Clean Restructuring: Design Elements for Low-Carbon Wholesale Markets and Beyond

A 21st Century Power Partnership Thought Leadership Report

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CLEAN ENERGY MINISTERIAL
Accelerating the Transition to Clean Energy Technologies

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Preface

The recent Paris climate commitments represent an unprecedented global coalescence of social, economic, and political will. In principle, this coalescence is a shared vision for the long-term sustainability of the planet; in practice, it is a call to convert our energy systems, and particularly our power systems, to use predominately low-carbon energy sources and to rethink our energy use paradigms, plotting a markedly different course for future infrastructure investment.

Energy systems are a manifestation of various technical, economic, and political factors, distinct to each local situation. The exact path forward for each nation is necessarily distinct, as evidenced by the approach of formulating country-specific nationally determined contributions (NDCs). However, one trend remains clear among the landscape of potential solutions for emissions reductions strategies:

Power sector decarbonization presents a significant opportunity to reduce greenhouse gas emissions, while promoting inclusive economic growth, energy security, and innovation.

This paper has grown out of ongoing work in the 21st Century Power Partnership, a multilateral effort under the Clean Energy Ministerial (CEM) aiming to accelerate the global transformation of power systems. The Power Partnership serves as a platform for public-private collaboration to advance integrated policy, regulatory, financial, and technical solutions for the large-scale deployment of clean energy in combination with energy efficiency and advanced grid technologies.

In addition to the growing collection of "on the ground" technical assistance and policy dialogues, several previous thought leadership reports from the Power Partnership include:

- *Flexibility in 21st Century Power Systems*, showcasing how planners and operators can best respond to changes in demand and supply that are an outgrowth of expanded variable (wind and solar) generators, demand response and smart grids.
- *Power Systems of the Future*, summarizing key forces driving transformations and offering approaches to achieve desired progress in power systems across the globe.
- A *Status Report on Power System Transformation*, highlighting the range of innovations emerging globally to facilitate power system transformation. A new web portal is being launched by the CEM that will track ongoing changes across countries.

This report is not intended to encourage or prescribe power market restructuring, nor imply that it may be appropriate in any given setting. Instead, this report focuses on providing insights on clean energy integration design elements to those regions that currently operate a wholesale electricity market, or are considering a transition into such a paradigm.

Many other examples of tools and activities from the Power Partnership are available at 21stcenturypower.org. We hope this report will help countries around the world advance their objectives in achieving cleaner and more efficient power sectors.

Acronyms

ACER	Agency for the Cooperation of Energy Regulators (European Union)
BMWi	Federal Ministry for Economic Affairs and Energy (Germany)
CAISO	California Independent System Operator (United States)
CEL	clean energy certificate (Mexico)
CENACE	National Center for Power Control (Mexico)
CFE	Mexico's state-owned power enterprise
CHP	combined heat and power (also known as cogeneration)
COP21	21st Conference of the Parties to the United National Framework Convention on Climate Change
CRE	Energy Regulatory Commission (Mexico)
CREZ	competitive renewable energy zone
DC	direct current
DSO	distribution system operator
EEG	Germany's Renewable Energy Act
ENTSO-E	European Network of Transmission System Operators for Electricity
EPEX SPOT	European Power Exchange
EU	European Union
FERC	Federal Energy Regulatory Commission (United States)
FiT	feed-in tariff
GHG	greenhouse gases
GDP	gross domestic product
IPP	independent power producer
ISO	independent system operator
ISO-NE	Independent System Operator New England (United States)
IVGTF	Integrating Variable Generation Task Force
LIE	Law on Power Industry (Mexico)
LMP	locational marginal pricing
LTE	Law on Energy Transition (Mexico)
MGC	Mexican Grid Code
MISO	Midcontinent Independent System Operator (United States)
MW	megawatt
NDC	nationally determined contributions
NERC	North American Electric Reliability Corporation
NordREG	Forum of Nordic Energy Regulators
PPA	power purchase agreement

PJM	(Originally) Pennsylvania, New Jersey, Maryland ISO (United States)
PRODESEN	Power Development Program (Mexico)
PV	photovoltaics
RTO	regional transmission operator
SENER	Mexico's Energy Secretariat
SHCP	Mexico's Secretariat of Finance and Public Credit
TSO	transmission system operator
USD	United States dollars
VRE	variable renewable electricity

Executive Summary

Countries around the world are in various stages of reforming and restructuring their power systems to better meet development needs and decarbonization commitments. Changes in technology, business models, societal needs, and environmental goals are increasing pressure on countries to consider improvements to their electricity systems.

This report addresses key issues associated with clean restructuring—the transition from traditional, vertically integrated utilities to competitive wholesale markets that rely increasingly on variable renewable electricity sources, demand response, and other clean electricity options.[1] It is not intended to encourage or prescribe power market restructuring, nor imply that it may be nationally appropriate in any given setting. It focuses on presenting key considerations for policymakers and power systems experts aiming for an *end state* with significant levels of clean energy, fully competitive wholesale markets, and best practice technical and regulatory approaches employed.

This report addresses **planning and procurement** for new generation; **market design and system operations**; and **infrastructure, interconnection, and grid codes** that can enable the transition to cleaner generation in restructured markets. It also includes case studies from Mexico, Denmark, and Germany to provide real-world examples of clean restructuring from different perspectives.

Planning and Procurement

In the clean restructuring context, resource planning and procurement efforts may become more complex with a geographically dispersed and diverse set of clean and variable energy resources. A heightened focus on the flexibility of the power system to accommodate variable renewable electricity may be needed.[2] Forward-looking flexibility and resource adequacy assessments, including high-fidelity wind and solar data, can be incorporated into planning processes.

In addition, some restructured markets with high penetrations of clean energy are experiencing revenue sufficiency issues for existing and new generators in the market. Planning and procurement processes can, to some extent, address these issues by promoting appropriate levels of new capacity deployment, reducing occurrences of over-generation, and striving to maintain the bankability of new infrastructure projects.

Market Design and System Operation

Several market design and system operation practices have also emerged as critical elements of a clean restructured power system. First, the design and implementation of unit commitment and dispatch rules—for example, faster dispatch—can significantly impact the ability to manage

[1] In this report, clean electricity refers primarily to wind and solar generation, as well as emerging grid technologies, demand response, energy efficiency, energy storage and other demand-side options. As deemed nationally appropriate, nuclear power and natural gas may also qualify as clean generation, the latter having relatively low carbon output compared to other fossil fuels, and may be important options for many countries to consider.

[2] For an overview of flexibility issues, see Cochran et al. (2014).

variable renewable generation on the system and has implications for the economic viability of renewables. Second, the structure of imbalance penalties and rules for curtailing generation for balancing are also key considerations for the viability and integration of clean energy sources.

Third, the integration of forecasting into market operations is important for continuous system balancing as well as planning for extreme weather events to avoid system outages. System operators need adequate data from generators to ensure accuracy of forecasts, which could be instituted as a condition of interconnection. Also, changes to ancillary service markets may be needed to ensure effective load following, frequency responsive reserves, inertial response, and reactive power support. Clean generation sources can provide many of these services if rules are updated. Finally, new market elements, such as ramping products, may be helpful for achieving the additional system flexibility needed to address the uncertainty introduced with variable renewables. Demand response can be an important component of cost-effective system flexibility.

Grid Infrastructure, Interconnection, and Grid Codes

As transmission assets are unbundled from generation, open and transparent processes for network expansion and investment become important in a restructured environment. To that end, streamlining the interconnection process for resources applying to connect to the network can alleviate barriers to entry for new resources in terms of the time and cost of the application process.

With higher levels of variable renewable electricity on the system, it is critical to ensure that grid codes—rules addressing how generators must connect to the grid—have been updated to reflect technologies with different operating characteristics to allow all resources to contribute to system reliability. For variable generators, grid code modifications may be needed for some ancillary services.

Case Study Insights

Insights can also be gleaned from the three case studies in this report. Two countries—Denmark and Germany—have restructured power markets that are evolving to better integrate clean energy. The third, Mexico, is in the midst of clean restructuring. In all three countries, strong stakeholder engagement processes can help create a competitive wholesale electricity market environment and a level playing field for market actors. Mechanisms for ongoing political and institutional support for clean restructuring, especially those of a transnational nature, can provide a long-term and stable policy environment within which markets can operate. Lastly, some elements of clean restructuring may also be phased in over time as the levels of clean energy in the power sector increase. In other elements, forward-looking changes to market rules could also be implemented in anticipation of future growth in clean energy.

While optimal solutions for transforming power markets will vary by jurisdiction, common considerations from global experience can help inform the direction and types of changes that may be needed in future power systems with expanded adoption of clean energy resources.

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1 Introduction

Countries around the world are in various stages of reforming and restructuring their power systems to better meet development needs and decarbonization commitments. Restructuring theory and practice can be highly complex, location-specific, and dependent on critical actors and champions. Still, there is a growing body of evidence that can be shared among countries about what works well under certain circumstances. In this report, we aim to catalyze sharing of these lessons so that countries can adapt and formulate their unique strategies to meet their energy, economic, and environmental goals in the most efficient manner possible.

Much of Europe and Australia, and parts of the Americas, have competitive wholesale power markets dominated by private companies. In much of Asia, the Middle East, and Africa, several countries have begun experimenting with new regulatory and market designs, although restructuring has occurred more slowly due to institutional constraints, financial barriers, and the lack of reform champions. In many countries, electricity remains highly subsidized, with little revenue available for new capacity investments and state-owned, vertically integrated utilities still dominating the landscape.

But changes in technology, business models, societal needs, and environmental constraints and goals are increasing pressure for countries to consider experimenting with new approaches. Cost reductions in some technologies like variable wind and solar photovoltaic (PV) generation options—combined with demand response, electrical storage, and smart devices—are creating the need for new planning and operational practices in some locations. Many countries are beginning to address the technical and economic questions around changes associated with significant deployment of clean energy resources, including:

- What is the best way to introduce flexibility into power systems so that they can accommodate larger amounts of variable generation?
- How can the grid operate more efficiently and economically with clean energy resources with different operating characteristics from conventional generating sources?
- How do planning and reliability assessments change when significant shares of variable generation begin to enter the system?

This report addresses key issues associated with the transition from traditional, vertically integrated utilities to competitive wholesale markets that rely increasingly on variable renewable electricity sources including wind and solar, but also demand response and other clean options. It is not intended to encourage or prescribe power market restructuring, nor imply that it may be nationally appropriate in any given setting. Instead, it is focused on providing useful information on clean energy integration market design elements to those contexts that currently operate a restructured electricity market, or are considering a transition into such a paradigm.

There are a number of dimensions upon which clean restructuring efforts could occur:

- The extent of deregulation in the supply chain: generation, transmission, and in some cases distribution

- The first sets of reforms in the transition from vertically integrated sector as well redesigning more mature restructured markets
- The level of clean energy in the system.

The report focuses on the design of competitive wholesale markets that rely increasingly on variable renewable electricity sources, demand response, and other flexible, clean energy options. Retail sector deregulation and off-grid or distribution system design, though emerging areas of innovation, will not be addressed in this report.[3]

In the transition to establishing a wholesale market, vertically integrated sectors will have a broader set of issues to address than those presented here and may fully implement restructuring over a longer period of time (Gratwick 2008; Besant-Jones 2006). Power systems may also build on design elements as penetrations of clean energy increase and there are frameworks that explore a more phased approach.[4] This report focuses on presenting key considerations for policymakers and power systems experts aiming for an *end state* with significant levels of clean energy, fully competitive wholesale markets, and best practice technical and regulatory approaches employed.

