determines if new rules should be created or the old rules need to be adapted to new action situations.

1.7.2.1. Relation between Regulatory Rules and Changes of Technological Paradigm

As Freeman and Perez (1988) point out, there are four innovation types. The emergence of new meta-paradigms, or technologies that affect one or more industries can imply in changes in technological base of the regulated industry. In this way, the physical attributes of the industry changes radically. These types of innovation are resulted of a confluence of different factors ranging from purely scientific advances to the realization of public policies.

A new paradigm may imply in the complete redefinition of the regulatory framework during its development process. In theory, the need for regulation might even cease to exist in the end of that process.

In this context, we consider two cases. In the first, the regulated industry is affected by the diffusion of the new technology (or the set of new technologies) that are “born” in other industries. In the second, the regulated industry is the “birthplace” of the new paradigm.

In the first situation, the element of change is completely exogenous to initial interaction process in which the regulator participates and makes her decisions. The new paradigm lead to a leap in the physical attributes of the industry. It changes the outcomes of the industries creating the need for regulatory adaptation. The adaptation of the regulatory framework take a while to occur once the regulator is an agent with limited rationality and these types of innovations imply in an extreme degree of procedural and substantive uncertainty. Nevertheless, although it delays, it cannot stop the diffusion of those technologies in the industry since the core factors that promote their development is outside the regulation jurisdiction.

In the second situation, the element of change is partially endogenous to initial interaction process. It means that, although regulator still don't have enough knowledge of the technology and there is uncertainty, the regulators have more information about the consequences of the diffusion of the new technologies than in the first case. It could speed up the adaptation process of the rules adopted.

On the other hand, adaptation process of the rules becomes important for the initial development of the new technology, so its delays can imply in a longer time of technological development of the new technology. In consequence of that, the lack of synchrony between the current rules and the technological capabilities may imply a situation of technological lock-in (the development of a new technology is blocked and old technologies are not replaced) (HESS & OSTROM, 2007; ARTHUR, 1989).

Further, we stress the emergence of new paradigms are accomplished by changes at the Constitutional Level. In that level is defined the regulatory design, that is, the rules that establish what the Regulators can and cannot do, what they must or mustn't do, and the penalties in the case of the rules are broken (HALLACK & VAZQUEZ, 2017). Therefore, the Regulation itself can be redefined in presence of strong technological change or the regulator's actions may be subordinate to the objectives of other policies (MICHELL & WOODMAN, 2010).

1.7.2.2. Relation between Regulatory Rules and Changes of Technological Trajectory

When the technology is "born" in the regulated industry, the regulation becomes an important factor in its technological development at least initially. As already mentioned, the choice of the technological trajectory defines how a technology (or paradigm) will be developed. This choice is selected ex-antes and ex-post (DOSI, 1984). The regulatory rules can be identified as an ex-post element of selection.

The regulation establishes the governance structure based on the characteristics of the transactions. The transaction in turn reflect the physical aspects of the good or service transacted (or the physical aspects of the production of this good or service). Thus, both the market and tariff designs are highly specific to set of specific technologies which are often already diffused in the industry (that is, in a mature phase of technological development).

Given that in its early stages of development, a new technology has not yet defined the technological trajectory (or trajectories) that will be developed, the established governance structures can work as an initial selection mechanism directing which technological trajectories would have more likely to succeed. In other words, the technological trajectories that can in some degree be transacted under the established rules would have more probability of being developed. Nevertheless, we stress out the rules in use are only one element among many others that define the technological trajectory that will be developed.

Further, it does not mean that for those selected technological trajectories there would not be changes in the technological basis of the industry and the need of adaptation the regulatory rules, but they reflect in some degree the established regulatory framework. It implies the process of change of technologies and regulatory rules has as one of its fundaments the own regulatory framework.

Thus, we conclude the degree of disruption of the technological change in a regulated industry is conditioned by the flexibility of the governance structures in force. By regulatory flexibility in turn, we refer (i) the ability of the rules to regulate a wide and different set of transactions within the industry, (ii) ability to adapt quickly to changes or possibility of changes.

Considering that, the more flexible the set of regulatory rules, greater the probability of development of technological trajectories that lead to radical changes. In contrast, insufficient flexibility can select the technological trajectory less efficient by a technological view (DOSI, 1988). It can lead to the degradation of own regulatory framework once the technological inefficiency can be reflected in the industry outcomes that are used to evaluate the regulation itself.

1.7.2.3. Relation between Regulatory Rules and Changes of Routines

As we saw in table 1, the Routines are in the same level of analysis of Governance. It means that, while the regulator is defining the set of rules that will coordinate the transactions of the industry, the firms are defining the rules regarding the way their technologies will be developed and produced.

The action of developing a new technology is considered a function of the firms. They interact with other agents, with the biophysical characteristics of the industry and with the regulatory rules (OSTROM, 2010). From this process of interaction, they create expectations about the chances of success or failure for the different patterns of development of the technology, that is, for different technological trajectories. Based on it and on their competences, experiences, and old routines; firms take their decisions of which technological trajectory will be developed as well as establish new routines. Once those new routines are established, the way in which the technology will be developed is also defined. Therefore, the new routines work as a selection mechanism for technologies that will emerge (HESS & OSTROM, 2007; LUNDVALL, 2005; DOSI, 1984).

In this context, the regulatory rules affect indirectly the definition of routines of the firms through its impact on the probability of success of the technological trajectories. As already mentioned in the previous section, the trajectories that better fit in the current regulatory framework will have more probability of being developed. The development of those trajectories in turn can imply in the need of redefinition or creation of new routines in the same time that can lead to changes in the physical attributes of the industry and the need of adaptation of the regulatory rules.

1.7.2.4. Relation between Regulatory Rules and Changes of Operation and Management

The firms' routines are rules that establish how the day-to-day operation and management of the actives of research and development occur inside the firms. The regulation's influence on those actives is indirect, as in the case of firm' routines. In the same way, changes in the daily operation and management actives can lead to changes in firms' routines that are reflected in the attributes of the technology which in turn led to the need of change of regulatory framework.

1.8. CONCLUSIONS

Understanding the role of regulator and its rules in an industry facing technological change under institutional perspective developed by Elinor Ostrom and Oliver Williamson imply in understanding first:

i. The Role of Regulator under the institutional perspective, that is, in which levels of institutional analysis the Regulator acts. The Regulator operates in two different levels with different frequency of change: Resource Allocation Level. At Governance Level, the regulation defines the rules that will coordinate the transactions in the regulated industry. The process of definition of those rules it is not immediate taking some time.

ii. The role of regulatory rules in the industry under institutional perspective. The regulatory rules give rise to a regulatory structure or governance structure of the regulated industry. Those rules are prescriptions of what players can do, must do, and the penalties in the case of the rules are broken. In network industries, they define how the agents trading and the incentive mechanisms for network investors and users. Further, the regulatory rules are not static changing over the time. The process of change of regulatory rules is result of a complex and continuous process of interaction of those rules with the characteristics of the agents and biophysical attributes of the resources that create patterns of interaction over the time that lead to the specific outcomes. Those outcomes in turn reveal the need for change in the rules.

iii. The meaning of technological change. Technology in terms of Hess and Ostrom (2007) are classified as a physical attribute of the industry. As the institutions, it can be study at different levels of analysis: the technological practices. Each level of technological practice has its own speed of change and means different degree of change in the industry characteristics.

In view of that, the sectorial regulation can work as a technology selection mechanism. However, we stress the regulator does not have control over the innovation process. The research and development of a new technology is made by firms as well as there are other factors that directly promote the technological change (e.g. the dynamic of accumulation of scientific knowledge). Further, the emergence of new paradigms can occur in other industries beyond the regulated industry.

Nevertheless, when the new technology aims to solve specific problems of the regulated industry, the regulatory rules become a crucial aspect in technology development process. The regulatory framework influences the process of choosing of the technological trajectories that will effectively be developed by the technology providers. Further, it does not mean that rules in force will not change: as the physical attributes changes, the need of adaptation of the rules becomes greater. In this sense, the degree of disruption of the technological change is conditioned by the flexibility of the regulatory structure. Hence, insufficient regulatory flexibility can create technological lock-ins. Those in turn lead to bad outcomes in the long-term which can create the need to redefine the regulatory framework itself at higher institutional levels.

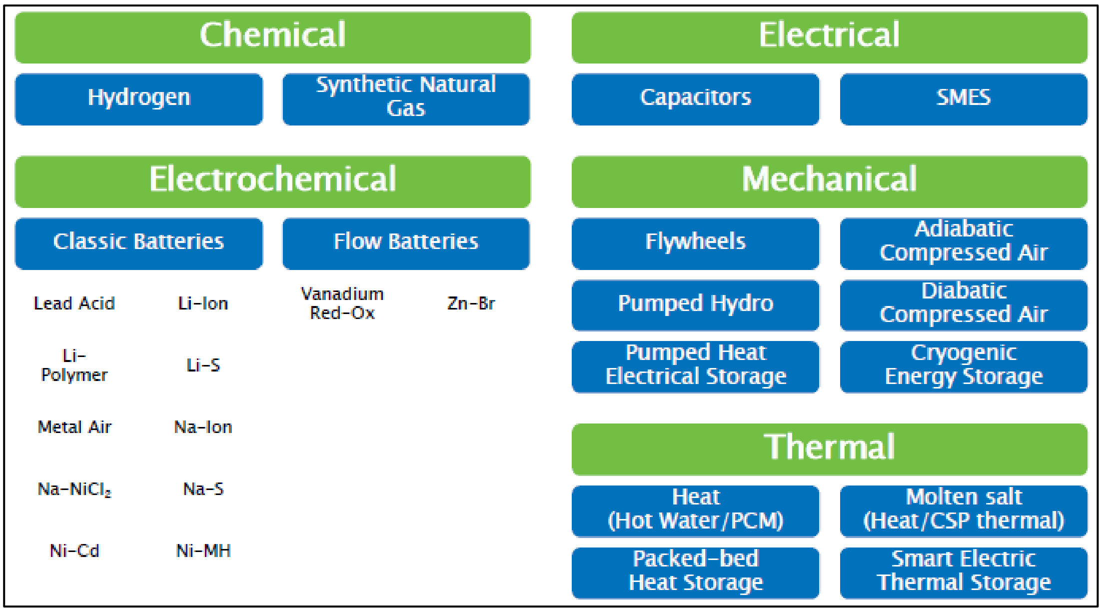
2. BATTERY STORAGE SYSTEMS IN ELECTRICITY INDUSTRY

2.1. INTRODUCTION

Energy Storage Systems are essential technologies in many industries including transport, medical devices, mechanical and electronics. Their production had consolidated inasmuch the demand of battery by those industries had emerged and grown throughout 20th century. They can employ different chemical and physical principles and are classified in diverse types (as shown in figure 3). Despite that diversity, in electricity industry only few types were effectively adopted before the last decade. The first effective applications of energy storage in that industry goes back the oil and gas price crises in the early 1970's, when the utilization of pumped hydro and compressed air storages as energy reserve became economically viable (where hydroelectric dams were not available). Nonetheless, before the development and application of others types of energy storage technologies (as batteries) were made, the interest in energy storage investments had fallen with the posterior decrease of oil and gas prices, and the increase of efficiency of flexible combined-cycle and simple-cycle natural gas turbines in the 1980's (DENHOLM ET AL., 2010).

The recent change process that electricity industry has been facing resulted in the emergence of the opportunity to expand the utilization of energy storage in that industry. It has been reflected in the increase of public policies that have as target the development and diffusion of those technologies in last years: the 6th Energy Research Program of Germany allocated a budget of EUR 3.4 billion for new energy technologies like energy storage between 2011 and 2014; the Cool-Energy Innovative Technology Plan released by Japan in 2008 elected energy storage as one of the 21 technologies to be financed; the American Recovery and Reinvestments Act (ARRA) signed in 2009 provide a budget of USD 2 billion in grants available to support battery manufacturing located in US (IRENA, 2017).

Figure 3: Energy Storage Classification by Chemical/Physical Principles



Source: EASE (2015).

Denholm et al. (2010) argue there are five factors that can explain the renewed interest in energy storage applications in the change process of the electricity industry: (1) development of deregulated energy markets (including markets for ancillary services); (2) policies that wish reduce fossil fuel use; (3) challenges to siting new transmission and distribution installations; (4) the need to new flexibility solutions due the increase of renewable generators; and (5) the recent technical improvement in some storage technologies.

Among the energy storage technologies pointed out as with the highest potential to be employed in electricity systems are Battery Storage Systems (BSS). They are considered more efficient compared with other energy storage technologies regarding lifetime, weight and mobility, scalability and round trip efficiency (KYRIAKOPOULOS AND ARABATZIS, 2016; SCHIMIDT ET AL., 2016; FEW, SCHMIDT AND GAMBHIR, 2016). They also represent almost all energy storage projects registered in DOE Energy Storage Database. Further, batteries have presented a downward trajectory of their costs falling from $1,000.00 per kWh in 2010 to $227.00 per kWh in 2016 (FRANKEL & WAGNER, 2017). In this context, it is expected batteries will reach economic viability for a large set of services for electricity industry in next decades (EASE & EERA, 2017).

The BSS full adoption still requires their technological development. The battery has potential to provide a wide set of services for various agents within electricity systems which imply into two kinds of problems for battery innovation process. The first has a technical nature: different services require different technical characteristics and different battery technologies (lead-acid, lithium based, flow batteries) have different potential to improve their performance in each of those characteristics. The second has an economical nature: it is hard to electricity industry agents to calculate the battery economic benefits since they use it for many services in the same time and those services have different mechanisms of remuneration. The last problem means the battery diffusion faces some challenges related to external factors to battery providers. The factors related to the mechanisms of remuneration of the services in electricity systems have their origins in the way in which the industry is organized, especially, in the way that the industry has been regulated since its restructuration process described with more detail in next chapter (CARBON TRUST AND IMPERIAL COLLEGE LONDON, 2016).

In this chapter we will concentrate in first problem.

The study of the development of a technology can incorporate several aspects (from the strictly technical ones to the social effects of its diffusion, or from the implementation of an incentive policy to the internal decisions and routines of technology provider firms). Generally, the studies of BSS in electricity system with a more technical view try to establish a relation between the battery types and the services that they can provide with more technical efficiency (FEW, SCHMIDT AND GAMBHIR, 2016; PALIZBAN AND KAUHANIEMI, 2016; U.S. DEPARTMENT OF ENERGY, 2013). In other words, if only technical aspects matters, then external factors (such the regulatory framework of electricity industry) that can influence the set of services BSS will provide would have effect on the types to be develop, as modeled by Schimidt et al. (2016).

Nevertheless, empirically, we observe the most of the projects that has been developed in last years are developing only four battery types: Lithium-Ion, Lead-Acid, Sodium Based and Flow Batteries. Those battery types are identified in the literature as having the highest potential for providing services in electricity system (FEW, SCHMIDT AND GAMBHIR; PALIZBAN AND KAUHANIEMI, 2016). Specifically, when we look the distribution of projects among the technologies, we observe more than 60% of the analyzed projects are Lithium-Ion Battery projects (a technology that has not yet reached the technological maturity). The dominance of Lithium-Ion Battery projects shows that may be more factors that are influencing the choice among the battery types that will be used in electricity system besides the technical efficiency[2].

In view of this, since our main purpose is to study the relation between regulatory rules and the battery innovation process, first, we need to identify which aspects are still "open" in BSS innovation process that could be affected by those rules, that is, the regulatory framework though the demand of BSS by the agents of electricity industry can influence the choice of battery type to be developed by firms or the choice of which technical characteristics of their batteries will be improved. In this sense, we need to not only comprehend the battery characteristics and the demand for that technology by electricity industry, but also the characteristics of battery supply. Since Battery Industry is already a consolidated industry, analyzing which factors have been taken into account in the decision-

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[2] Indeed, the recent development of the market of electric vehicles (EVs) and hybrid electric vehicles (HEVs) can explain the increase of the interest in utilization of lithium ion battery in electricity industry since this battery type dominates that market (as well as the market of electronics). However, in this point, our focus in this work is the applications of BSS in electricity industry. Thus, we analysis the different battery types with a pure technical view, that is, we analyzed the battery types with technical potential to be used in electricity industry applications. We not consider the success trajectories of them in other industries.

making process of battery provider firms is essential to comprehend their insertion in the electricity industry.

Considering that, in this chapter, we analyze the batteries technical characteristics as well as how their supply and demand (within electricity systems) have been taking shape in recent years. We start our analysis from the data about energy storage projects available in US Department of Energy (DOE) Energy Storage Database. The data were complemented with information from different sources: websites of battery providers, scientific papers, and technical reports from research laboratories, agencies, government organizations and consultancies.

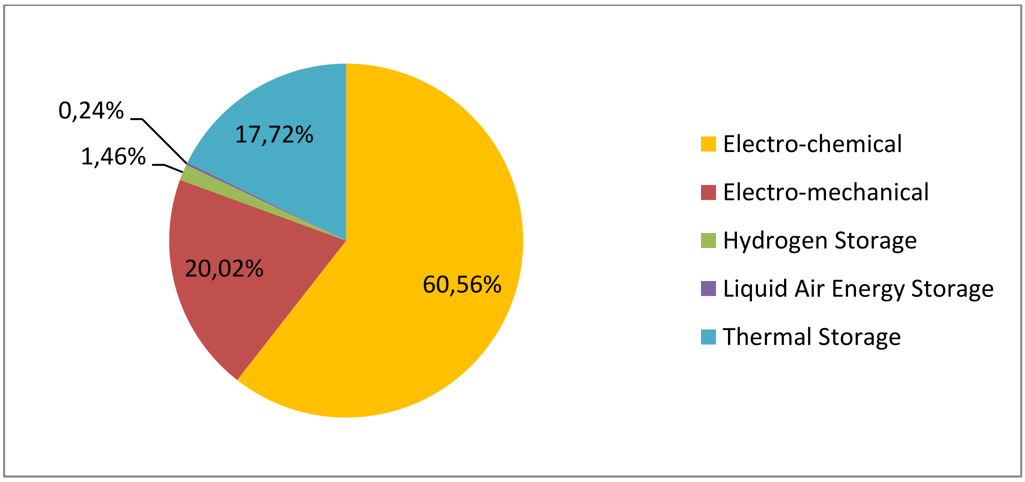
This chapter is divided into more five sections. In the next section we describe how the data was treated. The third section summarizes battery technical features. The fourth analyzes the services that BSS could provide in electricity industry and the technical requirements of some services. The fifth describe the main characteristics of battery supply. Finally, the main conclusions are summarized in the sixth section.

2.2. THE DATABASE

The study of the battery started from the data available in US Department of Energy (DOE) Energy Storage Database. The database was funded in 2011 as an initiative of US Office of Electricity and Sandia National Labs. It provides a dynamic catalogue of energy storage projects and policies with a continuously updated data. However, we point out that although it has by objective cover all energy storage projects in the world, we don’t have information whether the database has recorded already all current projects that each country developed or is developing at this moment. The information of the projects is uploaded by independent power producers, renewable energy developers, utilities and power providers, policy makers, environmental organizations, integrators, software companies and public. The information goes through a third-party verification process with the communications with the principal equity owners.

The last data update was made in November of 2017 and the total of energy storage project was 1.354. The original database was worked of the following way. First, we excluded the projects whose status were “annunciated” and “annunciated/never built”. Then, we remove the projects without information about the energy storage provider or the complete information of the technology. In this point, the database was composed by 824 projects of which the 60.56% (499 projects) were electro-chemical storage projects (Graphic 1). Lastly, we restricted the sample to only BSS projects.

Graphic 1: Distribution of Energy Storage Projects by Technology Type



Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

To select the battery providers, we restricted again the sample to countries with more than 5 projects[3] since one of objective is to study the characteristics of the potential battery supply. The selection of battery providers had as criterion the number of projects by firm since we wanted only firms that could have high relevance in development of batteries for electricity industry applications, it was selected the 25 firms with more number projects. This

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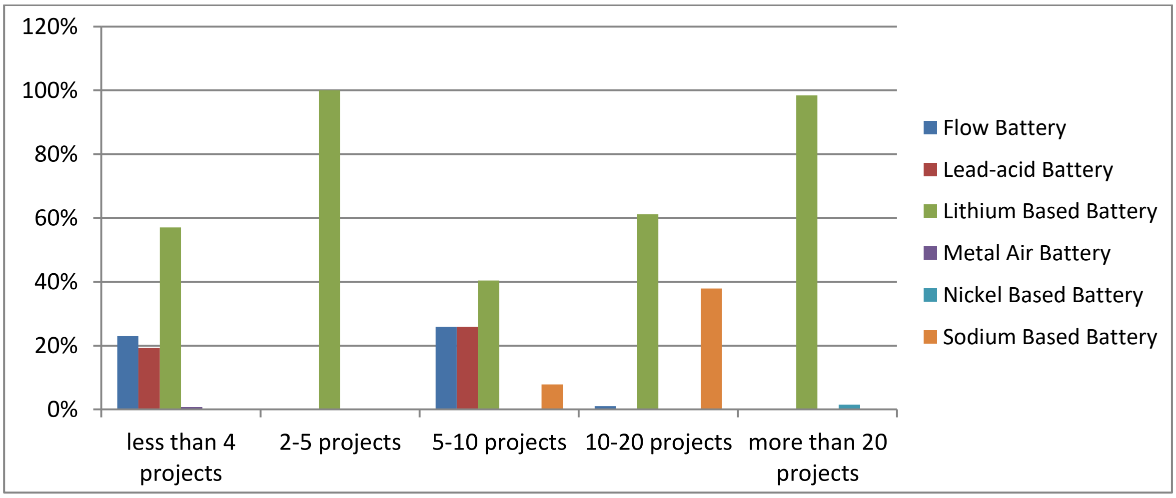
[3] The countries selected were Australia, Canada, China, France, Germany, Italy, Japan, Korea (South), Spain, Netherlands, United Kingdom, and United States. We exclude the following countries: Ireland, Switzerland, Chile, Czech Republic, Finland, Hong Kong, Switzerland, Antarctica, Antigua and Barbuda, Austria, Bolivia, Denmark, Equatorial Guinea, Faroe Islands, French Guiana, Greece, Haiti, India, Indonesia, Martinique, Nigeria, Philippines, Portugal, Puerto Rico, Qatar, Russia, Sweden and Vanuatu.

group of firms is formed by firms with 5 or more projects each. Since we opted to study only firms with more projects, we run the risk to remove the startups from the sample which could cause a problem of reliability of our analysis once such companies are generally those who develop new technologies.

In the graphic 2, there is the distribution of battery projects by technology type for four groups of firm. The first group is composed by 89 firms that have less than 4 projects each. Most of them provide lithium based batteries. This fact is also observed in the others groups. Differently from the others groups, in group 1, there is a metal air battery (specifically, zinc air battery). It is a different battery type which it is not present in the groups of firms with 5 or more. To avoid the problem of not selecting companies that are developing new technologies, among the firms with only less than 4 projects, we selected the firm producing zinc battery (Eos Energy Storage). In this sense, we believe the firms selected represent a good sample of the battery providers making possible a robust study of the characteristics of battery suppliers.

Graphic 2: Distribution of Energy Storage Projects by Technology and Firms' Group



Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

In summary, we study 26 firms and our sample has firms that produce all categories of battery present in the database. For each firm, we completed the information of energy storage project database with information available in the firms' website about the country and industry of origin, industries where they operate, energy storage products and services, partnerships, and strategies. This information was compiled into a second database to be analyzed in section 2.5. Before analyzing the battery providers firms, it is necessary understand battery from a technical perspective.

2.3. TECHNICAL FEATURES OF BATTERY STORAGE SYSTEMS

Battery is a chemical form of energy storage. It has three parts: cathode (part positive), anode (part negative) and electrolyte (chemical substance that splits the positive and negative part). The cathode and anode are linked by an electric circuit. The chemical reaction causes an electrical difference between the anode and cathode which causes a flow of the electrons from anode to cathode by the circuit when it is open. This electrons flow is known as electricity and it is responsible for the operation of diverse products and services. The recharged process, on the other hand, corresponds to the reverse reaction: the addition of electricity restore the anode and the cathode to their original state, which makes the battery available to use again (U.S. DEPARTMENT OF ENERGY, 2013).

Batteries can be characterized by many technical characteristics. In this work, we will describe those characteristics pointed out as being significant for the success of BSS in electricity industry (PALIZBAN AND KAUHANIEMI, 2016; SCHIMIDT ET AL., 2016; ANEKE AND WANG, 2016). The first is **power** that is the total of energy that the device can store (expressed in KW, MW or GW). The scale of energy stored is essential for determining the battery costs. The battery **life-cycle** is the number total of charges and discharge cycles that battery could complete before losing performance considerably. The greater the life-cycle of one technology, lower will be battery **depth-of-discharge** (DOD). The DOD informs the amount of energy that has already been used of the full energy capacity (it is measured in percentages). It depends on the environment conditions (as temperature) and the materials used in the technology fabrication. The battery life-cycle is different of battery **lifetime** or **duration**. The last is the amount of time that the device can operate from a full charge. The lifetime can be considered a measure of network autonomy and each service requires different lifetimes raging from milliseconds to hours.

