**Title**

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# EVOLUTION OF THE GRID TO EMBRACE NEW TECHNOLOGIES IN THE PRESENCE OF DIVERSE REGULATORY SCHEMES

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## ABSTRACT

Regulatory change in Mexico and the United States, along with advances in market structures, pricing mechanisms, and technology enable electricity markets to evolve and incorporate new technologies. From the regulatory and institutional front, the U.S. has faced various levels of promotion and intervention from federal and sub-federal levels of government into balancing markets, while Mexico faces similar challenges in a more integrated way, given more recent regulatory reform and the size of its market. We address the incentive problem to "create" new markets from the transactions cost approach of how easy or difficult it is for new renewable energy agents, incumbents, ISO/RTOs and balancing regions to actively be part of the power markets.

Key words: electricity regulation; grid evolution; renewables; balancing regions, best practices

# EVOLUTION OF THE GRID TO EMBRACE NEW TECHNOLOGIES IN THE PRESENCE OF DIVERSE REGULATORY SCHEMES

## 1. INTRODUCTION

Since at least 1978,[1] U.S. regulators and policy makers—on a federal level (FERC) and state level (public utility commissions and legislatures) must quickly respond to the dynamics of evolving electricity markets. The electricity market continues to advance, increasingly integrating renewable sources and market adjustments, such as distributed energy. In the case of Mexico, the country has faced a rather deep deregulation more recently, between 2013 and 2017, where new technologies are faced with market changes and regulatory readiness is not fully completed. As technology evolves, do U.S. markets efficiently enable state and federal policy goals, including increasing renewable energy, maintaining grid reliability and resiliency, and environmental sustainability, and what best practices can be incorporated into the Mexican market and regulatory system to achieve similar policy goals? Are all barriers to entry reduced, eliminated, or do policy goals include incentives for new players to participate in these new markets?

Public utility transmission providers (CFE Transmission in Mexico as a subsidiary of the incumbent utility CFE), are characterized first, by their natural monopoly aspects that make governments regulate their layout, maintenance, and expansion, with payments to the grid owners of rates equally distributed or “postage stamp” rates. Hence incentives for the uptake of new technologies and large investment projects are difficult. For example, the Federal Energy Regulatory Commission (FERC) in its Order 1000, has challenged the flat pricing approach. However, a “beneficiaries pay” approach is also challenged by the fact that it might not create enough incentives for the transmission grid to attain economic efficiency (Bushnell, 2014; Joskow & Tirole 2005). Some have proposed a

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[1] In 1978 the United States passed the Public Utilities Regulatory Policy Act, which encouraged the development of alternative power suppliers.

combined merchant-regulatory mechanism for transmission expansion (Hogan, Rosellón & Vogelsang 2007).

Secondly, grid operations and "optimal" modeling assume that generation is a given, and define origins of cost allocation to combine market-driven tariffs along with government rate controls that weigh in energy costs, congestion costs, and energy losses. This provokes a transaction costs approach to pricing and cost recovery where part of the costs is paid by the end users (load) and some is paid for by generators (Rosellón & Weigt 2011).

Thirdly, some of the cost measurement is "forward looking," (e.g., operation and management, plus some capital costs of expansion), the so-called residual cost. However, some parts of depreciation, or asymmetry in the balancing of injections and extractions in a location, call for coverage instruments to equalize or balance the supply and demand of electricity or capacity. That justifies the use of instruments such as day-ahead versus real time prices, financial transmission rights FTRs, ancillary service sub-markets, and renewable energy credit submarkets, not present in all regions and countries (Harris, 2006; Leautier, 2001; Ley de la Industria Eléctrica (Mexico LIE) 2014; Pollitt, 2012).

Moreover, the objective of CO2, and NOX footprint reduction, extends beyond the increasing uptake of renewable sources of energy and sub-markets. The "green agenda" is housed in different regulators (EPA in the U.S., SEMARNAT in Mexico), institutions (U.S. State Department, state legislatures in the U.S.; ASEA and CONNUEE in Mexico), and instruments (tariff incentives, fiscal incentives, and financial models), and affects renewable uptake in energy output[2]. Thus, the framework for a thorough analysis of renewables, renewable portfolio standards, and other incentives can be tested, using an evaluation technique to measure "best practice" across regional markets.

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[2] At the time the present monograph is finished, the U.S. Trump administration has decided on June 1, 2017, to withdraw the country from the Paris Climate Change agreement that entails 195 countries to commit efforts against climate change. After the announcement, states like California, Washington, and New York, responded that at their state level, commitments will continue and even be reinforced, showing that institutional commitment needs to be addressed at federal and sub-federal levels.

The evolution of the grid to increasingly integrate new technologies is complex, incorporating multiple levels of government and often requiring new legislation and institutional updates. Moreover, it involves more stakeholders than the grid of our past: legacy fossil fuel generators, non-conventional sources of energy, merchant developers, and renewable energy advocates all participate in the evolution of our grid. Our systems to regulate public utility transmission providers and balance supply and demand through emerging electricity markets also impact the evolution of the grid.

Given this framework, the main objective of the present investigation is to use a transaction-cost approach to determine the ease or difficulty to participate in an expanded market of new technologies, broadly comparing U.S. state or regional markets cases of successful renewable energies and grid operations, and then define some key lessons for the Mexican recent reform and its effects. Main effects can be focused on extended markets, entry conditions, prices, and market reliability measures. U.S. cases could be used as lessons to the Mexican recent regulatory changes. The present study initiates with an overview of the state of electricity and renewable regulations in Mexico in section 2. Section 3 follows with highlighted U.S. and California renewable regulations and electricity structure, emphasizing current trends in U.S. wholesale markets as they pertain to the incorporation of renewables. Current issues and forward-looking grid planning in CAISO, California's wholesale market, is highlighted in Section 3.4. Technology trends—costs, capacity, and highlighted U.S. policies are presented in Section 4. Section 5 concludes and highlights further areas of study, followed by an Appendix describing recent advancements in renewable energy technologies.

## 2. THE STATE OF ELECTRICITY AND RENEWABLE REGULATIONS IN MEXICO

### *2.1 Mexico's Recent Experience with Energy Reform*

Between 2013 and 2016, Mexico embarked in a deep and wide Energy Reform (ER) that entailed the unbundling of the former state-owned enterprise (SOE), Federal Electricity Commission (*Comisión Federal de Electricidad* – CFE) and the creation of a new independent system operator or ISO, the National Center for Energy Control (*Centro Nacional de Control de Energía* - CENACE), separated legally and in assets, from the transmission part of the utility CFE. This decision by Mexican authorities is different from other markets where the ISO was allowed to own (or partially own) the transmission segment of the market, called RTO (Srivastava *et al.*, 2011; Pollitt, 2008, 2012).

The Energy Regulatory Commission (CRE) also increased its competences to issue permits for newly established generating interests from the utilities company CFE, now horizontally separated into six generating companies in competition, and private participants from the supply side of the market, like the U.S. Qualifying Facilities (QFs).[3]

Additionally, the *Ley de la Industria Eléctrica* enacted in 2014 or (LIE 2014) defined the following structures among various new players: external legacy contracts (private large generating companies for sale of power to CFE in formerly defined *Productores Independientes de Energía*; and other legacy contracts among CFE subsidiaries. Then on the demand side, the law (LIE 2014) established load centers, similar to the U.S. Load Service Entities (LSEs), for both basic service CFE utility, plus private-transition ones. From the demand side also, the law defined qualified users (with capacity larger than 0.5 MW), and basic service users (basically residences served by the utility CFE). For intermediation, the law defined suppliers who own load facilities, and also traders with no facilities' ownership (aggregators), according to the secondary laws (LIE 2014), plus rulings of the wholesale market operation under the independent system operator called CENACE. In the wholesale market, the following products are traded: power, capacity, ancillary

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[3] It is important to note how the various definitions of market participants in Mexico have similar counterparts in the U.S. mature markets. A basic glossary is the following: a) under the former Mexican law of 1993, Independent Power Producers or IPPs, were large private producers of more than 30 MW of installed capacity for exclusive sale to incumbent CFE, now called external legacy contracts; b) the incumbent's generating facilities, ready to be unbundled, are called Legacy Electric Facility, similar to the deregulated generating actions under Senate Bill 7 of 1999 that unbundled investor-owned utilities (IOUs) into companies called power generating company or PGC which could resemble the Mexican ones called IPPs; c) permits to non-utilities for self-supply, co-generation, plus imports/ exports, could be taken to be similar to the U.S. definition of Qualifying Facilities, or QFs; d) load centers and suppliers for various market targets, similar to load servicing entities or LSEs; e) the retail electric providers or REPs in the U.S. do not have a clear similar definition in Mexico in 2017. All of the above are subject to CRE permits and operate in the wholesale market.

services, financial transmission rights, renewable energy certificates or RECs, and other products to be defined. CENACE with oversight of the secretary (SENER) and the regulator CRE has been charged with the development of a wholesale market (CENACE 2015, 2016). Mexico's recent reform redefined policy making procedures and regulating agencies. A hierarchy of Mexican players are summarized Table #1:

**Table #1: Mexico's Institutional Setting at the launch of Energy Reform and main competences by each stakeholder in Electricity, 2013-2017**

| | |
|---|---|
| Secretary of Energy (SENER) | • Launch of entire Energy Reform to oil, gas, and electricity sectors, voted in Congress (December 2013).<br>• Definition of time frame to launch all "secondary laws."<br>• Launch and oversight of the Law of Electricity Industry (LIE), the main legal piece, and the law of CFE (August 2014).<br>• Set members of the boards of deregulated state productive enterprises (SPE) Pemex, and CFE, their subsidiaries and affiliates, and limits of ownership and unbundling.<br>• Approves CFE expansion plans.<br>• Sets renewable (clean) energy provisions and requirements, as a key bridge between energy and environment regulations.<br>• In December 2015, an additional law was proposed by SENER and voted, called the Ley de Transición Energética, or LTE, that is the Environmental Law that set targets (35% renewable consumption) of clean generation (consumption) by 2025, from a base of 17.9% in 2014 (See below). For that matter, SENER published guidelines before, for RECs in October 2014.<br>• Sets minimum consumption limits to be considered qualified users.<br>• Hierarchical decrees from secondary laws, in layers as follows: a) market bases; b) market practices' manuals; c) operating guides for all electrical markets and products; and d) Operating criteria.<br>• From the former set of decrees, administrative provisions have been published and enacted under manuals for market practices (between 2014 and 2016, 28 new provisions separated in further layers.[4] |

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[4] The new provisions were divided into four groups according to SENER's administrative capacities: in Group 1, the following provisions are published: Long term auctions; short term markets; guarantees; market information system; forecasting exercises; invoicing and payment scheduling. Under Group 2, the following are provisions: registry for wholesale market participants; legacy interconnection contracts; opportunity cost calculations; market models; legacy transmission financial rights; measurement provisions; export/ import contracts. Under Group 3: coordination with natural gas providers; capacity markets; rest of interconnection; reliability measures; market monitoring provisions; operating planning; and maintenance provisions; and Group 4: structure of market rules

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| Secretary of the Treasury (SHCP) | • Sets regulated maximum prices for markets in transition (gasolines, oil liquids, natural gas, basic utility services. Latter a tripartite decision between SHCP, SENER, and CFE).<br>• Sets final tariffs & prices for suppliers at load nodes (distributed geographically on a yearly basis along with SENER, after consultation with CRE).<br>• Fiscal treatment and adjustment to oil, gas, and electricity SPE (Pemex and CFE and its subsidiaries and affiliates).<br>• Co-participates in designation of members of boards in CFE and its subsidiaries & affiliates. |
| Energy Regulatory Commission (CRE) | • Created in 2005 as an independent and autonomous energy regulator of non-utilities, similar to its counterpart federal U.S. regulator FERC.<br>• Using the Mexican Public Service Electricity Generation Law, called in Spanish *Ley del Servicio Público de Energía* Eléctrica, or LSPEE enacted in 1994, CRE was in charge of administering all private contracts for generation (IPPs, auto-generation, co-generation, imports, exports); gas transport and storage; open seasons to incentivize renewable investment beginning in 2008.<br>• Administers permits and non-utility contracts, excluding state company CFE.<br>• With the Constitutional Reform (2013); Secondary Laws (August 2014), CRE was given new powers, extended legal and administrative endowments, new role to proceed towards overseeing de-regulated prices and participants, given new grandfathered contracts for generation and supply, and contracts under the new LIE-2014 and other market rules (Bases, beginning in 2017).<br>• Under LIE, CRE sets contracting requirements in the vertically unbundled industry for generation, transmission, supply, trading, distribution, and commercialization of electricity and related wholesale products (for private permits in legacy and new contracts). |

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and change management; controversies; medium term auction provisions; transmission financial rights from network expansion provisions and their auctions; small electrical systems, and oversight of renewable certificates auctions.