Key topics include planning and procurement for new generation; market design and operations; and infrastructure, interconnection, and grid codes that can help enable the transition to cleaner generation in restructured markets. These topics deserve special attention by decision makers in the clean restructuring transition. The report also includes case studies from Mexico, Denmark, and Germany to provide practical examples of clean restructuring from different perspectives.

1.1 Power Market Restructuring—Setting the Context

The 21st Century Power Partnership Report *Power Systems of the Future,* published in 2015, articulated several pathways for power systems transformation and decarbonization, pictured in Figure 1 (Zinaman et al. 2015). One of these pathways was coined "Clean Restructuring" and described a "big-bang" approach to transforming a vertically integrated power sector toward a more participatory and clean energy-friendly power sector.[5]

[3] One of the power system transformation pathways defined in Zinaman et al. (2015) included innovative approaches for the distribution system operator (DSO), *Unleashing the DSO* (see Figure 1). This is an active area of innovation in many parts of the world.
[4] This reports builds on prior best practices as identified in Cochran et al. (2012).
[5] Although, the Power Systems of the Future Report focused on describing the endpoint of "Clean Restructuring," power market restructuring is a process, and one with many potential endpoints, as has been witnessed in countries that have embarked on reforms over the previous decades. Currently, there are many "hybrid models" of reform across the globe in which varying degrees of restructuring have occurred.

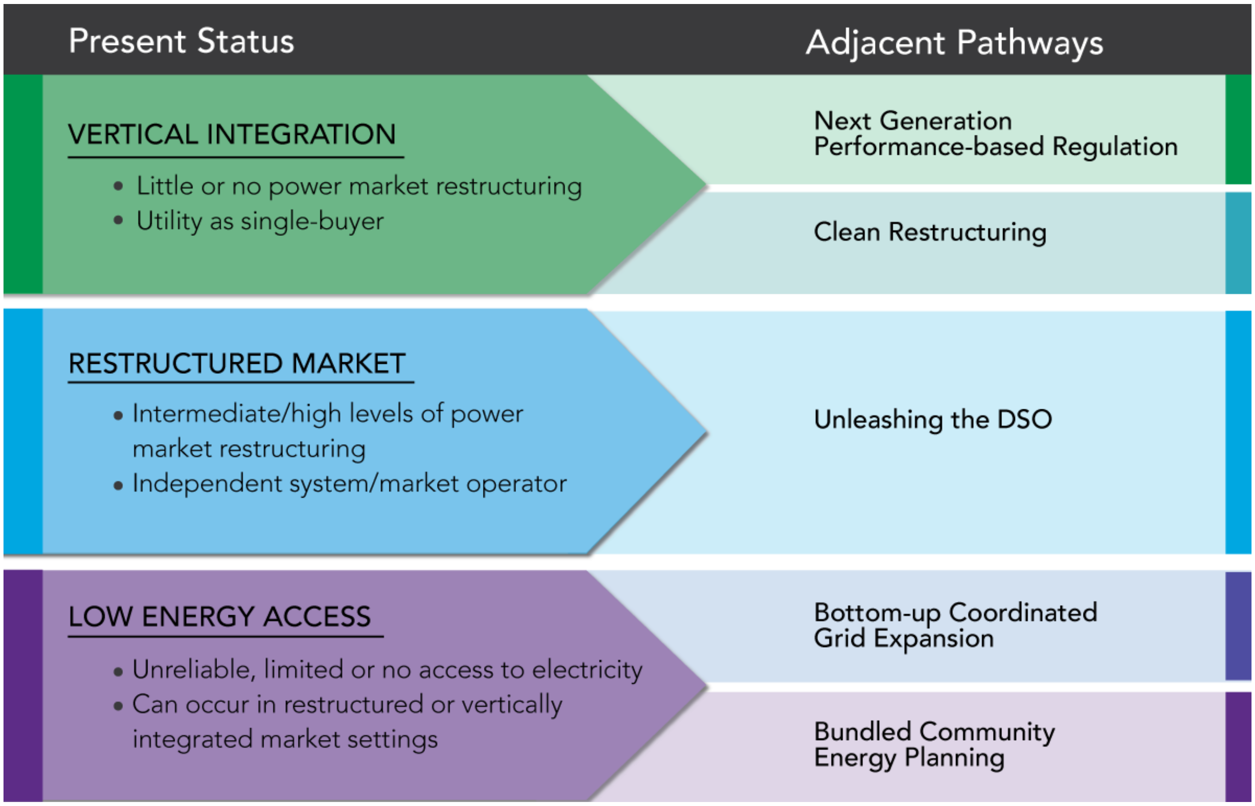

Figure 1. Power systems of the future—pathways for transformation

Source: Zinaman et al. (2015)

The "Clean Restructuring" pathway hinges on the introduction of a wholesale electricity commodity market and creation of an independent system/market operator, along with clear policy and regulatory guidance and strong private sector participation. In the language of strategic change, this transformation pathway represents a "reconstructive shift" in power sector organization, as it is inclusive of already established market actors (e.g., utilities, independent power producers [IPPs]) but reshuffles their roles, responsibilities, and the way in which they invest.

Power market restructuring can be generally defined as the:

> "…breaking up or unbundling of the incumbent power utility into multiple generators and distributors of power that trade with each other in a competitive wholesale power market."
>
> - Besant-Jones (2006)

In the restructuring process, generation and transmission assets may be vertically and horizontally unbundled as well as privatized to enable open access and efficient operation of the electrical power industry, without undue aggregation of market power. In cases where many of the generation assets were owned by a state-run utility, these assets may also be divested and privatized to enable competition and in some cases improve the financial solvency of the utility (see Figure 2).

As a wholesale market is established, an independent system operator (ISO), also known as a regional transmission operator (RTO) or transmission system operator (TSO), is often created to independently operate the markets (Hurlbut et al. 2015). This ISO will likely also control the dispatch of all interconnected power generators and the operation of the transmission grid.[6] The role of the regulator evolves as well, as markets must be monitored for manipulation, price collusion and other undesired activities. This may be realized through the establishment of an independent market monitor (Wolak 2005).

These reforms have been driven globally by a number of policy objectives and conditions, *inter alia*: providing consumers more affordable electricity, ensuring sufficient investment in the electric sector, encouraging competition in a sector that may be inefficient, and meeting stronger environmental goals (Stoft 2002). Some electric sectors, especially in developing countries, may need to address issues of utility financial insolvency, lack of sufficient investment, and interest in bridging the energy access gap, poor technical or financial performance, or national government budgetary constraints (Besant-Jones 2006; Gratwick et al. 2008).

Restructuring represents a substantial political commitment to fundamentally alter the ownership, operation and investment constructs of the power sector. The political economy drivers and implications of such decisions are significant and often years in the making and historically speaking have had little to do with decarbonization objectives,[7] and much to do with the policy objectives and conditions mentioned above.

1.2 Intersection of Clean Energy and Restructuring

Clean energy, in the context of the power sector, primarily focuses on low-carbon forms of electricity generation and in particular variable renewable energy (VRE), but also includes electric vehicles, energy efficiency, combined heat and power (CHP), energy storage, demand response and other forms of clean energy which have or will have some interaction with power systems of the future.

Increasing levels of VRE introduce unique conditions for power systems. First, unlike more traditional forms of electricity generation, e.g. fossil-fuel or nuclear generation, wind and solar resources are variable in nature and thus introduce uncertainty into the power system with respect to the electricity than can be expected in any given hour (Miller and Cox 2014). Variability may be greater with wind energy, although advanced forecasting techniques can reduce uncertainty. Second, wind and solar resources can vary significantly by region, and new generating capacity may be built based on policy, regulatory, and other factors in addition to where resources are strong (Ela et al. 2014). These installations might be concentrated in certain regions, and may or may not be located near load or transmission availability (OECD/IEA 2016). Lastly, VRE systems, unlike conventional generators that are synchronous, have historically

[6] In some cases the transmission assets are also owned by the transmission operator, but in other cases they are independent functions.

[7] The recent passage of Mexico's Energy Transition Law, which resulted in power market restructuring along with explicit policy goals for clean energy deployment and decarbonization, presents a novel divergence from this historical trend.

been asynchronous and are not directly coupled with system frequency except through more advanced power electronics (Weimar et al. 2016).

With higher penetrations of clean energy resources being deployed in electricity markets around the world, a number of jurisdictions are making modifications to their electricity markets and system operations to accommodate the characteristics of clean energy technologies. Certain market design and policy considerations are emerging for countries just embarking on a restructuring process (Cochran et al. 2012) or already restructured while also accommodating increasing levels of clean energy.

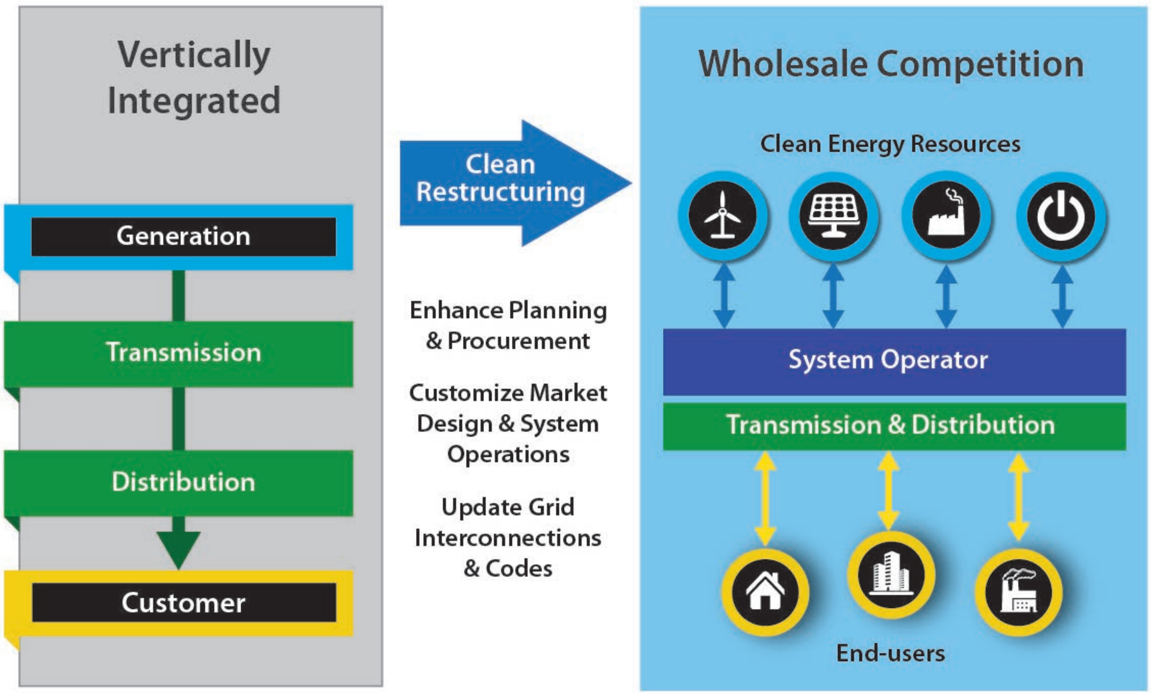

Figure 2. Clean restructuring: transition from vertically integrated sector to a fully restructured power system with wholesale competition

Source: Adapted from Gratwick (2008)

These considerations and others begin to articulate an end-state vision for clean restructuring efforts, including those articulated in the *Power Systems of the Future* report:

- "Bulk power market design characteristics that encourage clean energy and energy efficiency investment, reduce investment risk, and promote efficient competition in wholesale market
- Transparent planning processes for network expansion, particularly those attempting to incorporate remote renewable energy sources or those that take into account the value of distributed energy resources
- Planning and dispatch practices can be optimized to facilitate integration of clean energy, including use effective forecasting methodologies, creation of platforms for demand-side participation, and coordination with other balancing areas

- Simplified interconnection rules and clear forecasting and system operation protocols to reduce investor risk
- Regulatory frameworks to incentivize efficient interconnection and line-loss reductions for transmission owners and operators" (Zinaman et al. 2015).