The life-cycles is also important to determine the battery **round trip efficiency** that informs the parcel of the amount of charged energy that can be recovered. The **energy density** corresponds the total of energy that can be stored in the system per volume, this characteristic is fundamental for some customers since it determines the space the technology will occupy and its capacity of mobility. Finally, the power density is the total of power product by the battery volume. Generally, a battery with high power density is better in application that requires high power quantity with big discharge current and fast response time. Additionally, we stress the battery type (lithium ion, sodium based, metal air batteries) can drastically affect the performance of battery in all these characteristics: e.g. lithium ion batteries have a high density while flow batteries have a low energy density, but last battery type has better performance in depth-discharge than the lithium ion battery. (KYRIAKOPOULOS AND ARABATZIS, 2016; ANEKE AND WANG, 2016; SCHMIDT ET AL.; 2016; IRENA, 2015; U.S. DEPARTMENT OF ENERGY, 2013). As mentioned, there are different battery types. In generally, the battery type is determined by the chemical material involved in its fabrication (e.g. sodium-sulfur batteries have sodium as anode and sulfur as cathode). In the project database, we observe 22 battery types that can be classified into 6 categories (table 2).

Table 2: Technology Type by Technology Category

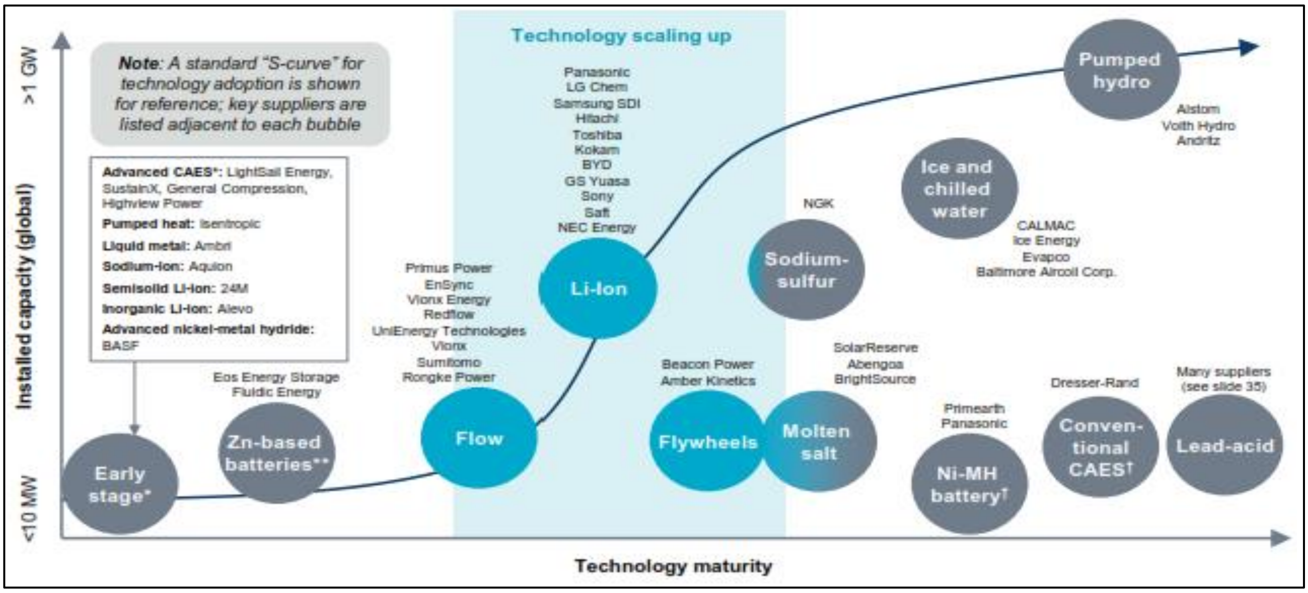
Technology Category	Technology Type	Technology Category	Technology Type
Flow Battery	Iron-Chromium Flow Battery	**Lithium-Ion Based Battery**	Non Specified Li Ion Battery

	Vanadium Redox Flow Battery		Li Iron Phosphate Battery
	Zinc Bromine Flow Battery		Li Manganese Oxide Battery
	Zinc Iron Flow Battery		Li Nickel Cobalt Aluminum Battery
	Zinc-Nickel Oxide Flow Battery		Li Nickel Manganese Cobalt Battery
Lead-acid Battery	Advanced Lead-Acid Battery		Li Polymer Battery
	Hybrid Lead-Acid Battery/Electro-Chemical Capacitor	**Metal Air Battery**	Zinc Air Battery
	Lead Carbon Battery	**Sodium Based Battery**	Non Specified Sodium Battery
	Non Specified Lead-Acid Battery		Sodium-Ion Battery
	Valve Regulated Lead-Acid Battery		Sodium-Nickel-Chloride Battery
Nickel Based Battery	Nickel-Cadmium Battery		Sodium-Sulfur Battery

Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

Each battery type is in a distinct degree of technological development or maturity for electricity industry applications, as shown in figure 4 (HART & SARKISSIAN, 2016). The maturity of a battery varies greatly according to their application. While lead-acid batteries are mature for internal combustion engines in vehicles, they still need to be developed for stationary applications. In the same way, lithium ion batteries are already a commercial technology for portable electronic devices, but they are still subject of much research for larger scale applications (FEW, SCHMIDT AND GAMBHIR, 2016). Further, the different types of battery need to improve different characteristics – for example, generally, to reduce storage cost, Lithium Ion, Sodium-Sulfur and Vanadium Redox Batteries must reduce their Power Cost, while Lead Acid Batteries need to increase their lifetime (KYRIAKOPOULOS AND ARABATZIS, 2016). But again, the set of technical characteristics that need to be developed must take into consideration the service in electricity systems will be provided.

Figure 4: Technological Maturity by Energy Storage Technology

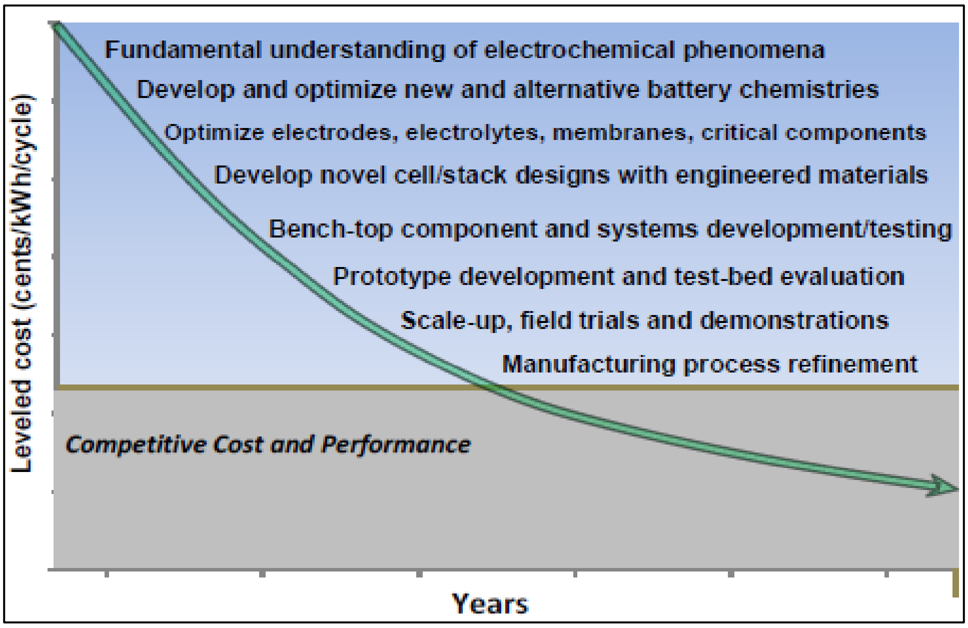


Source: Hart and Sarkissian, 2016.

Each battery technology has its own trajectory of technological development and faces different technical trade-offs among the development of the characteristics described above. Indeed, the biggest challenge in the technological development of BSS (independently of the battery type and its application) is the improvement of their performance in one of the characteristic described above in general means the deterioration of their performance in another characteristic (BCG, 2015).

The technological development of battery goes through many phases over time (displayed in figure 5). When the technology is emergent, its cost is high. Its technological development incorporates since the development of new and alternative battery chemistries until the tests in the technology prototype (case of zinc and flow batteries).

Figure 5: The Phases of Battery Development



Source: U.S. Department of Energy, 2013.

During the process of scaling up, field trials and demonstrations are made and the battery cost begins to reduce (lithium batteries are an example of technology in this phase). Finally, when the battery is a mature technology, its cost decreases and the innovation process is focused on optimizations in the manufacturing process (U.S. DEPARTMENT OF ENERGY, 2013).

In table 3, we summarize some technical characteristics of some battery types. The lithium ion battery consists of a diversity of different technologies that have in common the lithium metal or lithium compound as anode (as Lithium-Ion, Lithium Iron Phosphate, Lithium Polymer, Lithium Nickel Manganese Cobalt, Lithium Manganese Oxide). They are diffused in electronics and medical device industries since they are lighter, smaller and more powerful than other batteries. Those technologies have a high density, a good life-cycle, and have a high efficiency and low self-discharge rate which make them good at applications that required relatively short discharge cycles (of less than four hours) such as frequency regulation and power quality. Among the obstacles they face are their high capital costs, intolerance to deep discharge, and their high sensibility to temperature changes requiring a special protection circuit to avoid overload. Moreover, lithium ion batteries can cause some damage to the environment when it is improperly dumped (ANEKE AND WANG, 2016; IRENA, 2015; U.S. DEPARTMENT OF ENERGY, 2013).

Table 3: Technical Characteristics of Battery Types for Applications in Electricity Industry

Characteristics	Lead–acid	Lithium-ion	Sodium-Sulfur	Vanadium Redox	Nickel-Cadmium	Zinc Air
Power (KW)	≤ 100	≤ 100	≤ 50	≤ 50	≤ 40	≤ 10
Response Time	Miliseconds	Miliseconds	.	≤ 10 Minutes	Miliseconds	.
Lifetime	≤ 4 hours	≤ 1 hour	≤ 6 hours	≤ 8 hours	≤ 8 hours	≤ 24 hours
Maturity	Demonstration/ Commecial	Demonstration	Commecial	Demonstration	Commecial	Demonstration
Longevity (Years)	≤ 20	≤ 15	≤ 15	≤ 10	≤ 20	.
Efficiency (%)	70 - 90	85 - 90	75 - 90	75 - 85	60 - 90	50 - 55
Capital Cost ($/KW)	200 - 400	1,200 - 4,000	300 - 500	600 - 1,500	800 - 1500	100 - 200

Source: Elaboration based on Palizban and Kauhaniemi (2016), Kyriakopoulos and Arabatzis (2016), Luo et al. (2015).

Sodium based batteries are considered a mature technology being economical and with low maintenance cost. They have high density, efficiency, lifetime, long cycle capacity and discharge time (approximately 6 hours), and good scaling potential. These characteristics could allow them to be used in congestion relief, renewable source integration, grid power quality regulation, and in EVs and HEVs. Their high operational temperature requirement and high operational hazard due to the utilization of metallic sodium (that can contaminate the environment) are their main drawbacks. However, as Lithium Ion batteries, their components can be recycled (ANEKE & WANG, 2016; SCHMIDT ET AL., 2016; U.S. DEPARTMENT OF ENERGY, 2013; EASE, 2015).

The flow batteries are reaction stacks separated whose electrolytes are stored in external storage tanks. They have the ability to perform many discharge cycles with deep discharge having long life cycle. They have a high lifetime and tolerance to overcharging, a low maintenance cost, and they don’t need to maximize the energy density since they are designed to optimize the power acceptance and deliver specified properties. They could be used for ramping, time shifting, frequency regulation and peak shaving services. Nevertheless, in many cases they have a complicated design and need many components (pumps, sensors, power management and secondary containment) which make them inappropriate for small scale applications due to their low density. Further, they are still too expensive for electricity industry applications (ANEKE & WANG, 2016; U.S. DEPARTMENT OF ENERGY, 2013).

The lead-acid batteries could be used to integrate renewable generation resources, grid stabilization and load following. They have good lifetime, fast response, low costs of maintenance and investment, reliability and their components can be recycled. However, they have limited depth discharge (that is, low life cycle) and low density, and need constant maintenance as well as being localized in a vented area (ANEKE & WANG, 2016; GATTIGLIO, 2013).

Zinc-air battery corresponds to one specific battery type: metal air batteries. Metal air batteries have an electropositive metal (as zinc, aluminum, magnesium or lithium) in an electrochemical couple with oxygen (from the air) that obtains electricity. Zinc-air battery is a technology in early phases of development. It has a high life-cycle, but also a high cost. It could be used in off-grid applications, and in EVs and HEVs (ANEKE & WANG, 2016; IRENA, 2015).

Finally, nickel based battery used to be a dominant technology in the 1990’s and begins of the 2000’s. They have a short time of recharger, long life cycle and lifetime, a good deep discharge rate, and high resistance to extreme temperatures. Nevertheless, in electricity system, their application imply in high costs (compared to others technologies). Further, they can also have negatives effects on the environment when it is improperly dumped (ANEKE & WANG, 2016; EASE, 2015; IRENA, 2015).

The database provides only the expected duration (h) and power (KW) of the projects in development. In table 4, we can observe that considering those two technical characteristics in aggregated form, we find that flow batteries seems to have the best potential to technological development. Regarding the lifetime, flow and sodium based batteries have the highest average and median, but when we look the maximum values (that can be seen as a proxy of their potential of technical development) lithium ion battery has the best result followed by flow and sodium based batteries. Further, sodium based batteries have the best result regarding the minimum lifetime. Thus, in general, flow and sodium based batteries in the database have the best lifetime results as described above. With respect to battery power, flow and lithium ion batteries have the highest average, and the sodium based and lithium ion batteries have the highest median values, but those values (as also happens with flow batteries) are smaller than the average values. It means most of the projects that are developing those technologies have a low expectation of power storage scale-up. Nevertheless, flow and lithium ion batteries projects have the highest power maximum values while flow and sodium based battery projects have the highest power minimum values. Considering that, flow and lithium ion based batteries in the database have the best power results. The advantages of flow batteries may be explained by the fact of they are still in process of scaling up (as figure 4 shows). However, we stress out that we don't have information about the others technical characteristics that are equally important to determine if one technology are better than other for electricity industry applications. Further, the table above considers only the aggregated values per battery type not considering the services (which will be analyzed in the next sections).

Table 4: Duration (h) and Power (KW) by Technology Category

Technology	Duration Min	Duration Max	Duration Median	Duration Average	Power Min	Power Max	Power Median	Power Average
Flow Battery	0.27	16.80	4	4.44	10	200,000	200	4,887
Lead-acid Battery	0.25	15.67	1.66	2.42	5	20,000	262.50	2,172

Lithium Based Battery	0.17	25.00	1.5	2.13	1	129,000	500	4,309
Metal Air Battery*	4.00	4.00	4	4.00	10000	10,000	10,000	10000
Nickel Based Battery*	0.25	0.80	0.53	0.53	3	27,000	15,000	15,000
Sodium Based Battery	0.70	11.67	4	4.43	10	50,000	750	2,793
Total	.	.		2.99	.	.		6,527

Source: Elaborated from US Department of Energy (DOE) Energy Storage Database. *Metal Air Battery has only one project and Nickel Based Battery has two projects. Because of that, their values were not considered in the analysis.

Considering that, if we look only by the technical characteristics of BSS and the database information, the flow batteries is a technology with more potential to future technological development. Nevertheless, the establishment of dominant technology during its diffusion process is influenced by other factors besides the potential of technological development. One important factor is the degree to which the technology is suitable for its application, that is, to which extent the technology attends the technical requirements necessary to be technically efficient and economically viable to provide a specific service (or a set of services as the battery case) in electricity industry. Therefore, studying how the demand for BSS has been taking shape is next step to understand the recent development of that technology.

2.4. THE DEMAND FOR BATTERY STORAGE SYSTEM BY ELECTRICITY INDUSTRY

As it will be described in the next chapter, the electricity industry has consolidated a particular form of service supply. Two main technical aspects explain that. The first is until recently, most of energy storage systems were not technically developed for large scale applications, which implied in need for electricity production be made in the same moment that its consumption. The second is the characteristics of electricity demand: the end-customers are always connected to the network and their electricity consumption varies strongly over the day. It makes the electricity demand in each moment of the time unpredictable. During the process of consolidation of electricity supply, those factors had given rise a model in which many agents participate in the process of electricity production, transportation and delivery (Generating Firms, Networks Owners, System Operator, Load Serving Entities and Utilities). That model is characterized by the electricity generation made away from the consumption centers, by the high dependence of transportation electricity networks, and by strong regulatory mechanisms to ensure the continuous balance between supply and demand through the definition of rules for electricity markets and network access and use (JOSKOW, 2003).

Battery is a multiuse technology. BSS can be used for all the agents that participate in the process of electricity production, transportation and delivery. Further, each of them can use BSS to provide more than one service. In view of that, the demand for BSS must be defined by each service that BSS has potential to provide in electricity system (and not only by the type of electricity system agent) since those services have different return rates as well as they require batteries with different performances in the technical characteristics already described (SCHMIDT ET AL., 2016). In the project database, there are 31 services that batteries have been developed to provide, as shown in table 5.

Table 5: Services provided by Battery in Electricity Industry

Services	
Black Start	Onsite Renewable Generation Shifting
Demand Response	Ramping
Distribution Upgrade due to Solar	Renewables Capacity Firming
Distribution Upgrade due to Wind	Renewables Energy Time Shift
Electric Bill Management	Resiliency
Electric Bill Management with Renewables	Stationary Distribution Upgrade Deferral
Electric Energy Time Shift	Stationary Distribution Upgrade Deferral
Electric Supply Capacity	Transmission Congestion Relief
Electric Supply Reserve Capacity - Non-Spinning	Transmission Support
Electric Supply Reserve Capacity - Spinning	Transmission upgrades due to Solar
Frequency Regulation	Transmission upgrades due to Wind
Grid-Connected Commercial	Transportable Distribution Upgrade Deferral
Grid-Connected Residential	Transportable Transmission Upgrade Deferral
Load Following (Tertiary Balancing)	Transportation Services
Microgrid Capability	Voltage Support

On-Site Power	.

Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

i. Black Start

Black Start occurs when a power station restarted without relying on the external electric power network due a partial or total shutdown of transmission system. The restarted of the power station can be made by diesel generation and energy storage systems. These technologies are used to re-energize the network which allows other energy generators to go online. For to do that, the storage systems have to have a big power and a duration enough to allow restating generators from a cold state (e.g. for a gas turbine, the duration have to be 15 minutes at least) (DENHOLM ET AL., 2010; IRENA, 2015).

ii. Demand Response

"Demand response can be defined as the changes in electricity usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time" (ALBADI & EL-SAADANY, 2008, p. 1990). It allows reducing electricity prices, to improve system reliability, or to reduce price volatility. In this application, energy storage technologies increase the customers' ability to postpone electricity consumption. From a technical perspective, the requirements of storage power depend on the needs of the users that are different among commercial and residential customers (MA & CHEUNG. 2016).

iii. Distribution upgrade due to Solar (or Wind)[4]

In generally, distribution upgrade refers to an increase in voltage capacity, circuit efficiency and in voltage stability, or a reduction of outage times. When there is a large participation of customers with solar panels (or small wind turbines), the voltage stability of distribution network can be engaged. In this sense, energy storage utilization by network

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[4] It describes together the services Distribution upgrade due to Solar and Distribution upgrade due to Wind.

owners helps not only to reduce outage times but also to increase the voltage stability and the quality of electrical supply.

iv. Electric Bill Management (with Renewables)[5]

Batteries can be used to reduce the electricity bills of end-consumers. When the consumers have access to renewable generation resources (as solar panel and small wind turbines), the energy storage technologies allow they storage their electricity produced. This storage later could be consumed or sold to the grid, reducing their electricity bills.

v. Electric Energy Time Shift

Electric Energy Time Shift is the temporal displacement of the electricity production and network injection to profit from the price differences in different periods. It involves two dimensions: storage of electricity when its price is low, and use (or sell) the energy stored when the price is high.

vi. Electric Supply Capacity

Electric Supply Capacity could be an application of energy storage for electricity generating firms. To ensure the system reliability, it is necessary to have a generation capacity bigger than the demand which imply in the need to invest in increase of supply capacity by generating firms. Thus, here, the utilization of energy storage technologies could be used to defer and to reduce the need to invest in new generation stations or to rent generation capacity in the wholesale electricity markets.

vii. Electric Supply Reserve Capacity – Spinning and Non-Spinning[6]

When there are suddenly generation (or transmission) outages, then it is necessary to use reserves. The spinning reserves are generators that are online but unloaded and can

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[5] It describes together the services Electric Bill Management and Electric Bill Management with Renewables.

[6] It describes together the services Electric Supply Reserve Capacity – Spinning and Electric Supply Reserve Capacity – Non Spinning

respond within 10 minutes. Usually, when all spinning reserves are in use, then non-spinning reserves are called when more generation capacity is necessary. These reserves consist in generation capacity that can be offline or comprises a block of curtailable and (or) interruptible loads, and can be available in 10 minutes. Here, the energy storage systems work as generators over a period until the reserves come in line.

viii. Frequency Regulation

Frequency regulation is also known as primary control reserve. It corresponds to the service of maintain the grid frequency at a predetermined level reconciling short-duration differences (in seconds) between demand and supply of electricity (BATTKE ET AL., 2013)

ix. Grid-Connected Commercial or Residential[7]

Those services increase the reliability and quality of the grid into two ways. The first is the utilization of energy storage to protection against complete power outage with more than some seconds of duration. The storage technology must have enough duration and power to ride through outages of large duration, to complete the shutdown of some process orderly, and transfer to an on-site generation. The second is the utilization of batteries to maintain an electricity quality standard in the case of voltage variations, low power factor, currents (or voltages) at primary different frequencies, and interruptions in the electricity services of any duration (seconds. minutes or hours).

x. Load Following (Tertiary Balancing)

Load Following is characterized by a power product that changes frequently over time frames ranging from minutes to a few hours in a specific region. The power product changes in response to the changing balance between electricity supply and end-user demand (load). This variation is caused by changes in system frequency, timeline loading, or in the

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[7] It describes together the services Grid-Connected Commercial and Grid-Connected Residential.

relation of them. The energy storage can mitigate the cycling of power plants through frequency regulation and other short-term power management techniques (U.S. DEPARTMENT OF ENERGY, 2013).

xi. Microgrid Capability

Microgrid is a group of interconnected loads and distributed energy resources that form a small grid which can be connected or not with the main grid. Generally, energy storage technologies have been used as a substitute of diesel generation and as a complement of renewable generation.

xii. On-Site Power

On-site power is also known as distributed generation and refers to the electricity generation at the site by the electricity end-customers. It is a form to reduce or eliminated the electricity consumption from distribution networks. Batteries can store the produced energy increasing the efficiency and economic return of the on-site power. The technical characteristic required of battery depends on the type of electricity end-consumers (industrial, commercial or residential) and their needs.

xiii. Onsite Renewable Generation Shifting

Onsite Renewable Generation Shifting refers to the Electric Energy Time Shift (item v) for the electricity end-customers that also generate local-renewable electricity.

xiv. Ramping

Ramping is the alteration of the loading level of a generating unit in a constant manner over a fixed time. The energy storage allows the generators to do this alteration quickly over a short period.

xv. Renewable Capacity Firming

The renewable generation has fast changes in production due to variation of wind speed and shading of solar panel generation due to clouds. This variation has a cost in electricity system since it must be compensated by other fast-dispatchable-generation technologies. Energy storage systems works as a substitute of those technologies since they can smooth the high variation of renewable generation (IRENA. 2015).

xvi. Renewables Energy Time Shift

Renewables Energy Time Shift refers to the Electric Energy Time Shift (v) specifically related to the uncontrollable nature of renewable sources of generation.

xvii. Resiliency

The resiliency of electricity systems is their ability to respond and recover rapidly from disruptions. The energy storage can improve the resiliency of electricity system in different ways already mentioned.

xviii. Stationary/Transportable Transmission/Distribution Upgrade Deferral[8]

In these applications, energy storage technology can reduce the need to upgrade (or to replace) of T&D equipment as well as to increase the life extension of these equipment.

xix. Transmission Congestion Relief

During the periods of demand peak, the transmission network can congest which increase the need of investments in transmission capacity. It could increase the transmission access charges or the local marginal pricing for electricity transportation. In this case, batteries can avoid the need of investments ensuring the system affordability.

xx. Transmission Support

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[8] It describes together Stationary Distribution Upgrade Deferral, Transportable Transmission Upgrade Deferral, Transportable Distribution Upgrade Deferral and Transportable Transmission Upgrade Deferral

This service refers to the ability of improving T&D system performance. It can be done by alleviating electrical anomalies and disturbances (as unstable voltage, and sub-synchronous resonance).

xxi. Transmission upgrades due to solar (or wind)[9]

The increase of renewable generation often requires upgrades in transmission networks due to high volatility in energy generation. In this case, the utilization of BSS help reduce outage times and to increase the voltage stability and the quality of electrical supply.

xxii. Transportation Services

Transportation Services correspond to services related to mobility (especially, applications in rail networks, EVs and HEVs).

xxiii. Voltage Support

The Voltage Support is an ancillary service that aims to offset reactive effects restoring or maintaining the network voltage. The energy storage systems allow damped with minimal draw of real power these voltage fluctuations increasing the system technical efficiency (U.S. DEPARTMENT OF ENERGY. 2013).