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| | • Specific powers to regulate asymmetric parts of the industry when incumbent holds market power. Sets prices called “first-hand” or maximum tariffs, mainly for utilities.<br>• Coordinates and delegates illegal conduct activities to Mexico’s Competition Commission.<br>• CRE extended powers in new products, such as administering Clean Energy Certificates (CELs, similar to U.S. RECs) since October 2014 and March 2016, and new products to appear in the wholesale market (energy, capacity, renewable energy additions and obligations, ancillary services, financial transmission rights (FTRs), CELs proper, and other that emerge.<br>• Monitors wholesale market under the ISO called CENACE.<br>• Sets reliability standards.<br>• Legal capacity to determine transmission and distribution regulated tariffs (postage stamp until 2017, that may extend into the near future given market conditions).<br>• Supervising power for interconnection in all types of loads, and eventually to set basic electricity service (utility) final prices, once revenue need calculation is presented and approved by SENER, with CRE opinion.<br>• Beginning in 2017, CRE sets performance measures and targets for the incumbent CFE under horizontal unbundling of 6 CFE generating companies.<br>• Supervises true competition amongst 6 CFE generating companies as CFE subsidiaries and affiliates that compete in the market (wholesale and bilateral contracts beginning in 2018).<br>• Regulates transactions between suppliers (load centers) and generating companies.<br>• Ensures open access to grids by all market participants, given physical limitations.<br>• Determines contract models between CENACE and transmission and distribution grids for public service activities, plus wholesale activities under CENACE’s auctions. |

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| Independent System Operator (CENACE) | • A public institution, was unbundled from the former CFE to become the Independent System Operator or ISO in 2014, to become the operating control center for wholesale energy markets, plus guaranteeing open access of all wholesale participants.<br>• Determines types of products traded at wholesale in a stable manner: compulsory nodal spot market (day ahead market since 2016, plus spot hourly market and intra-hour in 2017); coverage contracts and basic service contracts; CELs and FTRs; ancillary services. Municipal aggregators might follow in the future.<br>• Sets dispatch rules under market design unit (ordered dispatch with economies in mind).<br>• Obligations of market monitoring and data.<br>• Beginning in February of 2016, first auctions have been for supply (by the CFE utility) of basic services. Market for energy only began then, to be followed by wholesale long term supply and utility generation. Then in March, 2016 first auction for CELs was implemented at CENACE (Second renewable energy auction took place in June, 2016, for projects in solar-photovoltaic, solar co-generation, some wind, and one hydro-generation project). Between two and three renewable auctions are programed for 2017 and 2018. Second renewables auction included capacity.<br>• Auctions for long term (3 years) and medium term, were given precedent in the time frame, to give rise of short term (quarterly, monthly) energy, capacity, ancillary services during 2017-2020. Wholesale markets are emerging in Mexico at the time of the present research.<br>• CENACE is responsible of planning the expansion and modernization of the national transmission grid infrastructure and the general distribution networks of the national interconnected system. Once programs are accepted by SENER, planning is inserted in the National Development Program of the Electric Sector (called PRODESEN).<br>• Oversees the migration of load centers, from 59 regions to around 4,000 nodes, and sets loading centers with critical congestion with calculation of load nodal marginal costs. |

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| | • Has obligations to promote entrants to the wholesale market. At the time of this research, CRE reports 1,070 legacy private contracts/ permits, out of which 8 have migrated to the new law LIE; 127 private generation permits; plus 161 CFE permits. Additionally, 16 permits have been issued as qualified users until December 2016, but will grow during next months and years.<br>• CENACE has produced 19 market bases to govern the market, and more than 100 manuals and administrative documents, and technical definitions.<br>• CENACE in charge of determining interconnection with neighboring systems (not part of the national electricity system, including U.S. and Central American systems).<br>• All stakeholders that are participants in the wholesale market pay fees to CENACE. |
| National Utility Company (CFE) | • From the Constitutional changes in Arts. 25, 27, and 28, the Mexican state deregulates the two main State-Owned Enterprises Petróleos Mexicanos (PEMEX), and Comisión Federal de Electricidad (CFE). They are renamed into State Productive Enterprises with new mandates: produce social products and services for the public good, while they should seek economic value. The intent is for CFE to become a corporation, with a strategy towards corporate practices.<br>• Further, a new law called Ley de la Comisión Federal de Electricidad or LCFE (and the Ley de Petróleos Mexicanos), was published in July 2014, and enacted since August 2014, that sets the vertical unbundling of the company into generation for basic services, generation for non-basic services, separating transmission and distribution as subsidiaries for public service, plus supply activities at load centers, and trading activities, separated from the rest as a new type of economic activity.<br>• Further, the LCFE created a special regime in terms of: a) subsidiaries and affiliates; b) wages and remunerations; c) acquisitions, rents and leases, services, and construction; d) valuation and appropriation of goods and facilities; e) responsibilities towards the state; and f) payments to the state. |

| | |
|---|---|
| | • CFE corporate governance and that of its subsidiaries and affiliates was changed in the composition of their governing board into 10 council members from government (SENER, SHCP, 3 other designees by the federal government; 4 independents, 1 designated by the CFE union.<br>• The CEO of CFE manages, operates, and executes CFE objectives under the strategies, policies and orientation approved by the board of directors. The same principles apply to CFE's subsidiaries and affiliates.<br>• CFE fiscal and budgetary regime was changed into corporate practice with an adjustment period between 2014 and 2016, covered temporarily along with Pemex, by the federal budget. Beginning in 2017, CFE and its subsidiaries should follow corporate practices with no subsidies (in principle the fiscal and subsidy regimes transit towards such practice but need fine tuning by 2017).<br>• Subsidiaries became SPEs with legal separation, and own capital, to operate under their own board (consisting of 5 to 7 council members), and one designated director. Affiliates are not SPEs but CFE participates directly or indirectly in more than 50% of equity, and can be established under Mexican or foreign legal status. This allowed for CFE to create a company called CFE International in June 2016, along with CFE-Energía, to manage the gas business as a separate entity.<br>• Subsidiaries and affiliates became open to make contracts with other private companies, under the new LCFE (August 2014).<br>• Since 2014, many decrees and agreements were published in the National Gazette regarding tariffs, calculus methods for payments, rents, and regulated aspects of contracts.<br>• Further within CFE restructuring process, a decision by CFE board was announced in March 2016, to be officially published in June 30, 2016 of CFE horizontal separation.<br>• Under CFE as a holding company, 4 generation EPS are to compete amongst themselves and in face of private participants, in the wholesale market at CENACE. They are called CFE II, III, IV, and VI and become generating companies by any technology to participate in the market.<br>• Two other EPS, separated from CFE but under its corporate wing are the EPS Transmission, and EPS Distribution. |

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|---|---|
| | - CFE I became a horizontally separated affiliate called Intermediation Generation to concentrate CFE legacy interconnection contracts and administer them and trade in the wholesale market.<br>- CFE V became horizontally separated as a EPS to concentrate and represent in the wholesale market (CENACE), all former IPP producers.<br>- Finally, another EPS, called CFE Basic Services, is under a special legal regime and under CRE supervision of its tariffs, for utility basic (residential) service. |
| Agency for the Security, Energy, and Environment, dependent from the Secretary of the Environment (ASEA) | - Regulates aspects of security and the environment plus standards for the hydrocarbons industry, from exploration, transport, storage. |
| National Commission for the Efficient Use of Energy, dependent on SENER (CONNUE) | - Regulates via norms and standards the Mexican renewable portfolio standards (RPS) at national level.<br>- Needs to coordinate to be able to issue strategic plans for fiscal, financial, and regulatory incentives.<br>- Gives opinion and represents Mexico in international for a as delegated technical commission from SENER. |

Source: generated by the authors with information from all Mexican Energy Reform laws, regulations, decrees, guidelines, and market standards

One needs to emphasize that Mexico faces a unified Energy Reform (ER) at the federal level, while California and other U.S. states respond to federal and state regulations towards energy business, grid operations and management, grid expansion, and uptake of new stakeholders and company players. Mexico's energy reform legislation was added by what is called *Ley de Transición Energética*, or Law for Energy Transition, which sets a target of 35% of clean energy (including hydroelectric generation) for year 2024, from a base of around 17.9% in 2014 (plus 3.2% in nuclear). The reader can place this law within the table #1 that describes the map of institutional setting ecosystem. One exceptional ruling relates to rights of way and water management in Mexico that combine federal laws and state, or local regulations.

### *2.2. The Clean Energy and Environment Institutional Interface*

The clean energy agenda and electrical reform, seem to be conceived by legislators as independent of each other. The two main pieces of regulation relate to electricity, on the one hand, and the green agenda, on the other. For instance, secondary laws for electricity liberalization date back to August 2014, as is pointed out in the above Table #1, although SENER embraced the target clean energy consumption percentage for 2025.

Now, the clean energy agenda is under the Law of Electricity Transition that substitutes the former law called Renewable Energy and Financing Energy Transition Law LAERFTE from 2012, and was passed by the Mexican congress in December of 2015. Under it, provisions are set for clean energy targets, but also include inventories of pre-gasses, CO2, NOx, contaminating particles. They are under supervision of the Commission for the Efficient use of Energy, or CONUEE, that depends on the Secretary of Energy SENER. CONUEE also sets areas of competence in transport, clean buildings and materials, consumption of clean energy at public buildings, norms of sulfur content in gasoline, diesel, and aircraft fuels. In a sense, CONUEE and its agenda is similar to U.S. state agencies overseeing Renewable Portfolio Standards (RPS). However, legal, administrative, jurisdictional, adjudication endowments are not totally clear in the Mexican case. (Ibarra-Yunez, 2016). Moreover, in a recent meeting with the president of Mexico's regulator CRE, Mr. Guillermo García Alcocer, stressed the fact that while the regulator hears opinion from the ASEA agency related to hydrocarbons environmental issues, it does not relate much to the other agency CONUEE on RPS (meeting held on May 19, 2017 in Monterrey).

Furthermore, institutions to oversee the turn towards clean (and renewable) energies are somewhat superimposed and still evolving. New regulatory agencies seem to have diverging policy objectives. For instance, CENACE, the ISO, aims to balance the market with a new energy mix, thus its stance seems not to be neutral. The Energy Regulatory Commission (CRE) is the energy regulator and registrar of "Clean Energy Certificates" or CELs with comprehensive institutional attributions and powers before the creation of CENACE. The Ministry of Energy (SENER) is in charge of long term planning of energy markets and infrastructure in transition.

The Ministry of the Environment and Natural Resources (SEMARNAT), on its part, is responsible for introducing pollution control measures as well as developing and maintaining accurate emission inventories of greenhouse gases (GHG) and co-pollutants. Dependent on SEMARNAT is the ASEA (*Agencia de Seguridad, Energía y Ambiente, or Agency for Security, Energy and the Environment*), in charge of overseeing security and environmental protection of the oil sector, while the above mentioned CONUEE (*Comisión Nacional para el Uso Eficiente de Energía*)*,* is in charge of efficiency programs that cover utilities, private power providers in the new market, the transport sector, construction, and government users, as well as oversees the deployment of renewable energy in the electric sector to meet the targets set in the LTE.  The following Table #2 accounts for the similarities and differences between the Energy and Environment Laws LIE, and LTE.

**Table #2: Scope and Objectives of Mexico's Energy Law (LIE) and Energy Transition Law (LTE)**

| LIE | LTE |
|---|---|
| Clean energy goals compliance (obligations, fines for non-compliance, by CRE) | Emissions reduction compliance (obligations and fines for non-compliance, by CONUEE, and also SEMARNAT) |
| Clean energy certificates (CELs) issuance and obligations to a quota (35% by 2024) | Emissions national registry by type of GHG, particles, and by type of producer |
| Oversight of wholesale market participants to use the wholesale market for energy, capacity, CELs, ancillary services, transmission financial rights, other products (pro-competition segment) | Direct mandate for GHG emission reductions |
| CEL market must link to carbon market | Register advances in the clean energy targets 2018, 2020-2024, and further |
| Promotion of distributed energy (generation), with no obligation | Eventually launch a cap-trade market mechanism linked to the carbon market, and the CEL market |
| Indirectly contribute to reduction in GHG emissions in electricity sector | |

**Source:** generation by the authors with input from LIE and LTE, Mexico, May 2016.

## 3. THE STATE OF ELECTRICITY AND RENEWABLE REGULATIONS IN THE UNITED STATES

In the U.S. case, the first significant Congressional effort to introduce federal legislation to curb GHG emissions failed. The American Clean Energy and Security Act of 2009 (ACES) known as the Waxman – Marquee Bill was criticized for its potential economic impact to the economy, concerns and politicization around the creation of a carbon cap-and-trade emissions trading system and the lack of action by major emitters such as China and India.