Lastly, open questions exist regarding some aspects of clean restructuring. Current approaches to addressing these issues are discussed in the report while acknowledging that these challenges persist.

1.3 Structure of Report

There are a variety of ways countries can begin to restructure their electricity systems to achieve cleaner power services, or to improve existing wholesale competition. Three topics, however, stand out as essential for all to consider along the way:

- Planning and procurement,
- Market design and system operations,
- Grid infrastructure, interconnection, and grid codes.

Sections 2-4 of this report discuss these three topics, respectively, and provide examples of how various countries and electricity markets across the world have developed approaches for better integrating clean energy into their markets. In addition to this discussion, three case studies from Mexico, Denmark and Germany are introduced in Section 5, and then detailed in Sections 6-8, respectively. These case studies illustrate how each country has addressed specific market design and policy issues to promote clean energy integration practices. Section 9 synthesizes the findings and key takeaways from the entire study.

2 Enhancing Planning and Procurement

In a liberalized electric sector, long-term decisions about investments in new generation may be increasingly made by a dispersed set of market actors instead of by a single or a concentrated set of state-owned or private sector vertically integrated utilities (Besant-Jones 2006; Gratwick 2008). This can introduce additional complexity to activities such as generation and transmission planning, and designing a procurement process for the wholesale market to cost-effectively achieve the desired reliability and environmental outcomes with the resource mix. However, this shift can also allow for diverse revenue streams for generators and other resources, resulting in new investment needed in generation capacity for the electricity sector as well as reduced barriers to entry for new generators and emerging resources.

Resource procurement practices in restructured markets focus on facilitating cost recovery for investors while maintaining the efficiency of the market. The design of these mechanisms is intended to provide the appropriate investment signals for decarbonizing the power system while ensuring sufficient supply to meet demand requirements. System planners around the world face a range of disruptive technologies that are altering the landscape of planning- and procurement-related analyses, processes, and ultimately decisions. Particularly in light of cost-competitive VRE resources, **system planning and the design of procurement practices** are becoming more complex. The signature challenges of these efforts nevertheless remain to ensure:

- Long-term security of supply (i.e., resource adequacy)
- Revenue sufficiency for existing and new generation resources
- A cost-effectively planned system, with a procurement process that supports least cost deployment (often via facilitated competition)
- "System-appropriate" amounts of new capacity deployment
- Short-term security of supply (i.e., system reliability) in terms of long-term planning exercises
- Compliance with various public policy directives (e.g., clean energy, energy efficiency or other goals or standards)
- Transparency and stakeholder engagement.

These trends have been well characterized in the literature, and Section 2.2 discusses many of these challenges as applicable to clean restructured markets.

2.1 Shifting Roles and Responsibilities for Planning and Procurement Under a Restructured Paradigm

Under vertically integrated paradigms, long-term planning exercises and procurement processes for generation and transmission are usually run by the utility.[8] Different models exist for

[8] These least-cost planning exercises tend to be influenced by government policy, and in some cases are run by government agencies with support from the utility.

planning and procurement in the United States and in Europe.[9] In restructured markets in the United States, load serving entities typically retain their autonomy to plan and procure energy on behalf of their customers, but must do so in close coordination with the ISO.[10,11] Further, load serving entities are able to procure energy and ancillary services through the commodity market (or they may still, to varying extents, procure via bilateral contracts) (Zhou et al. 2016).

The ISO is also responsible for monitoring generator interconnections and ensuring broader reliability criteria are met. Long-term generation and transmission planning exercises are frequently conducted by ISOs, but do not always directly drive investment decisions. Instead, they are often meant to educate market participants on likely development pathways, in order for load serving entities, regulators, and other stakeholders to plan for evolutions in the generation mix and the broader interconnected system in which they participate (see Section 4).

2.2 New Challenges for Planning and Procurement in Clean Restructuring

Key considerations for markets undergoing restructuring and expecting growth in clean energy are:

- How can planning of generation and transmission assets and other clean energy resources better incorporate flexibility and VRE, and also be more integrated across the supply chain?[12]
- How can the results of planning efforts be translated into procurement practices that encourage private developers to help achieve system-efficient outcomes?
- How can procurement practices allow for subsidies, if desired, without distorting the market?
- How can procurement practices be enhanced to ensure that there are appropriate price signals to incentivize sources of flexibility—conventional generation and other forms—to remain in or enter the market, both in terms of quantity and quality?

Low-carbon and VRE resources tend to have high upfront capital costs relative to their operational costs; in order to foster an adequate risk/return profile for such an investment, procurement processes frequently rely on long-term contract offerings.[13] In addition, it is sometimes observed that VRE curtailment can be cost-effective for the *system*; however, it may not be economically desirable for the *individual project*. Thus, aligning the interests of the

[9] In Europe, some TSOs own transmission assets, and are involved with their planning, construction, ownership, maintenance and operation. Planning of generation can be independent of any particular customer. In the TSO model, independent power exchanges administer the market, and it is the TSO who procures the ancillary services.
[10] Power sector regulators also remain heavily involved in these processes on behalf of ratepayers.
[11] Mexico offers a different example, where the ISO administers auctions for energy, capacity, and clean energy certificates on behalf of the regulated, state-owned load serving entities.
[12] Significant levels of VRE are also connected at the distribution system, and planning efforts may also need to address the interaction of the transmission and distribution systems. However, this will not be captured in this report.
[13] One such means to effectively procure VRE through long-term contracts is auctions. For an overview of best practices for renewable energy auctions, see IRENA/CEM (2015).

system with the interests of the investor (often through procurement processes) may be a challenge in specific circumstances.

In some settings, the best VRE resources are located far from load centers and existing transmission assets, suggesting that new transmission may be needed to access these low-cost generating sites. Projects in such areas can present a "co-investment conundrum" because IPPs typically cannot secure project financing unless there is certainty that the transmission capacity will be available, and the transmission capacity typically cannot be financed without firm commitments from IPPs to utilize the new lines.[14] Furthermore, system planners are now increasingly tasked with considering a range of future transmission expansion scenarios and how system costs might be affected given the VRE resources that might be accessed if a transmission line is built; such assessments require more integrative techniques and processes in terms of how they consider the tradeoffs of various generation and transmission investments (see Section 4).

In restructured contexts, the potential sources of cost recovery for new and existing generators may include a range of options such as power purchase agreements (PPAs) and participation in a commodity market. When participating in the market, generators can sell energy and ancillary services to collect costs and seek profit.

Today's restructured markets are dispatched based on the lowest short-run marginal cost resources. Because generators bid into the market near their marginal cost of generation, they primarily present their variable costs to the wholesale market. For conventional sources of generation, variable costs largely depend on fuel costs. VRE has nearly zero marginal costs because the "fuel" costs of wind or solar irradiation are free. Some demand response resources are able to shift their energy consumption without major cost impacts for on-site operation, which also enables them to bid in their services at quite low marginal prices (see Section 3.7). As a result, VRE and other low marginal cost resources are frequently dispatched first. Additionally, VRE generators have, in many contexts, received government incentives in addition to revenue collected from the wholesale market. This allows them to bid into the market with very low—and even occasionally negative—prices (Buck et al. 2016; Hogan and Weston 2014; Weimar et al. 2016).[15]

While these low market prices are perhaps desirable for buyers, the unique market characteristics of VRE can create revenue sufficiency issues for non-VRE generators, both by receiving lower overall market clearing prices and by being dispatched less frequently. In fact, an outlook of lower prices and lower utilization can also impact the ability to attract sufficient investment in the power system for all generation technologies. Another factor exacerbating this issue is that some regions are experiencing an excess of capacity beyond reserve margins, with an existing fleet of older generation units and increasing levels of VRE entering the power system due to public policy objectives, further depressing prices.[16]

[14] Some approaches to this issue are discussed in Section 4.
[15] If a market-clearing price is negative, this implies that generators must *pay* the system operator to receive their power.
[16] This follows basic economic theory that if a market is oversupplied with a product, prices will be lower.

The gap in revenue sufficiency to provide incentives for new generation has been referred to in some of the literature as the "missing money" problem (Borenstein and Bushnell 2015; Hogan 2005; Joskow 2008; Spees et al. 2013; Felder 2011; Papalexopoulos et al. 2015).[17] These sets of issues are affecting several more mature wholesale markets with higher penetrations of clean energy generation in the United States and the European Union, in particular.

A few markets have sought to deal with these circumstances. Germany (see Section 8) launched an effort in 2015 to explore market design approaches for addressing similar issues. After much public debate, a white paper was published by the German Federal Ministry of Economic Affairs and Energy (BMWi 2015a) with the decision to enhance its existing energy-only market, *electricity market 2.0*, instead of creating a supplementary forward capacity market (see Section 2.4 for more background on capacity markets). ERCOT, the wholesale market in the state of Texas, also considered a capacity market for similar reasons in 2014 (Newell et al. 2012), but for a variety of both political and technical reasons, decided to continue with a slightly modified energy-only market with price caps.

2.3 Planning and Procurement Design Elements for Clean Restructuring

There are a variety of strategies that can be employed across all market paradigms to improve planning and procurement processes, but these are particularly germane for clean restructuring. These are listed below in Table 1.

[17] In some of the literature (Cramton et al. 2013; Hogan 2005), the "missing money" issue is more narrowly defined, and focuses on circumstances in which market rules in an energy-only market, e.g. administrative caps on scarcity pricing, have limited the level of resources in the market to address peak demand.

Table 1. Strategies to Improve Planning and Procurement Processes for Clean Restructuring

Enhancing Foundational Planning Data
Conduct resource potential analyses for energy efficiency and demand response[18]
Conduct system flexibility assessments and potential studies, including consideration of existing fleet retrofit opportunities
Utilization of high-fidelity wind and solar data
Conduct foundational power sector risk analyses on potential water constraints, shifting climate change conditions, and fuel price and availability aspects
Enhancing System Planning Practices
More integrative generation and transmission planning which holistically consider cost tradeoffs of investments
Utilization of advanced flexibility metrics[19] and constraints in planning exercises
Utilization of water-, climate-, and fuel-related related constraints in planning exercises, including by conducting scenario analyses of potential futures
Enhancing Market Structures and Procurement Practices
Perform scenario analyses that explore transitions in market structure (e.g., moving from preferential dispatch to least-cost dispatch) to explore economic issues across the system's stakeholders under various market structures
Provide clear guidance on grid expansion plans for renewable developers
Include reasonable "right-to-curtail" provisions for new VRE contracts;
Formulate clear guidance on cost/risk allocation strategies for retiring existing generators, as required

Many mechanisms for remuneration of low carbon technologies have been employed over the past decades, including feed-in tariffs (FiT), renewable energy certificates, and carbon pricing in some markets. Other approaches have combined some of these elements with long-term power purchase agreements obtained with increasing frequency through auction systems. Tax and investment incentives, where applicable, are typically included in the power producers' calculation of their finances, codified into the contract prices, bid prices, and profit structures.