From the distribution of projects among the services (table 6), we observe the services with more number of projects (Capacity Firming, Electric Energy Time Shift, Frequency Regulation, Renewables Energy Time Shift and Onsite Renewable Generation Shifting) are those related to the change process of the industry toward renewable generation incorporation and shift of role of electricity end-customers recently. Indeed, many public actions in recent years have been encouraging technologies (as batteries) capable to reduce the negative impacts of renewable generation on the efficiency and reliability of electricity system, to increase price arbitrage, and to promote the decentralized generation in electricity

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[9] It describes together Transmission upgrades due to Solar and Transmission upgrades due to Wind.

systems. The fact of those services also have a bigger number of firms highlights that in electricity industry there is a potential demand for a specific set of services. That potential demand is partly explained by public policies and attracting the interest of technology providers.

Table 6: Projects and Numbers of Firms by Services

Service	Projects	%	Firms	%
Renewables Capacity Firming	156	33,84%	68	58,12%
Electric Energy Time Shift	137	29,72%	65	55,56%
Frequency Regulation	119	25,81%	48	41,03%
Renewables Energy Time Shift	102	22,13%	60	51,28%
Onsite Renewable Generation Shifting	97	21,04%	52	44,44%
Electric Bill Management	90	19,52%	41	35,04%
Voltage Support	83	18,00%	41	35,04%
On-Site Power	63	13,67%	32	27,35%
Electric Bill Management with Renewables	58	12,58%	33	28,21%
Microgrid Capability	56	12,15%	36	30,77%
Electric Supply Capacity	55	11,93%	31	26,50%
Electric Supply Reserve Capacity - Spinning	36	7,81%	24	20,51%
Grid-Connected Commercial (Reliability & Quality)	36	7,81%	24	20,51%
Load Following (Tertiary Balancing)	35	7,59%	22	18,80%
Ramping	34	7,38%	20	17,09%
Grid-Connected Residential (Reliability)	33	7,16%	19	16,24%
Distribution Upgrade due to Solar	30	6,51%	13	11,11%
Resiliency	30	6,51%	20	17,09%
Black Start	22	4,77%	16	13,68%
Stationary Transmission/Distribution Upgrade Deferral	21	4,56%	16	13,68%
Transmission Congestion Relief	20	4,34%	13	11,11%
Transportation Services	18	3,90%	12	10,26%
Electric Supply Reserve Capacity - Non-Spinning	16	3,47%	13	11,11%
Transportable Transmission./Distribution Upgrade Deferral	12	2,60%	7	5,98%
Demand Response	12	2,60%	9	7,69%
Transmission Support	9	1,95%	9	7,69%
Transmission Upgrades due to Wind	4	0,87%	4	3,42%
Distribution Upgrade due to Wind	2	0,43%	2	1,71%
Transmission Upgrade due to Solar	1	0,22%	1	0,85%

Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

We perceive there are few numbers of projects that intend to develop BSS to provide electricity network services. The battery network services are those that aim to increase the transmission and distribution network efficiency and reliability. The BSS utilization in those cases, generally, decreases the maintenance costs or avoids the investments in the network expansion. The low participation of those services compared to others services can be a reflex of the difficult of distribution and transmission companies (or utilities) to calculate the return rates of the investment in BSS since the complementarity degree of the BSS use for different services is not yet defined and some of those services don’t have yet clear remuneration mechanisms (EYER, 2009).

Regarding the complementary benefits (operationally and financially) of BSS utilization for more than one service, it is necessary to emphasize the complementarity depends on: (i) the degree in which BSS use affects the grid operations and the performance of others equipment beyond the own reliability, safety and affordability of electricity systems, (ii) the incremental costs for a battery provide more than one service, and (iii) the coincidence among the technical requirements for BSS provide different services (EYER, 2009).

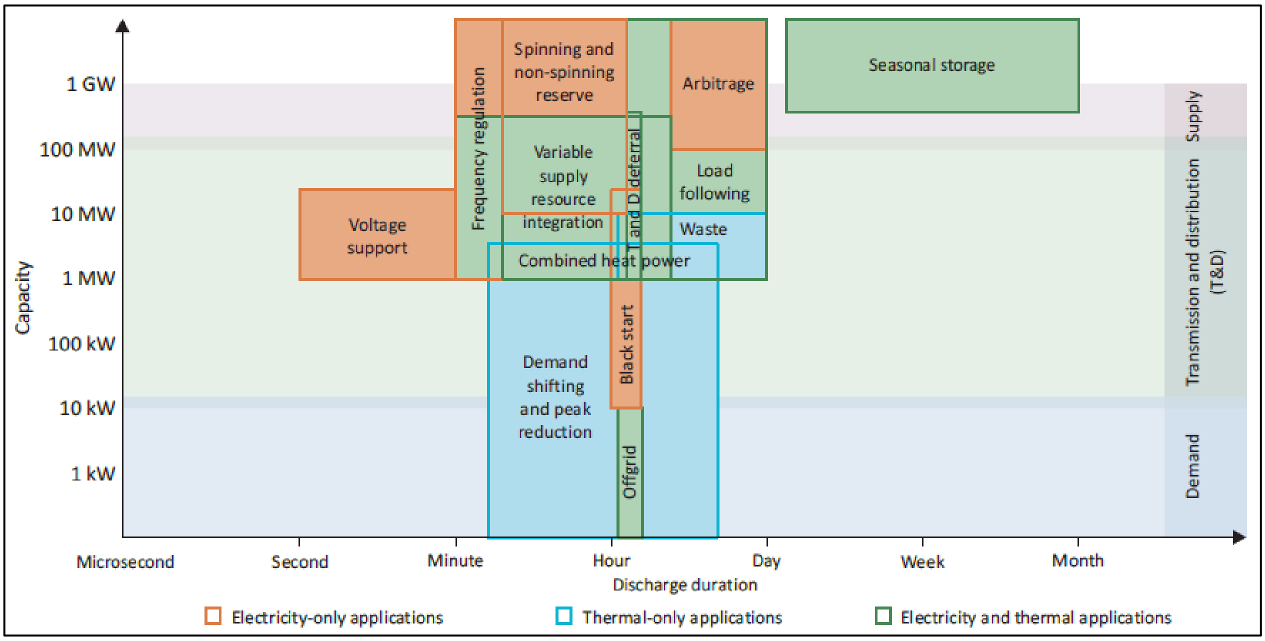
The services described in table 5 require different technical characteristics from BSS. Table 7 shows the characteristics that BBS should have to provide some services described above. We observe that depending on the service, battery must have different technical performance in each characteristic. Further, there is not a clear relation among the characteristics. For example, as we can see in figure 6, there is not a pattern between power and duration: services that require bigger power don’t necessarily require a bigger or a shorter duration, but they can require both a bigger or shorter lifetime depending on the service.

Table 7: Desired Characteristics of BSS Applications in Modern Grids.

Service	Power (MW)	Reponse Time	Lifetime	Cycle	Longevity (Years)
Capacity Firming	≤ 500	≤ 30 Minutes	≤ 4 hours	300-500/yr	≤ 20
Time shift	≤ 500	≤ 30 Minutes	≤ 5 hours	≤ 4,000/yr	≤ 15
Frequency Regulation					
Primary	≤ 40	Instataneous	15 Min ≤ t ≤ 30 Min	8,000/yr	≤ 15
Secondary	≤ 40	Minutes	30 Min ≤ t ≤ 1 Hour	.	.
Tertiary	≤ 100	.	≥ 1 hour	.	.
Voltage support	≤ 10	≤ 100 Miliseconds	≤ 1 hour	5,000/yr	≤ 20
Energy Arbitrage	≤ 500	Minutes	≤ 10 hours	300-400/yr	≤ 20
Peak shaving	≤ 500	.	≤ 6 hours	50-250/yr	≤ 20
Load following	≤ 100	.	≤ 4 hours	.	≤ 20
Spinning reserve	≤ 100	≤ 4 Hours	≤ 5 hours	.	≤ 20
Black start	≤ 50	≤ 2 Hours	≤ 16 hours	10-20/yr	≤ 25
Power quality	≤ 10	≤ 200 Miliseconds	≤ 2 hours	50/yr	≤ 10
Power reliability	≤ 10	Minutes	≤ 4 hours	≤ 400/yr	≤ 15

Source: Elaboration based on Palizban and Kauhaniemi (2016).

Figure 6: Power Requirement versus Duration for Some Application in Electricity Systems



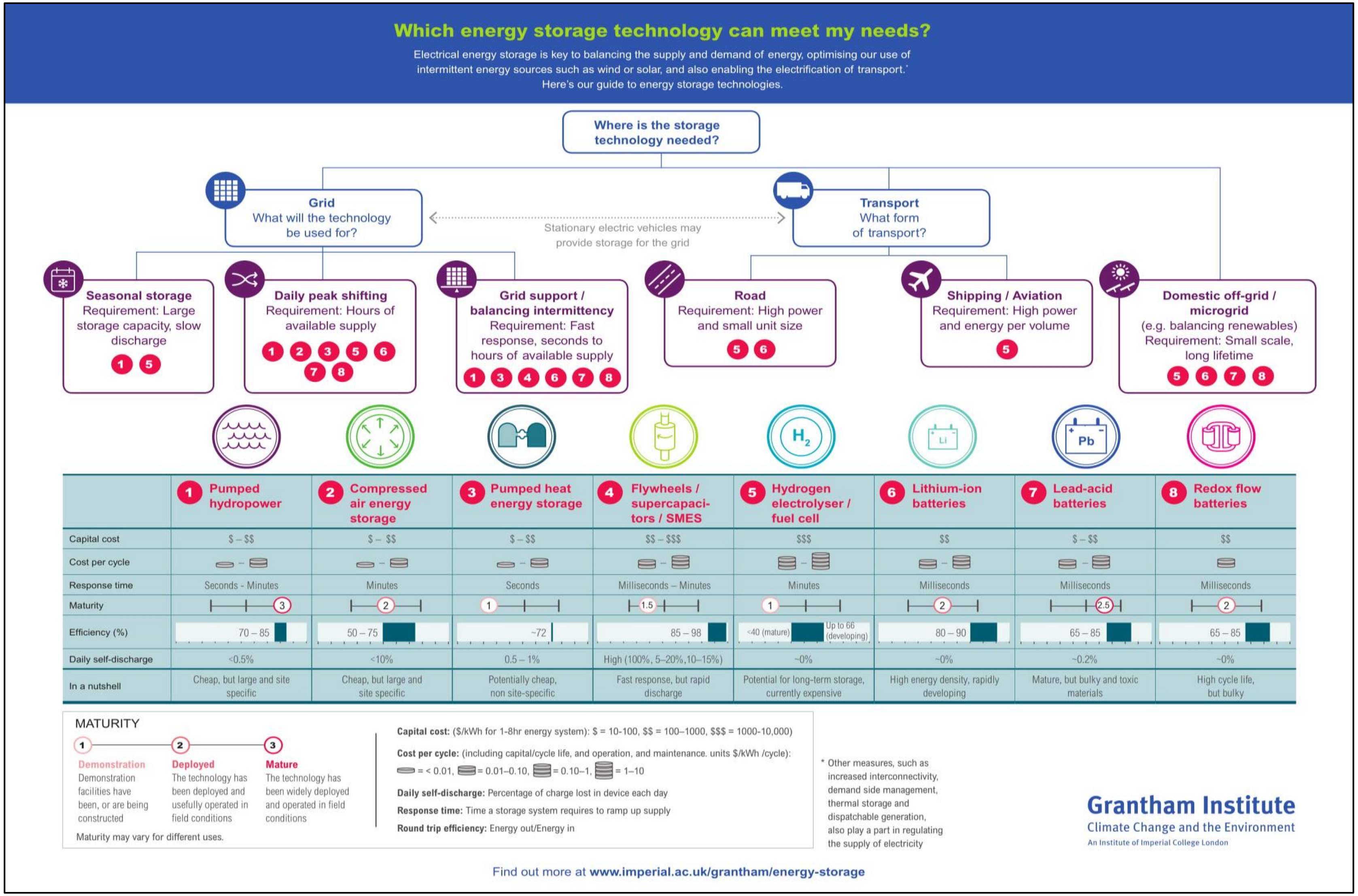
Source: IEA (2014).

Considering that, many battery studies (FEW, SCHMIDT & GAMBHIR, 2016; KYRIAKOPOULOS & ARABATZIS, 2016; LUO ET AL., 2015; U.S. DEPARTMENT OF

ENERGY, 2013; CHEN ET AL., 2009) try to establish which battery type is more technically adequate to provide the services above.

In figure 7, Few, Schmidt and Gambhir (2016) identify which energy storage technologies could be used to provide a broad set of new applications for those technologies that have emerged in last decades. Regarding the services of electricity system, they find the lithium-ion, lead-acid and flow batteries could provide services associated with Daily Peak Shifting, Grid Support and Microgrid applications. Palizban and Kauhaniemi (2016) elaborate a matrix of the relationships between the available energy storage technologies and their applications in electricity systems (figure 8). They consider the high or low rate service, the response and discharge times, and the environmental matching as parameters. As Few, Schmidt and Gambhir (2016), they find lithium-ion, lead-acid, sodium sulfur and flow batteries can provide management services, as well as renewable energy integration.

Figure 7: Energy Storage Technologies according to the Service Provided



Which energy storage technology can meet my needs?

Electrical energy storage is key to balancing the supply and demand of energy, optimising our use of intermittent energy sources such as wind or solar, and also enabling the electrification of transport.* Here's our guide to energy storage technologies.

Where is the storage technology needed?

Grid
What will the technology be used for?

Transport
What form of transport?

Stationary electric vehicles may provide storage for the grid

Seasonal storage
Requirement: Large storage capacity, slow discharge
1 5

Daily peak shifting
Requirement: Hours of available supply
1 2 3 5 6 7 8

Grid support / balancing intermittency
Requirement: Fast response, seconds to hours of available supply
1 3 4 6 7 8

Road
Requirement: High power and small unit size
5 6

Shipping / Aviation
Requirement: High power and energy per volume
5

Domestic off-grid / microgrid
(e.g. balancing renewables)
Requirement: Small scale, long lifetime
5 6 7 8

	① Pumped hydropower	② Compressed air energy storage	③ Pumped heat energy storage	④ Flywheels / supercapacitors / SMES	⑤ Hydrogen electrolyser / fuel cell	⑥ Lithium-ion batteries	⑦ Lead-acid batteries	⑧ Redox flow batteries
Capital cost	$ – $$	$ – $$	$ – $$	$$ – $$$	$$$	$$	$ – $$	$$
Cost per cycle	🪙 – 🪙🪙	🪙 – 🪙🪙	🪙 – 🪙🪙	🪙🪙 – 🪙🪙🪙	🪙🪙🪙 – 🪙🪙🪙🪙	🪙🪙 – 🪙🪙🪙	🪙🪙 – 🪙🪙🪙	🪙🪙
Response time	Seconds - Minutes	Minutes	Seconds	Milliseconds – Minutes	Minutes	Milliseconds	Milliseconds	Milliseconds
Maturity	3	2	1	1.5	1	2	2.5	2
Efficiency (%)	70 – 85	50 – 75	~72	85 – 98	<40 (mature) Up to 66 (developing)	80 – 90	65 – 85	65 – 85
Daily self-discharge	<0.5%	<10%	0.5 – 1%	High (100%, 5–20%,10–15%)	~0%	~0%	~0.2%	~0%
In a nutshell	Cheap, but large and site specific	Cheap, but large and site specific	Potentially cheap, non site-specific	Fast response, but rapid discharge	Potential for long-term storage, currently expensive	High energy density, rapidly developing	Mature, but bulky and toxic materials	High cycle life, but bulky

MATURITY

①	②	③
Demonstration	**Deployed**	**Mature**
Demonstration facilities have been, or are being constructed	The technology has been deployed and usefully operated in field conditions	The technology has been widely deployed and operated in field conditions

Maturity may vary for different uses.

Capital cost: ($/kWh for 1-8hr energy system): $ = 10-100, $$ = 100–1000, $$$ = 1000-10,000)

Cost per cycle: (including capital/cycle life, and operation, and maintenance. units $/kWh /cycle):
🪙 = < 0.01, 🪙🪙 = 0.01–0.10, 🪙🪙🪙 = 0.10–1, 🪙🪙🪙🪙 = 1–10

Daily self-discharge: Percentage of charge lost in device each day

Response time: Time a storage system requires to ramp up supply

Round trip efficiency: Energy out/Energy in

* Other measures, such as increased interconnectivity, demand side management, thermal storage and dispatchable generation, also play a part in regulating the supply of electricity

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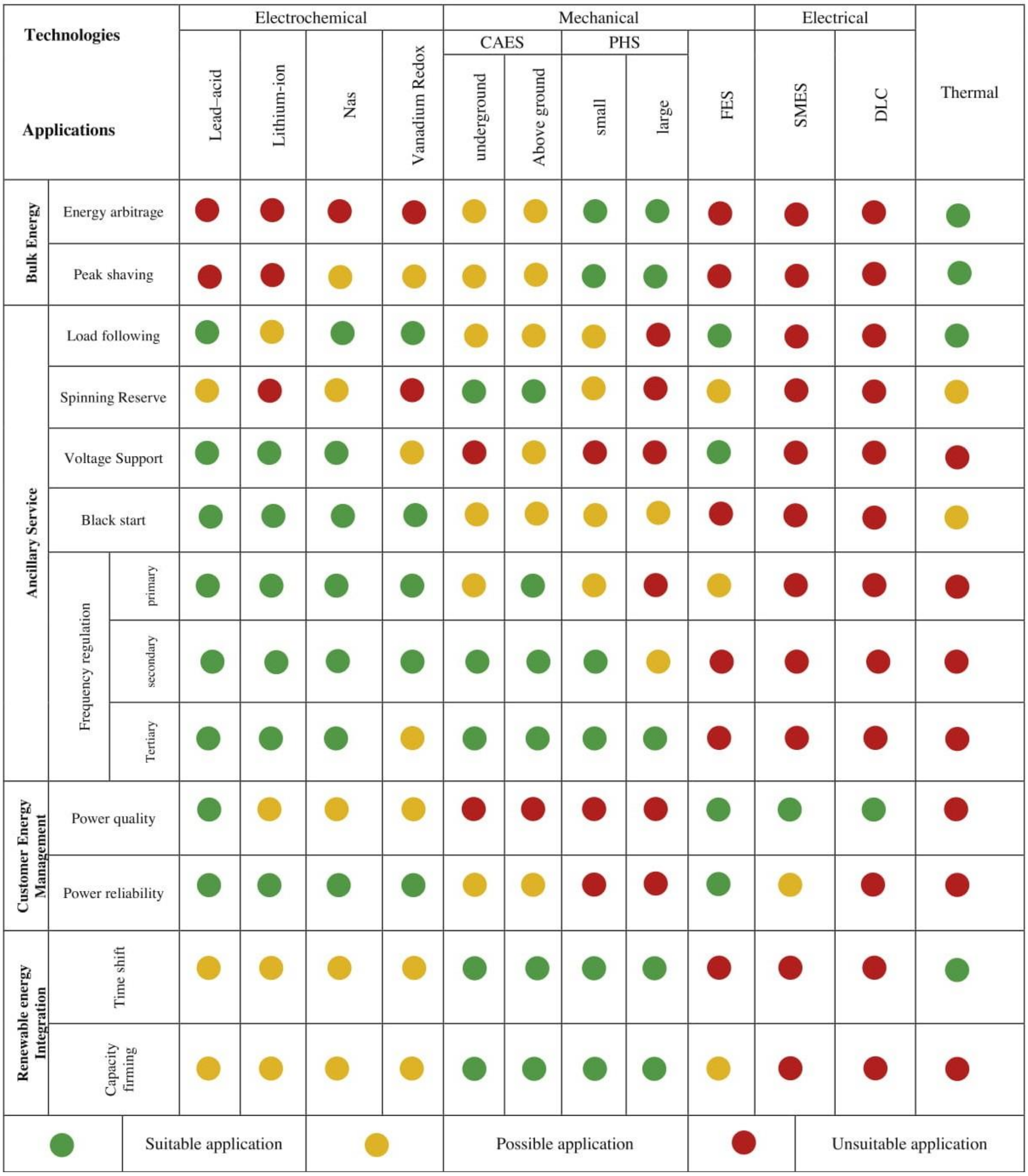
Source: Few, Schmidt and Gambhir (2016).

Figure 8: Possibility of Applications of Energy Storage Technologies according to the Service Provided



Technologies / Applications			Electrochemical				Mechanical					Electrical		Thermal
							CAES		PHS					
			Lead–acid	Lithium-ion	Nas	Vanadium Redox	underground	Above ground	small	large	FES	SMES	DLC	
Bulk Energy	Energy arbitrage		🔴	🔴	🔴	🔴	🟡	🟡	🟢	🟢	🔴	🔴	🔴	🟢
	Peak shaving		🔴	🔴	🟡	🟡	🟡	🟡	🟢	🟢	🔴	🔴	🔴	🟢
Ancillary Service	Load following		🟢	🟡	🟢	🟢	🟡	🟡	🟡	🔴	🟢	🔴	🔴	🟢
	Spinning Reserve		🟡	🔴	🟡	🔴	🟢	🟢	🟡	🔴	🟡	🔴	🔴	🟡
	Voltage Support		🟢	🟢	🟢	🟡	🔴	🟡	🔴	🔴	🟢	🔴	🔴	🔴
	Black start		🟢	🟢	🟢	🟢	🟡	🟡	🟡	🟡	🔴	🔴	🔴	🟡
	Frequency regulation	primary	🟢	🟢	🟢	🟢	🟡	🟢	🟡	🔴	🟡	🔴	🔴	🔴
		secondary	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟡	🔴	🔴	🔴	🔴
		Tertiary	🟢	🟢	🟢	🟡	🟢	🟢	🟢	🟢	🔴	🔴	🔴	🔴
Customer Energy Management	Power quality		🟢	🟡	🟡	🟡	🔴	🔴	🔴	🔴	🟢	🟢	🟢	🔴
	Power reliability		🟢	🟢	🟢	🟢	🟡	🟡	🔴	🔴	🟢	🟡	🔴	🔴
Renewable energy Integration	Time shift		🟡	🟡	🟡	🟡	🟢	🟢	🟢	🟢	🔴	🔴	🔴	🟢
	Capacity firming		🟡	🟡	🟡	🟡	🟢	🟢	🟢	🟢	🟡	🔴	🔴	🔴

🟢 Suitable application 🟡 Possible application 🔴 Unsuitable application

Source: Palizban and Kauhaniemi (2016).

From those works, we conclude different battery types considered have similar potential to provide the same set of services. In this way, if only technical aspects were considered, it would be expected a more equal distribution of projects among the battery technologies, that is, that the demand for BSS by electricity industry would be met by those technologies in a uniform way.

2.5. THE SUPPLY OF BATTERY STORAGE SYSTEMS

The analysis of the project database shows the BSS demand by electricity system agents has been met by four battery types that correspond to 99,35% of the total of projects (table 8). The projects that are developing lithium ion battery are 66.81%, followed by flow battery projects with 11.93%. Projects that involve lead acid and sodium based batteries correspond to 10.63% and 9.98%, respectively.

Table 8: Distribution of Battery Projects by Technology Type

Technology	Projects	%
Lithium-Ion Battery	**308**	**66,81%**
Lithium Iron Phosphate Battery	69	14,97%
Lithium Polymer Battery	15	3,25%
Lithium Nickel Manganese Cobalt Battery	5	1,08%
Lithium Manganese Oxide Battery	1	0,22%
Lithium Nickel Cobalt Aluminum Battery	1	0,22%
Not Specified Lithium Ion Battery	217	47,07%
Flow Battery	**55**	**11,93%**
Vanadium Redox Flow Battery	32	6,94%
Zinc Bromine Flow Battery	18	3,90%
Zinc Iron Flow Battery	3	0,65%
Iron-Chromium Flow Battery	1	0,22%
Zinc-Nickel Oxide Flow Battery	1	0,22%
Lead-Acid Battery	**49**	**10,63%**
Advanced Lead-Acid Battery	12	2,60%
Hybrid Lead-Acid Battery/Electro-Chemical Capacitor	9	1,95%
Valve Regulated Lead-Acid Battery	7	1,52%
Lead Carbon Battery	1	0,22%
Not Specified Lead-Acid Battery	20	4,34%
Sodium Based Battery	**46**	**9,98%**
Sodium-Nickel-Chloride Battery	21	4,56%
Sodium-Sulfur Battery	18	3,90%
Sodium-Ion Battery	6	1,30%
Not Specified Sodium Based Battery	1	0,22%
Nickel-Cadmium Battery	**2**	**0,43%**
Zinc Air Battery	**1**	**0,22%**
Total	**461**	**100,00%**

Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

The disaggregate distribution of projects by service and battery technology (table 8) also shows the services with more number of projects are the same that the studies cited above identified as being able to be provided by BSS (specially, lithium-ion, flow lead-acid, and sodium based batteries). In table 9, we observe for most of the services, lithium ion batteries dominate in project numbers, while sodium based, lead-acid and flow batteries always appear with a small participation. The fact of for all battery applications within electricity systems (with more or less number of projects) the lithium-ion batteries have the largest number of projects revels the choice of which battery types will be developed for electricity industry applications might not be influenced by the demand of each service (as Schimidt et al. (2016) argue).