We use the case study of California, a subnational jurisdiction, but also a major economy at global level to illustrate the evolution of a regulatory system that addresses the efficiency, security and reliability of the electric sector while also mitigating carbon emissions. California has been the leader in climate policy institutional developments in the United States passing its first climate bill in 2006, thus setting a major precedent for local and regional climate action domestically and around the world.

However, other states have enacted policies to increase the use of new technologies to increasingly embrace renewable sources of energy at the same time that stakeholders act dynamically to reach standards in renewable targets. They also have as objectives reducing the carbon footprint, increase self-sufficiency in energy portfolios, and reach clean and sustainable targets, at the same time that market balances are aimed at state-wise and across states in relevant regions. Renewable resources have been overall incentivized by financial, regulatory, and fiscal measures, such as greenhouse gas (GHG) prices, renewable energy credits (RECs), and even direct subsidies. Some authors have compared such incentives across interconnects in the United States and state markets, such that net benefits can be measured (Sivaraman & Moore 2012).

With more than a decade of learning-by-doing implementing a clean economy model, a key component of this process has been the transforming of its electricity industry by introducing clean tech, and smart technologies to upgrade the electric sector’s infrastructure. Thus, it is key to compare institutional perspectives on how these two sets of regulatory mechanisms are evolving. Moreover, we analyze below the shared energy agenda and the institutional setting and readiness in both Mexico and the United States at the federal and sub-federal levels, and policy makers on both sides of the border, as new players are attracted to the dynamic markets (the ease of market entry from the transaction cost approach).

Renewable energy targets are ambitious on both sides of the border. As mentioned above, Mexico has targeted 35% of clean energy attained by 2024 while California has set a 50% target for 2030 via an RPS (*Ley de Transición Energética* 2015; California SB-350 Clean Energy and Pollution Reduction Act of 2015). The two markets have relied on their own sources of renewable energy. Additionally, while U.S. rules promote access to

Canada's hydroelectric sources as part of the target, until now no Mexican clean sources such as solar, wind, sea-waves, or geothermal have been promoted under the reform.

For Mexico's LTE, it relies on its own sources to reach renewable standards, mainly through the issuance of Clean Energy Certificates (CELs).[5] Could Mexico and California increasingly rely on each other to share projects and policy objectives? The enacted LTE has set goals of clean energy consumption of 25% by 2018, 30% by 2021, and as shown above, 35% by 2024. Mexico's official clean projects' permits reached 639 by December 2015, of which 593 are private (LTE 2015; CRE 2016). These permits are concentrated primarily in generation, a part of the system with low barriers to entry. The official clean energy base was 17.9% in 2014, excluding 3.2% from nuclear sources (Sener data 2015).

However, policy design for the wholesale energy market requires careful consideration of the imbalanced market power between new entrants and that held by CFE and larger incumbent producers. California dealt with these imbalances in its clean energy market evolution as well, and thus provides some valuable information for Mexico's policy design. The strength of laws, regulations, and regulatory endowments, follow previous work (Adelman & Spence, 2015); Andres, Guasch, and Lopez; Bunn & Muñoz, 2016; Egerer, Rosellon & Schill, 2015; Griffin & Puller, 2005; Harris 2006; Jacobsson & Lauber, and Pollitt 2008, 2012. The present analysis that compares Mexico and California regulatory systems has not been done before for Mexico.

### *3.1 California and Federal Regulatory Compacts in the United States*

One needs to face at least the two main levels of federal and state regulations regarding energy and climate policy on the one hand, and energy policy on the other,

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[5] Mexico's standard is centered on non-fossil generation that includes wind, solar, geothermal, biomass and biogas energy, and also includes hydro-generation (subject to efficiency criteria but not capacity), nuclear, and "efficient" co-generation, excluding the weight of natural gas. It also stresses distributed generation from clean energy sources. It focuses on electricity generation, and only touches on transport and building materials with no targets. Hence clean is somewhat different than non-traditional renewables (See Mexico LAERFTE 2012, and Mexico LTE 2015).

which includes non-traditional sources of energy and technological development for market balances and the setting of the grid of the future.

To begin with state legislation, climate policy is the key driver for the energy transition. To meet such targets in the context of the power sector requires "detailed long-term planning due to complexity, inertia, and path dependency in the energy system" (Wei *et al*., 2013). A central policy driving transformation and innovation in the California economy has been the introduction of a carbon price through a market-based system also known as a cap-and-trade emissions trading system (ETS), not implemented so far in Mexico. In addition to accounting for the negative externality of greenhouse gas emissions (GHG), there is strong policy support and commitment to technological advance for energy systems' low-carbon transformation and cost saving efficiency measures, that extends beyond and evolving energy mix to embrace renewable sources of primary energy, such as solar.

The State has also become a world leader in energy efficiency and conservation. The California Energy Commission (CEC), established in 1974, is tasked with decreasing energy costs and use, while maintaining energy reliability (CEC, 2017). California has been a leader in energy efficiency policy, with its first Building Energy Efficiency Standards adopted in 1976. Currently, California is widely known for two successful energy efficiency polices: Title 20 and Title 24. Title 24 is California's building energy efficiency standards for residential and nonresidential buildings, which is continuously updated to reflect changes in current technologies. For instance, new buildings and gut rehabs all require lighting control systems that conserve energy use (CEC, 2015a). Title 20, which has been passively adopted in other parts of the country due to California's large market share, requires that manufacturers of home appliances certify specific efficiency standards (CEC, 2015b). The CEC estimates that energy efficiency standards have saved Californians over U.S. $70 billion in reduced electricity bills since 1975.

California implemented and gradually expanded the goal of its renewable portfolio standard (RPS), which requires that a minimum of 50 percent of the state's energy be procured from renewable sources by 2050, under the 2015 Senate Bill 350. The law authorizes the use of tradable renewable energy certificates (credits or RECs) for compliance with that program. The California Public Utilities Commission (CPUC), established over a century ago, in 2015 reformed its rate structure to account for the expansion of renewable energy supply, technological innovations, and energy efficiency efforts.

Additionally, as of 1982 California introduced a policy aimed at decoupling quantity of electricity sold from revenue generation for utilities. Once a revenue goal is set by regulators, utilities are required to return revenues in excess of that goal to customers, and are allowed to charge customers for the shortfall if revenues do not reach the goal. Prior to this, there was a perverse incentive among utilities to encourage growth of electricity consumption as their revenue was directly tied to how much electricity was sold. This is rather different than in Mexico, where load centers have the obligation to reach quantitative (percentage) goals in renewable consumption, and issuing via auctions, RECs to generating facilities that shift towards renewable projects. Auctions are organized federally by the CENACE twice a year so far into the reform implementation, where RECs are registered at the regulator CRE.

### *3.2 Highlighted U.S. Federal Compacts*

The skyrocketing electricity costs during the U.S. energy crisis of 1973, coupled with stagnating efficiencies of traditional power plants led to increasing concerns over the productivity and efficacy of natural monopoly utilities, ultimately resulting in the passage of the Public Utility Regulatory Policies Act (PURPA) of 1978 (Hirsh, 1999). At the federal level, PURPA established the base for energy regulation and modernization. It set the institutional oversight for standards of electricity utilities, intervention and judicial review, retail regulation, and all administrative provisions for a modern electricity industry to be secure, reliable, with supply expansion mechanisms, and demand provisions for energy efficiency and savings. As a base mechanism, it could compare to the recent Mexican revolution in modernizing regulations under the mentioned Energy Reform of 2013-2017. From PURPAs enactment, the number of market participants skyrocketed in the U.S.

Moreover, the Fuel Use Act of 1978 stimulated the growth of qualifying facilities (QFs) by not allowing utilities to build new generation plants that used relatively lower-priced natural gas, but allowing qualifying facilities to do so. Although the law was repealed in 1987, it assisted many qualifying facilities to become established in the market. FERC Order #888 promoted wholesale competition through open and non-discriminatory transmission access, thereby lowering costs for small power producers and incorporating new technologies into the market. Specifically, FERC Order #888 established Open Access Transmission Tariff (OATT) provisions that: (a) ensure fair and open transmission access, (b) establish transmission planning processes, and (c) outline transmission owner/transmission customer rights and access fees.[6] Moreover, FERC Order #888 established a market for ancillary services—an increasingly important component of the U.S. wholesale market. Even in markets not under FERC's oversight, display of new technologies and an increasing number of participants in power markets were stimulated.

The Energy Policy Act of 1992 included several provisions for the growth of alternative fuels and renewable energy and most notably first introduced the Production Tax Credit for wind energy, which subsidized the production of wind at $0.0015[7] per KWh (U.S. Congress, 1992). The Production Tax Credit first lapsed in 1999, and has since lapsed and been extended several times, creating policy uncertainty and a "boom and bust" cycle for wind development in the United States (U.S. DOE 2015). The most recent extension of the Production Tax Credit is estimated to result in an additional 12 GW of wind installation in 2017 alone (NREL, 2016).

Now, the Federal Energy Regulatory Commission, the Energy Policy Act (EPA) of 2005 encompasses many aspects of updating market operation and conduct by main

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[6] See "U.S. Federal Energy Regulatory Commission, Order No. 889, Open Access Same-Time Information System (formerly Real-Time Information Networks) and Standards of Conduct,Docket No. RM95-9-000, 75 FERC 61,078, Final Rule, issued April 24, 1996, xx, www.ferc.gov/legal/maj-ord-reg/land-docs/order889.asp."

[7] The Production Tax Credit is inflation adjusted, worth $0.024/KWh in 2017.

participants, at the same time that it introduced a 30% subsidy—known as the Investment Tax Credit—for the installation expenses of solar PV and other renewable energy systems (U.S. Congress, 2005). Since the implementation (and subsequent extensions) of the residential and commercial Investment Tax Credit, solar installations in particular increased by a compound annual growth rate of 76% (Perea, 2017). The Energy Policy Act of 2005 also included reviews of potential illegal excessive charges by incumbents in California's market during the energy crisis of 2001 (Sec. 1824), and actions for refunds. FERC under the EPA 2005, included measures for increased reliability, review of status and upgrading of Qualifying Facilities (Order 671, and 671A); guaranteeing RTOs and transmission organizations to insure transmission expansion and operation to satisfy needs of load-serving entities (LSEs) for a market of long financial transmission rights in RTOs and interconnections.

On its part, the Energy Independence and Security Act of 2007, aimed at regulating and setting bases for vehicle and transport standards and fuels, savings standards, buildings and materials, savings in government and public institutions, carbon capture and sequestration, smart grids, among other provisions. It set a framework for further regulations at the state levels. However, it was at the state levels that Renewable Portfolio Standards (RPSs) have been enacted in 19 states and the District of Columbia. The federal Act 2007 includes a set of provisions for international cooperation that could be used in Mexico's parallel regulations under the CONUEE's mandate, with similar subject aims of energy mix, construction materials and standards, government aid and responsibilities, and cleaner public transport, and fuels.

Interstate transmission is mandated as a federal regulation in U.S., for which some legislative pieces and mandates, such as Order #888, promoted Regional (Interstate) Transmission Organizations, or RTOs, not comparable to Mexico's wholesale market clearance house CENACE, as a true nationally integrated ISO (Pollitt 2008, 2012). However, it was FERC Order #2000 that established rules for RTOs: a) on setting tariffs and partially allocating costs; b) congestion management and scheduling; c) parallel transmission flows for unscheduled transmission while systems are interconnected, part of balancing provisions; d) define needed ancillary services at nodal levels and balancing services; e) planning and expansion of the grid, and interregional coordination (FERC, 1999). The latter order is relevant for contrasting it to Mexico's set of regulatory and legal provisions regarding transmission cost allocation and long term planning (Jamasb & Pollit 2011; Pollitt, 2012).

In closing this section, one must be aware that the U.S. regulatory changes began in 1978 and have taken more than 20 years to reach a mature structure. However, even today, legal upgrading and institutional changes internalize the fact that technology and markets are an evolving and living body of stakeholders with new and unexpected opportunities and transaction costs for new technologies and participants. This learning-by-doing that gives the dynamics for the U.S. phenomenon should be integrated to the recent Mexico's energy reform that began with the Constitutional changes of 2013, the 22 secondary laws enacted in August of 2014, more than 100 market bases and administrative rulings from 2014 into the beginning of 2017, as this research project is implemented. Three and a half years seem promising but far from settled in Mexico's experience with a transition market.