These mechanisms are sometimes characterized as having a distorting effect on wholesale market prices. They may contribute to the lower marginal prices for low carbon generators and thus lower market-clearing prices for all generators. Many of these external subsidies are under review in markets where there are higher penetrations of VRE, and the levelized cost of energy of these technologies is declining (IEA 2015b).

[18] Demand response potential studies such as the 2015 California Demand Response Potential Study (Alstone 2016) could inform these types of assessments.

[19] New metrics are emerging for assessing the flexibility of power systems (Lannoye et al. 2011; Lannoye et al. 2012).

However, there are few examples of low carbon generation incentives that are slightly more linked to wholesale market design. For example, in Mexico, there are long-term auctions for clean energy certificates (CELs) (see Section 6) facilitated by the system operator on behalf of the major load serving entities (Watson et al. 2015). These are long-term PPA arrangements that take away the market price risk for generators. In Germany, VRE generators have access to up to 20-years of guaranteed payment, and can also opt to sell directly into the wholesale power market and receive a market premium matching the gap between the FiT level and the wholesale power price (Fulton and Capalino 2012). This allows for exposure to short-term power markets, while the FiT provides a failsafe option to assist with access to low-cost financing (Miller et al. 2013). In all of these cases, payment structures required to secure financing are kept independent from decisions on system operations, so that the system can be operated on a least-cost basis without unnecessary distortions. This reflects a greater trend in many markets, where VRE is treated like any other (dispatchable) generator.

Forward capacity markets have been established to provide generators with compensation for capacity that they will provide at some point in the future. Forward capacity markets exist in various markets including in the United States, Western Australia, and in the U.K. Thus far, capacity markets in the United States have contributed to the goal of achieving the required level of system reliability. However, careful market design is warranted because some argue that these structures lead to potential economic inefficiencies and an oversupply of capacity (Bhagwat et al. 2015). Capacity market rules are constantly evolving to better ensure the right incentives to solve the "missing money" issue while meeting resource adequacy requirements (Bowring 2013, Spees 2013, Jenkin et al 2016). In restructured markets with high variable renewable energy penetrations, Milligan et al. (2014) have stressed the need to consider the linkages between energy, ancillary services, and capacity payments carefully when determining system needs, though this may be challenging given the different temporal scales on which systems operate.

2.4 Key Takeaways

- In the clean restructuring context, resource planning and procurement efforts may become more complex with a more dispersed and diverse set of clean and variable energy resources. An increased focus on the flexibility of the power system may be needed.
- Market planning and procurement processes may strive to align the best interests of the system with what is desired by market participants looking to invest.
- Markets that expect significant penetrations of variable energy sources can consider incorporating forward-looking flexibility and resource adequacy assessments and analysis into planning processes, including the use of high-fidelity wind and solar data.
- The exact nature of flexibility and resource adequacy issues will be distinct for each power system.
- Under certain circumstances, revenue sufficiency concerns may arise for existing and new generators in the market; planning and procurement processes can (to some extent) address these issues by promoting appropriate levels of new capacity deployment (to ensure a system without an undesirable excess of generation capacity), reducing occurrences of over-generation at certain times of day or in certain locations, and striving to maintain the bankability of new projects.

- Determining how to most effectively allocate cost and risk while retiring fully or partially amortized conventional generators in a market—in order to “make room” for new clean energy capacity—remains an ongoing, often politicized, and context-specific issue without a universal solution.

3 Market Design and System Operations

This section explores how market design and operations are evolving in restructured markets to accommodate and manage variable generation. Careful market design and operation can ensure short-term and long-term security of supply. Key considerations for markets undergoing restructuring and expecting growth in clean energy are:

- How can market operations, rules, and regulations be designed to address increased variability and uncertainty?
- What market design elements or new products are emerging to ensure that appropriate levels of flexible resources are available and enter the market?
- How can market designs and operations change to enable the system to maintain system stability with high penetrations of VRE?

3.1 Larger Balancing Area Coordination

Transitioning from a vertically integrated utility context to a competitive wholesale market may involve integration of smaller balancing areas, managed formerly by individual vertically integrated utilities, into a larger, more comprehensive wholesale market. In other cases, national centrally managed balancing area arrangements could be maintained in a restructured environment. A market with larger geographic coverage has a number of advantages that facilitate the integration of variable renewable generation.

By enlarging balancing areas, the relative variability and uncertainty in both the load and system-wide renewable energy generation can be lowered. The larger the market size, the more likely these changes will balance and enable the system to operate with less variability and more flexibility (Weimar et al. 2016; Cochran et al. 2012). Greater geographic distribution of renewable resources can reduce the system-wide variability because weather patterns are generally more diverse if considered over a larger region.[20] Larger geographic areas also tend to reduce aggregate forecasting errors (Bird and Milligan 2012) and can enable more customers to participate in demand response programs, which can help with balancing and reserves.[21] However, the size of the balancing area is subject to transmission grid constraints.

Larger balancing areas can be achieved through a variety of mechanisms, including regional cooperation, interconnections with surrounding jurisdictions, and through planning and infrastructure investments. For example, Denmark has had very effective regional agreements with its neighbors that facilitate interchange with surrounding regions (see Section 7).

3.2 Unit Commitment and Dispatch

Compared to a vertically integrated market where generators are typically scheduled by the utility, dispatch in a restructured market is managed with a day-ahead, real-time, and in some

[20] For example, declines in wind output in wind farms in one area may be offset by strong winds and greater output in another area.

[21] Just having a larger market area may not lead to geographic diversity in the renewable development in all cases because siting is influenced by locational factors such as access to quality wind resources, transmission lines,, and a numerous other issues.

cases intraday markets, where generators bid on available generation. Based on the bids, the system operator creates a generation dispatch stack sufficient to cover the load. The market clearing price is determined based on the marginal generator—the last most expensive generator in the dispatch stack needed to meet the load (and other services). In addition, certain system services need to be procured by the system operator. This can be done by operating a separate market/procurement mechanism or by factoring in these services when clearing the wholesale electricity market (known as co-optimization). Other resources, such as demand response, may also participate in these markets (see Section 3.7).

The design and implementation of dispatch rules can significantly impact the ability to manage variable renewable generation on the system and has implications for the economic viability of renewables as well. Some of the key considerations for renewables are the frequency of dispatch, the structure of imbalance penalties, rules for curtailing generation particularly for system balancing, and the ability of generators to revise bids based on more updated forecast data (Hogan et al. 2015; Bird and Milligan 2012; Porter et al. 2012; Cochran et al. 2012; IEA 2014).

Short dispatch increments and the ability to revise bids during the day based on updated forecast data enable markets to more effectively use available renewable generation. Typically, competitive wholesale markets dispatch generation every five minutes. Fast dispatch (e.g., every five minutes) can help effectively utilize available VRE ensuring that merit-order dispatch, rather than more expensive regulation, responds to intra-hour variability. Moreover, VRE that is dispatched in five-minute increments can maintain a relatively steady output over that time and is more likely to remain at the generation set-point. The use of intraday markets and shorter gate-closure can also be helpful and lead to more efficient market operations by enabling renewables to provide more accurate information about their expected potential output, which can be incorporated into dispatch decisions (Ela et al. 2014).

The design of imbalance penalties that are assessed when scheduled generation deviates from actual delivered generation can be important for effective utilization of renewable generators, particularly wind energy. These penalties can also encourage improvements in forecast quality, which is important for efficient operations. The band of acceptable schedule deviations and the magnitude of penalties for violation of imbalances are of critical importance for the economic viability of wind generators and for effective system operations (Cochran et al. 2012).

Similarly, rules regarding curtailment are an important consideration for markets with substantial penetration of renewable generation because there may be instances where renewable curtailment is the most economic means to balance supply and demand. Rules and procedures for implementing curtailments can be important considerations for markets with substantial clean energy resources. Automated and market-based procedures can reduce the amount of overall curtailment of wind generation by reducing the duration of the curtailment event (Bird et al. 2104; Lew et al. 2013).

3.3 Use of Forecasting

Forecasts are important both at the system operator level as well as for all generators and market actors (e.g., demand response providers) for maximizing revenues and for the market operator to maintain system reliability (Tian and Chernyakhovskiy 2016). The trend across large RTOs is to employ system-wide forecasts, potentially in addition to individual plant forecasts. System-wide forecasts employ a consistent forecasting methodology and, aggregated across the system, provide more accurate results than individual plant forecasts.

Integration of forecasting into market operations is important for continuous system balancing, as well as planning for extreme weather events to avoid system outages (Cochran et al. 2012; Porter and Rogers 2012). Forecasts of available renewable energy can reduce the amount of conventional generation committed day-ahead and thus improve the efficiency of operations. The use of centralized forecasts can enable the system operator to ensure that adequate capacity is brought online to meet demand when significant storm events are predicted (Bird and Milligan 2012; Cochran et al. 2012).

3.4 Provision of Ancillary Services

Ancillary services include a variety of system support services, such as frequency response, reactive power supply and voltage support, and the restoration of the system after a contingency event (Stoft 2002). Many wholesale electric markets have ancillary service markets for spinning reserves, non-spinning reserves, and regulation service for minute-to-minute balancing. Some ISOs in the United States use wholesale market dispatch software that uses a co-optimization approach to optimize for least-cost provision of energy and ancillary services. For systems that may be expecting high penetrations of variable renewable generation, consideration of revised and/or more sophisticated ancillary service market design may be warranted (Ela et al. 2011).

Newly restructured markets with an eye toward clean energy, in particular VRE, may wish to consider market designs that change the way that the following services are provided to the system: load following, frequency responsive reserves, inertial response, and reactive power support (Ela et al. 2011; Ahlstrom et al. 2015). Some of these services have been provided automatically by system participants in the past, particularly load following and inertial response, but may not be automatically provided with a mix of generators with such distinct generation characteristics.

Market rules can enable renewable generators to compete fairly to provide these services (Ela et al., forthcoming), or alternatively they could be required through incentive support mechanisms (e.g., feed-in tariffs) or grid codes, as discussed in Section 4 (Jacobs et al. 2016).

3.5 Flexibility Resources and Emerging Market Products

Some market operators have recently introduced new market products (beyond traditional energy, capacity, and ancillary services markets) that they believe may be helpful for achieving the additional system flexibility needed to address system requirements as they transition toward a decarbonized system. New market products are being introduced in some jurisdictions to address ramping needs resulting from greater variability in the system net load (Wang and Hobbs 2014). For example, CAISO’s flexible ramping (“Flexiramp”) products—that can ramp both up and down—are meant to address short-term load uncertainty. The Flexiramp products, which are co-optimized with energy and reserves, provide a “safety margin” in case net load unexpectedly differs from forecasted levels. Most other ISO’s in North America are also developing flexible ramping capacity products or modifying existing capacity incentive mechanisms to enable the system to address ramping needs (Kara 2016; Navid and Rosenwald 2013). Remuneration of assets for their flexibility services is also maturing, including those services provided by variable renewable generation (Hogan et al. 2015; Ahlstrom et al. 2016).

3.6 Retrofitting Existing Generators

In some jurisdictions, system operators have provided incentives to conventional generators to increase their operational flexibility. In certain cases, conventional generators cannot run below a minimum threshold level. In periods of low load and high VRE generation, this creates situations in which the operator may have to curtail generators or encourage reductions in output through pricing mechanisms or incentives. Conventional generators can also play a role in alleviating these situations through equipment upgrades and operational changes that can enable them to run at lower output levels and improve ramping capabilities (Porter et al. 2012; Cochran et al. 2014). South Australia, for example, offers incentives for plants to increase their flexibility and be better able to take advantage of market opportunities. As such, older coal generators with steam bypass capabilities are using them to reduce generation below previous minimum generation levels to avoid negative prices in periods when loads are low and there is excess generation on the system (Cochran et al. 2012).