Table 9: Distribution of Projects by Services and Battery Technology

Service	Flow Battery	Lead-Acid Battery	Lithium Ion Based Battery	Metal Air Battery	Nickel Battery	Sodium Based Battery
Renewables Capacity Firming	27	16	98	1	1	13
Electric Energy Time Shift	15	20	86	1	0	15
Frequency Regulation	9	9	88	0	1	12
Renewables Energy Time Shift	20	8	63	1	0	10
Onsite Renewable Generation Shifting	17	12	62	0	0	6
Electric Bill Management	9	10	61	0	0	10
Voltage Support	10	12	48	0	1	12
On-Site Power	7	8	40	0	0	8
Electric Bill Management with Renewables	4	7	45	0	0	2
Microgrid Capability	8	9	33	0	0	6
Electric Supply Capacity	5	4	43	0	0	3
Electric Supply Reserve Capacity – Spinning	5	7	16	0	2	6
Grid-Connected Commercial	6	4	20	0	1	5
Load Following	4	3	23	0	0	5
Ramping	4	7	21	1	0	1
Grid-Connected Residential	3	3	24	0	1	2

Distribution Upgrade due to Solar	1	1	27	1	0	0
Resiliency	5	4	21	0	0	0
Black Start	8	1	8	0	0	5
Stationary Transmission/ Distribution Upgrade Deferral	2	3	14	0	0	2
Transmission Congestion Relief	2	0	13	0	0	5
Transportation Services	1	1	15	0	0	1
Electric Supply Reserve Capacity - Non-Spinning	1	4	7	0	0	4
Transportable Transmission/ Distribution Upgrade Deferral	1	0	7	0	0	4
Demand Response	1	2	9	0	0	0
Transmission Support	1	2	4	0	0	2
Transmission Upgrades due to Wind	0	0	2	0	0	2
Distribution Upgrade due to Wind	0	1	1	0	0	0
Transmission Upgrades due to Solar	0	0	1	0	0	0

Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

Summarizing, so far we have shown batteries still need to be developed to provide services in electricity systems, and each service have specific technical requirements (in relation of battery lifetime, life cycle, efficiency, among others characteristics) that batteries must reach to be competitive. Further, the fact of lithium ion batteries correspond to most projects cannot be explained only by technological factors since by technological view there are other battery types with the same potential to provide services in electricity industry. It means that battery type may not be a variable that could be affected by the demand of electricity industry and consequently by regulatory framework. In that case, considering that the development of new technology is directly affected by the internal factors of the technology provider firms, in the remainder of this chapter, we try to clarify by studying those firms what is the role of the battery demand in the battery development process for applications in electricity industry. In other words, we are trying to identify how the regulatory rules through BSS demand for the provision of the services described above can influence the BSS development by the analysis of the characteristics of battery suppliers.

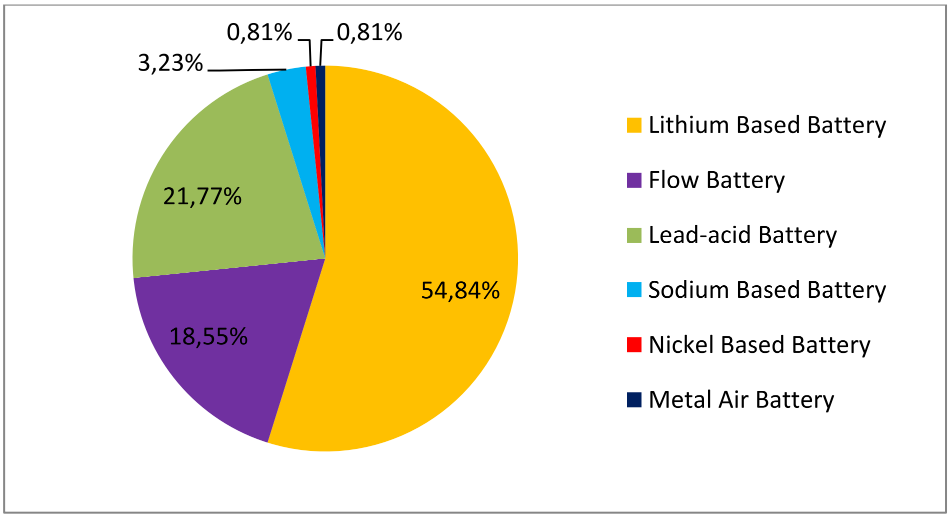
The project database has 124 firms providing batteries for electricity industry. From those, we selected 26 to make a more detailed study (as explained in section 2.2). Those firms correspond to 62.65% of the projects in database. Nevertheless, before studying the characteristics of the selected battery providers, it is necessary understand the main aspects of the BSS supply chain.

The BSS supply chain is simple, being composed by 5 phases. Batteries are manufactured from chemical materials. Most of the chemical elements are negotiated in mineral commodities markets. Their purchased in those markets or their production (by the battery firms when they are vertically integrated) is the first phase while the battery production is the second. The battery production consist in the transformation of those chemical materials into chemical components and the arrangement of these components into modules. Those modules have sensors and controls that are used together with a software to control and manage the battery power, charging and temperature. After that, batteries are installed and integrated with power components to meet the project specification forming a battery storage system (third phase). Each BSS is specific for each customer according with her needs which makes the BSS customized products. Many providers can produce storage media with extra service lifetime to accommodate additional charge-discharge cycles and/or deeper discharges. The fourth phase is the battery use and maintenance – as seen, some kinds of batteries needs more maintenance than others. Finally, some firms provide uninstall and disposal services since many battery components can cause environmental damage (if discarded improperly) and a high set of them can be recycled (IRENA, 2015; EYER, 2009).

In table 10 shows some characteristics of the selected firms. We observe a fraction of them are integrated (42.31%), that is, besides supplying the energy storage technologies, they also provide the other downstream services of the BSS value chain.

Most of the analyzed firms (95.16%) are supplying only three battery types (lithium ion, lead-acid and flow batteries) (graphic 3 and table 10). From the 124 identified firms, 8 produce more than one type of battery, lithium ion batteries are produced by 68 firms and lead-acid and flow batteries are produced by 27 and 23, respectively. In this way, the dominance of lithium ion based battery projects can be in part explained by the technology provider features.

Graphic 3: Distribution of Battery Providers by Technology Type



Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

Table 10: Battery Technologies provided by Studded Firms

Technology	Firms
Lithium Ion and Sodium Based Batteries	Aquion Energy
Lead-Acid Battery/Electro-Chemical Capacitor	Ecoult
Zinc Based Battery	Eos Energy Storage
Sodium Based and Lead-Acid Batteries	FIAMM
Lithium Ion and Sodium Based Batteries	General Electric
Flow Battery	Gildemeister, ZBB Energy Corporation, Rongke Power.
Lithium Ion and Lead-Acid Batteries	GS Yuasa Corporation, Woojin Industrial Systems
Lithium Ion Based Battery	LG Chemical, Samsung, BYD, Kokam, NGK Insulators, Green Charge Networks, Alfen, NEC Energy Solutions, Tesla, Clean Energy Storage Inc., Stem, Altair Nanotechnologies.
Lithium Ion and Nickel Based Batteries	SAFT
Lithium Ion Based Battery and Pumped Hydro Storage	Toshiba
Lead-Acid Battery	Xtreme Power, Exide.

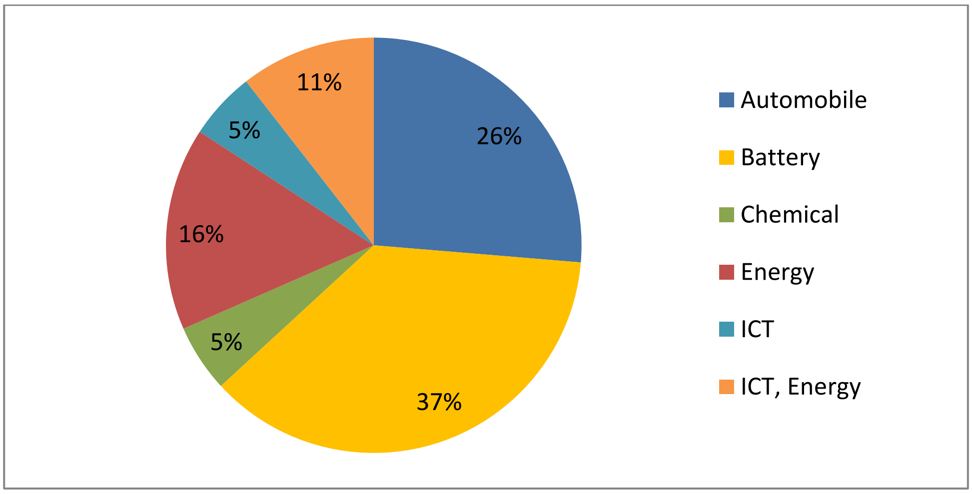
Source: Own Elaboration.

When we analyze the firms that are developing BSS for electricity industry applications, we identify two types: Multinationals (M) and Startups (S) (table 10). The startups are predominantly from US, they were funded during the 2000 years with a clear objective to provide BSS for applications in electricity industry. Of the six firms, two of them provide energy storage systems composed by lithium battery and software which allow their customers to control their consumption (reducing their electricity bills). Two firms that was manufacturing lead-acid and zinc battery went bankrupt, and the only non-American startup works with a new technology that combine lead-acid batteries with ultra-capacitor design forming the ultra-battery (an Australian technology) (IRENA, 2015).

The multinationals are a group with more diversity. They come from different countries and many of them act as battery providers in others industries besides electricity industry. The firms whose origin industry is the electricity industry have a big experience in providing diverse products and services for electricity systems. They have a tendency to concentrate their activities in only that industry. One typical example is General Electric, an American firm founded in 1878 which provide services in electricity systems in diverse countries. It has as objective to provide BSS solution for any possible application in electricity grid. Inside the group of firms whose focus is electricity industry, we also observe two firms that have high experience in Information and Communication Technology (ICT) and provide batteries for electronic devices.

As the graphic 4 shows, 26% of battery providers have consolidated as suppliers of the automotive production chain or supplier of EVs and HEVs(as the case of Tesla). Generally, those firms entered as provider for electricity systems via development and production of battery for EVs and HEVs seeing electricity industry as a new market opportunity. It shows although the BSS development for EVs and HEVs have increased the interest in application of that technology in electricity industry, the electricity industry is considered by battery providers a different market niche. Indeed, as we saw in the last section, BSS application in electricity industry must consider the technical requirements to provide electricity services. In table 11, this fact is clear since those firms have as objective to provide batteries for electric vehicles and general grid applications.

Graphic 4: Distribution of Multinationals by Origin Industry



Source: Own elaboration.

The third group of multinational with bigger participation is composed by firms that since their foundation operate as battery supplies. Those firms provide energy storage for a plenty of others industries, working as provider in their production chain. Most of them are developing lithium-ion based batteries and have as strategy to provide battery for many markets ("where there is demand"). One example is Saft, a centenary French firm leader in number of projects. It is one of the leaders in battery market, providing its technology for many industries. It has as main objective to continue as market leader and for that Saft is committed to developing lithium-ion batteries for electricity market (this strategy shows electricity industry could be of large importance for battery industry). Its work with lithium battery is relatively old so that the firm is using their knowledge and experiences to explore new market opportunities.

Table 11: Battery Provider Characteristic - Part A

Firm	Foundation Year	Origin Country	Firm Type	Origin Industry	Does it operate as battery provider for which industries?
SAFT	1918	France	M	Battery	Electronics, Equipment, Defense, Medical, Transportation, Petroleum & Gas, and Electricity Industry.
LG Chemical	1947	Korea	M	Chemical	Electronic, Transportation, and Electricity Industry.
Samsung	1970	Korea	M	ICT	Electronic, Transportation, and Electricity Industry.
BYD	1995	China	M	Battery	Electronic, Transportation, and Electricity Industry.
Kokam	1989	Korea	M	Battery	Electronics, Naval, Transportation, Industrial Applications, and Electricity Industry.
NGK Insulators	1936	Japan	M	Automobile	Transportation and Electricity Industry.
General Electric	1878	US	M	Energy	Electricity Industry.
Green Charge Networks	2009	US	S	Battery[3]	Electricity Industry.
Alfen	1937	Netherlands	M	Energy	Electricity Industry.
NEC Energy Solutions	1899	Japan	M	ICT, Energy	Electronic and Electricity Industry.
Tesla	2003	US	M	Automobile	Transportation and Electricity Industry.
FIAMM	1942	Italy	M	Automobile	Transportation, Industrial Applications, and Electricity Industry.
Gildemeister	1870	Germany	M	Energy	Electricity Industry and Industrial Applications.
Clean Energy Storage Inc.	.	US	S	Battery	Electricity Industry.
ZBB Energy Corporation	1986	China	M	Battery	Electricity Industry.
Ecoult	2007	Australia	S	Battery	Electricity Industry.
Toshiba	1939	Japan	M	ICT, Energy	Electronic, Chemical, and Electricity Industry.
Aquion Energy	2008	US	M	Battery	Electricity Industry.
GS Yuasa Corporation	2004	Japan	M	Automobile	Electronic, Transportation, Mechanics, and Electricity Industry.
Stem	2009	US	S	Energy[2]	Electricity Industry.
Xtreme Power[1]	2004	US	S	Battery	Electricity Industry.
Exide	1973	US	M	Battery	Transportation, Industrial Applications, and Electricity Industry.
Altair Nanotechnologies	1888	US	M	Battery	Electronics, Defense, Transportation, Medical Equipment, and Electricity Industry.
Rongke Power	2008	China	.	Battery	Electricity Industry.
Woojin Industrial Systems	1974	Korea	M	Automobile	Transportation and Electricity Industry.
Eos Energy Storage[1]	2007	US	S	Battery	Electricity Industry.

Source: Own elaboration. [1] Firm does not longer exist. [2] Firm buys battery from others firms and sells them with its software to manage the electricity use to reduce costs and bills. [3] Battery is sold with a software to measure and manage data of consumption. M: Multinational, S: Start up.

Although the experience of most of analyzed firms in the battery production, many of them have partnership with research and development centers, utilities and others battery provider firms to develop BSS for electricity industry applications, specially, when they are developing lithium ion and flow batteries.

The last column of table 12 shows whether the firm has business and commercial relationships with other organizations. There are 18 firms that have partnership with research and development centers. Those firms are from diverse countries and have different origin industry. Regarding the battery type provide, 44% of the firms are developing lithium ion batteries while 11% are developing flow batteries. In that group, there are yet 5 firms that are developing lithium ion based batteries together with other battery type.

Table 12: Battery Provider Characteristic - Part B

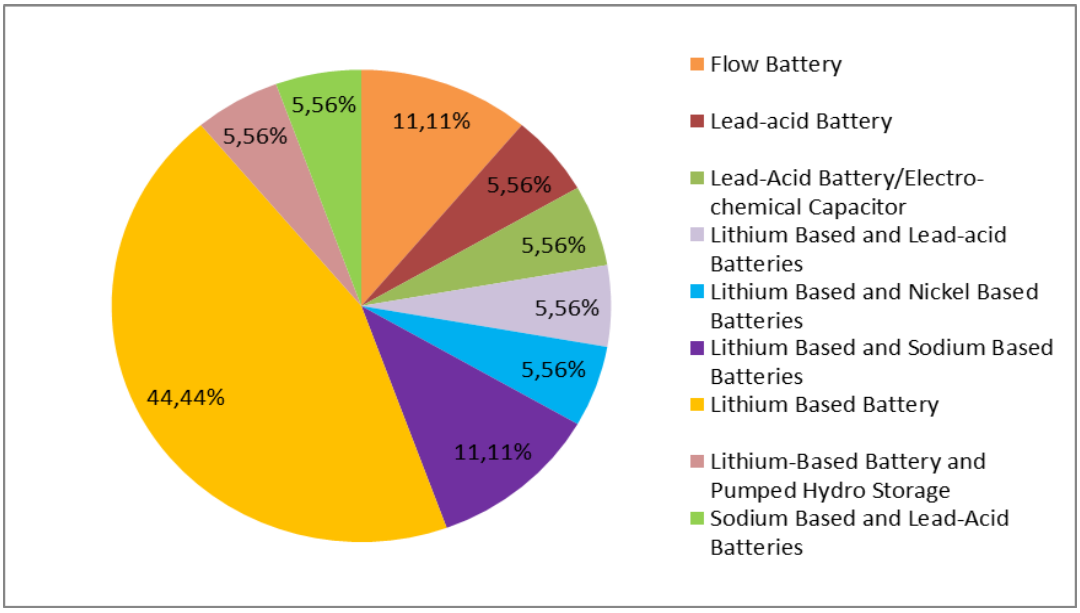
Firm	Strategie	Projects	Services	Integration	Partnership[4]
Saft	To maintain its leadership through the quality of its products and the support of its customers in multiple markets.	34	24	No	U, OBP, R&D
LG Chem	To provide batteries for all on and off grid electricity applications, for electronics and EV's.	28	20	Yes	U, OBP, R&D
Samsung	To provide battery for all on and off grid applications, EV's and electronics.	24	20	No	U
BYD	To provide batteries for all off grid electricity applications, for electronics and EV's.	23	16	No	U, OBP, R&D
Kokam	To provide energy storage systems for various industrial uses.	21	20	No	U, R&D
NGK Insulators	To provide battery for all on and off grid applications, and automobiles.	18	18	No	U, OBP, R&D
Green Charge Networks	To provider energy storage system for both side of the meter.	17	6	Yes	U
General Electric	To provide battery for all on and off grid applications.	17	17	Yes	U, R&D
Alfen	To provide battery for all on and off grid applications, and EV's integration.	15	4	Yes	OBP, R&D
NEC Energy Solutions	To provide batteries for families and system operator (advanced back up).	14	15	No	OBP, R&D
Tesla	To provide battery for all on and off grid applications, and EV's.	12	12	Yes	U, OBP, R&D
FIAMM	To provide battery for all on and off grid applications, and EV's.	11	17	Yes	U, OBP, R&D
Clean Energy Storage	To provide batteries for micro grid applications.	9	8	Yes	U
Gildemeister	To provide battery for all on and off grid applications	9	15	Yes	U, OBP, R&D
ZBB Energy Corporation	To provide battery for micro grid and both side of the meter applications.	8	8	Yes	U, R&D

Ecoult	To provide energy storage systems that increase the renewable sources utilization in electricity systems.	8	13	No	U, R&D
Toshiba	To provide energy storage to smart city applications coupled with wind and solar generation.	8	7	No	U, R&D
GS Yuasa Corporation	To provide batteries for EV's and systems of photovoltaic generation.	7	6	No	U, OBP, R&D
Aquion Energy	To provide battery for all on and off grid applications.	7	10	No	U, R&D
Stem	To provide energy storage systems and software to manage energy cost for industrial and residential customers.	7	5	Yes	U, OBP
Xtreme Power	To provide battery for all on and off grid applications.	6	7	No	U
Woojin Industrial Systems	To provide battery for all on and off grid applications, and EV's.	5	4	Yes	U, OBP
Exide	To provide energy storage system for diverse industrial applications, among them for all on and off grid, and EV's.	5	9	No	U, R&D
Altair Nanotechnologies	To provide batteries for diverse industrial uses: medical equipment, all on and off grid applications, and EV's.	5	5	No	U, OBP, R&D
Rongke Power	To provide energy storage system to large scale grid applications.	5	9	No	U, OBP, R&D
Eos Energy Storage	To provide battery for all on and off grid applications	1	5	No	U

Source: Own elaboration. [1] Firm does not longer exist. [4] U: Utility, OBP: Other Battery Provider, R&D: Research and Development Center.

More than 50% of the firms that have collaborations with R&D centers have partnerships with others battery providers. The high collaboration between firms that are developing lithium ion and flow batteries and others organizations may be explained by the fact of those technologies has not yet reached their technological maturity (as seen in the section 2.2). Further, that fact also shows the utilization of battery in electricity industry requires the battery technological development, that is, its diffusion in electricity industry depends on both the decision of battery suppliers in research and development investments and the decisions of investment by electricity industry agents in BSS.

Graphic 5: Distribution of the Firms that have Partnerships by Battery Technology

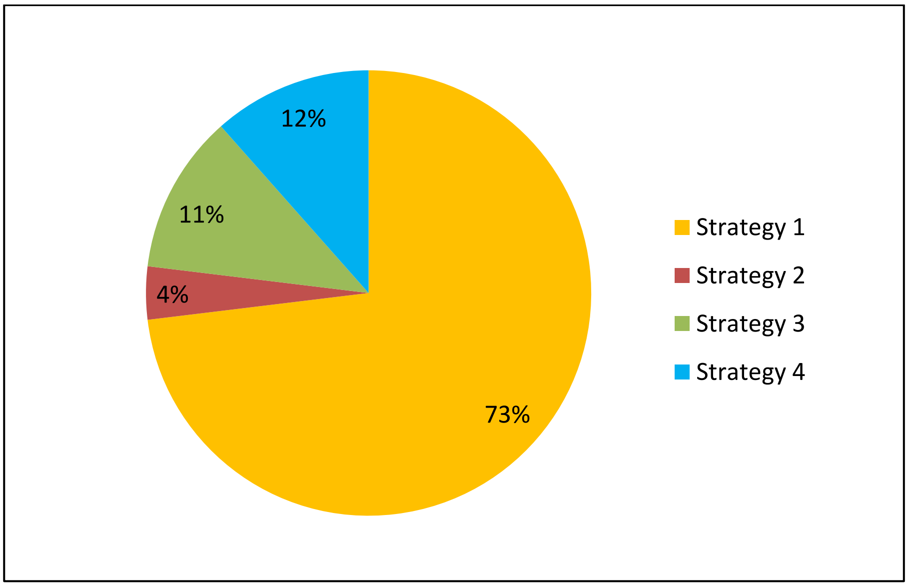


Source: Own elaboration.

Most of the analyzed firms are developing projects together with Utilities. It indicates that BSS applications to provide services within the traditional electricity supply model are considered an important market niche for battery providers. Utilities have been required to invest in energy storage technologies as well to encourage the participation of electricity end-customers in the electricity markets in some regulatory framework (EASE & EERA, 2017). In this way, considering that the investments of end-customers in BSS have a bigger degree of uncertain than the investments of utilities, the investments of utilities in BSS can be a strong incentive for encouraging battery technical development.

That uncertain regarding the definition of battery demand of electricity industry can be verified analyzing the information about technology providers' strategies (in the second column of table 10). The firms' strategies can be classified into four main types. The first strategy adopted by firms is to develop BSS to provide all the services in electricity industry that will be possible given the demand conditions. The firms that adopted that strategy have three types of general purposes: to provide BSS for all type of services in different industries, to provide BSS only for electricity industry applications, and to provide BSS for applications in electricity industry and transportation industry (EV and HEV). The second strategy is to provide BSS only for large scale applications in the grid, that is, provide batteries only for utilities or System Operators. Two firms adopted that strategy (graphic 6). The third strategy is to provide BSS for specific agents of electricity industry as electricity end-customers (industrial and residential), system operator and agents in microgrids. There are three firms that adopted that strategy; two of them are developing battery for electricity end-customers. The last strategy is to provide BSS capable to decrease the negatives effects of the increase of renewable generation electricity system reliability and affordability. Three firms have that strategy; they are from Japan and Australia and have projects related to smart city concept.

Graphic 6: Distribution of Firms among the Strategy Types



Source: Own elaboration.

As we see in graphic 6, most of BSS providers have by strategy to consolidate themselves as suppliers of BSS capable to provide many services in electricity industry. It also can be observed in the number of services provided by BSS: the firms are developing BSS for an extensive set of services even the firms with the lowest number of projects. Nevertheless, considering the possibility of the existence of discrepancies between the firms' strategies and what they are actually doing, we analyze in tables 13 and 14 the relationship between their strategies, the services that their BSS projects intend to provide, and the characteristics of their technologies.

Most of the firms that have adopted the first strategy are developing battery projects for diverse services in electricity system. The exceptions are Alfen, Green Charge Network (already mentioned above), and Aquion Energy. The first firm is a Dutch multinational that develop BSS projects for electricity industry applications related to the concept of "smart grid". It searches to promote a sustainable electricity system with high participation of electricity end-customers using EVs. In this way, most of its projects aim to develop batteries for charging stations where EVs can be charged using onsite solar electricity generation. Green Charge Network is an American startup. It provides BSS together with a software to measure and control the electricity consumption. Although it has as strategy provide batteries for both sides of the meter (Strategy 1), all its projects are developing BSS to electricity end-customers that wish to participate of Demand Response Programs of California. Similarly, all Aquion Energy's projects develop BSS for industrial end-customers (US DEPARTMENT OF ENERGY, 2017).