### *3.3 Current Trends in U.S. Wholesale Markets*

About two-thirds of U.S. electricity is sold through wholesale markets, which compared to non-market alternatives save $3 billion in electricity generation costs (Cicala, 2017). Overall, U.S. wholesale markets have a similar structure to that of the CENACE market. Both have power markets, capacity markets, ancillary service markets, financial transmission rights, and renewable energy certificates (known as CELs in Mexico). Current trends in U.S. wholesale markets can provide insight for Mexican policymakers as they continue to design a competitive market that ensures reliability, resource adequacy, and efficiently incorporates renewable technologies that align with policy mandates of SENER.

Wholesale electricity markets within the U.S. vary slightly, each with successes and challenges that provide lessons for Mexico's energy reform. Both the U.S. and Mexico share similar objectives in establishing wholesale markets: supporting electric utilities to acquire or invest in distant generation resources in a more efficient and flexible manner, providing price transparency, and also reducing barriers to entry for new technologies such as renewable energy. Analogous to CENACE, there are seven Regional Transmission Organizations[8] in the United States. RTOs were voluntarily established per FERC Order 2000 in order to promote economic efficiency in the wholesale marketplace, increase reliability, and manage transmission planning (FERC, 2016). Before the existence of RTOs, some bilateral and organized energy markets existed, but procuring reliable energy was still a challenge. For instance, if a utility wanted to procure non-adjacent generation sources it would have to pay transmission rates from each transmission owner, resulting in an inefficient and less competitive wholesale market place.

Over the past decade, dynamics have evolved from both the supply and demand side of wholesale markets, which have implications for policymakers in Mexico and the United States. Due to low natural gas prices and expansion of technologies such as wind and solar, the resource mix continues to shift toward these sources and away from coal-fired plants. With U.S. natural gas prices at an almost twenty year low, natural gas continues to be the marginal resource determining the clearing price in markets and is expected to set market prices in the foreseeable future (EIA, 2017). The fast-ramping gas resources complement variable output renewables such as wind and solar, which are generally strongest at night and day respectively. The zero fuel costs of renewables will continue to drive energy prices down, decreasing overall market revenues. Anticipated lower energy prices could be offset by higher ancillary service costs such as frequency regulation or voltage support. However, the decline in overall energy prices could stifle investment signals for natural gas or infrastructure, both of which are needed for reliability.

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[8] Some organized markets are referred to as Independent System Operators or ISOs. While there are slight differences between RTOs and ISOs, they are overwhelmingly similar in their objectives and operations. We will refer to RTOs henceforth to represent both RTOs and ISOs.

From the demand perspective, new technologies such as demand response and energy storage have resulted in an overall flatter demand curve. Per FERC Order 745, wholesale markets must allow demand response participation and compensate providers at the same locational marginal price as if they generated energy. Demand response is a cost-effective mechanism to reduce price volatility and enhance reliability on the grid. Energy efficiency, suggested federally per FERC Order 1000 as a non-transmission alternative to meet reliability needs, can also bid into wholesale markets and receive compensation at the locational marginal price of energy (FERC, 2011). FERC Orders 755 and 784 initially defined revenue streams for energy storage on the federal level (Mullendore, 2015). While this resulted in an increase of grid-scale energy storage, particularly in PJM frequency regulation market,[9] energy storage experiences barriers to the market place including not receiving compensation as a generation resource, or outdated technical requirements that are not compatible with current technologies (FERC, 2016b and ESA, 2016). From the federal level, FERC is considering the inclusion of energy storage in the wholesale energy market place as an additional non-transmission alternative to ensure reliability (FERC, 2016c).

Overall, U.S. wholesale power markets experience several challenges to be considered in Mexico's Energy Reform. First, policy and market design continually lag behind the reality of an evolving grid. Much of the country's current market designs were modeled after traditional commodities markets and tailored toward traditional central station fossil-fuel generating resources that have less variability in output than renewable energy resources. Moreover, markets were initially designed for resources with fuel costs, thus zero marginal cost renewables are incompatible with long-term market design tailored toward fossil fuels.[10] As technology changes, requirements of generation and transmission evolve, forcing policy makers to continually remunerate new technologies or

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[9] PJM has 74% of the U.S. utility-scale battery market, mostly for frequency regulation.

[10] For instance, most day-ahead or spot markets line bids up in merit order from lowest to highest. The highest bidder sets the price of energy, and all participants receive that price. Thus, zero marginal cost resources such as wind and solar can bid into the market at zero and receive the clearing price. If expansion of renewables continues as projected, markets could see more load-serving entities bidding in at zero, perhaps until the market-clearing price also meets zero.

benefits provided to the grid. Establishing a mechanism to continually update remuneration design and technical operating manuals is a best practice that can be considered by Mexican authorities at CENACE and CRE. For instance, the PJM region incorporates stakeholder feedback in the revision of operating procedures, followed by a two phase implementation process of revisions. Moreover, some wholesale markets have advisory committees and committees where all stakeholders have a say in long term planning that could be useful in the transition market in Mexico (Sweeny, 2017).

Second, policy mandates and subsidies are often not accounted for in wholesale market design, and policy mandates or consumer preferences are not monetized in the market. Many states have requirements for renewable energy procurement, without consideration for costs or how resources will efficiently participate in markets. Twenty states as of 2016 have attempted to balance the desire for renewable energy and need for cost-effective energy by also incorporating price ceilings on renewable energy mandates. Eighteen states have included carve-outs for specific technologies, requiring a certain percentage of generation to be met with sources such as wind, solar, or biomass (Barbose, 2016). Other states, most recently Illinois and New York, distort the market through subsidization of preferred generation sources, such as nuclear power (IGA, 2016 and McGeehan, 2016).

Third, market structures are inflexible, often designed with one grid service in mind, which may inadvertently prevent participation or ignore potential value streams from ancillary services that provide myriad reliability benefits. For instance, the PJM capacity market requires that resources bidding into the capacity market be available all hours of the day, all year long, thus preventing the participation of variable renewables like wind and solar. Other markets have tunnel vision, only compensating a generation sources for one characteristic, such as fast ramping, when other values to the grid are not remunerated. This leads to market inefficiencies, with consumers overpaying for generation, reserves, or ancillary services. Current issues in U.S. capacity and ancillary markets are highlighted below.

### *3.3.1 Current Challenges with Capacity Markets and Incorporation of New Technologies to the Grid*

Capacity markets pay for resources one to three years before needed, and were created to send an investment signal to ensure that future generation resources will adequately meet future resource availability. Three U.S. RTOs (PJM, NE-ISO, and NY-ISO) have mandatory capacity markets, with one or three year-ahead markets. These regions with mandatory capacity markets also correspond with high proportions of restructured utilities and more retail competition. Notably, capacity markets were created before the existence of ancillary markets, or technologies such as demand response, energy efficiency, and energy storage. In other words, at the time of capacity market design, all units of generation capacity were equal in value, and markets had yet to assign values to capabilities that align with new technologies, such as flexibility or fast-ramping (Glazer et. al., 2017 ).

Some experts debate the appropriate design of capacity markets, or if capacity markets are necessary at all (Cramton, et. al 2013). It should be noted that several RTOs do not have formal capacity markets, but rather supplementary mechanisms to ensure long-term reliability. For instance, ERCOT's reserve shortage pricing mechanism, implemented in May 2014, has had positive results. In times of scarcity, the price of energy surges to as much as $9,000/MW, encouraging load-serving entities to enter the market (Hogan, 2017). CAISO has capacity requirements for load serving entities as its administrative mechanism to ensure long-term generation needs. Given that CENACE has a one- year capacity market auction (although long term auctions for three year ahead markets are planned to be implemented in the future), it is helpful to survey a brief history of capacity markets in the U.S. and current issues with capacity markets to incorporate new technologies.

Capacity markets in the United States have been in existence for over a decade. For example, the original PJM market design created in 1999 included elements of capacity markets, and its formalized capacity market structure was established in 2007 (Bowring, 2013). Broadly speaking, until 2011 load-serving entities were able to enter into bilateral capacity contracts and were guaranteed that they could use specific resources to meet state RPS goals regardless of bidding price. Many utilities would bid into the market as price takers to meet RPS requirements, and then buy an equivalent amount of capacity to demonstrate capacity requirements. Then in 2011, new resources built by load serving entities were no longer guaranteed to clear the auction. Only the least cost resources per the RTO would clear the auction, meaning that many LSEs building generation to meet state policy goals[11] could pay twice for generation (once to meet state-prescribed policy goals and a second time to meet RTO-specified resource adequacy obligations). The premise behind the modification was to "level the playing field" so that LSEs could not continue to self-supply, which could saturate the market and drive down prices, posing a barrier to new non-utility generators to building new resources. Likewise, states could oversupply the market through subsidies or mandates. In other words, in the eyes of organized capacity markets each megawatt of capacity is equal to the next, regardless of policy mandates, environmental benefits, or consumer preferences. Notably, demand response and energy efficiency are eligible to bid into the capacity market and are compensated at the full locational marginal price of generation (Glazer et. al., 2017). The capacity-clearing price is calculated from the intersection of the aggregate of all bids (supply curve) and the RTO-determined marginal cost of entry for the most efficient resource (demand curve) and serves solely as an investment signal for generation needs three years (or one year) out. Projected demand, also determined administratively, is sometimes referred to as the variable resource curve (Plewes, 2016).

Capacity markets may ensure longer-term resource adequacy, but the three-year investment signal with a clearing price calculated from levelized fixed costs is optimally matched for natural gas, which can be built in three years. Moreover, current market

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[11] Unlike in Mexico, there is no federal-level renewable energy procurement mandate in the United States. Although renewable mandates come from the state level in the U.S., these lessons in state U.S. policy can be applied to Mexico's federal policy.

designs do not embrace new technologies and can cause economic inefficiencies. Price floor requirements, dispatchability requirements, and the failure to include demand-side resources in projected demand forecasts result in economic inefficiencies and misalignment of policy mandates and wholesale market design.

Price floor requirements in auctions can result in unintended consequences of failing to properly account for generation reserves. Renewables (e.g., wind and solar) are subject to buyer-side mitigation rules, which are intended to prevent resources from entering the market that will artificially suppress prices (Morrison, 2016). Specifically, resources must meet a minimum offer price rule (MOPR), and if a resource cannot clear the MOPR then it is prevented from entering the auction. Renewable resources, which are often subsidized, can fail to clear the market despite the value they bring to the grid. Several inadvertent consequences of the MOPR—and therefore renewables failing to clear the capacity auction—result. First, excluded resources are not incorporated into future capacity projections, thereby resulting in consumers paying for additional, unnecessary capacity additions. Second, MOPRs result in costlier demand response programs, causing demand response providers to choose between wholesale or retail marketplaces, and sometimes may result in duplicative spending (Glazer et. al., 2017).

Markets seeking to address these MOPR challenges have initiated technology specific exemptions to MOPR or a secondary auction mechanism. Demand-side resources are exempt from MOPR in NYISO, which has been approved by FERC (FERC, 2017). NE-ISO exempts a small amount of state-subsidized renewables from MOPR, and recently proposed its dual-auction, which creates a “cash for clunkers” market for retiring resources. The first step in the dual auction would be a primary auction with current MOPR and administratively set demand projections. Retiring resources that meet bid requirements receive a capacity supply obligation. Then in the second “substitution auction,” the retiring resources with capacity supply obligations can transfer their capacity supply obligations to new resources that did not clear the primary auction. The second auction does not include a MOPR, and the transfer price would be the clearing price of the second auction. In the case that there are no retirements, subsidized resources that did not clear the first auction would be able to participate the following year (van Welie, 2017). This technology-neutral proposed solution aims to slowly incorporate subsidized resources into the market over time and more accurately reflect future capacity needs.

Capacity market dispatchabilty requirements serve as a barrier for renewable energy technologies to participate, resulting in costly over-procurement. PJM requires that generation resources must be dispatchable all hours of the day, year round. This requirement inheritably discriminates intermittent wind and solar, which are strongest at night and day, respectively, in some parts of the country. Both resources also experience seasonal variations, with some times of the year windier or sunnier than others. Demand-side resources must also be able to reduce the need to generate at all times (Glazer et. al., 2017).