3.7 Platforms for Demand-side Participation

In addition to generation resources, other technologies and practices can also provide flexibility. Demand response has conventionally focused on peak load shaving through "the reduction of a customer's electric consumption in response to market signals" (King 2015). With new technology options and market reforms, demand response is increasingly used across a range of wholesale energy, ancillary service, and capacity markets to provide not just peak reduction but reserves and other services (Cappers et al. 2011; Cochran et al. 2013). There is evidence of higher demand response participation and activity in wholesale markets versus vertically integrated utilities in the United States (Hurley et al. 2013).

Depending on the time frame in which the demand response provider can curtail load and requirements for telemetry and dispatch control, they can provide spinning, non-spinning, regulation, and load following services (Lauby et al. 2009). Texas has proven demand response programs that act as spinning and non-spinning reserves to provide resources during system emergencies. In a few European countries, demand response has gradually been allowed to participate in balancing markets and to provide reserves. Demand response has also been integrated in capacity mechanisms, which are being implemented at the moment in France, the U.K., and Belgium (see Figure 3).

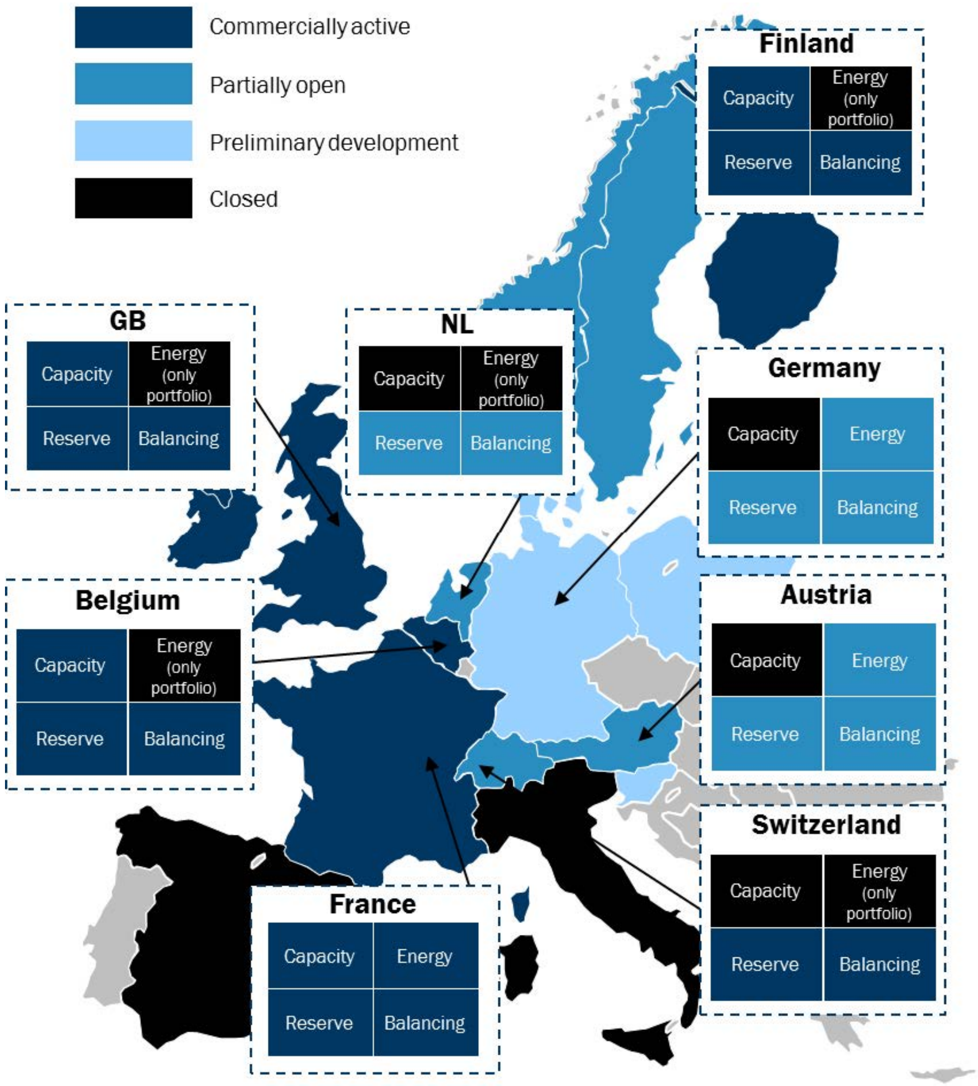

Figure 3. Extent of demand response in wholesale markets in Europe

Source: Roques et al. (2015)

Demand response providers and system operators are experimenting with different technology options for regulation and load following services, e.g., water heaters, electric vehicles, water pumping, and space heating. New market designs and products are emerging to incentivize flexible resources to participate in wholesale markets, including demand response. Demand response may be able to participate via the ramping products in CAISO (see above) and incentives for flexible balancing services in MISO. A nascent area is storage-type demand response that can shift load to absorb excess generation and reduce the peaks, also helping mitigate system ramping needs.

Barriers still remain to deploying the full market potential of demand response, especially as a flexible resource. The following are considerations for designing and implementing demand response in wholesale markets (Smart Energy Demand Coalition 2016):

- Whether demand response can participate in all energy markets (wholesale, balancing, ancillary services and capacity) as other generation sources do.
- Whether third party aggregators can access all markets and effectively acquire customers.
- What range of applicable technologies can participate (e.g., distributed generation and storage).
- How market prices are set and whether they reflect the value of electricity in real time.

3.8 Key Takeaways for Market Design and Operations

1. The design and implementation of dispatch rules can significantly impact the ability to manage variable renewable generation on the system and has implications for the economic viability of renewables as well. Short dispatch increments and the ability to revise bids during the day based on updated forecast data enable markets to more effectively use available renewable generation.
2. The band of acceptable schedule deviations and the magnitude of penalties for violation of imbalances are of critical importance for the economic viability of all flexible assets and for effective system operations.
3. Rules and procedures for implementing curtailments, particularly for system balancing, can be important considerations for markets with substantial vRE.
4. Integration of forecasting into market operations is important for operational and economic efficiency, including continuous system balancing as well as planning for extreme weather events to avoid system outages. System operators need adequate data from generators to ensure accuracy of system level forecasts, so data requirements may need to be instituted as a condition of interconnection.
5. Newly restructured markets with an eye toward clean energy may want to consider market designs that change the way that the following ancillary services are provided to the system: load following, frequency responsive reserves, inertial response, and reactive power support.
6. New market products, such as ramping products, may be helpful for achieving the additional system flexibility needed to address the variability and uncertainty introduced with variable renewable generation.
7. Demand response can be an important component of system flexibility and can help address system balancing during extreme weather events when renewables are unavailable. Using responsive loads can be more cost effective than maintaining a larger reserve pool.

4 Grid infrastructure, Interconnection, and Grid Codes

Addressing **grid infrastructure, interconnection protocols, and access to the grid for VRE generators and other forms of clean energy** is essential for reliable, fair, and efficient electricity markets. Key considerations for markets undergoing restructuring and expecting growth in clean energy are:

- How can grid expansion be adapted to meet the needs of the current and future generation resource portfolio?
- How can a fair and transparent interconnection process for all forms of generation, including VRE, be created and maintained?
- How can the grid code be updated or enhanced to incorporate requirements for VRE and other forms of clean energy?

A key element for encouraging a robust competitive wholesale market is an open-access transmission system in which all eligible market participants receive nondiscriminatory treatment. Systems expecting high penetrations of variable renewable generation may require additional transmission investments, modifications to transmission planning processes, revised interconnection procedures, and updated grid codes for clean energy generators.

4.1 Transmission Network Planning and Expansion

As mentioned in Section 2.1, new grid investments may be required to accommodate greater penetrations of variable generation in addition to a number of other factors. Clean energy resources may be more geographically dispersed than conventional generators. The most suitable sites (i.e., windy or sunny areas) may or may not be optimally located with respect to availability on the transmission network and load centers. Renewable generation can also differ from conventional plants in that wind projects, or other renewables, can often be built more rapidly than transmission infrastructure.

To address these issues, one practice that has emerged in several markets (e.g., Texas and Mexico) with high penetrations of clean energy is to integrate generation and transmission long-term planning and create renewable energy zones. In Texas, high quality wind resources are distant from large load centers, the investment time frames for VRE deployment and transmission extension were not aligned, and there was a co-investment conundrum. The state legislature gave the Public Utility Commission of Texas the authority to conduct a planning process to create Competitive Renewable Energy Zones (CREZ), which identified areas to build a few strategic high-voltage lines based on wind potential (Hurlbut 2010; Zarnikau 2011). This practice, which involves a diverse set of constituencies, has also been adopted in Mexico (see Section 6). High-Potential Renewable Energy Zones will be updated on a five-year time horizon and incorporated into the annual 15-year electricity market plans produced by the Mexican Department of Energy.

The EU, via the European Network of Transmission System Operators for Electricity (ENTSO-E), is also working on pan-Europe transmission plans to enable better regional cooperation and integration of larger balancing areas. Australian Energy Market Operator's National

Transmission Network Development Plan specifically delivers a forecast of the network and market development over the next 20 years (AEMO 2015).

4.2 Cost Allocation for Transmission Investments

One key consideration in developing network expansion policies and regulations in a restructured environment is how to appropriately allocate the cost and risk of network expansion among developers and ratepayers in accordance with policy goals. Costs for network expansion might be borne by generators, transmission providers, or consumers, and the allocation amongst these actors can vary. In cases where the primary driver for expansion is reliability the costs may be "socialized" uniformly across the electricity users, and in other cases cost may be partially or completely allocated to the end-users that benefit the most (MIT 2011). In the United States, Federal Energy Regulatory Commission (FERC) Order 1000 specifies, for example, that "regional transmission planning processes must designate one cost allocation method for all utility transmission providers and neighboring regions must have a common interregional method" (FERC 2011). The cost allocation method can impact the financial viability of clean energy projects, especially if the resources must bear a greater burden of the costs.

Transmission usage costs generally come in two flavors, flow-based or postal-rate methods. The postage stamp method—where there is a fixed charge for transmission access that is not related to the sending or receiving location—generally reduces the financial burden on VRE generators. The flow-based or "pancaking" method—where access is charged according to the level of use—tends to increase the financial burden for VRE generators, especially in cases where the generator is located further away from load (Madrigal and Stoft 2011).

4.3 Interconnection Processes and Queue Management

Interconnection processes and queue management can also impact clean energy project economics and the ability for clean energy resources to participate in the wholesale market. Streamlining the interconnection process for resources applying to connect to the network can reduce the project burden in terms of time and resources needed for the application process.

Often generator interconnection procedures are separated into those for large generators and more simplified procedures for smaller generators. In some cases, generators requesting interconnection bear the cost of studies or upgrades required for interconnection (Madrigal and Stoft 2011). For example, in the United States, large generators (greater than 20 MW) are subject to interconnection procedures where the review of the interconnection request by the relevant grid operating entity is conducted through a series of studies, which become more stringent in the level of detail and financial commitment (Fink et al. 2010). Because of the potential time and cost of these processes, details regarding the stringency of requirements and rules regarding fast-track procedures for small generators are vitally important to the ability of clean energy generators to connect to the grid (Barnes et al. 2013).