Finally, among the firms that have by strategy to develop battery for specific agents in electricity industry, NEC Energy Solutions are not following its strategy to provide BSS only for families and System Operators. It also has projects to meet utilities needs regarding the decrease of their costs that arise from the increase of the participation of renewable sources in electricity system.

The relation between the firms' strategy and the characteristics of the technology is not clear unless we take in account the objective of the projects that they are developing. Among the firms that adopt the fourth strategy, the GS Yuasa Corporation is developing BSS with different performances regarding the others two firms. The batteries of GS Yuasa

Corporation have a bigger duration and lower power, while the batteries developed by the other firms have a capacity of more than 1 MW and duration of less than 1 hour. It can be explained by the fact most of GS Yuasa Corporation projects involve the BSS application to increase the efficiency and decrease the electricity costs of railway system, or to provide recharge units for EVs, that is, the firm is developing projects that seek the integration of renewable energy through a renewable urban mobility system (US DEPARTMENT OF ENERGY, 2017).

The two firms that have adopted the second strategy have projects that expected to delivery batteries with an expected lifetime of more than four hours. One was founded in 2008 in China and its projects are developing a Vanadium Redox Flow Battery to be used in the process of integration of wind power generation in Chinese electricity system. As consequence of that, its batteries have a high average power (1.8 MW). The other firm is Aquion that as already mentioned is developing battery for services for electricity industrial customers. Thus, its batteries have a lower average power (21 KW).

Table 13: Relationship between firms' strategies and the Services their BSS Projects intend to provide by Firm

Firm	Strategy Type	Services
Saft	S1	Renewables Capacity Firming, Frequency Regulation, Onsite Renewable Generation Shifting, Renewables Energy Time Shift, Voltage Support, Grid-Connected Commercial and Residential, Electric Energy Time Shift, Electric Bill Management (with Renewables), Electric Supply Capacity, Stationary Transmission/Distribution Upgrade Deferral, Distribution upgrade due to solar or wind, Ramping , Electric Supply Reserve Capacity – Spinning and Non-Spinning, On-Site Power, Transmission Congestion Relief, Transportable Transmission/Distribution Upgrade Deferral, Black Start, and Load Following.
LG Chem	S1	Frequency Regulation, Renewables Capacity Firming, Electric Energy Time Shift, Onsite Renewable Generation Shifting, Voltage Support, Renewables Energy Time Shift, Electric Bill Management (with Renewables), Transmission Congestion Relief, Transportable/ Stationary Transmission/Distribution Upgrade Deferral, Load Following, Electric Supply Capacity, Grid-Connected Residential, Distribution upgrade due to solar, Electric Supply Reserve Capacity – Spinning and Non Spinning, On-Site Power, Transmission upgrades due to wind
Samsung	S1	Renewables Capacity Firming, Frequency Regulation, Electric Energy Time Shift, Voltage Support, Electric Bill Management (with Renewables), Ramping, Black Start, Onsite Renewable Generation Shifting, Renewables Energy Time Shift, Electric Supply Capacity, Electric Supply Reserve Capacity – Spinning and Non-Spinning, Stationary Transmission/Distribution Upgrade Deferral, Transmission Congestion Relief, Load Following, On-Site Power, Transmission Support.

BYD	S1	Frequency Regulation, Electric Energy Time Shift, Renewables Capacity Firming, Renewables Energy Time Shift, Load Following, Ramping , Onsite Renewable Generation Shifting, Electric Supply Capacity, Electric Bill Management (with Renewables), Electric Supply Reserve Capacity – Spinning, Voltage Support, Black Start, Stationary Transmission/Distribution Upgrade Deferral, Transmission Support, Distribution upgrade due to solar.
Kokam	S1	Electric Energy Time Shift, Voltage Support, Renewables Capacity Firming, Electric Bill Management (with Renewables), Frequency Regulation, Transmission Congestion Relief, Grid-Connected Commercial and Residential, Onsite Renewable Generation Shifting, On-Site Power, Renewables Energy Time Shift, Load Following, Electric Supply Capacity, Transportable/Stationary Transmission/Distribution Upgrade Deferral, Transmission Support, Electric Supply Reserve Capacity - Non-Spinning.
NGK Insulators	S1	Electric Energy Time Shift, Frequency Regulation, Electric Supply Reserve Capacity – Spinning and Non-Spinning, Voltage Support, Transmission Congestion Relief, Transportable/ Stationary Transmission/Distribution Upgrade Deferral, Renewables Capacity Firming, Electric Bill Management, Grid-Connected Commercial and Residential, Renewables Energy Time Shift, Load Following, Electric Supply Capacity, On-Site Power, Ramping, Black Start.
Green Charge Networks	S1	Electric Bill Management (with Renewables), Electric Energy Time Shift, Grid-Connected Commercial.
General Electric	S1	Frequency Regulation, Renewables Energy Time Shift, Electric Bill Management, Electric Supply Reserve Capacity – Spinning and Non-Spinning, Voltage Support, On-Site Power, Black Start, Electric Energy Time Shift, Grid-Connected Commercial, Renewables Capacity Firming, Load Following, Transmission Congestion Relief, Stationary Transmission/Distribution Upgrade Deferral, Transmission Support, Transmission upgrades due to wind.
Alfen	S1	On-Site Power, Electric Supply Capacity, Distribution upgrade due to solar, Grid-Connected Commercial.
NEC Energy Solutions	S3	Frequency Regulation, Electric Energy Time Shift, Renewables Energy Time Shift, Voltage Support, Renewables Capacity Firming, Load Following, Ramping, Electric Supply Reserve Capacity – Spinning and Non Spinning, Stationary/ Transportable Transmission/Distribution Upgrade Deferral, Electric Bill Management (with Renewables), Onsite Renewable Generation Shifting, Electric Supply Capacity, Distribution upgrade due to solar, Grid-Connected Commercial, Transmission Congestion Relief.
Tesla	S1	Electric Energy Time Shift, Electric Bill Management (with Renewables), Electric Supply Capacity, Renewables Energy Time Shift, Renewables Capacity Firming, Voltage Support, Onsite Renewable Generation Shifting, Frequency Regulation, Electric Supply Reserve Capacity – Spinning.
FIAMM	S1	Renewables Capacity Firming, Voltage Support, Onsite Renewable Generation Shifting, Renewables Energy Time Shift, Frequency Regulation, Load Following, Electric Energy Time Shift, Electric Supply Capacity, Electric Bill Management with Renewables, On-Site Power, Black Start, Electric Supply Reserve Capacity - Non-Spinning, Transmission Support, Transmission upgrades due to wind, Grid-Connected Residential.
Clean Energy Storage	S3	Electric Bill Management with Renewables, On-Site Power, Onsite Renewable Generation Shifting, Grid-Connected Residential, Renewables Energy Time Shift, Electric Supply Capacity, Electric Supply Reserve Capacity - Non-Spinning.
Gildemeister	S1	On-Site Power, Onsite Renewable Generation Shifting, Renewables Energy Time Shift, Renewables Capacity Firming, Electric Energy Time Shift, Electric Bill Management (with Renewables), Grid-Connected Commercial, Electric Supply Capacity, Voltage Support, Frequency Regulation, Load Following, Black Start.
ZBB Energy Corporation	S1	Renewables Capacity Firming, Black Start, Electric Bill Management, On-Site Power, Onsite Renewable Generation Shifting, Renewables Energy Time Shift, Electric Energy Time Shift.
Ecoult	S4	Renewables Capacity Firming, Onsite Renewable Generation Shifting, Electric Energy Time Shift, Voltage Support, Load Following, Electric Supply Reserve Capacity – Spinning and Non-Spinning, On-Site Power, Electric Bill Management with Renewables, Grid-Connected Commercial, Frequency Regulation, Ramping, Stationary Transmission/Distribution Upgrade Deferral.

Toshiba	S4	Frequency Regulation, Renewables Capacity Firming, Electric Energy Time Shift, Voltage Support, Grid-Connected Commercial, Electric Supply Reserve Capacity – Spinning, Electric Bill Management, Renewables Energy Time Shift, Electric Supply Capacity.
GS Yuasa Corporation	S4	Electric Energy Time Shift, Renewables Capacity Firming, Onsite Renewable Generation Shifting, Grid-Connected Residential, Voltage Support.
Aquion Energy	S2	Renewables Capacity Firming, Onsite Renewable Generation Shifting, Electric Bill Management (with Renewables), Renewables Energy Time Shift, On-Site Power, Electric Energy Time Shift, Voltage Support, Load Following.
Stem	S3	Electric Bill Management, Electric Energy Time Shift, Renewables Capacity Firming.
Xtreme Power	S1	Renewables Capacity Firming, Frequency Regulation, Ramping , Voltage Support, Electric Supply Reserve Capacity – Spinning, Electric Energy Time Shift, Renewables Energy Time Shift.
Woojin Industrial Systems	S1	Electric Energy Time Shift, Electric Bill Management, Voltage Support.
Exide	S1	Voltage Support, Frequency Regulation, Electric Supply Reserve Capacity – Spinning, Electric Energy Time Shift, Electric Bill Management, Grid-Connected Commercial, Stationary Transmission/Distribution Upgrade Deferral, Black Start, Transmission Support.
Altair Nanotechnologies	S1	Frequency Regulation, Renewables Capacity Firming, Voltage Support, Grid-Connected Commercial, Renewables Energy Time Shift.
Rongke Power	S2	Onsite Renewable Generation Shifting, Renewables Capacity Firming, Frequency Regulation, Voltage Support, Renewables Energy Time Shift, Grid-Connected Commercial, Electric Supply Reserve Capacity – Spinning, Electric Energy Time Shift, Black Start, Transmission Congestion Relief.
Eos Energy Storage	S1	Renewables Capacity Firming, Renewables Energy Time Shift, Electric Energy Time Shift, Ramping, Distribution upgrade due to solar.

Source: Own elaboration from US Department of Energy (DOE) Energy Storage Database. S1: Strategy 1; S2: Strategy 2; S3: Strategy 3; and S4: Strategy 4.

When we look the set of the firms that have adopted the first strategy, we can observe (in average) most of them are providing BSS with less than four hours of lifetime and with less than 1 MW of power.

There are six firms that develop BSS with duration higher than four hours. NGK Insulators whose most projects aim to provide services for electricity end-customers and utilities. Clean Energy Storage is manufacturing batteries for use together with residential photovoltaic panels for microgrid applications. Gildemeister and Aquion whose most of their projects aim to increase the participation of electricity end-customers in electricity system operations through Demand Response Programs. Eos Energy Storage, a firm that does not longer exist and was the only firm in the database developing zinc-air battery for one project that intended to use such technology in a Utility's Solar Farm. Finally, Altair Nanotechnologies has most its projects with the objective to delivery BSS with lower duration (less than 30 minutes) for System Operator to deal with the high variation of renewable electricity production. It also has two projects that are developing batteries in laboratories with high lifetime (15 hours) which raise its battery lifetime average and explain the difference between its battery lifetime average and median.

Three firms that adopted the first strategy have (in average) projects of BSS with expected duration less than one hour, they are: Saft, Toshiba and Ecoult. The first has the biggest number of projects and all of them have a lifetime smaller than three hours. Most of its projects aim provide BSS for large scale application in electricity system such as Frequency Regulation, Power Quality, Voltage Support, and Solar and Wind Farms Integration. Toshiba (in similar) way has all of its projects with the main purpose to delivery battery to provide Frequency Regulation and other grid support services. Ecoult is following its strategy to provide BSS to increase the participation of renewable generation in electricity system, so its projects aim to provide BSS to decrease the diesel use in microgrids increasing the utilization of solar photovoltaic technologies, as well as promoting a better wind farms integration in the electricity systems (US Department of Energy, 2017).

Table 14: Expected Performance in Power and Lifetime of Battery Storage System by Firm

Firm	Average Power (KW)	Median Power (KW)	Average Lifetime (h)	Median Lifetime (h)
Saft	7,861	500	0.97	1.00
LG Chem	6,149	2,500	2.04	1.50
Samsung	6,368	1,000	2.51	1.00
BYD	5,326	1,500	2.22	2.16
Kokam	4,628	400	1.12	1.00
NGK Insulators	6,589	2,000	6.74	6.50
General Electric	3,468	3,700	2.00	2.00
Green Charge Networks	80	30	1.18	1.00
Alfen	50	50	2.00	2.00
NEC Energy Solutions	4,994	2,000	1.20	1.00
Tesla	15,490	1,220	3.75	4.00
FIAMM	216	100	1.86	1.70
Clean Energy Storage	11	5	6.22	5.00

Gildemeister	293	30	6.13	4.33
Ecoult	1,011	20	0.82	1.00
Toshiba	13,429	3,000	0.85	0.50
ZBB Energy Corporation	164	100	2.56	2.00
Aquion Energy	21	15	4.55	4.00
GS Yuasa Corporation	343	64	2.00	2.00
Stem	262	36	1.85	1.56
Xtreme Power	21,100	6,500	1.00	0.46
Altair Nanotechnologies	1,360	1,000	6.13	0.25
Exide	3,600	1,500	1.55	1.00
Rongke Power	1,815	1,100	4.50	3.00
Woojin Industrial Systems	388	250	2.00	1.33
Eos Energy Storage	10,000	10,000	4.00	4,00

Source: Elaborated from US Department of Energy (DOE) Energy Storage Database

Regarding the values of capacity, firms with higher number of projects also have in average projects with power higher than 1 MW. The three firms with the highest average power are Xtreme Power, Tesla, Eos Energy Storage. Xtreme Power and Eos Energy Storage went bankrupt and do not longer exist. They were startups which were developing projects of lead-acid battery (Xtreme Power) and zinc-air battery (Eos Energy Storage) to deal with the grid voltage, frequency fluctuations, and others negative effects of large scale renewable generation (solar and wind farms). Although most of Tesla projects seek to delivery BSS for industrial and commercial electricity end-customers (and have a power less than 1 MW of power), it has three projects with more than 10 MW of power whose customers are Utilities that aim to use BSS to reduce the demand in peak hours.

Further, the firms with the lower capacity (less than 0.1 MW) are those that we identified above that only are developing BSS for electricity end-customers (residential or industrial): Clean Energy Storage, Aquion Energy, Alfen, Green Charge Networks (US Department of Energy, 2017).

From that, we conclude:

i. Firms whose most clients wish to use BSS for services related to use of electricity end-customers (as Time-Shift or Onsite Renewable Generation Shifting) tend to developed BSS with higher lifetime than those firms whose most clients aim to use BSS to provide Network or Renewable Generation Integration Services (as Frequency Regulation and Voltage Support).
ii. Firms whose consumers are electricity end-customers that intend to use BSS to provide services of Time Shift, Onsite Power or Bill Management tend to develop technologies with lower power than those firms whose consumers are utilities that aim to use BSS for grid services (as Frequency Regulation, Network Upgraded Deferral, Voltage Support, Power Quality, System Reliability or Renewable Integration).

Based on what has been exposed in this section, the supply of BSS for electricity industry is characterized by a production of energy storage systems that takes into account the needs of customers. Nevertheless, the demand seems do not have influence on the battery type that provider firms will develop. Those firms can be divided into two groups: startups founded in the 2000s and multinationals with vast experience in supplying batteries to other industries. Most of them manufacture lithium-ion batteries. Since batteries still need to be developed for electricity industry applications, most of the firms have partnership with R&D centers, other battery providers, and utilities. The partnership with utilities shows the BSS demand for services of interest to utilities (such as, Frequency Regulation, Voltage Support, Peak Demand Reduction or others services related to reductions of the effects of renewable generation on electricity system reliability) is an important part of BSS demand, though the utility may not have direct control over the utilization of this technology in the provision of these services (as will be discussed in the next chapter). It in turn can influence the development of the BSS.

Furthermore, most of the firms adopt a strategy to develop battery to provide all the services in electricity industry that will be possible given the demand conditions. There are also more three types of strategies: to provide BSS for large scale applications, for specifics agents of electricity industry, and to provide BSS capable to decrease the negatives effects of the increase of renewable generation in electricity system reliability and affordability. We can observe that in general firms follow their adopted strategies developing BSS for services associated with them. Looking at the technical characteristics of the batteries by firm available in the database (power and lifetime), we also observe there is not a tendency to standardize the performances of batteries among the firms, and that the technology has been developing according to its utilization. In that sense, the demand is a strong element in the process of BSS development for electricity industry application, however, it only has influence on the technical characteristics to be developed (that is, the increase of the BSS performances regarding to lifetime, life-cycle, density, capacity, efficiency, among other technical characteristics).

2.6. CONCLUSIONS

One of the results of the process of change of electricity industry in last years was the emergence of a new demand for battery industry. The battery industry has a well consolidated structure, being formed (in large part) for multinational firms that have extensive experience in the provision of batteries for others industries (or in the provision of others products and services for the electricity industry itself, as in the case of some firms). However, the emergence of that new demand implied in the challenges for those firms to develop BBS capable to provide a broad set of different services that require different performances in wide set of technical characteristics at a time in which such demand is still in structuration process.

The uncertainty in the BSS demand of electricity industry is in part reflected in the fact that the strategy adopted for most of analyzed firms (even for the startups with financial restrictions) is to provide BSS for all the services in electricity industry that will be possible given the current demand conditions. In this sense, the battery decisions regarding which set of technical characteristics of BSS to improve are function of the process of consolidation of the demand of electricity industry. It is also observed in the fact that there is not a standardization of the BSS performance regarding to power and duration among the firms. It shows that although there is a clear relationship between the services and technology expected performances (for example, projects that aim to provide Frequency Regulation for utilities have in average low lifetime and high power), the BSS are in some degree customized products.

Firstly, the battery type (e.g. whether they are nickel based or lithium ion based) is an internal decision factor of battery providers. In their decision-making process, those firms consider their competences and experiences as well as the potential demand not only from electricity industry but from other industries they provide. Besides, there are important geopolitical considerations regarding the mining of the basic materials that likely affect those decisions. This means the effects of electricity needs is relatively unimportant in this choice.

On the other hand, the demand has an essential role in the process of battery development determining which characteristics (e.g. duration, density, capacity, round-trip efficiency) must have their performance improved in the technology. Once those rules affect directly the decision-making process of the electricity system agents, those rules influence indirectly the decisions of battery providers about the innovation process of their technologies. Therefore, the regulatory rules of electricity industry have influence indirectly on the technical characteristics of BSSs.

3. THE INFLUENCE OF REGULATORY RULES ON THE DEVELOPMENT OF BATTERY STORAGE SYSTEMS ON ELECTRICITY INDUSTRY

3.1. INTRODUCTION

Just as happens with others technologies, the demand is an important element for the development of BSS. The decision process of a customer regarding to buy (or not) BSS to provide a specific service in electricity industry (as Bill Management by electricity end-consumers or Voltage Support by utility) is naturally a function of the expected revenue of that service. However, the electricity industry is a regulated industry which means many of its transactions follow specific rules. These rules determine which and how the transactions can or cannot occur, and how they will be remunerated.

As we showed in last chapter, there are different services that BSS could provide in Electricity Systems. Some of those services are under influence of specifics rules having an established mechanism of remuneration (e.g. in many electricity systems, the service “Electric Supply Reserve Capacity” is remunerated in the wholesale market, while “Transmission Congestion Relief” is remunerated by a network tariff incorporated in the end-consumers’ electricity bills). In contrast, others services (e.g. the service “Electric Supply Capacity” or “Onsite Renewable Generation Shifting”) are relatively recent in the industry and a suitable regulatory framework haven’t been yet established even to ensure those services will be done in many systems. Thus, regulatory rules are a fundamental element in the development process of BSS, since according to the way of those services are regulated, the BSS will be developed to provide some services and not others.

By the Regulator perspective, BSS is a new technology whose effects on the electricity system reliability and affordability is not yet clear. The BSS diffusion may have positive effects once they provide flexibility solutions in a system with high participation of renewable generation, and batteries can be an alternative to expensive network and generation expansions. On the other hand, the diffusion of that technology may affect negatively the electricity system – for example, it combined with the expansion of distributed generation can lead to a "death spiral" situation[10]. In that case, the Regulator can change some rules to mitigate negative effects of BSS diffusion ensuring the electricity supply for all customers and for reasonable prices which would have negative effects on BSS development.

In this way, not only the current regulatory rules, but also the adaptation of those rules is important for the BSS development. Recently, some regulators have been taking some steps to incorporate BSS (as well as other new complementary technologies, specially, decentralized solar generation and electric vehicles) without affecting negatively the reliability and affordability of their electricity system. It is the case of regulator in Australia, Germany, Korea and United States (HERMEIER & SPIEKERMANN, 2018; CHIN & JOONKI, 2018; HAGAN, RUEGER & FORBUSH, 2018; AEMC, 2015).

United States is the country with more number of battery projects (US DEPARTMENT OF ENERGY (DOE) ENERGY STORAGE DATABASE, 2017). Each American state has its own regulatory framework under regulation of Federal Energy Regulatory Commission (FERC). FERC in 2017 issue a final rule that establish reforms to remove the barriers for the integration of Energy Storage Resources (ESRs) in the electricity wholesale markets, and a policy statement to provide guidance on the utilization of ESRs to provide network services (HAGAN, RUEGER & FORBUSH, 2018). In addition, each state has its own measures to encourage the utilization of those resources in electricity system. Among the states with more number of projects, California and New York have already

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[10] A significant number of self-generation customers force the power providers to increase the bill in order to cover past investments. It can lead to increase of the expected revenue of the self-generation, which can lead to a more reduction of electricity purchases and a fall of power providers' revenues, compromising in this way the system reliability and affordability (BORENSTEIN & BUSHNELL, 2015).

established a set of measures that seek to promote the integration of ERS in their systems even before FERC's actions (NYISO, 2017a; CAISO, 2018d; 2018e).

In view of that, in this chapter, we aim to understand how the regulatory rules of electricity industry can influence the development of battery. We consider the California and New York Electricity Systems as cases of study .

To that end, we identify the main features of electricity industry and how it is regulated. We use as case of study two different electricity systems: California System and New York System in United States. We classify the services described in section 2.4 adopting the perspective of the regulator as main criterion. From this classification, we analyze how different regulatory scenarios can influence which technological trajectory of BSS probably will be developed.

We use information collected in technical reports and documents from research laboratories, public agencies, and consulting, scientific papers, public commissions' websites, websites of California Independent System Operator and New York Independent System Operator, and US Department of Energy (DOE) Energy Storage Database.

The organization of the chapter is as follows. In the second section, we present the characteristics of electricity industry and its regulatory framework using as example the experience of California and New York. After that, we expose how those states have incorporated the BSS in their system (section 1.3). In fourth section, we propose a classification of the services described in last chapter and identify the possible regulatory scenarios. In section 1.5, we analyze how regulatory rules regarding the market design can influence BSS development. In next section, the influence of tariff design on BSS development is analyzed. Finally, in section 1.7, we present the main conclusions of the chapter.

3.2. THE ELECTRICITY INDUSTRY

The electricity is an essential good used in all type of actives of any economy. Two aspects have structured the way in which the electricity supply was organized over the first decades of XX century: the economical unviability of electricity storage in bulk at utility-scale level (as mentioned in chapter 2) and the high variation of the electricity consumption during a short period. Those aspects implied in the need to a constant balance between the electricity supply and demand for that good could be traded.

In addition to that, the development of the technological base of the electricity supply was predominantly based on gain of production scale which led to the geographic distancing of the electricity production from its consumption increasing the importance of the electricity transport (JOSKOW, 2003; CHANDLER, 1990). The electricity transport is done by transmission and distribution power lines and is technically complex involving specifics requirements for injections and withdrawals. Economically, the investment in network infrastructure configures a natural monopoly situation with high fixed cost and a low operation cost. Further, the existence of economies of scale together with discrete investments implies frequently in excess of capacity (DI CASTELNUOVO AND VAZQUEZ, 2018). In this way, the combination of the need to constant balance supply and demand with the high importance of electricity transport has dramatically increased the degree of complexity of operation process of electricity supply.

The supply of this good can be divided into four segments: Generation, Transmission, Distribution, and Billing Services. The Generation is responsible for the electricity production that can be made by plenty type of plant units with different generation technologies as thermoelectric, hydroelectric, solar farms, geothermal plants, nuclear power plants or wind farms. The Transmission integrates the generation with the distribution lines making the large distance transport of a large amount of electrical power in high voltage;

while the Distribution is responsible for delivery the energy in low voltage to end-consumers. Finally, the fourth segment is the electricity commercialization.

In the most countries of the world, electricity was supplied by a vertically-integrated monopoly firm (that provided from Generation to Billing Services) until the last decade of XX century. While in the Europe that firm (also known as utility) was usually state-owned, in the United Stated it was generally a private-owned firm under regulation of the Federal Energy Regulatory Commission (FERC). FERC was under the authority granted by the 1938 Federal Power Act. The FERC applied a “cost-of-service” regulation in which the firm had ensured the recovery its operational costs plus a regulated return rate of the capital invested. Further, in United States the agents of electricity industry was regulated by state rules established by Public Utilities Commissions (PUCs). The PUCs regulate in state level essential services provided by utilities (e.g. electricity, gas, railroad, passenger transportation, water, and telecommunication) to ensure customers will have a good and reliable service at reasonable rates (CPUC, 2018a; NYPSC, 2018a; BORENSTEIN & BUSHNELL, 2015; OCDE, 2001).