By imposing these requirements, renewables are not included in forward projections of capacity. Therefore, more generation will be procured than needed, resulting in consumers paying twice for future reliability. Given that resources are paid if they run or not, this creates real economic inefficiencies in the marketplace (Gimon et. al., 2013). Moreover, such capacity market dispatch requirements reflect a misalignment between policy goals and market structures. On a federal level, wind and solar-generated energy are subsidized by the production tax credit and the investment tax credit, respectively. Many states require specific percentages of generation needs come from technologies such as wind and solar, yet the dispatchability requirements prevent them from being counted as future capacity (Glazer, et. al., 2017).

Another challenge in accurately predicting future capacity needs is the exclusion of demand-side resources in projected demand (sometimes referred to as variable resources curve). While it should be noted that demand response and energy efficiency are eligible to bid into the capacity market and are compensated at the full locational marginal price of generation, load forecasts do not include demand-side resources. Therefore, more generation sources may be called for than truly required (Clements, 2016).

Thought leaders and policy makers have considered the barriers that capacity markets pose in the evolution of the grid to incorporate new technologies, and suggested several solutions including eliminating capacity markets entirely, modifying time horizons, or establishing new “capabilities markets.” Energy only markets, such as ERCOT, are without formal capacity markets, having established supplementary mechanisms such as reserve shortage pricing mechanism (Hogan, 2017). Theoretically, energy only markets should be as efficient in running a dependable grid, because when the system is stressed, new resources capitalize on opportunities to provide flexibility and reliability. On the other side of the coin, policy makers are concerned that when electricity prices drop in the coming years, new load serving entities will not enter the less-profitable market without the guaranteed payment provided by capacity markets (Bade, 2017). It is also theorized that capacity markets draw revenues away from and dilute the profitability of energy markets. Some industry leaders recommend that eastern RTOs (e.g., PJM) restore capacity markets to residual, supplementary markets instead of mandatory markets (Glazer et. al., 2017). In surveys with U.S. energy industry sector leaders, almost half of the participants (41%) advised European Union officials to not implement capacity markets. Other concerns voiced in the survey included incongruity in capacity auction time frames, economically inefficient procurement of power (excess generation), and higher overall consumer costs (Pradyumna et. al., 2016).

Appropriate time frames for forward capacity markets have also been debated by U.S. industry leaders, which may be of relevance to Mexican policy makers. CENACE’s capacity market has a one-year ahead auction at the time of the present research. Longer-term investment signals from a 3-year, 5 or 10-year capacity market could send investment signals (and provide lead time for appropriate debt financing) that encourage the production of capital-intensive resources, such as wind-generated energy and associated transmission infrastructure. While a longer lead time in capacity markets may allow for the construction of larger projects, it poses a barrier to technologies with shorter lead time (e.g., demand response, energy efficiency) that provide flexibility to the grid. Moreover, customers are aggregated into programs such as demand response, and are susceptible to exiting the program (FERC, 2013). Demand-side technologies, such as demand response and energy efficiency, perform well under shorter time horizons. Three-year lead times of U.S. RTOs are optimally suited for the construction of natural gas, which can be built in that timeframe. Such time frame has been published in the market bases (Bases del Mercado), as a lesson from U.S. markets into Mexico, but yet to be implemented (CENACE Bases del Mercado Eléctrico, 2015).

Entirely new market structures have been proposed as a replacement for current-day capacity markets. “Capabilities markets” have been suggested by thought leaders and system operators as means to encourage resource adequacy and flexibility, the latter of which is lacking in current capacity market constructs (Gimon et. al., 2013). Capabilities markets consider a step-wise, incremental approach to demand after renewable energy has been deployed and included in demand projections. The design of capabilities markets also incorporates demand-side technologies, assessing projected net demand for a more accurate picture of future needed resources (RAP, 2015). Issues with capacity markets, and the best manner to address them (i.e., a complete overhaul or incremental changes) are currently points of discussion with policy leaders at the FERC regulatory summit, the outcomes of which may be of interest to Mexican thought leaders as they design a competitive, reliable energy market that aligns with policy goals (Bade, 2017b).

### *3.3.2 Current Challenges with Ancillary Markets and Incorporation of New Technologies to the Grid*

Renewable energy technologies such as wind and solar have variable energy output, that can fluctuate seasonally or based on time of day. Given increased penetration of renewables, an adaptable and flexible grid provided by ancillary markets, is more important than ever. Ancillary markets provide a broad set of services such as regulation reserves, spinning reserves and non-spinning reserves that enable system reliability. Regulation reserves match supply and demand during fluctuations throughout the day, which can be achieved through fast-ramping generation (e.g., natural gas) or other technologies like energy storage. In the event of a grid outage, spinning reserves provide power from generators that are online but not at full capacity, or by fast-ramping demand response technologies. Similarly, non-spinning reserves are generation units that are not currently online, but can quickly ramp up to provide power for the grid. In both spinning and non-spinning reserves, time values (e.g., 10 minute) indicate that amount of time to synchronize onto the grid. Generally, prices for regulation reserves are highest in the ancillary market. Ancillary service markets have grown substantially in terms of market size, in both revenue and capacity from the period of 2009 to 2014 (Zhou et. al., 2016).

Each ancillary market has distinct technical requirements and considerations that provide lessons for Mexico's Energy Reform. Due to reforms in compensation for frequency regulation, energy storage is highly subscribed in the PJM frequency regulation market with vendors rewarded on a pay for performance basis (PJM, 2017). However, other RTOs have been slow to incorporate new energy storage technologies in the frequency regulation market. For example, MISO's frequency regulation protocols were designed for flywheel batteries, forcing lithium ion batteries to degrade quickly (FERC, 2017b). Demand response, a tool to balance fluctuations in supply and demand, has witnessed varying levels of market participation due to minimum size requirements. In the PJM market, resources as small as 100 kW can participate in demand response, while MISO requires facilities to meet a 5 MW requirement to participate, creating a barrier to participation (Glazer, et. al., 2017).

RTOs are not only trending toward smaller, more flexible sources, in size requirements, but also considering shorter ramp-up times for reserves. While most RTOs have time values akin to 30 minutes and 10 minutes for reserves, ERCOT, has contingency reserves available for periods of seconds (Glazer et. al., 2017). In addition to modifying ramp-up times, new flexibility products and requirements are increasingly common, recently with RTOs such as MISO and CAISO created non-bid market products that aim to ensure short-term ramping and flexibility requirements. In MISO territory, its "ramp capability product" optimizes real-time and day ahead bids to cover short-term inadequacy through a non-bid product (FERC, 2014). Likewise, CAISO has established a flexible ramping product in conjunction with flexibility requirements to ensure the grid can respond considering increased penetration of renewables (FERC, 2016d).

As more variable renewable energy generation penetrates the grid, ancillary service markets must increase flexibility: providing appropriate technical and size requirements, encouraging smaller, and faster ramping reserves, and consider new ancillary services that promote grid resiliency. For the Mexican case, the reform predicts to launch auction markets for ancillary services in the second half of 2017, according to the published market bases (CENACE Bases del Mercado Eléctrico, 2015).

### *3.4 CAISO Current Trends and Issues*

Due to policies such as a 50% renewable energy mandate by 2030, California leads the nation in installed capacity of renewable energy, with over 18,000 MW of solar, and upwards of 5,600 MW of wind (CA Senate, 2015; GTM, 2017; AWEA, 2017). Moreover, the state is the first in the U.S. to require an energy storage target, demonstrating leadership in the incorporation and procurement of grid-advancing technologies (CPUC, 2013). With evolving directives from the state legislature or the California Public Utilities Commission, CAISO must quickly adapt market mechanisms to align with policy mandates and plan for a changing grid. California's success in procuring renewable energy—a shared goal with Mexico—provide lessons for Mexico's leaders as they work to ensure wholesale market mechanisms and policy mandates to ensure a reliable, competitive electric grid that evolves with a changing resource mix.

CAISO was founded in 1998 when the state underwent electricity sector restructuring. CAISO serves to match supply and demand of energy on the grid, and manages 26,000 miles (41,842.94 kilometers) of transmission in the state -while CFE subsidiary CFE transmission manages around 32,000 miles at national level. Every five minutes, CAISO forecasts demand, enabling almost 30,000 market transactions on any given day. A neutral party, the RTO is dedicated to "ensuring fair and transparent access to the transmission network and market transactions" (CAISO, 2017a). As of February 2017, CAISO helped manage transactions for most of California's 1,170 power plants, with over 150 generation and transmission companies in the CAISO market. (EIA, 2017b and

CAISO, 2017b). CAISO has continued to expand regional market partnerships with its Energy Imbalance Market (EIM). Created in 2014 in partnership with Pacificorp, EIM was established with the objective of increasing grid reliability and cost-efficiency, allowing other market operators to buy and sell energy in real time (CAISO, 2017c). NV Energy joined EIM in 2015 followed by Puget Sound Energy and Arizona Public Service in 2016, seeking a more diverse pool of resources to meet reliability needs (FERC, 2016c).

Oversight from the ISO Department of Market Monitoring mitigates risk, ensures price transparency, and appropriate operating conduct within the market (CAISO, 2017d). The annual ISO budget, as well as policies, market designs, and grid planning are approved by a five-member Board of Governors (CAISO, 2017e ). As of March 2017, the Market Monitor is under the oversight of the Board of Governors, in efforts to ensure that CAISO executives do not unduly influence the independence of the market monitor.[12] CAISO updates its transmission planning process on a yearly basis, modeling numerous scenarios that incorporate new policies and technologies, interconnection queues, and plant closures. Long term grid planning occurs every 15 months, projecting future supply and demand needed to ensure reliability and meet policy goals (CAISO, 2017f).

The CAISO market includes several market mechanisms to ensure reliability. The day-ahead market uses a full network model that assesses current generation and transmission assets to find least-cost energy allocations. Three phases in the bidding process ensure adequate and efficient bids to meet the next-day's energy needs. The real time, or spot market, ensures that marginal fluctuations in demand are met throughout the day. Convergence bidding, or virtual bidding, encourages alignment between day-ahead and real time markets by requiring day-ahead buyers and sellers to participate in the real-time market. Convergence bidding also disincentivizes market participants from waiting until the real time market to participate—a participant behavior that makes it challenging to plan ahead. An ancillary services market provides services to maintain grid stability, including regulation up, regulation down, spinning reserve, and non-spinning

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[12] In 2016, FERC recommended similar changes after Southwest Power Pool executives were found to have "inappropriate" involvement with its internal market monitoring unit.

reserve. Congestion Revenue Rights (CRR), another market product, are calculated from the marginal cost of congestion, traded via allocation, auction, and bi-lateral trades with the intent of counteracting grid obstruction costs in the day ahead market (CAISO, 2017g). No formal capacity market exists in CAISO, but rather supplementary resource requirements to ensure future resource adequacy.

### *3.4.1 Current Trends in Wholesale Pricing and Installed Capacity in California's Market*

With California progressing toward its renewable energy goals, current trends in the CAISO wholesale marketplace could provide insight for policymakers at CENACE. In 2016, the CAISO marketplace remained competitive with wholesale costs reflective of "efficient and competitive conditions." Wholesale costs fell by 9% to about $34/MWh, due to lower natural gas prices, increased solar resources, and better hydroelectric conditions. More than 3,300 MW of new generation were connected to CAISO last year, including 1,900 MW of solar and 50 MW of storage. Not including hydropower, renewable generation comprised 20% of total generation in CAISO for 2016. Retirements for 2016 included more than 1,200 MW of aging natural gas plants (CAISO, 2016). More recently, CAISO has experienced periods with record-breaking proportions of capacity from solar-powered generation: Almost 40% of CAISO's net grid power from 11 am to 2 pm on March 11, 2017 came from solar energy.

While the record-breaking percentage of solar-powered energy in CAISO territory is a notable milestone that indicates the state is en route to achieve renewable energy goals, this trend has sparked concerns regarding market stability and grid reliability (EIA, 2017c). First, the increase in solar coupled with abundant hydro resources has resulted in more instances of below zero wholesale pricing in March 2017. Low and sometimes-negative wholesale energy prices create unprofitable conditions for traditional load serving entities like natural gas, which the grid still needs to balance the intermittency of renewables. Second, grid operators must plan for various grid scenarios, including oversupply of renewables and their intermittency. During periods of oversupply from bountiful hydro and solar, CAISO will continue to curtail renewables (EIA, 2017c), as CAISO did with increasing frequency in the latter half of 2016 to prevent surplus power and negative prices (CAISO, 2017h). Curtailment generally happens in the real-time market place, since the day-ahead markets are already stabilized. Because it is more challenging and expensive for natural gas resources to shut down plants, renewables are the resources curtailed during times of excess, since they are subsidized and drive down power prices until other plants (e.g., natural gas) are forced to turn off.