Interconnection queues impact the ability of generators to connect to the system and the costs they may face for interconnection. Queues can be more efficiently managed through various practices to weed out less serious applicants, conducting the queuing more cost-effectively, and streamlining the process overall (Fink et al. 2010). Often, transmission providers assign generator interconnection queue positions according to the date and time that an interconnection request is received. The interconnection queue position then determines the order in which the series of interconnection studies are conducted and how interconnection construction costs are allocated.

The “first come, first served” allocation method may not truly reflect the user’s willingness to pay for the transmission rights as compared to a competitive tendering process (ERRA 2014; Miller and Cox 2014). Deposit requirements for connection rights could encourage only serious resources to apply and inserting milestones into the application process could help to keep the original time frame of the connection schedule and prevent blocking the connection point by stalling projects. Interconnection assessment fees were adopted in Mexico based on experience with their previous interconnection process (see Section 6). In Ireland, EirGrid, the system operator, created a queue management protocol called the “Gate System” by which a group of applicants with unique criteria could be processed together (Miller and Cox 2014; CER 2008).

ERCOT and other ISOs throughout the United States are increasing the technical requirements for interconnection of renewable generators, particularly for wind and solar generators. This includes requiring more technical data (e.g., voltage regulation, frequency response, or reactive power), meteorological data, commissioning plans, testing requirements, and more stringent review from the ISO during registration. Some of these new requirements depend on the location of grid interconnection and can significantly affect design and cost, but also ensures that projects in the queue are viable (Mena 2013).

4.4 Modernizing Network Connection Grid Codes

With higher levels of VRE and demand-side resources on the system, it is critical to ensure that the grid code has been updated or reflects the necessary components to enable system reliability with any mix of resources and reduce curtailment (Ackermann et al. 2016). Grid codes are rules addressing how generators or other resources must connect to the electric power grid in order to maintain system reliability. Grid codes include interconnection and operating procedures such as real power control; reactive power and voltage control; frequency and inertial response; voltage and frequency ride through; and communications between the power plant and grid operator (Altin et al. 2010). Development of enhanced grid codes in systems with higher penetrations of clean energy can address the technical complexities that clean energy adds to the system as a result of their operating characteristics. In general, generators should contribute to grid reliability to the extent feasible based on their physical characteristics and capabilities.[22] Strong grid codes can benefit renewable energy manufacturers, developers, and utilities and allow plants to support system reliability requirements.

When updating grid codes, a necessary first step is to evaluate existing rules to determine if new approaches to design and implementation are needed for high penetrations of renewable energy. Two recent examples include grid code modifications in Europe by ENTSO-E and in North America by North American Electric Reliability Corporation (NERC). The network codes drafted by ENTSO-E, with guidance from the Agency for the Cooperation of Energy Regulators

[22] For example, see NERC requirements http://www.nerc.com/comm/PC/Integration%20of%20Variable%20Generation%20Task%20Force%20I1/IVGTF%20Summary%20and%20Recommendation%20Report_Final.pdf

(ACER), are unique in that they include grid codes for integrating demand side resources and are working to create a an environment for harmonized solutions and products necessary for an efficient pan-European market. ENTSO-E grid connection codes include a network code, demand connection code, and high voltage direct current connection code (Paquel 2014).

NERC led an Integrating Variable Generation Task Force (IVGTF) process that involved a broad array of relevant stakeholders: utilities, ISOs, turbine manufacturers, project developers, research organizations, consultants, trade associations. The objective was to develop standards that were fair, transparent, and performance based (Piwko et al. 2012). The NERC IVGTF efforts resulted in a number of detailed technical recommendations for the following topics: reactive power and voltage control, performance during and after disturbances, active power control, harmonics and subsynchronous interactions, models for facility interconnection, and communications between plants and operators.

Both the ENTSO-E and the NERC processes, though different in approach and scope, demonstrate open and transparent efforts to modernizing grid codes to better incorporate clean energy. Power systems have different operating challenges and requirements; therefore, required grid codes can differ across jurisdictions. Also, the level of penetration of clean energy sources has implications for when requirements may need to be instituted. There is a balance to be achieved in setting requirements so that they do not need result in retroactive requirements on generators, but not so stringent that they unduly burden clean energy generators (Cochran et al. 2012).

4.5 Key takeaways for Infrastructure, Interconnection, and Grid Codes

1. For network expansion and investment in a restructured environment with significant clean energy resources, key policy and regulatory considerations are how to expand infrastructure investment to accommodate clean energy resources and appropriately allocate cost and risk of network expansion among developers and ratepayers in accordance with policy goals.
2. To enable continued development of clean energy resources, it is important to streamline the interconnection process for resources applying to connect to the network to reduce the project burden in terms of time and resources needed for the application process.
3. With higher levels of VRE on the system, updated grid codes can reflect the necessary requirements that enable system reliability and reduce curtailment. Modifications may be needed for grid codes for variable generators pertaining to: power control, reactive power and voltage control, frequency and inertial response, and voltage and frequency ride through.

5 Clean Restructuring in Practice: Introducing the Case Studies

The previous sections articulated critical elements for any clean restructuring effort, and distinct pathways will be charted for each individual power system due to local resources and technologies, economic drivers and the political environment. To illustrate this, three 21st Century Power Partnership countries are featured in case studies in the following sections. Germany and Denmark are both previously restructured markets continuing to evolve to further incorporate higher penetrations of clean energy, and Mexico is in the midst of power sector reforms where policies and market structures have been designed with an eye toward increasing levels of clean energy in the near future.

The Mexico case study focuses on the domestic impetus for restructuring and the first steps that are being taken from transitioning market actors to the launch of the first clean energy certificate auction. The Mexico case study also provides a more comprehensive overview of the main elements of clean restructuring that are being designed and implemented. The case study for Denmark focuses on its efforts to create and maintain a well-functioning regional cooperation on energy trade and balancing of their electricity markets. Lastly, the case study for Germany provides some historical background for the power sector including the factors in the energy transition that led to the resulting domestic debate regarding an energy-only market vs. energy plus capacity markets. The case study describes the policymaking process and also key elements of the final electricity market 2.0 design.

Critical insights can be gleaned from these individual case studies that can be applied to the global context for future clean restructuring efforts. First, creating a truly competitive market environment that attempts to establish a level playing field for various market actors requires a diversity of perspectives and inputs. Strong stakeholder engagement mechanisms seem to be a critical aspect of successful wholesale market design and grid infrastructure planning, interconnection and expansion in restructured markets. Including primary market participants, generators, consumers, grid operators and system operators as well as other relevant stakeholders in market design processes helps to contribute to an open and transparent environment and alleviated information asymmetries.

- In 2015, the German Federal Ministry for Economic Affairs and Energy conducted a structured process to collect multiple perspectives on methods for addressing recent electricity sector challenges. Several phases of public engagement were conducted, including publishing a “green paper” of initial proposals, public meetings, technical meetings, comment periods, publishing a white paper (BMWi 2015a) that outlined the debate and the decisions, and finally legislation to codify the outcomes of this process.

In addition to strong public engagement, mechanisms for ongoing political and institutional support for clean restructuring efforts, especially those of a transnational nature, can also provide a long-term and stable policy environment within which markets can operate.

- Denmark participates in the Nordic Council of Ministers subgroup on energy that has prioritized electricity market development for Nordic Pool. This political support has enabled key decisions to be made on pressing issues while also providing the long-term certainty that system operators and regulators need to be able to focus on the more technical aspects of the regional cooperation.

Particular elements of clean restructuring may also be phased in over time, especially as the levels of clean energy in the power sector gradually increase. With higher penetrations of clean energy, in particular VRE, more sophisticated policies may be needed to address more acute changes in the power sector. However, there may be ways to lay the groundwork with policies that would anticipate future growth in clean energy. The *Overview of Variable Renewable Energy Regulatory Issues* (Miller and Cox 2014) provides one framework for categorizing and envisioning how clean restructuring policies and practices might be phased in.

- Mexico is planning to implement a capacity market, which may not be fully utilized in the early stages of the power system reform, but may play a greater role as the power system transitions to cleaner energy sources.

These highlights and some of the examples in the previous sections demonstrate that clean restructuring has successfully been in practice across the world and though each power system transformation must be handcrafted, there are emerging best practices and evidence of effective market design approaches that can be shared universally.

6 Clean Restructuring in Mexico

Mexico is undergoing a sweeping energy reform away from a power system centered on a vertically integrated state-owned enterprise and into a restructured market that can accommodate the call for market competition and political commitments on clean energy transitions.

Mexico's energy transition policy is informed by a broader climate change framework, which mandates Mexico to reduce greenhouse gas emissions by 50% in 2050 from the levels observed in 2000: about 320 million metric tons of carbon dioxide equivalent or 2 tonnes carbon dioxide equivalent per capita. The power sector will need to revise its prospective role in realizing evolving climate commitments, but mechanisms that can realize the potential growth in renewable energy in the short and mid-term must first be successfully deployed.

The reform emphasized a two-pronged strategy of structural transformation: 1. improving productivity through market competition and restructuring, and 2. reducing power production costs and emission through the increase of natural gas and renewable energy supply in the market against the share of heavy fuel oil. Power sector legislation in Mexico mandates that 35% of electricity generation is sourced from clean energy (including nuclear, efficient co-generation, and hydropower) by 2024, but Mexico's Nationally Determined Contributions indicate that this share might surpass 43% by 2030.

Until recently the deployment of VRE, mainly wind power, was geographically concentrated in the southern state of Oaxaca. This location managed variability through coordinated dispatching of rich hydropower resources. But as the expansion of VRE accelerates with a much more diverse geographic profile, markets should allow for enhanced system flexibility. As an example, market restructuring can allow Mexico to integrate with neighboring energy markets. Mexico could not only become a more significant player in the Central America Integrated Energy System and Market, but also with power systems in the north, in California and Texas, developing fully integrated cross-border balancing regions.

Amongst developing countries Mexico stands out because of two relevant achievements. First, it is one of the top five geothermal power producers in the world, which has incidentally facilitated the development of geothermal power in Central America. And second, more than 98% of the population has access to electricity in Mexico. Nonetheless, Mexico will also evolve in the management of the geothermal industry which until recently has been entirely publicly developed and owned. The Mexican government has also developed a novel approach to finance and addressing the remaining population without access to electricity, in many cases through the deployment of renewable energy based solutions.

In March 2016, the result of the first long-term energy auction, a cornerstone of energy transition policy, provided an optimistic perspective on the role that renewable energy will play in Mexico's power market evolution. With the lowest power purchase agreement price for a solar power plan in the world—less than 40 USD per megawatt hour—renewable energy is expected to grow as long as power system expansion is conducted accordingly.

6.1 Background and Overview of Timeline

In December 2013, the Congress approved power sector reform as part of a larger energy reform, which also included the entire value chain of the oil and gas industry, transforming the investment and policy framework of the entire energy sector. The first sets of power sector reforms were initiated more than 20 years earlier in 1992. Mexico allowed private investment in generation enabling the state-owned utility and monopoly Comisión Federal de Electricidad (CFE) and large power consumers to tap into private capital and business models to invest in power generation. This system was comparable to what is observed today in South Africa and Eskom.

Regarding clean energy deployment, the 2013 reform builds on the previous policy experiences, including those that established climate change commitments and the policy goal of developing renewable energy. In 2008, legislation was introduced for the first time on the promotion of renewable energy and the sustainable use of energy, and provided the first steps to develop institutions that were oriented to guide the energy transition. For this reason, the Constitutional amendment of 2013 articulated the need for adequate policies for the deployment of low carbon emitting technologies (herein clean energy) through market-based instruments. Key economic principles included the policy requirement to maintain a balance between clean energy deployment and the economic burden to market participants, and that the government would not carry any direct burden, e.g., subsidies, for clean energy deployment policies.