During the nineties, most of the countries followed the Britain experience and began a restructuration process of their electricity industry. The base idea of the restructuration was to end with the vertical integrated monopoly, separating the segments of the electricity supply that could be competitive (e.g. generation, marketing and retail supply) from those that by technical constraints were considered a natural monopoly (as distribution and transmission segments) (JOSKOW, 2008). Nonetheless, the implementation of that idea in a context of constant need to maintain the balance between electricity supply and demand of energy was only possible through the implementation of a regulatory reform. In Europe, the restructuration of electricity industry implied in the creation of a Regulatory Agency, while in the United States, it implied in restructuration of the regulatory mechanisms used by FERC and PUCs. After the Regulatory Reform, the Regulator became responsible for: (1) defining the rules of the electricity trade (that is, the best market design) to maintain the constant balance between electricity supply and demand; and (2) ensuring the network access as well as defining a socially fair network tariffs capable to remunerate the investments made in the network build (and stimulate new investments) (BORENSTEIN & BUSHNELL, 2015; JOSKOW, 2008).

The restructuration of the industry was made by the countries through three main actions: the creation of electricity wholesale market, the creation of electricity retail market, and the establishment of network regulation.

3.2.1. The Electricity Wholesale Markets

The wholesale market operates the short and long term electricity markets as well the real time markets. In those markets are determined the generators' revenue and the price paid for the electricity by customers (retail agents, System Operators, and electricity end-customers).

To create those markets, besides the privatization and vertical separation of the state-owned electricity monopolies, it was necessary to restructure the generation segment creating enough number of generators to ensure the competition on that segment and mitigating market power. The implementation of that measure was facilitated in US since the Public Utility Regulatory Policies (PURPA) of 1973 (that ensured the utilization of electricity produced from small power sources and industrial cogeneration schemes) had encouraged the built of a large volume of new generating plants by non-traditional generating companies (MEZ, MIDTTUN & THOMAS, 1997).

In general, to participate of the wholesale markets, the agents of the industry must register indicating the activity they wish to pursue in the market. A system that export electricity to the grid is a Generating System (the owner of that system is call generator), a system that only draw electricity from the grid is a Load (the owner is call customer), and a system that import and export electricity is a Load and Generating System (the owner is both generator and customer). To ensure the well operation of the market and the reliability of the system, there are registration requirements (AEMC, 2015).

Additionally, once the network continued to be a monopoly, the access to it had to be ensured to inhibit market power from network owners. It was done through the separation between the management of the network use and the ownership/investment in the network. The planning and management of network use have become responsibility of the Independent System Operator (ISO). The ISO is a new independent entity created to ensure the system reliability in short term through the management of network operations, and the scheduling of generation to meet demand maintaining the physical parameters of the network (such as frequency, voltage, and stability) in all time. It is also responsible to guide the need of investments in network infrastructure. In this sense, the System Operator is a key agent for the viability and operation of electricity markets once it ensures the others agents will be able to use the network in the same time that carries out the balance between electricity supply and demand.

The ISO’s dispatch system matches the generation resources to load using the least costly generating units. For the dispatch system works without problem, it is necessary that ISO considers the transmission constraints having a good contingency analysis, and that the electricity markets have a good operation (KRISTOV & KEE, 2013).

In many electricity systems around the world, the electricity trading in wholesale markets is centralized (that is, through auctions) and in some regions, the electricity trading through bilateral contracts are allowed. The wholesale markets are operated by an independent entity or by the ISO. Nevertheless, all market participants (including the ISO) must follow the markets rules established by the Regulator. In electricity systems of California and New York, the wholesale markets are operated by the California Independent System Operator (CAISO) and New York Independent System Operator (NYISO), respectively. They and other markets players are regulated by FERC and PUCs. FERC establishes the rules that all wholesale markets in United States must follow in relation of market access, services that can be trade in the markets, and penalties in case of non-competitive behavior; PUC determines the loading order among different technologies of generation and authorizes the construction of new generation plants. Although FERC establishes the rules regarding the operation of electricity wholesale markets, there are differences among the markets in different states. The states (specifically, their ISOs) are allowed to establish their own rules regarding the market operation and price mechanisms as long as the FERC's rules are fulfilled (HAGAN, RUEGER & FORBUSH, 2018).

The wholesale markets comprehend different markets that negotiate different services necessary to maintain the system reliability in the short and long term. Those markets occur at different moments regarding electricity delivery.

3.2.1.1. Energy Services

The first services that are traded in wholesale electricity markets are the Energy Services. They are defined as "those functions performed using energy which are means to obtain or facilitate desired end services or states" (FELL, 2017, p.129). To ensure the demand will be met when required, the energy is trade into different markets at different point of the time: the long-term markets (as the forward or capacity markets) and short-term markets (as the day-ahead market).

3.2.1.1.1. The Long Term Electricity Markets

The long-term markets ensure that will be electricity supply to meet the demand in the long-term. The demand for forward generating resources is formed by utilities and electricity providers that by regulatory enforcement must have enough resources to meet their demand plus a reserve amount for next few years. The long term markets are required since the need for forward generating resources cannot be meet in short-term energy markets. The short-term energy markets (that will be described below) only remunerate the existing power plants and usually adopt a bid cap. The adoption of a bid cap is justified by need to eliminate the possibility of market power by generators (JOSKOW, 2003). Nevertheless, as Kiesling (2006) argues a bid cap (that means an energy price cap) also mutes or eliminates a price signal. The absence of price signals reduces the scarcity rents affecting negatively the investment in generating capacity and its substitutes (as transmission capacity and technologies to management and reduction of demand). Thus, the forward markets are essential for reliability of the system in the long term since through them it is established the payments to power generators for their available capacity. At the same time that those payments provide incentives for existing generators remain open, they also encourage the investments in new generation capacity. The functioning of long term markets is also important for the affordability of the electricity systems, since it reduces the dependency of short term markets to meet the demand (JOSKOW, 2003).

The utilities and electricity providers can enter into bilateral long-term contracts to supply capacity and other market services, or can participate of auctions conducted by the System Operator. In an auction, the System Operator manages the process of selling capacity based on the electricity customers' load for a certain timeframe.

As mentioned, in United States, the PUCs regulate the construction and operation of generation facilities, although FERC has authority over that when the state regulation fails and the reliability of the system is at risk.

In California, since 2004, all the capacity contracting is done through the Resource Adequacy (RA) Program within the jurisdiction of California Public Utilities Commission (CPUC). The RA Program establishes resources obligations applicable to all Load Serving Entities (LSEs) based on the forecast future demand given by California Energy Commission (CEC) (including an additional 15% planning reserve margin) and from CAISO studies of local and flexible requirements. The LSEs (investor owned utilities, energy service providers and community choice aggregators) meet their RA obligations by procuring resources bilaterally from the pre-existing fleet of generation resources (CPUC, 2018b; CPUC, 2016).

In New York, the NYISO uses the Unforced Capacity Methodology to determine the amount of capacity that each generator is qualified to supply and LSEs must procure. 65% the state's capacity requirements are transacted through bilateral contracts. In the state, there is not limit for the duration of those contracts, so they can have a commitment of energy purchase/delivery for only one day or for more than a decade. The rest of state's capacity requirements are transacted through the Installed Capacity (ICAP) Market administered by NYISO. The LSEs to satisfy their obligations purchase capacity in ICAP market. The ICAP market is composed by a series of auctions that happens throughout the course of the year where suppliers offer their capacity and LSEs bid to purchase the capacity. The offers are selected from the lowest to the highest offers until the demand plus the reserve requirements are satisfied (NYISO, 2018a; HIBBARD ET AL., 2015).

3.2.1.1.2. The Short Term Electricity Markets

The short term markets usually happen a day before the energy delivery. In those markets, energy is bought and sold by retailers, ISO and generators proving a dispatch schedule to be followed by the ISO on the following day.

In California, the day-ahead market determines the price for all commodities simultaneously. The state adopted a nodal based pricing mechanism (called Locational Based Marginal Pricing (LBMG)) that establishes a marginal price for every particular grid location (nodes) considering all transmission capacity constraints (KRISTOV AND KEE, 2013). The market also allocates the available transmission capacities in an implicit auction. In this way, the prices established in the electricity markets reflect both the generation capacity and transmission capacity scarcities (CAISO, 2018a; MOHRHAUER, 2016).

The Californian day-ahead market includes two separate market applications: Integrated Forward Market (IFM) and Residual Unit Commitment (RUC). The IFM commits generating resources, procures part of ancillary services, and clears (physical and virtual) energy supply and demand schedules. The resources that are committed in IFM are kept online and its schedules are protected in RUC. The RUC commits extra resources and plans additional capacity beyond physical energy schedules to meet the demand forecast. The role of RUC is to deal with the uncertainty created by unexpected variation in electricity consumption and generation. Furthermore, the system operator schedule is set every fifteen-minute of the next day. This fifteen-minute granularity combined with the RUC ensures the commitment of generating resources that will be not available in Real Time Market increasing reliability of a system with high penetration of renewable generation (CAISO, 2018b).

The Californian day-ahead market follows four sequentially processes. First, the markets players submit their bids. Then, CAISO runs a test for market power mitigation in which the bids that fail in the test are revised to predetermined limits (cap bid). Third, the integrated forward market determines the amount of generation will be needed to meet forecast demand. Finally, the additional power plants that will be needed and must generate electricity in the next day are designed by a residual unit commitment process. The last generator bid accepted sets the clearing price (ANGELIDIS, 2018; CAISO, 2018b).

In New York, the energy is negotiated in both centralized and decentralized markets. About 45% of daily delivered energy is traded through bilateral contracts between generators/power markets and Load Serving Entities (LSEs). Frequently, the contracts adopt an agreed price structure for a certain period. 51% of energy is negotiated in a day-ahead market where the LSEs and generators submit bids to purchase and provide electricity for each zone of the system. Differently from California, in New York was adopted a locational based pricing mechanism (LBPM) by zone that establishes marginal prices for each zone considering differences of transmission capacity constraints among the zones (MOHRHAUER, 2016; NYISO, 2014).

As in California, the generators bids are subjected to a bid cap and mitigation rules. The day-ahead market works as a uniform clearing auction in which after the bids of generators and LSEs, NYISO selects the mix of generating resources to supply the hourly demand with the lower cost capable to maintain the reliability of the electricity system. The NYISO’s selection begins with the lowest bids and progress through the higher offers until the expected demand be met. If the generator is selected, the generator receives the bid price of the last unit chosen. In a case in which it is not possible to pay the uniform clearing price, the generators will be paid by a price that recovery their annual fixed costs plus a reasonable return on equity into their bid price (to maintain a reasonable level of profit) (NYISO, 2016).

3.2.1.2. Adjustment and Ancillary Services: The Intra-Day Electricity Markets

Even with the operation of the electricity market one day before energy is delivered, changes in operating conditions and variations in load and generation lead to differences between the expected demand and supply and real demand and supply. To deal with this imbalance, there are two types of solutions: to readjust the electricity supply to the load or to change the electricity demand to the supply at all time. Due to the lack of developed technologies of demand response, historically, the real time balance between electricity supply and demand has been doing through the utilization of adjustment and ancillary services. Adjustment Services are traded in markets that occur in the current day (as intraday or real time markets). Those markets are operated by the System Operator and work with similar principles of day-ahead market. In them, the sale market agents sell more or repurchase energy while the buy market agents buy more or resell energy, ignoring virtual energy schedules. In this way, part of the energy negotiated in those markets is already part of the ISO's Schedule.

In the real time markets, the ISO and LSEs can also contract additional ancillary services. The Ancillary Services are unbundling services necessary to support the electricity transmission from the generating units to maintain reliable operations of the transmission system. They are provided by Generation Resources and other facilities. They include Voltage Support, Regulation Service, Spinning and Non-Spinning Reserve, Replacement Reserves, Black Start, Loss Compensation Service, Energy Imbalance Services, Load Following.

Ancillary services are the primary mechanisms in place for ISO ensures the operation and reliability of the electricity systems. The payments receive by their providers are determined either in the market in which the trading is carried out between the ISO and others markets players, or by a cost-based price in which the ISO's costs are recovery by a tariff paid by transmission customers. Since the System Operators expect it will be necessary the contraction of ancillary services (specially, spinning and non-spinning reserves), they already contract a certain amount of these services in the day-ahead markets. If additional services are necessary after the day-ahead markets, then they will be purchased through the real time market in both New York and California electricity systems.

In California, the real time market is a spot market that dispatches power plants every 15 and 5 minutes (dispatches with 1 minute can also occur in specific grid conditions). The services regulation up and down, spinning reserve and non-spinning reserve are trade in the markets. For the rest of ancillary services, Scheduling Coordinators[11] pay an allocated proportion of the service charge contracted by CAISO (CAISO, 2017; ZHOU, LEVIN & CONZELMANN, 2016).

CAISO determines its demand for ancillary services based on an internal demand forecast. The ISO can obtain them through self-scheduling resources or participating of electricity markets. Its selection process of resources to provide those services is based on the resources' capacity bid price and their deliverability. The ancillary service bids may be accompanied by an energy bid in the day ahead and real time markets.

Moreover, to ensure the system reliability, the LSEs are required to procure ancillary services. In the same way of the ISO, they can obtain those services either through self-provision or through purchase on the markets. If they contract an amount of services bigger than their currently needs, the LSEs can bid their excess of ancillary services in real time markets (CAISO, 2017).

In this point, it is necessary to highlight that although the evaluation of ancillary services bids is made simultaneously with energy bids, the prices of energy and ancillary services are different. In the day-ahead market, the Integrated Forward Market co-optimizes energy and ancillary services determining the Ancillary Service Marginal Price (ASMP). The

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[11] Scheduling coordinators are companies that participate of the ISO markets. They can directly bid or self-schedule resources as well as handle the settlements process (CAISO, 2017).

ASMP represents the marginal cost of providing an additional unit of that service. When ASMP is not well-defined in supply shortage conditions, CAISO uses the scarcity reserve demand curves (based on the stepwise demand curve corresponding to the shortage of Spinning Reserves, Non-spinning Reserves, and Regulation-up, and on the stepwise demand curve corresponding to shortage of Regulation-down service) to set the administrative values for ASMPs (CAISO, 2017; EDMUNDS & SOTORRIO, 2015; CAISO, 2013).

If the purchases under New York day-ahead market by electricity supplies and bilateral contracts are not enough to meet an LSE's real needs, the LSE buys the remainder of their requirements from NYISO real-time market. The NYISO real time market is an hourly spot market that dispatches power plants every 5 minutes. In that market, 5% of energy delivered to end-customers in the state is traded (NYISO, 2014). The operation of real time markets is the same of day-ahead markets: the suppliers offer a quantity of electricity for a price, and the NYISO selects the lowest-priced suppliers until demand is met. In those markets are traded the ancillary services: Operating Reserve, Energy Imbalance, and Frequency Response Service. The others services (Scheduling, System Control and Dispatch Services, Voltage Control and Black Start) are remunerated by an embedded cost-based price. Beyond the System Operator, the Transmission Customers and Suppliers can also participate to the markets contracting Regulation, Frequency Response, and Operating Reserve Services (NYISO, 2018b).

The NYISO coordinates the provision and arranges for the supply of all ancillary services that are not self-supplied. Some Services must be provided by the NYISO, and others can be provided by NYISO or procured by Transmission Customers and Suppliers themselves. All provided Ancillary Service must be scheduled by the System Operator (rule settled by FERC). The procedures adopted by NYISO, Transmission Customers and Suppliers of New York System are the same that those adopted in California (NYISO, 2018b).

Nevertheless, the methodology used by NYISO to determine the market price for some services is different from that used by CAISO. NYISO and Transmission Customers and Suppliers also determine their expected demand of ancillary services and obtain those services in day-ahead market. If they contract an amount of services smaller or bigger than their currently needs, they can buy more or bid the excess of ancillary services in the real market. In the day-ahead and real time markets, NYISO calculates the market clearing price for each ancillary service for every hour and for each zone of the system. Generally, the payments of ancillary service providers consider the locational constraints, the day-ahead/real time market capacity bid price, and the real time regulation movement bid price of each supplier (NYISO, 2018b).

3.2.2. Electricity Retail Markets

As already mentioned, throughout most of the electricity industry history, the retail prices were established based on the average cost of utilities. To approximate the price of electricity services paid by end-customers to the marginal cost of electricity production, the market was open giving the end-customers access to electricity services provide by new energy retail providers (also known as electric/power companies). The new retail providers can produce their own energy (as the incumbent utilities do) or can acquired energy in the wholesale market. Together with the energy, those companies also provide others complementary services (as metering and billing). The electricity bill usually has five components: (i) energy and energy associated services; (ii) network tariffs determined by the regulation that intend to recovery the network investments made by incumbent utility, (iii) fee, taxes and levies (to recovery social and environmental costs of society), (iv) “surchases” (recently, associated to incentive policies for the creation/expansion of renewable generation), and (v) operation costs and reasonable profit rate of electric company. Considering that, the restructuration process of electricity retail market was basically concentrated in the energy component of end-customer's bills (item (i)) (BAYER, 2015).

In most electricity systems, the incumbent utility was allowed to continue in the retail market. To ensure a competitive market, the unbundling of retail tariffs to separate the prices for retail power and associated services from the charges of network use was carried out. In locations where the retail competition was not possible, the utilities was regulated to supply the customers by purchasing electricity in the wholesale market, or the new electric companies was allowed to build their own generating facilities to provider electricity services. Nonetheless, in the last case, the charges for power were subject to wholesale market-based regulatory benchmarks (JOSKOW, 2008).

In United States, the retail markets are regulated by state organizations and not by FERC. In the country, there are states with different degrees of retail market access. Kim (2013) identifies four different models of retail market in US: No default Service (Texas), Market pass-through (New York), Auction or request for proposal (RFP) (PMJ and New England states), and Hybrid or other models (California, Ohio, and Michigan) (KIM, 2013).

Many states (including California and New York) opened their retail markets. The end-customers became able to choose their electricity provider. The utilities were allowed to provide default contracts and the customers who switched their electricity provider started to receive a bill for energy services from the retailer they chose plus a separate charge for the utilization of the transmission and distribution networks (JOSKOW & TIROLE, 2004).

The California has a hybrid retail market due to the Energy Crisis of 2000/2001. The crises had negative effects on development of retail market that after crises set back its restructuring process based on the increase of end-customers participation. The end-customers were allowed to choice between continue to be provided by the incumbent utility or switch their electricity providers until September of 2001, when Directly Access was suspended. As a parcel of the customer have chosen to change, a limited retail market continued to existed, though many customers had decided to change back to default services provided by incumbent utilities (KIM, 2013). In 2009 was approved the Senate Bill (SB) 695. It requires the states commissions allow nonresidential customers to purchase electricity from an Electric Energy Provider in each utility territory, up to a maximum allowable total kilowatt hour annual limit. In California, the California Public Utilities Commission (CPUC) defines the limit as the maximum of the total kilowatt hours supplied by all other providers to retail customers of that utility during any sequential 12 months. Currently, the demand for Direct Access service exceeds the load allowed under the caps adopted in utility service territory (CPUC, 2018c).

New York adopted a retail market based on cost pass-through. In the nineties, the New York Public Service Commission (NYPSC) established the end-customers choice through individually negotiated utility settlement agreements and others policies. In view of this, the utilities can have different rate structures among them, but they must follow the rules and establish rates structures allowed by PSC. The New York utilities use a price mechanism in which part of their prices is based on the NYISO wholesale market clearing prices (for capacity, energy, and ancillary services). In this way, the default services are an important energy market component, which means there is a strong link between the energy markets and retail markets. In other words, in NY electricity system, changes in energy and reserve prices affect electricity end-customers. Hence, since the end-customers decisions can influence the electricity production, the electricity supply segments are integrated in the state in some degree (KIM, 2013).

One of the ideas of opening the retail market was to encourage the reaction of “demand-side” to variations in the wholesale market prices. In this way, the real time balance (needed due to existence of changes in operating conditions and variations in load and generation) could be also done by adjusting the electricity demand. Thus, the energy price paid by end-customer would be close to the marginal price of electricity production. To stimulate the demand responses, the energy tariff should be able to reflect the real time price at every location of the grid (JOSKOW & TIROLE, 2004). However, two main reasons decreased the incentive to implement price-responsive demand at restructuration process time. The first was the existence of technological constraint, mainly, in the metering. The meters did not have the capacity to collect information on when the electricity was consumed, only the aggregate amount of electricity consumption in certain period. The second is lack of retailer responsibility regarding the system reliability which is assured only by ISOs – who buy enough reserves in the day-ahead and real time markets, and (in most of the cases) charge to every per kilowatt-hour (kWh) supplied (without a differentiation on reliability) (BORENSTEIN & BUSHNELL, 2015).

Considering those reasons, in many electricity systems was adopted a charge with a simple constant price per KWh set to recovery all utility's variable and fixed costs. Although the charges were not time-varying, usually, they change according to the seasons. Further, to capture the additional needed revenues, in some electricity systems, it was added a fixed charge (for kW per month). Another alternative adopted in some states of United States was the Regulator does not establish the value or the type of retail charges but only a revenue cap. In that situation, the distribution firms determine the design of the electricity charges and of network tariffs for each type of customers (BORENSTEIN & BUSHNELL, 2015). For example, the three utilities of California (Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDGE)) offer two main plans: a standard plan and a time-of-use plan. In the first, the CPUC defines the limits of the Baseline Allocations or Tiers for each zone of the system. An amount of energy is allocated to the customers in a billing period at a specific price (a flat daily based charge paid by month plus a daily based charge by KWh). If the customers excess their Baseline Allowance, then they will pay the charges of the following Tier. In the second, the customers pay a tariff composed by a daily fixed charge plus an energy charge by KWh consumed. The value paid by KWh consumed is defined for different periods of the day. The utilities can also offer other different plans: the SCE's industrial customers can choose between time-of-use plans and real time price plans (in which the customers are billed the hourly electricity prices), while the SDG&E and PD&E only offer a time-of-use plans for industrial customers (SCE, 2018a; PG&E, 2018a; SDGE, 2018a).

In the last decade, there was a technological development of meters that became capable to record total electricity consumption in an hour or shorter periods. It opened the possibility for the electricity systems implement dynamic price (or time-varying price), primarily for commercial and industrial customers. Further, there was the emergence of new technologies to management of electricity consumption as well as a large diffusion of generating technologies in small scale between electricity end-customers (MARTIN, STARACE & TRICOIRE, 2017). The emergence of those technologies challenged the traditional form of end-customers participation in Electricity Industry, which increased the pressure to establish tariffs that encourages the participation of them in the markets.

Nevertheless, as argued by Borenstein (2013), the efficiency gain from the establishment of dynamic prices is dependent on the ability and willingness of electricity end-customers to respond to those prices. In view of this, in many electricity systems, the adoption of time-varying tariffs was carried out in conjunction with Demand Response Programs (RDPs).

In US, the penetration of smart meters reached about 23% in 2011 allowing a more participation of end-customers in RDPs. Each American state has its own demand response programs (generally, under supervision of ISOs). The RDPs of California is administered by the three regulated utilities and LSEs. The end-customer can enroll in the utility's RDP directly or through third-party Demand Response Aggregators. The Aggregators are independent commercial entities (customers or third part contractors) that have their own DRP. They make a contract with the utilities in which they negotiate the sale of the Aggregator Management Controls. When the utility needs a load reduction, it calls an Aggregator Management Control and the aggregators become responsible for delivering load reductions. The utilities have different programs for different clients (residential, commercial, agricultural or industrial) (CPUC, 2018d; SCE, 2018b).

The utilities offer different RDP: Critical Peak Pricing (or Peak Day Pricing), Automated Demand Program, Base Interruptible Program (or Time-of-Use Base Interruptible Program), Capacity Bidding Program – Day-Ahead or Day of Peak, and Summer Save Program (SCE, 2018c; PG&E, 2018b; SDGE, 2018b). Those programs can be categorized according to three characteristics: dispatchability, duration, and remuneration. For Shariatzadeh, Mandal and Srivastava (2015), the RDPs can be divided into two main types: dispatchable (event-based) and non-dispatchable (non-event based) programs. The first are voluntary programs in which the customers allow the system operators to control directly some of their electric appliances to reduce the load in emergency reliability events or peak load events. In those programs, the demand reduction follows the ISO time guidelines increasing the system reliability. The non-dispatchable programs are voluntary programs that customers can decide to reduce their consumption (usually) based on the energy real time price. In this way, in those programs, the load reduction is not ensured in emergence or peak load events which means their adoption does not necessarily increase the system reliability.

Some DRP are seasonal (as Summer Program or Peak Day Program that aim to reduce the demand in events of critical peak hours in the summer or days in the year with high load) while others programs the registered customers can be called in all year (as Base Interruptible Program, Automated Demand Program, and Capacity Bidding Program).