Although declining wholesale prices in the CAISO marketplace indicate a healthy and competitive market, a few recent trends should be noted. First, low wholesale costs do not transfer to the California consumer (also referred to as a “rate payer”). Despite low and sometimes negative wholesale energy prices, California’s retail electricity prices are one of the highest among all 50 states in the nation at 15.3 cents per kWh (EIA, 2017d). The low wholesale prices, caused by an influx of low marginal cost renewable energy supported by California’s renewable energy mandate, simply cannot support the costs of generation and transmission, resulting in utilities passing costs on to the consumer. However, some studies have shown that U.S. consumers support renewable energy and have a willingness to pay of 71 cents per month for a 1% increase in renewable energy (Murikami, et. al 2015).

Another notable trend in CAISO territory are the growing costs of the procurement of ancillary services that provide grid stability and resiliency. These capabilities have become particularly important in light of increasing proportions of intermittent renewable energy generation sources, such as wind and solar. From 2015 to 2016, the costs for acquiring ancillary services rose from $62 million to $119 million (CAISO, 2016). However, in contrast to comparable ancillary markets such as PJM, ancillary costs have been historically lower in CAISO. For instance in 2015, regulation costs were 2-3 cents per MWh in PJM, while it cost 1-2 cents per MWh in CAISO. Total ancillary costs in 2015 were much higher for PJM, at $2 per MWh in comparison to CAISO’s total of 3 cents per MWh. One explanation for CAISO’s lower costs is due to the co-optimization of ancillary and energy services, while PJM has distinct categories of ancillary services (e.g., RegD) (Xu, et. al.

2016). Given changing load profiles, products that provide flexibility and fast ramping could continue to drive profits in wholesale markets.

As California's grid undergoes dramatic changes in its resource mix and load patterns, CAISO must continually adapt, either with new market products, such as flexible ramping or modifying marketplace constructs to allow for participation of new grid-stabilizing technologies such as energy storage. Assessing best strategies for interconnecting to new, resource-rich territories or how and if supporting load serving entities that struggle to stay online during uneconomic periods is within the role of CAISO are also important queries during the evolution of California's grid to incorporate new technologies. Several technology-specific updates are underway at CAISO, with recent updates to the distributed energy resource and energy storage initiative. More accurate assessments of demand response potential for aggregated retail customers is expected to be achieved through improved methodologies, which will now use four day retroactive analysis timelines instead of 45 days (CAISO, 2016i).

Collaboration with CPUC to revamp station power protocols for battery storage is currently ongoing in order to distinguish between station power and wholesale charging energy. "Wholesale charging energy" will be resold in the wholesale market, while "station power" is used to serve a load-serving entity that is already under a retail tariff. The distinction is important to ensure that storage resources are not charged at wholesale level, then again at the retail level. Potential solutions include separate metering for wholesale charging energy and station power (CPUC & CAISO, 2016). Changes to these technology-oriented protocols will first be approved by the Energy Imbalance Market before going to the CAISO Board of Governors for approval in late July 2017.

### ***3.4.2 CAISO Ancillary Market and Resource Adequacy Framework Trends***

CAISO has traditionally been forward thinking: It was one of the first RTOs to enable distributed energy resources to be aggregated and sold in the ancillary marketplace (CAISO, 2016b). CAISO recognizes the shifting dynamics of the grid and the need to continually assess how current mechanisms enable grid stability. In November 2016, CAISO established a new ancillary market mechanism to address the need for more flexible ramping capacity in light of more intermittent renewables on the system. More specifically, CAISO replaced its previous flexible ramping constraint, created in 2011, with a new flexible ramping product that offers several advantages (CAISO, 2017l). First, the new product allows for bi-directional flexibility, whereas the old mechanism only obtained upward flexibility. Second, the new flexible ramping product has a shorter time frame built in, with 5-minute and 15-minute markets. Next, the quantity and price of the product is based on a sloped demand curve, allowing for variability as needed. This pricing scheme is more flexible than the previous set price and quantity at $60/MWh. Finally, the flexible ramping product rewards units that provide flexibility and penalize those creating the need for flexibility (CAISO, 2017k). Capacity factors are updated every month to ensure maximum flexibility in ramping and other ancillary mechanisms (FERC, 2016d).

Unlike PJM, CAISO does not have a formal forward capacity market to ensure future grid reliability. However since 2011, CAISO has mandated resource adequacy requirements on load serving entities (Bhagwat et al., 2016 ). FERC required that CAISO create structures that would procure capacity at reasonable costs, allow suppliers to recover fixed costs, and allow for long-term investments in maintenance of load-generating facilities. CAISO's capacity procurement tariff expired in in 2016, with a new mechanism implemented on November 1st, 2016. The new mechanism is created with the objective of fostering competition between various resources, in comparison to CAISO's previous flat administrative rate. Load serving entities bid into a competitive solicitation process (CSP), which serves as CAISO's first step in procuring future capacity. In order to create an accurate picture of future demand requirements, bids occur on three timelines: intra-monthly, monthly, and yearly. Tariffs now have a soft offer cap at $6.31/kW-month, which was determined by adding a 20% premium to forward-projecting fixed costs for a 550 MW combined cycle plant (CAISO, 2016).

The applied flexibility and continuous updating of regulations and incentives for market participants, could be applied in Mexico's new deregulation scheme, at least in the creation of mandated long-term capacity and ancillary service submarkets, at reasonable costs that also fosters competition.

### *3.4.3 CAISO Economically Efficiency in the Allocation of Transmission Costs*

As CAISO expands its grid to incorporate new resource-dense areas outside of its territory, a one-size-fits-all approach to interconnection may not be appropriate, which was illustrated with the recent proposal to connect to Valley Electric Association (VEA), located adjacent to CAISO region in the state of Nevada. In efforts to reach California's renewable energy mandate, CAISO plans to interconnect its grid with VEA to access the region's abundant solar-generated energy. However, VEA—a small transmission operator with peak load of 130 MW and no requirement to procure renewable energy—was faced with interconnection agreements of 150 MW, costing VEA up to $9 million in upgrade costs.

Since VEA did not comparatively benefit from the interconnection, the costs resulted in an unfair burden for the transmission operator. CAISO's proposal, approved in the spring of 2017, would avoid undue financial burdens on smaller transmission operators that interconnect outside CAISO service territory. CAISO will decide on a case-by-case if a smaller transmission operator in renewable rich areas will be able to incorporate costs into high-voltage transmission revenue requirements (Mullen, 2017). This is important for the Baja California Mexican region that is part of the Western Electricity Coordination Council: WECC, that coordinates and promotes reliability and interconnections in Western Canada, the U.S., and Northwestern Mexico.

### *3.4.4 CAISO Further Expands Regional Collaboration*

CAISO's strategic vision to achieve a sustainable energy future rests on three pillars, the third of which is "expanding collaboration to unlock regional benefits" (CAISO, 2015). [13] The Energy Imbalance Market (EIM), established in 2014, was created to increase grid reliability by allowing additional market operators to buy and sell energy. Pacificorp was the first to join EIM in 2014, followed by NV Energy in 2015, then Puget Sound and Arizona Public Service in 2016 (CAISO, 2017c). In March 2017, the Bonneville Power Administration and CAISO cemented an agreement for Bonneville to join the EIM, while still maintaining reliability in each jurisdiction. The Coordinated Transmission Agreement is postulated to be a model for additional collaborative market efforts in the region.

Highlights in the agreement include requirements and parameters for sharing transmission data; specifically CAISO must share market dispatch data and load forecasts in the EIM region, while Bonneville must share flows and limits on facilities. Both parties must meet quarterly to resolve operational issues, while a broader stakeholder EIM working group has been established to discuss challenges and opportunities in data sharing and transmission operations (DOE, 2017b). Given DC connections between Mexico and California, CAISO's continued EIM expansion could provide future opportunities for both parties as they seek to increase renewable energy in an economically efficient manner.

Moreover, an example of support during uneconomic periods, is presented as a best case as follows. As wholesale market dynamics evolve, some load serving entities—particularly natural gas—struggle to remain profitable during periods of low or negative wholesale energy prices. The gas-fired generation facility, La Paloma, filed for bankruptcy in 2016 because the facility could not generate enough revenue to stay online (Rucinski & Orlofsky, 2016). La Paloma requested the ability to shut down operations for several months, because it believed it could not economically operate its facilities. CAISO and FERC denied La Paloma's requests, arguing that they were not based on physical reasons—the usual use of CAISO's outage management system.

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[13] CAISO's other two strategies to achieve a sustainable energy future are leading the transition to a low carbon grid and reliably managing the grid during energy industry transformation.

In response to La Paloma's bankruptcy that occurred due to wholesale market conditions, CAISO is now considering ways to support struggling plants during uneconomic periods. CAISO's Temporary Suspension of Resource Operations, initiated in May 2017, will assess methods to support struggling generators without forcing them to retire. Depending on CAISO's research and stakeholder proceedings, the RTO may allow plants to temporarily[14] cease operations for economic reasons. CAISO Board of Governors should review a final proposal for Temporary Suspension of Resource Operations in November 2017 (CAISO, 2017j).

As CAISO's resource mix and load profile continues to evolve, the quires and stakeholder-driven processes to adapt the wholesale market provide lessons for CENACE. Remuneration of capabilities that will stabilize the grid, such as flexible ramping or establishing proper protocol and methodologies for incorporating new technologies such as energy storage may be issues that CENACE will need to address in the coming years as it integrates more renewable energy on the grid.

## 4. TRENDS IN TECHNOLOGIES: A REVIEW FOR FUTURE ANALYSIS

The following section provides a literature review to assess the technological development of renewable energy technologies for electricity markets. To simplify the review, technological developments are classified into generation, transmission, and final consumption. This section assesses aspects such as installed capacity and costs for key technologies in each of the subsection (generation, transmission and final consumption) that enable a more reliable and secure grid. Highlighted U.S. trends and policy drivers for each technology are also summarized. Finally, Figure 1 provides a graphical explanation on the interplay between technologies for generation, transmission and final consumption of renewables.

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[14] Outage timelines, among other details of the program are still to be determined.

### *4.1 General Overview*

In 2016, renewable energy sources' contribution to the energy mix experienced its largest growth ever especially in the global electricity sector (IRENA, 2017d). Electricity generation from renewables increased by 6% (IEA, 2017). Generation capacity increased from 1,845 GW to 2,006 GW between 2015 and 2016, an addition of 161 GW (IRENA, 2017c). Wind and solar photovoltaics (PV) were the technologies with the greatest contribution, accounting for 51 GW and 71 GW, respectively (IRENA, 2017c).

Renewables contribute greatly to the electricity generation sector worldwide. In 2016, an estimated of 24% of all electricity generated was produced with renewable sources. This accounts for almost 6,000 Terawatt-hours (TWh) (IEA, 2017). Renewable electricity generation has sustained growth; according to the International Energy Agency (IEA) the growth rate of renewable electricity generation is 3.6% annually. Trends regarding growth rates indicate an accelerated growth. For renewable power capacity, growth rates were around 4% in the early 2000's. By 2015, growth rates have increased almost to 10% (IRENA, 2017d).

As for installed generating capacity per technology, hydropower is still the dominant technology (International Energy Agency, 2016a). However, it does not correspond to what has been denominated "modern renewables," and additional hydropower generating capacity has been decreasing (International Energy Agency, 2016b). Modern renewables, such as solar PV and wind-generated energy have experienced relevant growth in 2016. Solar PV capacity increased to around 70-75 GW. Onshore wind capacity's growth was 15% less compared to 2015, with 50 GW of new installed capacity compared to 70 GW installed in 2015. As for offshore wind, new installed capacity accounted for 2 GW, compared to 3 GW of additional capacity installed in 2015 (IEA, 2017; International Energy Agency, 2016b; IRENA, 2017c).

### *4.2 Generation*

#### *Solar PV*

Solar power capacity grew from 39 GW in 2010 to 295 GW in 2016. Between 2015 and 2016 solar power capacity reached a new record with the addition of approximately 70 GW. It is the first time that solar additions surpass wind additions (IEA, 2017). This represents an approximate growth rate of 40 % (IRENA, 2016b, 2016d). Also in 2016, solar PV represented about 15% of total renewable generating capacity.

Regarding the cost of electricity produced from solar power, the capacity-weighted average levelized cost of electricity (LCOE[15]) fell around 60% (IRENA, 2016e). The LCOE for newly installed utility-scale solar PV in 2015 was USD 0.13/KWh, which may become competitive with coal and gas in coming years, at USD 0.05-0.10/KWh (IRENA, 2016b). These continued cost reductions make solar PV even more competitive with fossil fuel technology.