As in other economies, the concern for power prices has always been a driving force for reform in Mexico. In 2014, Mexico's power tariffs for industrial consumers were still significantly larger than those of the United States, its main trade partner. Industrial consumers, if dependent on CFE service, would pay on average 73% more than peers in the United States. By contrast, heavily subsidized domestic users would pay about 28% less than the average domestic consumer in the United States (IEA 2015a). The benefits of reducing power production costs would be two-fold: first, convergence to U.S. price could boost manufacturing output by 5.5–14%, and GDP by a significant range of 0.9–2.2% (Alvarez and Valenzuela 2015); second, cost reductions would significantly reduce the burden of domestic consumer subsidies on the federal budget (Hernandez 2006).

Based on the constitutional amendment of December 2013, the government, under the leadership of the Department of Energy (SENER by the Spanish acronym), proposed a legal framework that was presented to the Congress and approved in August 2014. The cornerstone of the new power market structure was the Law on Power Industry (LIE by the Spanish acronym), which established the new market structure, created an ISO, established the new responsibilities between authorities, and established the guidelines for the transition period, including the rules applicable to incumbent private stakeholders. These rules became fundamental to avoid undermining investors' confidence. The ISO under the acronym CENACE gained independence from its previous role as the system control unit within CFE.

In addition to LIE, the Congress passed the Law on the Federal Commission of Electricity, the Law on Coordinated Regulating Bodies on Energy, and the Law on Geothermal Energy, and several other important laws regarding distribution of competencies and administrative mandates. The Law on CFE established a new governing body, which would include independent Board members, and defined the general lines for horizontal and vertical unbundling, which would ultimately be defined by the Energy Secretariat. The latter two laws established new mandates and structures for decision making. The new structures applied to all of the work under the Energy Regulatory Commission (CRE), with most of the specific mandates provided in other substantive laws.

During the subsequent 18 months, the implementation work focused on meeting two goals: firstly to have the wholesale electricity market operating by January 2016 and secondly to complete a full transition period by 2018. To meet the first goal, SENER developed the body of regulation for the wholesale market, which included first and foremost the market rules. Various market manuals were also published on topics like long-term auctions, grandfathered interconnection contracts, bilateral transactions for market participants, and several more covering various topics concerning the operation of the market.

Other key items regarding system expansion policies and planning were developed from mid- and long-term perspectives. The development of the new system expansion planning process was finally linked to the rules and procedures for private participants to secure interconnection for new projects and sign provisional contracts. But the results of such new policies will take some time to have an evident effect, as new market participants join.

By June 2015, SENER published the first version of a Power Development Program (PRODESEN) with the participation of CENACE and CRE. PRODESEN mandated key infrastructure projects—such as the first direct current (DC) line to serve mainly wind power generation. During this time, clean energy certificate (CEL) mandates were established and long-term auctions were developed. The first CEL mandate was set three years in advance, in the month of March 2015 for compliance in 2018 by market participants. The second obligation was set in March 2016. CELs would be required for 5% of the total energy demanded by suppliers and large consumers. CELs would be granted to clean energy producers, excluding grandfathered projects.

Despite the fact that key instruments for the deployment of the clean energy transition were included in LIE and enacted as early as August 2014, different stakeholders felt that transition policies and institutions were still insufficient or weak. In 2014, a draft legislation, the Law on Energy Transition (LTE), was introduced in Congress, but was not approved by the Senate until late 2015, when the president joined other world leaders in Paris at the 21st Conference of Parties (COP21) climate conference. LTE mandates existing institutions to focus their work in the promotion, in particular, of energy efficiency and distributed generation, both of which had been left out of the main components of the previous regulation.

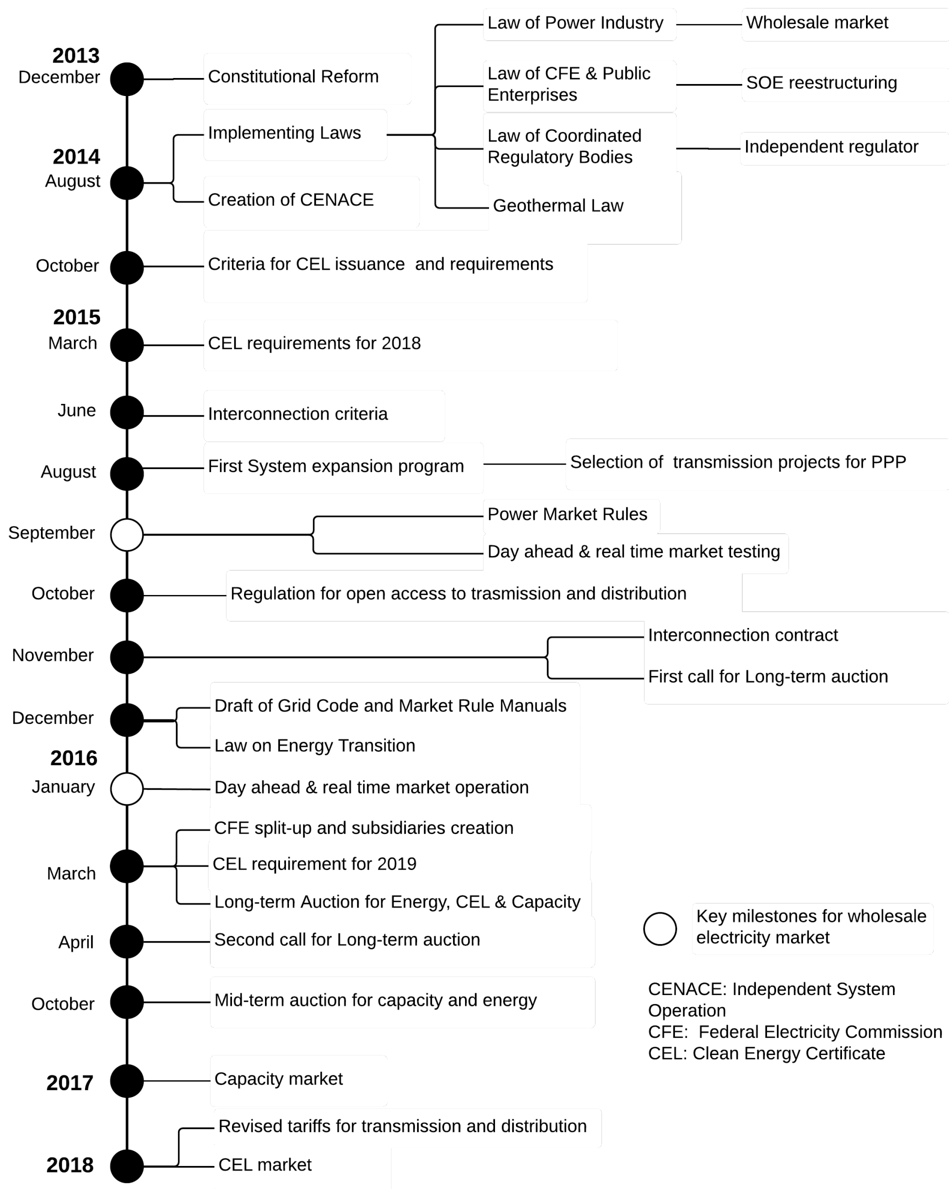

Figure 4. Timeline for Mexico clean restructuring efforts

6.2 Review of How the Roles of Various Actors Evolved

Energy stakeholders in Mexico are changing roles and internal structures to respond to new mandates and meet the goals that were the original objectives of the major energy reform in Mexico. On one hand, the authorities—SENER and the CRE—are in charge of setting the guidelines for the power sector development. CENACE remains in charge of the system control and energy dispatch, and CFE is now the main player in the recently created wholesale electricity market. The Secretariat of Finance and Public Credit (SHCP by its Spanish acronym) is no longer involved in the budget approval for CFE, but because CFE is a state-owned enterprise, SHCP retains control of debt approval levels for the state productive companies.

Institutions such as CENACE and CRE transitioned to their new structures by acquiring district governing bodies. In the case of CRE, new commissioners were elected. In the case of CENACE, an involved transition of assets and personnel had to take place over the course of a few months, which allowed CENACE to preserve highly experienced public servants able to continue the transition process.

As the head of Mexico's energy sector, SENER is responsible for issuing the Mexican Energy Policy, which sets the long-term goals that must be achieved in terms of clean energy, energy efficiency, electric reliability, smart grid, etc. For instance, in terms of clean energy, Mexico has committed to reaching 35% of power generation from clean energy by 2024. According to the new LIE, SENER's explicit authority includes:

- To conduct the national energy policy in terms of electric energy
- To align the development of the electric industry with the PRODESEN
- To lead the PRODESEN planning process and publication
- To elaborate the first market rules and monitor the performance of the wholesale electricity market (during its first year)
- To establish the requirements for acquiring and granting CELs
- Establish policies for distributed generation and smart grids
- Provide information on high potential zones for clean energy deployment
- Manage the newly created Fund for Universal Power Service.

A new Law on Geothermal Energy was issued at the same time as the LIE. The Law created the concept of geothermal exploration and production, which in the previous legal regime was treated as a subsidiary activity in the regulation of underground water reservoirs. That regime was meant to regulate water wells, providing no certainty for investors interested in the integrity and the value of entire geothermal fields. Hence, by providing a clear legal framework to protect the rights of field developers, this resource was finally made available to private investment or, as expected by many, to public-private investment between CFE and investors eager to develop vast geothermal resources in Mexico.

Energy reform made CRE a stronger regulator with more authority. CRE is responsible for issuing a suitable and predictable regulatory framework that encourages certainty for the former and new players in the sector. Since its creation in 1993, CRE has worked in both the hydrocarbons and power sectors, in which its main role was permit issuance. In terms of electricity, CRE has been responsible for issuing all generation permits in Mexico under six different schemes (self-supply, IPP, import, export, cogeneration, and small production). As a result of the energy reform, CRE's responsibilities have expanded not only in generation sector, but also in transmission, distribution, the wholesale electricity market. According to the LIE, CRE's authority includes:

- To issue all permits defined in the LIE and decide on their issuance, modification, and revocation

- To set the guidelines and rules for transmission, distribution, and energy supply, including tariffs
- To oversee CENACE's performance and set the tariff regulation for its cost recovery
- To issue the regulation in terms of electric efficiency, power quality, and electric reliability
- To update and modify the market rules and monitor the performance of the wholesale electricity market (after its first year).

CENACE is a former department within CFE, now reconstituted as an independent body created by Executive Order. CENACE's role is to control and operate the Mexican power system and to ensure open access to the grid in a transparent and equal manner, as well as to propose the expansion strategy for the transmission network and the wholesale electricity market infrastructure. Within this new context, and according to the LIE, CENACE's authority includes:

- To operate and control the transmission and distribution system to maintain a reliable and secure electricity supply
- To operate the wholesale electricity market and clearing all of its operations including energy dispatch, ancillary services, financial transmission rights, capacity, and CEL transactions
- To conduct auctions in the long and short term to acquire capacity, energy, and CELs, as well as to conduct specific auctions related to maintain reliability
- To propose to SENER and CRE the program to expand and modernize the transmission network as well as the wholesale electricity market infrastructure
- To propose to CRE technical specifications related to the interconnection of new generators and load centers.