In all Californian programs, the remuneration of the non-consumed electricity is included in the bills in a form of a month credit that decrease the final value paid by the customers. The price of the saved electricity is different among the programs and power providers. Usually, the Critical Peak Pricing and Summer Save Programs are remunerated by the market price of the peak hour in which the customers are called to reduce their consumption. The other programs can have a remuneration based on a rate per KWh saved, a fixed value of credit or a combination of both during different seasons of the year. Further, some programs penalize the customers if there is excess of energy use during a curtailment. The power provider can penalize the excess of energy use through a rate per KWh used in excess or a fixed value in the bill (SCE, 2018c; PG&E, 2018b; SDGE, 2018b). For example, the Base Interruptible Program of PG&E adopt an incentive of $8 per kW for reduction below 500 KW, of $8.50 per kW for reduction between 501 and 1000 KW, and of $9 per kW for reduction above 1001 KW, and a penalty of $6.00 per kW. The SDGE in turn offers different mechanism of remuneration and penalty in different periods of the year: from May to October, the customers receive a monthly bill credit of $10.80 per kW saved and are penalized in $7.80 for kWh used in excess; and from November to April, they receive $1.80 per kW saved and are penalized in $1.20 for kWh (PG&E, 2018b; SDGE, 2018b).

In New York, NYISO offers five types of RDPs. They aim to increase the electricity system reliability as well as to allow electricity end-customers to respond to wholesale market price in real time. The programs are divided into two categories: Reliability-Based Programs in which the NYISO determines the activation (dispatchable programs), and Economic-Based Programs in which the resource determines when to participate (non-dispatchable programs) (SRINIVASAN, 2018).

The Reliability-Based Programs have by purpose to reduce electricity demand in response to NYISO operation instruction for discrete period of time to supplement generation when Operation Reserves are forecast to be short, when there is an actual Operating Reserve Deficiency, or when there is other system emergency. There are three programs inside that category: Emergency Demand Response Program (EDRP), Installed Capacity-Special Case Resources (SCRs), and Targeted Demand Response Program (TDRP). The EDRP is a load curtailment voluntary program that offers an incentive for electricity end-customers to reduce their consumption in NYISO's reliability events. SCRs are a type of Demand Side Resource that may offer Unforced Capacity into the NYISO’s ICAP market as ICAP Suppliers. SCR are obligated to reduce their system energy consumption when called upon by NYISO. TDRP deploys existing wholesale market EDRP or SCR resources on a voluntary basis in targeted sub-load pockets to solve local reliability problems at the request of a Transmission Owner. The TDRP is only adopted in New York City (SRINIVASAN, 2018).

In the Economic-Based Programs, the end-customers compete with electricity generators and the load reduction is schedule by NYISO based on the economic offers. The Day-Ahead Demand Response Program (DADRP) and Demand-Side Ancillary Service Program (DSASP) are categorized as Economic-Based Programs. Those programs allow end-customers to participate in the day-ahead market or in ancillary service markets offering load curtailment with an offer floor of $75.00 per MWh. They are mandatory programs if their resources were schedule by NYISO. In the Ancillary Service Markets, end-customers can offer bids to provide Operating Reserves and/or Regulation Service and Frequency Regulation.

The payments of those programs are determined by NYISO. As we can see in Table 15, each program has its own mechanism of remuneration. All of them have a performance energy payment based on the market prices (LBMP or reserve prices). Some also receive a capacity payment. Further, with exception of EDRP (a voluntary program) the excess of energy use by the customers enrolled in NYISO's DRP are penalized (SRINIVASAN, 2018; NYISO, 2016).

Table 15: Characteristics of NYISO's Demand Response Programs.

Characterisitcs	EDRP	SCR	TDRP	DADRP	DSASP
Minimum Reduction	100 KW	100 KW, in aggregate	100 KW or 100KW, in aggregate	1 MW, in aggregate	1 MW, in aggregate
Performance Obligation	None	Minimum four hours for a mandatory event	Depends on the program in which the resource is enrolled.	Mandatory if scheduled	Mandatory if scheduled
Event Notification	2-hour in-day notice	Day-ahead advisory and 2-hour in-day notice	Depends on the program in which the resource is enrolled.	Notified by 11:00 a.m. of scheduled commitment for the next day.	Notified by 11:00 a.m. of scheduled commitment for the next day. Real-Time telemetered schedule.
Capacity Payment	None	Monthly - Based on ICAP auction	Depends on the program in which the resource is enrolled.	None	None
Energy Payment	Greater of real-time LBMP or $500/MWh and guaranteed 4-hour minimum	LBMP with a daily guarantee of Minimum Payment Nomination (strike price) recovery and guaranteed 4-hour minimum	Based on the payment calculation of the program in which the resource is enrolled.	LBMP with daily curtailment initiation cost guarantee	Reserve or Regulation market clearing price
Penalty for Non-compliance	None	Penalties and derated for non-compliance	Depends on the program in which the resource is enrolled.	May apply	May apply

Source: Elaborated based on Srinivasan (2018) and NYISO (2016).

3.2.3. The Regulation of Electricity Networks

The transmission and distribution are important actives in the Electricity Supply Chain having considerable weight in the bills paid by end-customers: the transmission and distribution tariffs represented in average 36.36% of the monthly value paid by customers in United States (BROWN & FARUQUI, 2014). Those segments also have characteristics of natural monopoly which historically implied in the need of public intervention or a Sectorial Regulation to ensure that transmission and distribution firms will provide quality and affordable services. With the restructuration, the regulation of network segments of electricity industry became even more crucial since the good performance of the electricity wholesale and retail markets rely on the infrastructure provided by those segments (JOSKOW, 2006).

In this way, the creation of electricity markets was accomplished by changes in the way the Transmission and Distribution Segments operated and was regulated. There was a separation between the network management and network ownership. The network owners lost the right to control the operations of the Transmission & Distribution System (T&D System), function transferred to the System Operators (ISO) or the Regional Transmission Organizations (RTOs)[12]. Those organizations became responsible for scheduling and dispatching generation and demand on networks with multiples owners, allocating scarce network capacity and planning network expansions. The network owner in turn after the restructuration process continued to provide the electricity transportation services and be responsible for making the investments in maintenance, repairs, and expansion of the T&D System (JOSKOW, 2006).

Additionally, there was a change in way electricity transmission and distribution segments were regulated. As mentioned before, during most of history of the electricity industry, the electricity supply was carried out by an integrated state-owned firm or by an integrated private firm under a "cost-of-service" regulation. The "cost-of-service" regulation determined a "bundled tariff": the customers paid a unique regulated tariff that cover together the firm's operational cost and capital invested in all segments (generation, transmission, and distribution). In other words, the Regulatory Agencies did not need to have a deep knowledge of the firms' costs of operation and investments in each segment of electricity supply chain since the allocation of revenue to cover the costs in each segment was made by the firms in presence of cross subsidies between the different segments. However, after the unbundling of

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[12] The Regional Transmission Organizations (RTOs) are not-for-profit independent organizations that control the operation of transmission systems, regional transmission tariffs, and network investment planning under rules established by the Regulatory Agency. In some regions of United States where a System Operator had already operated, it assumed the role of RTO having its geographic jurisdiction expanded (as the case of CAISO in California and NYISO in New York) (Joskow, 2008).

electricity industry segments, the regulatory rules had to be established regarding the specificities of each segment and an incentive-based regulation was adopted in the non-competitive segments (JOSKOW, 2003; 2008).

As Joskow (2006) points out, the regulation of electricity network can be studied looking at four aspects: entry regulation, service quality and reliability, access to the infrastructure, network service price. The entry requirements differ among the countries; and in United States, among the States, though FERC determines the entry requirements for the provision of transmission service when it is carried out on federal lands or on multi-states lands. Historically, the incumbent utilities continued to provide the transmission and distribution network services in accordance with the planning of FERC and State Planners in United States.

The power quality is the characteristics (in terms of continuity, voltage, frequency, and waveform) of the electricity delivered to end-customers under normal operating conditions. In a system without high participation of renewable generation, the decrease of electricity service quality are related to short-circuit capacity in the network (which depends on configuration of T&D System), the degree of reactive power in the electricity system, and characteristic of the load (with the diffusion of microelectronics that are more susceptible to voltage variations, the demand for increase the quality of service has increased since the 80’s). Those aspects can lead to failures and switching operations in the network (that result in voltage dips, interruptions, and transients), and to network disturbances from loads (that result in flicker, harmonics, and phase imbalance). They also mean always will have a voltage imbalance even when the T&D System is in a steady-state mode. In the case of high participation of renewable generation in the system, that voltage imbalance increase significantly having negative effects on the system reliability. The reliability of the electricity system is defined as the ability of electricity suppliers to delivery electricity in all consumption points of the system in the amount demanded and with accepted standards of quality. The reliability concept encompasses the concepts of adequacy and security. The first is the ability of the electricity supply system to supply the aggregate electric power and energy requirements of the customers at all moments of the time, which imply in the need to ensure enough generation and transmission resources with reserves contingencies to meet the demand (under peak demand conditions). The security is in turn the ability of the system to withstand unexpected disturbances. In this way, the security is relevant to system dynamics and short-term operations, while adequacy is relevant to static system operations being related to long-term planning and investment (OSBORN & KAWANN, 2001).

In the United States, the North American Electric Reliability Corporation (NERC) develops and promotes rules and protocols to enhance the reliability of the system. NERC is an Electric Reliability Organization (ERO) founded in 1968 by an initiative of the American Utilities to provide a standard-service quality as well as identify the need for network expansion. Nowadays, it is directly under supervision of FERC (NERC, 2012; JOSKOW, 2008). Table 16 presents the actions that the regulator (or the entity responsible for the system reliability) can take to improve the system reliability. Further, as we can see, BSS can provide some services in the table which makes the relation between BSS diffusion and T&D System reliability not clear (as mentioned in the beginning of this chapter).

Table 16: Actions to improve the Electricity System Reliability

Area	Segment	Action	Description
Demand	Energy Efficiency	Energy efficiency standards	Update/create standards for key appliances and equipment.
		Demand-side management	Improve consumer access to information about costs of energy consumption.
	Alternative Pricing	Real-time pricing	Implement new regulations and/or tariffs that allow consumers to see the true price of energy.
		Interruptible loads/load bidding	Develop and give small consumers access to low-cost metering technologies.
Supply	Generation	*Siting*	Upgrade and maximize resources at current sites.
		Distributed energy	Standardize new protocols for interconnection.
	Transmission & Distribution	Improved grid utilization	Promote load shifting of demand.
		Network management	Develop new optimization technologies.

		Load forecasting	Base forecasts on recent weather trends instead of long-term averages.
		Imports	Improve resource sharing with interconnected utilities.
		Planning	Develop new security monitoring and control systems.
		Standards and incentives	Adjust regulatory framework to accommodate reduced margins, more non-utility generators, and innovative rate treatments.
		Benchmarking	Make information on efficiency and reliability of transmission operations publicly available.
		Outage management	-
		Maintenance	Optimize economic trade-off between equipment replacement and maintenance.
		Underground cables	Develop low cost, highly reliable protection of system resources.
		Penalties	Value different levels of reliability for different customer needs (costs/benefits).

Source: Elaborated based on Osborn and Kawann (2001).

The transmission owners recover the costs associated with owning, maintaining, physically operating the transmission system, and with the costs of investments in new transmission lines through the network tariffs. The access tariff is the tariff paid by network users to be integrated in the transmission and distribution system and the network tariff (or service price) is the value paid by network users for the utilization of the network infrastructure. In United States, FERC determines directly the access tariff of transmission network and the network service price of the transmission infrastructure sitting on federal lands or on multistate lands. Since most of the power lines moves between states over transmission lines, the Commission has authority over the pricing for most transmission services in the country. The few transmission lines sitting only on state lands and the distribution networks have their rates, terms and conditions of the network service established by ISOs. Nevertheless, the transmission and distribution tariffs determined by ISO must follow FERC's guidelines: FERC determines the Annual Transmission Revenue Requirements (ATRR) that establish the total cost that each transmission owner can recover in a year as well as the methodology used by the states to determine their transmission access tariffs (CAISO, 2017; RAP, 2011).

In the transmission system regulated directly by FERC, the generators are required pay the full cost of their integration to the T&D System up front. In return, they receive credits for future transmission service in the amount of their cost with any network transmission facilities. FERC defines three different transmission services: (i) Firms Network Integration Service when there are vertical integrated firms that can monopolizes the network access, (ii) Firm Point-To-Point Transmission Service when there are transference of electricity flows inside and intra ISO's control area, and (iii) Non-Firm Point-To-Point Transmission Service when there is a congestion in the T&D System. In the first, the LSE purchase electricity transmission services paying a transmission access charge based on its proportionate peak demand in each "transmission zone" in which the electricity is delivered. The transmission access tariff is the sum of the average total cost of capital investments (depreciation, interest, return on equity investment and taxes) and the operating costs of the existing transmission assets included on the network. The firm point-to-point service can be available on a short and long term. The LSEs usually pay a price based on the average total cost of the transmission network per MW of peak demand on the network or on the day-ahead energy price per MW in a specific hour and zone/node of the system. The non-firm point-to-point transmission service is available monthly, weekly, daily or hourly basis only when there is a congestion indicated on the network day-ahead schedules. The non-firm customers are asked to curtail their schedules to relieve the expected congestion. They have two options: curtail their schedules or pay congestion charges determined by wholesale markets. FERC also regulates the pricing of wholesale transmission transactions, both what is charged to LSE and utilities and what is charged to individual industrial customers[13] (NYISO, 2018b; RAP, 2011; JOSKOW, 2006).

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[13] Industrial Customers whose electricity consumption is big is authorized by FERC to buy power directly at transmission voltages (RAP, 2011).

The PUCs regulate the distribution charges in the states. The regulation of distribution network depends on the degree of development of retail markets. In the electricity systems whose retail competition is not well develop, the customers pay a “bundled” tariff that usually is a two-part tariff. In California and New York where the retail competition is relatively developed, the utilities are allowed to determine the type of tariff to be adopted (volumetric charge, fixed charges, or a hybrid tariff model). In this way, each utility has its own way to charge for the network service and they can charge for it according to the customer type. However, they are subjected to revenue cap regulation with decoupling mechanisms. Annually, each utility report a proposal informing their marginal costs, allocate revenues, and design tariff for the service provided to its customers. From that information, CPUC and NYSC determine a value of revenue that utility will be allowed to have (and therefore, the recovery of the distribution costs among the demand charges) by comparing the firm’s actual revenue to an “ideal revenue” determined by a regulatory formula (CPUC, 2018d; NYPSC, 2018b).

In view of what was exposed above, three actions in the restructuration process of the electricity industry (the creation of electricity wholesale market, the creation of electricity retail market, and the establishment of network regulation) resulted in an organization of electricity supply highly based on a specific Regulatory Framework. The regulatory mechanisms adopted and the role of Regulator is different among the segments of the industry. The regulation determines the conditions to firms provide and/or purchase energy and adjustments and ancillary services in the markets in the same way that determine how the trade of those service must be made (that is, the market design). The regulation establishes the model or retail market, that is, the role of electricity end-customers within electricity systems. Finally, the Regulator also determines the conditions of network services as well as the network services will be remunerated. Looking at the California and New York Electricity

Systems, we can observe both present similar regulatory frameworks regarding the organization of wholesale markets, initiatives to encourage the participation of electricity end-customers in the electricity markets, and network regulation. Thus, in next section we describe how Battery Storage Systems (BSS) have been incorporated inside the current organization of electricity industry focalizing on the cases of those states.

3.3. BATTERY STORAGE SYSTEM IN ELECTRICITY INDUSTRY

The diffusion of BSS in electricity industry is in some degree conditioned to the regulatory rules of that industry. However, the reaction of the Regulator to the emergence of a new technology can vary greatly among the countries (and in the case of United States, among the States). It can be explain first by the fact that there are differences in the regulatory frameworks of the countries due to geographic, social, political and economic specificities. Additionally, although the Regulatory Agencies are independent entities, they are in some degree influenced by the policy makers' decisions regarding the future of the industry. Since the countries have different positions regarding to the adoption of policies to stimulate the development and diffusion of BSS in electricity industry, the reaction of Regulators to the possibility of utilization of BSS is also specific in each Electricity System.

In view of that, in this section, we describe how the states of California and New York have been incorporated the BSS in their current organization of electricity system. Further, as already explain, in United States the electricity industry is regulated in both levels: federal by FERC and state by PUCs. Thus, we begin by exposing FERC's decisions regarding the utilization of BSS to provide services in electricity markets and act as a network asset.

3.3.1. FERC's Decisions

The first action of FERC regarding the utilization of energy storage to provide services in electricity systems was in 2011 when it issued an order known as "pay for performance” that had by objective to ensure the fast ramping resources (such as Energy Storage Resources) will receive a regulation service payment for the amount of up and down ramping service (NYISO, 2017a). On November of 2017, FERC published a Notice Proposed Rulemaking (NOPR) to encourage the removal of barriers to the participation of ESRs in the ISOs’ markets.

From the NOPR, FERC issued the final rule called Order no 841 on November of 2017 that establish reforms to remove the barriers for the integration of ESRs in the electricity wholesale markets (capacity, energy and ancillary services markets) operated by ISOs and the RTOs. The Commission works with a definition of ESRs as “a resource capable of receiving electric energy from the grid and storing it for later injection of electric energy back to the grid regardless of where the resources is located on the electrical system” (FERC, 2017a, p.29). In that definition includes Battery Storage Systems as well as the other Storage Technologies of section 2.1.

FERC requires that Independent System Operators and the Regional Transmission Operators create models that allow the participation of ESRs in their markets. It implies in the revision of market rules recognizing the physical and operational characteristics of ESRs to allow they will be able to provide all services in the electricity markets they are technically able to provide.

The model to be created by ISOs and RTOs must have six characteristics regarding the participation of ESRs in the markets:

i. ESRs must be eligible to participate in all capacity, energy and ancillary markets providing all the services that they are technically capable of providing.
ii. ESRs must be dispatched.
iii. ESRs must be able to set market clearing price as seller or buyer.

iv. The bidding parameters or other means of the model must take into account the physical and operational characteristics of ESRs.

v. The minimum requirement for ESRs participate of the markets must not exceed 100 kilowatts.

vi. The sale of electric energy from wholesale electricity markets to an ESR that will resell back it to those markets must be at the wholesale locational marginal price (FERC, 2017a).

The Commission also issued on January of 2017 a policy statement to provide guidance on the utilization of ESRs to provide network services, that is, services under a cost based regulation, such as services in transmission system. FERC pointed out as the main challenge faced to allow ESRs act as a transmission asset is their hybrid nature: those technologies can provide services remunerated by both the electricity markets and tariffs determined by FERC, ISOs or RTOs.

The ESRs can provide two arenas of transmission services: (1) Transmission Services only when the storage technology is connected to the Network and under control of the ISO; and (2) Reliability-based Transmission Services that provide local solutions reducing local capacity requirements (through the reduction of congestion or as a network substitute). From that, FERC identified three main problems that can emerge when a storage resource aims to recover its costs through both cost-based and market-based rates:

i. Existence of double recovery of the costs;

ii. Potential for the cost recovery through cost-based rates to inappropriately suppress competitive prices in the wholesale markets to the detriment of other competitors who do not receive such cost-based rate recovery;

iii. The control of the operation of an ESR by an ISO/RTO can jeopardize its independence from market participants, especially when the ESR is providing Transmission Services Only (FERC, 2017b).

FERC's policy statement does not provide solution models for the three problems above, but establish four principles for the ESRs' participation as transmission assets in electricity systems:

i. Must be cost competitive with transmission;
ii. Must avoid double recovery for providing the same service;
iii. Cannot suppress market bids; and,
iv. Cannot jeopardize ISO/RTO independence.

Further, FERC points out from its experience from the cases of Nevada Hydro and Western Grid projects[14] that to deal with the double recovery of the costs, one alternative can be credit the market revenues (FERC, 2017b).

3.3.2. BSS in California Electricity System

The California was the first state of United States to approve an energy storage mandate. The CPUC approved a mandatory order that require the three Californian utilities (SCE, PG&E and SDG&E) must have implemented by 2024 1,325 MW of storage capacity. For the LSEs, the order forces them to have 1% of their annual peak load met with storage resources until 2024. The utilities can owner 50% of the storage capacity that will be installed. They can use their storage system to provide service in the market as well services for the T&D System. The other 50% of storage capacity must be owned by end-customers. They can use the energy storage technologies to provide energy services for themselves (in conjunction

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[14] The Nevada Hydro and Western Grid are two projects that aimed to provide Energy Storage System to provide Transmission Services in California. First project was not allowed by FERC due to the three problems exposed. The second was allowed by FERC under condition that the storage system will not be used to carry out price arbitration (FERC, 2017a).

to a decentralized generation unit and as an alternative for grid service) or to participate of Demand Response Programs of Utilities and LSEs (CPUC, 2010).

CAISO established those resources can participate as “Non-Generation Resources” (NGR) or Pump Storage in the electricity markets. The NGR are new types of resources that have the capability to act as generation and load. The Limited Energy Storage Resources, such as Flywheel, Batteries and EVs are classified as NGR. CAISO classified NGR into two groups: “Non-Generation Resources”/“Regulation Energy Management” (NGR/REM), and “Non-Generation Resources”/Non “Regulation Energy Management” (NGR/Non REM). The REM is a market enhancement that enables new types of resources to participate in CAISO regulation markets, especially in the short-term markets. The NGR/REM are elected to participate only of the CAISO regulation markets being dispatched to any operating level within of their entire capacity range (that is, negative/charge to positive/discharge operations). They must meet 10 minute ramping requirement (same as generator), the regulation up capacity must meet the 15 minute continuous energy deliver requirements, and the regulation down capacity must meet the 15 minute consumption of continuous energy requirements. The NGR/Non REM Resources are subject to existing ISO requirements for the traditional generators. They can participate of regulation, energy and (non) spinning reserves markets. The requirements to provide those services depend on their registration and certification (CAISO, 2018c; 2014; 2013).

Currently, CAISO is developing the Energy Storage and Distributed Energy Resources (ESDER) Initiative in which the storage resources installed by electricity end-customers will be able to participate of CAISO markets in two other ways besides as NGR. The first is through Demand Response Programs. CAISO is proposing a model with new bidding and real-time dispatch options; that will remove the single LSE aggregation requirement along with the need for the settlement application of a default load adjustment;

and to develop an energy storage load shift product; and to integrate the participation of EVs as a storage facility. The second is through of establishment of specific tariff and market design changes that allow the multiple use application of decentralized storage resources (CAISO, 2018d).

Moreover, CAISO is also discussing how to encourage the utilization of storage resources in the T&D System as transmission asset. The main problem faced by the ISO is to define a remuneration mechanism that allows the cost of investment in a storage system be recovered in the electricity markets and by the cost-based rates determined by the regulation (CAISO, 2018e).

Regarding storage project funding, the CPUC funds storage technologies through an Electric Program Investment Charge for the three Californian utilities (CPUC, 2018e).

3.3.3. BSS in New York Electricity System

On November of 2017, a law was signed instructing the NYPSC to create storage procurement targets for 2030. Based on that, NYPSC determined the goals of New York State Energy Plan. The Energy Plan is implemented through the Reforming the Energy Vision (REV) and the Clean Energy Standard (CES). REV aims to promote an electricity system with high participation of renewable generation and integration of Distributed Energy Resources (DERs). The utilities are required to have at least two energy storage projects attached to a distribution substation that offer a minimum two different services (like energy, regulation, or capacity). They must promote the electricity production of end-customers and they are not allowed to own DERs. The CES aims to increase the utilization of renewable energy: the power provider must have a certain percentage of their demand provided by renewable energy sources. CES does not include energy storage technologies as a renewable energy source (NYPSC, 2017; NYISO, 2017a).

Under the existing rules, BSS can only participate of NYISO's Demand Response Programs described in section 3.2.2. The NYISO is proposing a market design that allows the ESR to participate in wholesale energy, ancillary service, and capacity markets. That market design establishes two modes of participation of ESR in energy markets:

i. NYISO-monitored energy level in which the System Operator will use the state of the charge of ESR in the system to determine physically feasible schedules in the day-ahead and real-time markets.

ii. Self-monitored energy level in which storage system owners make their offers based on their state of charge. NYISO will determine the schedules based on those bids without knowing the actual state of the charge of the ESR in the electricity system. Negatives bids will be allowed once NYISO will be treated as negative generation rather than load.

In the proposed model, ESR will be eligible to provide Reserves and Regulation Services under the same rules applied for other suppliers (NYISO, 2018a; NYISO, 2018b).

In New York, the financing of energy storage projects is carried out by New York State Energy Research and Development Authority (NYSERDA) (NYISO, 2017b).

3.4. BATTERY STORAGE SYSTEM IN THE REGULATOR'S PERSPECTIVE

In electricity industry, the regulation act into two fronts. The first is to define the best market design that allowed an efficient electricity exchange between the supply and demand to deal with the need for a constant balance between demand and supply. The second is to define socially fair tariffs capable to remunerate the investments made in the network build. Considering that, Di Castelnuovo and Vazquez (2018) argue BSS provide two arenas of services by the Regulator's view:

i. "Time Shift": buy and sell electricity services in different periods of the time. This arena is related to the capability of BSS to postpone the electricity consumption or the need of generation.

ii. "Locational Shift": Avoid the need to transport the electricity between two different geographical points. This arena is related to the capability of BSS to avoid the investment in electricity transportation infrastructure.