The federal Investment Tax Credit, which provides a 30% tax subsidy, has been credited with the growth of U.S. PV installations: since the establishment of the ITC, installations have increased by a CAGR of 76%. State-level renewable energy requirements, widely known as Renewable Portfolio Standards, have also been accredited with the growth of solar-powered energy. States that have specific solar generation requirements, such as North Carolina, have some of the highest rates of installed solar capacity in the U.S. (Perea, 2017).

While states including California have witnessed vast growth in solar installations, other markets are hindered due to poorly designed or nonexistent third-party sales, net metering, and community solar. Although 60% of U.S. rooftop PV is installed through third party sales, some U.S. states still do not allow third party sales of electricity, either through power purchase agreements or leasing arrangements (Hausman, 2015 and NREL, 2010). Net metering, or the ability to sell back excess generation at full retail rate to the utility, provides the consumer with a guaranteed return on investment (EEI, 2013). Net metering policies continue to be in flux in the United States. Nevada and Arizona had contentious battles regarding fixed charges and rate design, while in 2015, California and

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[15] The levelized cost of energy (LCOE) refers to the net present value of the unit-cost of electricity over the lifetime of a generating asset.

New Hampshire instituted successor tariffs, and Hawaii ended its net metering program entirely (NC Clean Energy Technology Center, 2017). Aggregate, virtual, and community net metering[16]—essential for the growth of community solar—vary by state (Durkay, 2016).

### *Wind*

By the end of 2016, the amount of power generating capacity derived from renewables was over 2,000 GW. From this, 23% was attributable to wind technologies (IRENA, 2017c). Global installed wind-generating capacity increased from 7.5 GW in 1997 to more than 465 GW in 2016 for both onshore and offshore wind (IRENA, 2017c; IRENA & IEA-ETSAP, 2016). One of the most promising technologies is offshore wind production, and by the end of 2014 installed capacity worldwide was 8.8 GW (GWEC (Global Wind Energy Council), 2015).

The average LCOE for both onshore and offshore wind continues to decrease. In 2010, the average LCOE for onshore wind was 0.071 USD/kWh whilst in 2016 it decreased to 0.056 USD/kWh. As for offshore wind, LCOE in 2010 corresponded to .133 USD/kWh and it decreased to 0.123 USD/kWh in 2016. Between these technologies, onshore wind is still the most competitive against fossil fuels, which costs approximately 0.045 USD/kWh (IRENA, 2017b).

On a federal level, wind development has been stimulated by the $0.024/kwh subsidy known as the Production Tax Credit. Accelerated depreciation, which allows owners to depreciate capital costs, is another federal policy that has contributed to the growth of the industry (DOE, 2015). The U.S. currently has 75 GW of installed wind capacity, with Texas leading the nation at 18 GW of installed wind capacity (AWEA, 2016). Iowa generates about 35% of its electricity from wind, the highest percentage of any state

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[16] Aggregate net metering allows adjacent meters or several meters on the same property to combine load, while virtual net metering allows credits to be distributed among non-adjacent meters. Community net metering spreads benefits from a single generating system to multiple meters.

in the nation (EIA, 2017f). In 2016, Rhode Island was the first state in the U.S. to install an offshore wind pilot program, a 5 turbine project totaling 30 MW (Deepwater Wind, 2017). Offshore wind remains a challenge in the U.S. due to a lack of local supply chain, complicated logistics, and antiquated maritime laws. With respect to onshore wind, the main barriers to deployment include transmission (e.g., regulatory pushback on merchant developers), siting, and permitting. Setback limits, or the required distance from a structure or property line, have been modified by some state legislatures to deter wind development (AJP, 2016).

### ***Distributed Generation***

Currently, over 1 billion people lack electricity access and another billion have unreliable supply (IRENA, 2017d). Distributed generation or off-grid systems allow access to electricity for distant communities. Despite the population still lacking electricity access, off-grid systems have grown significantly in recent years.

Off-grid systems can be classified into two types depending on how they produce electricity: conventional systems and renewable off-grid systems. Today, renewable off-grid systems are the most economical option for off-grid electrification (IRENA, 2017d). Conventional systems use fuel and gas generators to produce electricity. Currently, installed capacity of diesel generators is 400 GW. However, from 50 to 250 GW of the total installed diesel capacity could be hybridized (Kempener et al., 2015). Renewable off-grid systems use renewable sources to produce electricity. Almost 26 million households benefit from off-grid renewable systems worldwide. Approximately 20 million households have solar home systems, another 5 million households use renewable-based microgrids, and finally 0.8 households use small wind turbines (Kempener et al., 2015).

Distributed generation also includes technologies such as small wind, fuel cells, and energy storage systems. Small-scale solar PV is the most common distributed technology in the U.S., and net capacity from the residential, industrial, and commercial PV sector was over 13 GW as of February 2017 (EIA, 2017e). Property Assessed Clean Energy (PACE), which finances residential and commercial energy efficiency and renewable installations through a property lien, has financed $1.37 billion in residential renewable energy installations from 2010 to 2016 (PACE, 2017). In addition to access to end-user financing, distributed generation requirements, streamlined permitting processes, and clearly defined interconnection procedures are all policies needed for growth of distributed energy technologies (CNEE, 2017).

## *4.3 Transmission*

### *Smart Grids*

Most of the technological development in grid improvement aims at achieving a balance between demand and supply, the so-called balancing of the market. Smart grid technology—or digital technology that enables two-way communication between a utility, its T&D system, and the end-user—includes technologies such as advanced metering infrastructure, voltage regulation equipment, power flow controllers, and equipment health sensors (DOE, 2015) . While early smart grid solutions were targeted toward distribution, there has been increasing incorporation of smart technologies in switches, substations and transformers, allowing for two-way flow and increased transmission flexibility. The increase in electricity generation from variable renewable energies (VRE) poses several challenges for the grid, including the need to rapidly synchronize supply and demand. This has become more of an issue in grid management, since the peaks of VRE are more pronounced. Therefore, grids need to become smarter and more flexible (IRENA, 2016c).

According to the IEA, the deployment of new smart meters slowed in 2015. Consequently smart grid investment faced a marginal increase (BNEF (Bloomberg New Energy Finance), 2016). Advanced metering infrastructure (AMI) developments intend to capitalize on “big data” (International Energy Agency, 2016b). This has increased the relevance of joint information technology and operation technology (IT/OT) solutions.

IT/OT solutions market grew approximately 65% per year and it is expected to grow six times by 2023 (Navigant, 2014). IT/OT solutions will allow utilities to have control over all connected devices and therefore have a “real time” management of supply and demand (IRENA, 2016c). Investments in smart grid technology, which incorporates IT/OT systems, increased by a 12% in 2015. Moreover, new business models such as virtual power plants (VPP’s) are expanding (International Energy Agency, 2016b). Over the next twenty years, experts predict that average yearly investments of $17 to $24 billion will be invested in smart grid upgrades (EPRI, 2011 and Chupka, et. al., 2008).

Smart grid deployment is mostly driven by state, not federal, policy. California, Massachusetts, and New York are rated highest in the U.S. for their smart grid deployments. Customer engagement and grid operations remain some of the biggest drivers of smart grid deployments. Specifically, data access/sharing, dynamic rate structures, advanced meter deployment, T&D sensors, and advanced GIS are common among states that lead in deployment of smart grid technology (Gridwise, 2016). Among largest policy barriers to increased deployment of smart grid technologies is cost recovery and allocation (BCC Research, 2013). Issues of privacy and access to customer data is an ongoing issue with the deployment of smart grid technologies in the U.S. (CNEE 2017).

### ***Energy Storage***

Electricity storage plays a key role in the integration of VRE to the grid. The extent to which the power generated during the peak production hours can be stored is crucial for full exploitation of renewable energies. Storage is also crucial for increasing operating system flexibility (IRENA, 2017d).

The most developed storage technology is pumped hydropower. This technology currently has over 145 GW in operation, accounting for the majority of energy storage worldwide. According to IRENA, pumped storage hydropower will increase from 150 GW to 352 GW by 2030.

Battery storage is the subsector with the most significant growth. In 2014, 400 additional MW were added, doubling 2013 installations (International Energy Agency, 2016b). Battery storage is expected to increase from 0.8 GW to 250 GW by 2030 (IRENA, 2015). Currently, lithium-ion batteries dominate the electricity storage market—a significant shift from decades prior when sodium Sulphur batteries were the dominant technology (IRENA, 2017d). The market for this type of batteries grew by 50% per year aided by the commercialization of the Tesla Powerwall, a 10 kWh lithium-ion battery. (International Energy Agency, 2016b).

Energy storage technologies are becoming increasingly cost-efficient. In 2005, costs for lithium-ion batteries were around $1,500 / kWh; in 2016 costs were around $350/ kWh (New York Battery and Energy Storage Technology Consortium, 2016). Between 2015 and 2016, prices for grid-scale batteries fell 12% for Peaker plant replacement uses and 24% for transmission use-cases (Lazard, 2016). Finally, it is expected that battery prices will continue to fall, forecast suggest a 50% decline by 2019 (Wilkinson, 2015).

In the U.S. over 450 non-hydro storage projects are deployed, comprising 2 GW of capacity (DOE, 2017). Storage continues to experience rapid growth in the U.S.: installations increased 100% from 2015 to 2016 (GTM, 2017). While participation in ancillary markets has increased dramatically, other wholesale market applications have less participation due to lack of clarity in particular remuneration scenarios, as seen with CAISO's current proceeding to distinguish between station power and wholesale charging energy.

Successful policies to promote the adoption of energy storage include energy storage mandates and rebate programs, both of which have been implemented in the state of California (Itron, 2017). Studying energy storage in the context of the local grid is vital to understanding costs and benefits of investing in the nascent technology. Massachusetts recently issued an extensive study on the costs and benefits to incorporating energy storage into its grid, finding that the state could save $800 million by 2025 through 600 MW of installed storage (MDER, 2016). With applications of energy storage ranging from generation to transmission and distribution, defining value streams is also important for policymakers (RMI, 2015). Oregon created clear remuneration guidelines for energy storage benefits, including improved reliability and reduction in peak demand (Oregon State Legislature, 2015). Unclear interconnection, siting, and permitting procedures for storage have hindered local development in the U.S. (IREC, 2017).

## *4.4 End Consumption*

### *Electric Vehicles*

Electric vehicles today can be classified into two main technologies, battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). BEVs use batteries only to store energy; therefore, they must be plugged-in in order to recharge (IRENA, 2017a). Additionally, PHVE use batteries as well as liquid-fuel storage. Moreover, liquid fuel can be refueled, allowing for greater ranges of travel (IRENA, 2017a). Worldwide the number of electric vehicles reached one million in 2015, and surpassed 2 million by 2016 (IRENA, 2017a). In 2015, 477 000 electric passenger cars were sold (International Energy Agency, 2016b). Typically, BEVs have dominated sales; however, PHEVs have been gaining strength. By the beginnings of 2016 the number of PHEV's sold was almost equal to BEVs (International Energy Agency, 2016b; IRENA, 2017a).

Electric vehicles face two main challenges: costs and distance traveled per full charge. Regarding costs, recent calculations estimate USD 350/ kWh. However, EVs cost approximately USD 10,000 more that internal combustion engine vehicles. Even though the net cost of vehicles increases after use, EVs have not reached cost parity with ICE vehicles (IRENA, 2017a). Concerning the distance traveled per full charge, the maximum attainable distance for EVs is around 300 km. The average distance for ICE vehicles is 750 km (IRENA, 2017a).

Beyond electric light duty vehicles, a market exists for two-wheeled vehicles. This type of vehicles is sold mainly in Asia, with China as the principal market. Over the past decade, over 200 million units have been sold (Cherry, 2016). Only in 2015, almost 40 million vehicles were sold mainly in China and Japan (IRENA, 2017a). Besides two-wheelers, there is an emerging market for electric buses. Again, it is in China where this market is being deployed. Between 2014 and 2015, the number of electric buses grew from 29,500 to 170,000 units (International Energy Agency, 2016b).

From 2015 to 2016, the U.S. plug-in electric vehicle market grew 48% (AEE, 2017). Federal and state tax credits are accredited with increased uptake of EVs, as well as loans, grants, rebates and vouchers (CBO, 2012). Parking and high-occupancy incentives also encourage the purchase of EVs. Infrastructure and planning is also paramount to the success of EV adoption; charging stations must be strategically placed in the range of EV consumers at grocery stores or other public parking lots. Some states have requirements for all parking lots to include a specified proportion of EV charging stations and parking spots (CNEE, 2017). States such as Nevada require municipal fleets to use electric or alternative fuel vehicles, while other states have amended municipal performance contracting laws to incorporate fleet upgrades (CGA, 2013 and NGOE, 2016).