Table 17 presents the classification in those arenas of the services described in section 2.4. The services classified as "Time Shift" are those transacted by agents who provide and/or consume electricity services. The investments in acquiring BSS to provide those services are defined by their expected remuneration, that can be determined in electricity wholesale markets, retail tariffs, or cost-based tariffs determined by the regulation of electricity industry (or by the regulated ISO). The services classified as "Locational Shift" in turn are those that are made by the agents responsible for the network construction and maintenance. Thus, the investments in acquiring BSS to provide those services are determined by their expected remuneration established directly by the regulation.

Table 16: Classification of the Services in Time or Locational Shift

Service	Classification
Renewables Capacity Firming	Time Shift
Electric Energy Time Shift	Time Shift
Frequency Regulation	Time Shift
Renewables Energy Time Shift	Time Shift
Onsite Renewable Generation Shifting	Time Shift
Electric Bill Management	Time Shift
Voltage Support	Time Shift
On-Site Power	Time Shift
Electric Bill Management with Renewables	Time Shift
Microgrid Capability	Time/Locational Shift
Electric Supply Capacity	Time Shift
Grid-Connected Commercial (Reliability & Quality)	Time Shift
Electric Supply Reserve Capacity - Spinning	Time Shift
Load Following (Tertiary Balancing)	Time Shift
Ramping	Time Shift

Grid-Connected Residential (Reliability)	Time Shift
Resiliency	Time Shift
Distribution upgrade due to solar	Locational Shift
Black Start	Time Shift
Stationary Transmission/Distribution Upgrade Deferral	Locational Shift
Transmission Congestion Relief	Locational Shift
Transportation Services	.
Electric Supply Reserve Capacity - Non-Spinning	Time Shift
Demand Response	Time Shift
Transportable Transm./Distribution Upgrade Deferral	Locational Shift
Transmission Support	Locational Shift
Transmission upgrades due to wind	Locational Shift
Distribution upgrade due to wind	Locational Shift
Transmission upgrades due to solar	Locational Shift

Source: Own Elaboration.

Since the regulator determines the design of the electricity wholesale and retail markets as well the network tariffs, the regulatory rules can have influence on the decision process of investment in batteries, and therefore on the battery technological development. To explore with more detail this possible influence of regulatory rules on BSS development, we work with different regulatory scenarios that describe different market designs and regulation of the network based on the cases of California and New York Electricity Systems.

To define the scenarios, we tried to consider the general characteristics of operation of electricity industry and the way its regulatory structure was built in the last decades, as well as the observed aspects of the integration of this new technology into the electricity systems of California and New York.

One of the fundamental institutional aspects of electricity industry studied so far is the current regulatory structure is based on the idea of separation of network services (which are directly regulated) and competitive services (which are transacted by market agents even though they are indirectly regulated). In this sense, a technology capable to make this separation blur implies in a big regulatory challenge since the established market design of the competitive segments and the rules regarding network use and investments would interact in a concise way leading to a big set of possible positive and negative outcomes. In view of that, to simplify our analysis we assume the network investors (the utilities) cannot use BSS to provide Time Shift services, only Locational Shift services.

Given that, in electricity industry, the decision-making processes of three different agents can be influenced by the market design: electricity generators, other power providers and end-consumers. Although, the BSS have potential to provide services for generators and power providers (that increase the quality of their electricity services or defer the investment in new productive capacity), their investments in BSS will be decided through the analysis of costs and benefits between BSS and its alternative technologies once allowed their use by the regulator. In this way, we focus in the decision-making process of electricity end-customers regarding the investments in BSS to provide energy and ancillary services in the electricity markets. Thus, we consider two aspects: how the end-customers are charged for the services they receive; and how they are paid for the services that they provide (for participating of Demand Response Programs). Regarding the network regulation, we focus on the decision-making process of investments in BSS to provide network services for the network investors.

We defined three scenarios with different market designs and two with different network regulation design; they are summarized in table 18 and analyzed in the next sections.

Table 18: Analyzed Scenarios.

Regulation	Scenario
Market Design	Scenario 1: The electricity end-customers pay an energy charge whose parameters are established by the Regulator or by their power providers.
	Scenario 2: The electricity end-customers pay an energy charge based on the market prices.
	Scenario 3: The electricity end-customers receive remuneration for the participation in DRP given by a charge based on the market price.
Network Regulation	Scenario 4: It is defined a volumetric tariff for the network services.
	Scenario 5: It is defined a two-part tariff for the network services.

Source: Own Elaboration

3.5. THE INFLUENCE OF REGULATORY RULES OF ELECTRICITY INDUSTRY ON BSS DEVELOPMENT THROUGH MARKET DESIGN

The three proposed market design scenarios are based on the experience of California and New York. In this way, the first scenario represents the traditional regulation adopted for many years in electricity industry in which a non-time-varying charge is established by the Regulator. The Scenario 2 corresponds to a simplification of the currently energy services charges adopted in California and New York that try to incorporated the results in real time of the electricity real time markets. Lastly, the third scenario is a simplification of the market design that the states have been developing which aims to allow greater participation of end-consumers in electricity wholesale markets. The following subsections analyze the influence of those three market designs on the BSS' development. The idea is to identify if the agents of electricity industry would have incentives to acquire BSS to provide the services classified above. Once the regulatory framework provide those incentives for the BSS demand, the analysis supposes the battery providers would also be encouraged to develop technological trajectories (that is, to develop the performance in BSS for specifics technical characteristics) that allow BSS provide those services.

3.5.1. Scenario 1

In this scenario, the end-customers pay a regulated energy charge invariable to the real-time energy prices. The charge is composed by a fixed part (per KW) and a variable part which is a function of their consumption (per KWh). These charges are set by different tier of consumption – we assume two tiers. Thus, the energy charge is given a generic formula expressed by:

$$EC_{\tau=1} = a + bX \quad if \quad X \leq T$$

$$a > 0 \quad and \quad b > 1$$

$$EC_{\tau=2} = a' + b'X \quad if\ X \geq T$$

$$a' > a \quad and \quad b' > b$$

Where X is the consumption of the customers in a period of time, τ is the tier and T is the limit of electricity consumption of the tier τ. The values of $a, a', b\ and\ b'$ are determined by Regulator or Power Providers.

We assume the customers are not allowed to inject energy into the electricity system or not participate of a DRP. Technically, they can charge their BSS with the electricity from local generators.

In this scenario, the customers do not receive revenues from the BSS operations. The BSS have as primarily function to decrease the costs with electricity consumption by changing their consumption level to tier 1 or by preventing their consumptions increase and a change in the tier occurs, or protect their devices or equipment from variation in the electricity flow or interruptions in electricity supply. Thus, the BSS could provide the following services: Electric Bill Management (with Renewables), On-Site Power, Grid-Connected Commercial, or Grid-Connected Residential.

The investment in BSS will depend on the value of the parameters $a, a', b\ and\ b'$, the level of consumption of end-customers, and service quality. The higher the values of the parameters and the customer consumption, greater will be the incentives to invest in batteries to provide Electric Bill Management (with Renewables) and On-Site Power. Further, if the quality of the service is not good, the customers (specially, the industrial ones) will have incentives to invest in batteries to provide Grid-Connected Commercial and Grid-Connected Residential. On the other hand, if the energy charges established by regulation are reasonable and electricity service maintains its quality standard, the incentives for adopting this technology will be small.

In this context, since the technical characteristics of the BSS are developed based on the services they will provide, the development of BSS to provide those services for electricity end-customers will depend on how good the current regulatory rules works. In other words, if the current regulatory framework has negative outcomes (regarding energy charges and service quality), there will be incentive for end-customers invest in a battery.

Nevertheless, even existing positive incentive for end-customer purchase a BSS, if there are limitations in the participation of end-customers in the electricity market and the energy prices do not reflect the results of wholesale market, the set of services provide by BSS for them will probably be very limited. In these scenarios, the technology providers only will develop BSS capable to provide 4 services which means the full potential of this technology will not be reached. In other words, the technological trajectories that will be developed are not those that may lead to a change in role of end-customers in the electricity system changing the way the electricity supply is organized.

3.5.2. Scenario 2

In this scenario, the electricity end-customers pay an energy charge based on the real-time market prices, such as:

$$EC = a + \sum_{t=1}^{n} b_t X_t$$

$$a \geq 0$$

$$b_t = \beta(p_t) \quad and \quad \beta' > 0$$

$$t \in [1, n]$$

The final energy charge is given by the customer consumption in each moment of the day multiplied by a factor that is a positive function of the energy market values.

We assume the customers are not allowed to inject energy into the electricity system. Technically, we assume they can charge their BSS with the electricity from the grid or from local generators.

The customers do not receive revenues from the BSS operation. The BSS adoption has by goal to decrease the costs with electricity consumption or to protect customers' devices or equipment from variation in the electricity flow or interruptions in electricity supply.

Nonetheless, while in the first scenario, the utilization of BSS avoids the customers to pay the energy charges of the higher tier, in this scenario, they can also decrease their energy bills through time shift: the BSS batteries can be charged when prices are low and the stored energy can be used when prices are high. In other words, the BSS can provide a set of services bigger than in the first scenario: Electric Energy Time Shift, Renewables Energy Time Shift, Onsite Renewable Generation Shifting, Electric Bill Management (with Renewables), On-Site Power, Grid-Connected Commercial, and Grid-Connected Residential.

As in the previous scenario, if the electricity provision has problems of quality, then the customers will have incentives to invest in BSS to provide Grid-Connected Commercial, and Grid-Connected Residential Services.

However, part of the end-customer's investments in BSS will be guided by energy market prices. The incentives for BSS investments will be higher when the prices are higher in most time of the day or they vary strongly during the day. On the contrary, the incentives for BSS investments will be lower when the prices are low even in the peak hours. In this way, the investment in battery by electricity end-customer will reflect the outcomes of wholesale electricity markets.

In view of that, we stress three aspects. First, it is common for regulator (or ISO) to adopt a bid cap which means that if it is too low, it may increase the time of return of the investment in BSS.

Second, although, the BSS are not allowed to inject electricity in the system, BSS diffusion in the niche market represented by electricity end-customers has impact on the electricity markets since it can change the electricity demand curve due to possibility of predicted reaction of the electricity demand to the levels of electricity prices.

Third, the electricity charge can have a fixed component. That component may have an essential role for the electricity system reliability since they could ensure the investments in generation capacity will be recovery. As described above, the capacity of electricity generation ideally is bigger than the current demand (even considering the peak times). As consequence of that, a fixed charge may have negative effects on the return rate of the BSS investment since customers that invest in BSS (especially, in conjunction with a local generation technology) want to reduce their energy bill as much as possible.

Similarly, as the first scenario, if the current wholesale market designs and regulatory rules have negatives outcomes regarding energy prices and service quality (respectively), then the incentives for end-customers to invest in BSS will increase. The technology providers will expect the development of batteries capable to provide the above services is not a risk investment, developing batteries for those applications. Nevertheless, differently from the first scenario, a market design that promotes a direct connection between the results in wholesale and retail markets increases the probability to develop a bigger number of different technological trajectories in BSS development. In this sense, the BSS diffusion can be accomplished for some changes in the way industry operates, though the new technology still does not reach its full potential.

3.5.3. Scenario 3

In this scenario, the electricity end-customers are allowed to provide energy and ancillary services in electricity markets receiving a payment based on the electricity market prices:

$$R_i = \sum_{t'=1}^{n} r_{i,t'} S_{i,t'}$$

$$r_{i,t'} = \rho\big(p_{i,t'}\big) \quad and \quad \rho' > 0$$

$$t' \in [1, n]$$

Their revenue to provide the service i are given by the amount of energy injected in the system multiplied by a factor that is a positive function of the service-market price in each time of the day t'.

We assume that end-customers pay also a charge based on the market prices (as in the scenario 2).

Here, the purchase of BSS can have as objectives:

i. To protect the customers' devices or equipment from variation in the electricity flow or interruptions in electricity supply, that is, BSS can be used to provide the services: Grid-Connected Commercial and Grid-Connected Residential.

ii. To decrease the customers' energy bills, that is, BSS can be used to provide the services: Electric Energy Time Shift, Renewables Energy Time Shift, Electric Bill Management, Onsite Renewable Generation Shifting, and On-Site Power.

iii. To provide income to the customer through the provision of energy services in the markets, that is, BSS can be used to provide the services: Electric Energy Time Shift, Renewables Energy Time Shift, Electric Bill Management, Onsite Renewable Generation Shifting, On-Site Power, Frequency Regulation, Voltage Support, Electric Supply Reserve Capacity – Spinning and Non-Spinning, Load Following (Tertiary Balancing), Ramping, and Demand Response.

Considering that, the decision to invest in batteries BSS by the electricity end-customers of electricity will be a function of the expected revenue that they will obtain by providing energy services in the market and the expected fall in their electricity bills. Directly, we observe the bigger the prices of energy and ancillary services in the market, bigger will be the expected revenue from the provision of those services, and the return rate of the BSS investment. Furthermore, the bigger the market prices, the higher will be the charges paid by consumers for the energy consumed from the grid and the greater the savings in energy consumption from the utilization of the battery.

This market design allows the end-customers to use their storage technologies to provide a broad set of services in electricity systems. In this scenario, the technology providers have incentives to develop batteries capable to provide different services, that is, more technological trajectories are developed and the full potential of BSS in uses behind-the-meter is reached. Thus, if this market design is adopted by regulator, the diffusion of the BSS use by the electricity end-customers probably will imply in radical changes in the way the electricity supply is organized.

3.5.4. What do we observe empirically?

In view of the analysis of the above scenarios (especially, the second and third), we return to our project database and analyze the numbers of projects for services for the states of California and New York (Table 19). As we can note, the Time Shift services that present the bigger number of projects are those we identified that could be encouraged in scenario 2 (scenario that represents the current regulatory rules). Further, we observe there are also projects that aim to use BSS to provide services in electricity wholesale markets (Scenario 3) which may be result of the recent regulatory adaptations that those states have been carrying out to promote the participation of this technology in the electricity markets. However, the California has relatively a greater number of projects of BSS that aim provide electricity services in the market than the New York. It can be explained by the specificities of those systems and by two regulatory differences: (i) in New York, the utilities are not allowed to own the BSS, so they would tend to invest in only the amount of BSS capacity imposed by the regulator; and (ii) in New York, the DRPs are operated by ISO while the in California they are administered by utilities, which especially for the residential and commercial electricity customers it can imply in higher learning costs.

Table 19: Number of projects by services in the states of California and New York.

Service	California	New York	S1	S2	S3
Electric Bill Management	38	10	x	x	x
Electric Energy Time Shift	27	6		x	x
Electric Bill Management with Renewables	29	2		x	x
Onsite Renewable Generation Shifting	25	3		x	x
Renewables Energy Time Shift	18	1		x	x
Grid-Connected Commercial	15	2	x	x	x
Grid-Connected Residential (Reliability)	13	0	x	x	x
On-Site Power	11	1	x	x	x
Electric Supply Reserve Capacity - Spinning	8	2			x
Load Following (Tertiary Balancing)	9	0			x
Voltage Support	9	0			x
Frequency Regulation	7	1			x
Demand Response	6	1			x
Electric Supply Reserve Capacity (Non-Spinning)	3	0			x
Ramping	2	0			x

Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

3.6. THE INFLUENCE OF REGULATORY RULES OF ELECTRICITY INDUSTRY ON BSS DEVELOPMENT THROUGH NETWORK REGULATION

To analyze the scenarios 4 and 5, we assume three hypotheses. First, the revenue of network investors is a function of the tariffs paid by electricity end-customers at time t:

$$R_t^U = \sum_i^n T_{i,t}$$

The customer i pays a tariff T for the network use in the time t. The Utility's revenue in t is the sum of the amounts paid by different network users. The tariff parameters are based on the revenue cap determined by the regulation.

Second, we assume that network investors are required to maintain a level of quality of service provided. We suppose they are deciding how to improve service quality through investment in network expansion or investment in BSS at the moment.

Third, the investment of end-customers in local generating technologies and BSS are a positive function of the network tariffs. The higher the tariff paid currently or the expected tariff in the future, higher the incentives for investment in those technologies. We also assume their investment in those technologies does not mean their disconnection with the grid, only a drop in their consumption of energy services.

3.6.1. Scenario 4

In this scenario, the end-customers pay a volumetric tariff for the network services.

$$T_{i,t} = vX_{i,t}$$

$$v > 1$$

For the network investors, the adoption of a volumetric tariff means the investment in network expansion in t will only be recovered by the network use in $t + 1$, where the value received depends on the amount of electricity services transported.

In a regulatory context in which end-customers are encouraged to invest in local generation and BSS in t (as in California and New York), the expectation regarding the revenue at time is it probably will decrease, that is, there is uncertainty whether the investments made will be remunerated. In this sense, the utilities may adopt as strategy to invest in substitute technologies to the construction of electricity network such as BSS. Thus, the provider firms can understand that the provision of BSS capable to provide location shift services for utilities is an important niche market.

On the contrary, the incentives for development of BSS to provide those services can be low in a context where: (i) there is not is uncertainty whether the investments made in network expansion will be remunerated; and (ii) the parameter v is based on the cap revenue determined by regulation as a function of the investments made in network expansion.

Therefore, in presence of volumetric tariffs, the investment in BSS by the utilities in locational shift services will depend on the outcomes of the market designs (specifically, of the role of electricity end-customer in the electricity markets).

3.6.2. Scenario 5

In this scenario, the end-customers pay a two-part tariff for the network services with fixed part and one that varies with amount of electricity services transported.

$$T_i = u + vX_i$$

$$u > 0 \quad and \quad v > 1$$

We assume u is similar a fixed investment costs in the network.

Considering that, the adoption of a two two-part tariff means the investment in network expansion will be recovery even in a case of absence of consumption of electricity services, though the return time of the investment will be longer. If u is not equal to fixed investment costs in the network, it will be true only for the firms which provide only transmission services since the distribution firms have others revenue sources (as seen above).

In this scenario, the regulatory decisions around the parameter are crucial for the BSS diffusion. The parameter u is determined by regulator to recovery the investment made by utilities to solve a set of specific network problems through the adoption of a set of specific technologies. Hence, if the regulation does not recognize the investment in BSS as a cost to be recovery through the parameter u, probability there will not be investment in this technology by the utilities. On the contrary, if the investment in BSS is recovery, then there will be incentives for adoption of this technology by utilities. In consequence, the battery providers will have incentives to develop BSS capable to provide Location Shift Services. Thus, the development of BSS to provide Location Shift depends on the regulatory decisions.

In this scenario, the decisions of the battery provider firms regarding which technological trajectories will be developed are based on their expectations of BSS demand in the electricity industry. Such expectations are result of a complex combination of BSS providers' beliefs on regulators future actions in network regulation and the opportunities perceived for Time Shift Services. Even if the electricity market design creates incentives for end-customers use BSS; in a context where the regulation recognizes BSS as a network asset and decides to provide incentives for their diffusion, the technology providers can expect the market for Locational Shift Services will dominate the market for Time Shift Services (since the first has less risk than the second).

3.6.3. What do we observe empirically?

From the Scenarios 4 and 5, we conclude the diffusion of BSS capable to provide Location Shift services depends on the regulatory actions, regarding the tariff design. Looking the table 20 that shows projects of BSS in California and New York that aim to provide those services, we note there are few projects with this purpose.

Table 20: Number of Projects by Locational Shift Services in California and New York

Service	California	New York
Stationary Transmission/Distribution Upgrade Deferral	5	0
Transmission Congestion Relief	3	1
Transportable Transmission/Distribution Upgrade Deferral	2	1
Distribution upgrade due to solar	2	0
Transmission Support	1	0
Distribution upgrade due to wind	0	0
Transmission upgrades due to solar	0	0
Transmission upgrades due to wind	0	0

Source: Elaborated from US Department of Energy (DOE) Energy Storage Database.

It can be a result of the lack of regulatory definition in those states regarding the utilization of BSS as a network asset. Indeed, the discussion about that by the FERC as well as by the ISOs is still recent. Nevertheless, we also observe California has a bigger number of projects than New York. Among other factors, it can be again explained by the fact of the BSS ownership by utilities are allowed in California. It can be interpreted as a sign of the interest of those agents to use BSS to provide Location Shift services when there are reforms in the electricity market designs that aim to increase the participation of end-customers in those markets.

3.7. CONCLUSIONS

Studying the technological development of BSS in electricity industry requires understanding the demand of BSS by the agents of the industry. Nevertheless, it is necessary to comprehend the regulatory structure of that industry to understand the BSS demand.

The restructuration process of electricity industry gave rise to a specific way to organize the electricity production, transportation and consumption that that works based on a strong regulatory framework. The Sectorial Regulation of that industry acts into two fronts. The first is to define the best market design that establishes how the electricity services will be traded. The second is to define socially fair tariffs capable to remunerate the investments made in the network build (and to encourage new investments).

From the cases of electricity systems of California and New York, we saw the definition of market design and network tariffs that allow the integration of BSS is a complex problem due to the multiplicity of services that such technology can offer. In this way, in this moment, there is not established a set of best market designs and network rules for a system with storage participation.

Nevertheless, from those experiences, we were able to classify the services analyzed in last chapter by the Regulator’s view as Time Shift and/or Locational Shift. While the investments in acquiring BSS to provide services classified as Time Shift would be guided by electricity market design, the investments in acquiring BSS to provide services classified as Locational Shift would be guided by electricity network regulation.

The analysis of different market design scenarios shows that according to the rules-in-use, the electricity end-customers would have incentives to buy BSS capable to provide specific set of services. The adoption of energy charge based on the market price as well as the possibility of participation of end-customers in electricity markets would allow a greater integration of BSS in the electricity systems (given the assumptions made). On the other hand, the analysis of the scenarios with two different types of tariffs shows the incentive to utilities to adopt batteries capable to provide location shift services without mandatory measures depends on specific regulatory circumstances.

CONCLUSIONS

Studying the technological development of Battery Storage Systems in electricity industry requires analyzing the demand of this technology by the agents of the industry. On the other hand, to understand that demand, it is fundamental to comprehend the regulatory framework of electricity industry.

The restructuration process of that industry resulted in a specific way to organize the electricity production, transportation and consumption that works based on a strong regulatory framework. The regulatory rules of electricity industry in the same time that define the best market design that establishes how the electricity services will be traded, also define socially fair network tariffs to remunerate the investments made in the T&D Systems expansions (as well as to encourage new investments).

The study of electricity systems of California and New York shows the definition of market design and network tariff that allow the integration of BSS is a complex problem in consequence of the multiplicity of services that such technology can offer. It can be observed in the fact that currently there is not established a set of best market designs and network rules for a system with storage participation.

From that, we were able to classify the services that BSS have potential to provide considering the Regulator’s view as Time Shift or Locational Shift. The investments in acquiring BSS to provide Time Shift services are guided by electricity market design, while the investments in acquiring BSS to provide Locational Shift services are guided by electricity network regulation.

The analysis of different market design scenarios showed that according to the rules-in-use, the electricity end-customers would have incentives to acquire BSS capable to provide specific set of services. The adoption of energy charge based on the market price as well as the participation of end-customer in electricity markets would allow a greater integration of

BSS in the electricity system given the assumptions made. Alternatively, the analysis of the scenarios with two different types of tariffs showed the incentive to utilities to adopt batteries capable to provide location shift services without mandatory measures depends on specific regulatory circumstances: the adoption of a volumetric tariff means the BSS' demand will ultimately be driven by electricity market results, while the adoption of a two-part tariff means the BSS' demand will be driven by what the regulator establishes as fixed investment in network. Those expected results can be observed when we look the distribution of projects developed in California and New York in the last years.

Therefore, our study shows the regulatory structure established by the Regulator is reflected in the demand of BSS by the agents of electricity industry that in turn affect which technological trajectories will be developed. In other words, the incentives or not provided by the regulatory framework in electricity industry influences the demand of BSS in that industry. This demand in turn is a crucial element in the process of definition of which technical characteristics need to be improve technologically for the BSS provide specifics services in electricity industry.

In this respect, we emphasize that our analysis was partially based on the experiences of California and New York. Thus, our results cannot be completely generalized to other electricity systems, mainly for those that have a different regulatory structure and generation physical resources. Further, we did not consider the influence of other public policies (that act together with the regulatory actions). Regarding the study of technological development of BSS, we stress although we saw that different services require the development of different technical characteristics and an BSS could be used to provide more than one service in the same time, we did not: (i) study closely the trade-offs of the technological development of this technology; and (ii) identify the real technical possibility to a BSS to provide more than one service in same time.

In view of that, from this work, we identify three points to be study in the future regarding the interaction between regulatory rules of electricity industry and the development of BSS. The first is to analyze that interaction on other electricity systems. The second is to study that interaction looking the effects of other public policies (in addition to regulatory actions)on BSS development. The third point is to analyze with more details the trade-offs of the technological development of BSS as well as the set of services in electricity systems that could be provided by only one storage system.

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