### ***Smart Buildings***

Energy consumed in buildings represents more than 30% of the total energy consumption (International Energy Agency, 2016b). Energy is consumed mainly through heating, cooling and powering appliances (IRENA, 2016c). In order to reduce energy consumption in buildings, several countries have developed building energy codes and energy efficiency policies. As a result global building energy performance has improved 1.5% (International Energy Agency, 2016b).

Global markets for smart buildings are growing. The estimated value of the market was USD 4.8 billion in 2012, however; value is expected to rise to more than USD 35 billion by 2020. Moreover, sales for smart appliances are also rising. Sales in 2015 accounted for USD 5 billion and they are expected to reach the USD 34 billion by 2020. From the energy requirements in buildings, space heating is the largest end use, accounting for 35% of energy use. However, space cooling is the sector with the highest growth rates, around 4% annually since 1990 (International Energy Agency, 2016b). Global investments in energy efficiency have been slow, with the most significant progress in countries like Germany and France, where investments in building energy efficiency average 15 to 20 million USD dollars (Robert, 2015).

In the U.S. building efficiency is worth $68.8 billion, dominating the national advanced energy sector (AEE, 2017). Per FERC Order 745, energy efficiency and demand response can participate in the market and must be compensated at the same locational marginal price as an energy generator. However, it is state level policy that drives energy efficiency, and therefore smart building technology. Policies that promote efficiency include decoupling, energy efficiency resource standards, demand response standards, building energy codes, and benchmarking (CNEE, 2017). In 2016, more states adopted Energy Savings Performance Contracting for municipal buildings, while others updated building code standards (CNEE, 2016). California's building efficiency standards, known as Title 24, requires adoption of new technologies that conserve energy, such as lighting control systems (CEC, 2015a).

## 5. CONCLUSIONS

Clearly, the state and dynamics of energy policy and regulations is a living body. For the United States and other places in the world, regulations to the energy sector, including technology changes, have evolved since the mid 1970s and continue to shift in response to technological and market changes. For the Mexican case, regulatory overhauls waited many decades until a political window of opportunity was open to pass one of the most deeply and revolutionary energy reforms, consisting of Constitutional changes, new secondary laws in nineteen key aspects and more than a hundred key directives, ruling, and decrees. Fully liberalizing Mexico's energy sector will require a continuum of regulatory changes for years to come—a process that could be informed by regulatory trends in the U.S. and elsewhere.

Beginning with the set of regulatory compacts in Mexico that seems to learn from deregulation in the U.S. and elsewhere, the present research put together how the various levels of (federal in Mexico) of regulation changes and institutions are changing Mexico's energy panorama, including electricity from fossil and clean sources of energy. In the case of the U.S., not only federal levels of regulatory change are important buy mainly state and local levels are fundamental to the change in the energy markets. As the present study was finalized, the U.S. federal administration has decided to pull out of the Paris Accord, provoking various state legislatures and executives to fortify their quest for more clean energy and climate change agendas, as has been evidenced by California, Washington, New York, Massachusetts, and other that might adhere to their own state targets. The above calls for studying not only federal, but sub-federal levels of commitment and incentives to private investors to find energy as a viable and rewarding set of investment projects.

Mexico started its energy new agenda in 2014 with the passage of all secondary energy laws. It has travelled the path with many expectations and some conflicting incentives for new markets. Transaction costs have arisen from too many regulations and directives that might clash against each other for the massiveness of their breadth but also from some strategic moves by formerly benefitted agents and firms, such as the former state monopolies PEMEX and CFE. On the U.S. side, deregulation and incentives' policies have also not been too terse in implementation but could become lessons from mature markets towards Mexico's recent regulatory changes. In the present analysis, we have addressed the dynamics of the U.S. and California policy and wholesale markets, as lessons for Mexico's recent reforms.

On the federal level, major U.S. policies that promoted uptake of renewable technologies were incentives such as the Investment Tax Credit for solar and Production Tax Credit for wind. Sub-federal policy has driven increased deployment of renewable and efficiency technology, as with California's Renewable Portfolio Standard and Building Codes, which promoted growth in renewables and energy efficiency, respectively. However, policy mandates are often not reflected in wholesale market designs that were originally designed for consistent baseload power from fossil fuel plants. Zero marginal cost renewable resources are often incompatible with this design, continually forcing policy makers to assess regulatory compacts and market structures. Current issues and trends in U.S. wholesale markets, with an emphasis on the integration of renewables into capacity and ancillary markets, highlight lessons to be considered in Mexican wholesale market design. CAISO's challenges with zero and negative wholesale prices, curtailment, and planning processes to expand the grid demonstrate the need for continued assessment as grid dynamics evolve. The processes to continually assess grid operations and incorporate stakeholder concerns could be useful to Mexican regulators. Technology-specific demand trends are also presented, as well as policies responsible for their growth and current regulatory challenges in the United States. For instance, energy storage mandates in California are responsible for the growth of battery technologies, but challenges with remuneration, interconnection, and technical standards remain.

In the above analysis renewable and clean technologies are also addressed as a framework for future work. In next research projects we plan to address best practices from other sub-markets in the United States, both from cases with deregulation and liberalization of market to private actors, as well as markets with no deregulation but where technology advances and market incentives have rendered "best cases" to learn from.

## Appendix: Technologies Description

### Generation

#### *Solar PV*

Developments in solar PV technologies are trying to find better performing materials to build solar cells. Wafer-based crystalline silicon (c-Si) cells are the dominant technology, with market shares around 93%. Their average efficiency of this technology oscillates between 21% and 23% with a theoretical limit of 29% (IRENA, 2016b). However, non-silicon technologies are beginning to gain relevance. Thin films are the non-silicon technology with the greatest development. CIGS (copper indium gallium (di)selenide) and CdTe (cadmium telluride) films represent 2.5% and 4% of market shares respectively. Furthermore, novel technologies are emerging, such as concentrating solar PV, organic PV (OPV), dye-sensitized solar cells (DSSC), advanced inorganic thin films and nanotechnology dependent solar cells. However, to date these technologies do not represent a significant part of the market. Their further development intends to decrease the cost of solar energy production and increase efficiency (IRENA, 2017d).

#### *Wind*

The power generated by a wind turbine correlates with rotor dimensions. Hub heights and rotor diameters have grown over the past decades, resulting in increasingly greater capacities. Turbines started producing an average of 0.05 MW with a rotor with a diameter of 15 meters in 1985 (EWEA, 2011). Nowadays, the largest commercially available turbine has a rotor diameter of 164 meters and produces approximately 8.0 MW of power (IRENA & IEA-ETSAP, 2016).

Wind turbines are classified into vertical-axis and horizontal axis turbines depending on the type of turbine. Vertical-axis turbines are primarily used for small generation capacities. They are characterized by a rotation axis that is vertical to the wind flow/ground (IRENA & IEA-ETSAP, 2016). Horizontal-axis turbines have the greatest commercial development. A rotating shaft parallel to the wind flow/ground characterizes them. They are sub-classified into up-wind and down-wind turbines. Down-wind rotors are the latest emerging technology and it is being developed mainly in Japan (IRENA & IEA-ETSAP, 2016). This new technology facilitates the installation of offshore wind farms since it improves the stability and safety of floating offshore wind facilities (IRENA & IEA-ETSAP, 2016).

Offshore wind is the technology with the greatest development potential. Its relevance relies on the premise that offshore wind is more intense and more stable than onshore wind thus increasing power generation. However, the cost of this type of facilities is higher (IRENA & IEA-ETSAP, 2016). Offshore wind generation can be sub-divided into fixed-bottom facilities and floating facilities. Floating facilities allow the exploitation of wind at greater distance from the coast. By 2014, offshore wind installed capacity was 14 GW (IRENA, 2017c).

Small wind turbines are also a relevant technological development. A small wind turbine is defined as a turbine capable of producing a maximum of 50 KW of power according to the International Electrochemical Commission (IEC). Their main function is the electrification of rural areas; however, these turbines are starting to be used in the urban environment as well, mainly in China (Global Data, 2015). By the end of 2013, small wind installed capacity was 755 MW. Most of the facilities were installed in China (41%) followed by the United States and the United Kingdom (30% and 15% respectively) (WWEA, 2015)

### ***Distributed Generation***

Off-grid systems are classified into conventional systems and renewable off-grid systems depending on how they produce electricity. Today, renewable off-grid systems are the most economical option for off-grid electrification (IRENA, 2017d). Off-grid renewable systems are also sub-classified into stand-alone systems and micro grids depending on the connections among systems. Stand-alone systems are characterized by not being interconnected with other off-grid systems. A micro grid consists of “an integrated energy infrastructure with loads and energy resources” (IRENA, 2016a). Usually, micro grids involve generation assets between 1 KW and 10 MW (IRENA, 2017d). Moreover, micro grids may or may not be connected to the main grid.

Most of the innovation related to distributed generation is developed in micro grid systems. Technological advancements can be classified, based on their functionality, into plan and design; storage, control, management and measure (CMM); convert; consume; and generate (IRENA, 2016a). The process of plan and design is characterized by a preliminary modelling, the development of a business model, resource planning and project engineering (IRENA, 2016a).

Most of  innovations are concerned with the development of specialized software that helps in the development of the process previously described (GIZ, 2015). CMM technological advancements include software and hardware aimed at controlling (Hooshmand, Poursaedi, Mohammadpour, Malki, & Grigoriads, 2012; Mao, Jin, Hatziargyriou, & Chang, 2014; Olivares et al., 2014), data communication (Setiawan, Shahnia, Ghosh, & Rajakaruna, 2014), metering and monitoring, and plug-and-play technologies that allow for interoperability and interconnections (IRENA, 2016a). The "convert" functionality include all technological developments related with power inverters, which allow the movement of energy between several parts of the micro grid (IRENA, 2016a). Finally, the "consume" functionality includes technological development aimed at end-users such as DC appliances (IRENA, 2016a).

### Transmission

#### *Smart Grids*

Perhaps the most interesting technological development, regarding smart grids, is the creation and implementation of virtual power plants (VPP). VPPs consist of an integrated network that unifies multiple micro grids, demand side management (DMS) and forecasting systems. Their principal goal is to provide a reliable overall power supply (IRENA, 2016c). Some examples of VPP projects being deployed are Nice Grid in France, PowerShift Atlantic in Canada, and Consolidated Edison of New York in the United States (International Energy Agency, 2016b).

### End Consumption

#### *Electric Vehicles*

Electric vehicles today are classified into battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). BEVs use batteries only to store energy; therefore, they must be plugged-in in order to recharge (IRENA, 2017a). Additionally, PHVEs use batteries as well as liquid-fuel storage. Moreover, liquid fuel can be refueled, allowing for greater ranges of travel kilometers (IRENA, 2017a).

Perhaps, the main limiting of BEVs is the distance they can travel with one full charge. The range of BEVs is around 250 km per full charge. There are some exceptions such as the Tesla model S and the BYD E6, which have a range over 300 km. Other companies like Chevrolet have announced models that claim to have a range almost 400 km (IRENA, 2017a). Alternatively, PHEVs have a range similar to internal combustion vehicles, around 750 km. Their all-electric range is between 30-50 km (IRENA, 2017a).

Batteries are one of the focus of innovation, since the higher cost of EVs is directly associated with batteries. Today, every commercialized EV relies on lithium-ion batteries. It is estimated that in order for EV to be competitive, batteries have to reach costs around USD 150/ kWh (IRENA, 2017a). Research shows that a target around USD 50/ kWh could be attainable by 2030 (Nykvist & Nilsson, 2015).

### ***Smart Buildings***

Energy in buildings is consumed mainly through heating, cooling and powering appliances (IRENA, 2016c). Regarding heating and cooling, renewable energy use has gained relevance. Solar thermal systems are used for water heating and space heating. Countries like China play a key role in the development of solar water heaters (SWH). Today, 70% of the global installed capacity of SWH is located in China. According to IRENA it is estimated that by 2030 3,200 million square meters of rooftop space will be used for solar thermal collectors.

Another interesting development is the deployment of district heating and cooling networks. They consist of networks of insulated pipes that pump hot or cold water to multiple buildings (IRENA, 2015). Through this arrangement cost-effective energy can be provided (UNEP, 2015). However, according to the IEA, the use of district energy is still limited. Only a tenth percent of the residential and commercial demand is covered through heating or cooling networks. Particular examples of district cooling networks using seawater include cities like Copenhagen and Port Louis, Mauritius, Africa. Developments in hot climate cities, like Port Luis, are more recent and still on development. Once completed, the system will provide around 6% of the 2014 peak electricity demand in the country (IRENA, 2016c).

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