The role of CFE is the one that has changed the most. Prior to the reforms, CFE was a state-owned company in charge of conducting the activities of generation, operation, control, transmission, distribution, and supply maintaining a vertically integrated sector. But after the reforms, the activities of control, operation, transmission, and distribution are considered strategic and therefore remain under federal government control. Control and operation activities were assigned to CENACE whereas transmission and distribution remained under CFE as regulated by CRE.

As a result of the energy reform, CFE's role in the power sector should be seen as follows:

- Generation: CFE competes in the wholesale electricity market, unbundled into four distinct and independent companies.
- Transmission: CFE is responsible for the operation of the transmission network, ensuring open access under CRE's regulation. CFE is also responsible for constructing the infrastructure for expansion and modernization according to SENER's instructions.

- Distribution: CFE is responsible for the operation of the distribution network, ensuring open access under CRE's regulation. CFE is also responsible for constructing the infrastructure for expansion and modernization according to SENER's instructions.
- Retail: CFE is a player in the wholesale electricity market, competing with other load serving entities to represent qualified residential users and to commercialize energy to end-use customers. According to SENER's mandate, CFE retail services must be unbundled into nine companies.

As a result of the energy reform, CFE has changed from a vertically integrated company into a state productive company with 10 branches (6 for power generation, 1 for distribution, and 3 more for basic supply, transmission and commercialization), and the new legal designation for both energy state-owned enterprises, CFE and Petróleos Mexicanos, the national oil company. The concept implies that the enterprise should focus on only value-creating activities, leaving the economic burden of social challenges—like rural electrification—to SENER. In the long term, under this new legal framework, CFE will move into other profitable markets and eventually rely entirely on its own revenue and not the federal budget.

The LIE also established a series of new responsibilities such as the development of a social impact assessment subject to SENER's approval and the consultation of indigenous communities for new power generation projects. Also, prior to the reforms, CFE was responsible for providing access to electricity to the citizens of Mexico with a limited budget, and this responsibility would be transferred to SENER with support from the Fund for Universal Power Service. This energy access trust fund was created to achieve universal electricity coverage not only in rural areas but also high risk and marginalized populations within large cities. The trust fund will obtain revenues from penalties for failing to meet with clean energy certificates requirements and from reduction of technical and non-technical transmission and distribution losses.

SHCP is no longer involved in the budgetary approval of CFE. In the former legal regime, CFE presented an entire power sector expansion strategy. The plan, known as POISE, was submitted to SENER and SHCP along with financial analyses for approval. The main requirement that CFE had to meet was to demonstrate that the projects included in the POISE presented only positive returns. In practice, the criteria used proved to be unsuitable to evaluate the economic return of renewable energy or demand response projects.

Now the process for budget approval has changed. Once CENACE and Distributors (CFE among them) submit the programs to expand and modernize both transmission and distribution networks, CRE will provide an assessment of them to SENER which finally will integrate the PRODESEN. Within PRODESEN is a collection of new infrastructure that SENER could instruct CFE to build. In that case, all costs should be recovered by the transmission and distribution tariffs approved by CRE.

6.3 Review of Key Clean Restructuring Design Elements

6.3.1 Grid Planning and Interconnection Rules

Before the reform, many private developers expressed that a clear and transparent process for interconnection would be critical for new projects to be competitive. In particular, developers identified two primary barriers: (1) the ability to access transmission infrastructure, and (2) the lack of an administrative process for project interconnection approval. SENER and CENACE designed the process based on the principles required by law and put CENACE in charge of the process. As compared to the original process which was free, CENACE would now be able to collect specific fees for each application, and be able to adequately respond to the volume of applications they might receive.

CFE, in its previous roles of system and transmission operator, faced challenges with the interconnection assessment process after the adoption of new promotion policies in 2009. In these policies, CRE and CFE were mandated to eliminate any charge for all the permitting required for renewable energy generation, including those relating to the interconnection. With no application fee and little or no available information regarding regional transmission capacities, most developers adopted a strategy of submitting as many applications as possible for interconnection assessments at a cost to CFE. Developers systematically complained about the time frame in which assessments were completed and the lack of transparency with respect to the technical criteria being used in the assessments that could inform more resource-efficient strategies.

Furthermore, based on the previous regulatory regime, grid expansion planning primarily focused on the interests of CFE. In practice this meant that it was difficult for private developers to have their projects included in grid expansion planning efforts, and CFE could not legally include an assessment of the potential growth of private sector projects. This resulted in limited spare capacity in transmission networks for the integration of large renewable energy projects, therefore making them uncompetitive because of required upgrades to the grid, or delaying their interconnection. If not reformed, these processes would have deepened administrative bottlenecks, prevented renewable competitive projects from going forward, and further complicated transmission and operational planning by CFE.

The new planning and interconnection rules are meant to enhance the development of a competitive market, reduce the regional differences on marginal cost of energy and prepare for rapidly rising share of variable renewable energy. A new 15-year planning document is issued by SENER in the first half of every year. Several components are developed by CENACE particularly those regarding grid expansion and includes significant detail for a 5-year period.[23] In addition to the economics of improving regional grid interconnection, the planning document incorporates all interconnection applications within a 12-month period. And as the legal regime unfolds, it will also take into account the new High-Potential Renewable Energy Zones, similar to the Competitive Renewable Energy Zones in Texas.

[23] PRODESEN: Programa de Desarrollo del Sistema Eléctrico Nacional 2015 http://www.gob.mx/sener/acciones-y-programas/programa-de-desarrollo-del-sistema-electrico-nacional-8397.

Table 2. Comparison of Interconnection Process Pre- and Post-Reform

Key Characteristics	Pre-Reform	Post-Reform
Reviewing authority	CFE	CENACE
Time (entire process)	Not defined	45-160 days depending on scale
Cost of application	Free	~45,000 ~165,000 USD depending on scale
Scale differentiation	No	Yes
Application independent from transmission expansion planning	Yes	Yes
Application for transmission expansion planning	No	Yes

One of the first regulations issued, even before new market rules, was the new criteria to apply for interconnection, and the process is characterized by two types of segmentation. First, there is segmentation based on project size, and second, based on its relation to grid expansion planning. Depending on the size, projects are subjected to a one- or two-step assessment before the permitting can be validated. The studies are developed by CENACE who is able to charge fees help to focus on projects with serious intentions, and provide CENACE with additional sufficient funding for conducting these studies. Depending on the choice of interconnection permitting process, the project can either be based on current or near-term grid characteristics for rapid development, or take part in grid expansion planning. Taking part in grid expansion planning allows them to inform the planning, and assure that they can benefit from the new infrastructure.

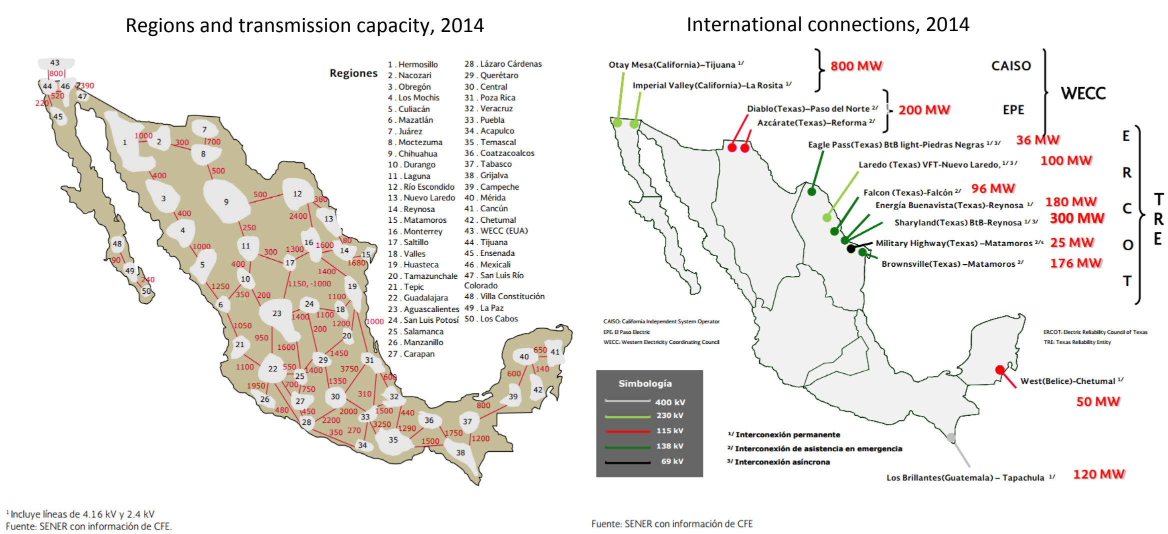

Figure 5. Power grid status, regional fragmentation and international connections

Source: Rionda et al. (2015)

6.3.2 Grid Code

The Mexican Grid Code (MGC) is a set of minimum technical requirements for the transmission grid that will be used to efficiently develop the activities of planning, operation, access and use of electricity infrastructure. The MGC consists of rules addressing how generators must connect to the electric power grid in order to maintain system reliability. The MGC also includes additional technical requirements related to transmission and distribution planning, system operation, interoperability and cybersecurity as part of the smart grid and those related to the interconnection between Mexico and the United States.

In terms of planning, the MGC includes general guidelines for CENACE and CFE to design expansion strategies for the transmission and distribution networks respectively. These guidelines include the n-1 criterion, the cost-benefit analysis and the approaches to assess the inclusion of renewable energy. With respect to system operation, it includes the technical limits for operating the transmission lines, the rules for economic dispatch, and the coordination between CENACE and the transmission and distribution companies.

According to the LIE, smart grid implementation will support the efficient and reliable operation of the system. Therefore, the MGC establishes the general criteria for interoperability and cybersecurity to consider the integration of information and communication technologies while maintaining security and minimizing threats. Finally, it is also important to highlight that the international interconnection between Mexico and the United States is considered in the MGC, and ten reliability NERC-like standards are adopted to maintain coordination and safe operation between both electric systems.

6.3.3 Dispatching and the Emergence of Ancillary Services

CENACE is still responsible for the economic dispatch of the system, and in order to do so, it will receive offers from generators based on auditable production costs and offers from load serving entities for consumption. The energy market in Mexico will be cost-based and CENACE will calculate and provide Local Marginal Price (LMP) signals for more than two thousand nodes in the system. Such LMPs will reflect the cost of energy, losses and congestion.

Economic dispatch will maintain the concept of creating a merit order table in which the cheapest generators will generate before the most expensive ones. As for renewable energy technologies, these will be considered as must-take sources of energy accepting all the generation they can provide when they provide it, and then the optimization will be performed with only the thermal power plants. Due to this practice, it will be important to improve the forecasting techniques for renewable resources.

Regarding ancillary services, these will be divided into the ones in the market and those outside of the market. The former includes operating reserves, spinning reserves, supplementary reserves, voltage and frequency regulation for which the market should set the price. On the other hand the ancillary services outside the market include reactive reserves, reactive power and black-start operation. CRE is responsible for setting specific tariffs for ancillary services outside of the market, taking into account the location of resources and other technical constraints.

6.3.4 Long-term Auctions

One of the cornerstones of the renewable energy expansion is the development of the auction system for long-term contracts. Regulated power supply, referred to as *basic service*, requires CFE to sign power and capacity supply contracts. These contracts are auctioned by CENACE, with short-, mid- and long- term contracts. But only the long-term contracts are intended for the supply of clean energy. The market rules first established the characteristics of the long-term contract auctions, and these will be supplemented with a specific manual. Auctions are called three years in advance of contract execution, allowing projects at an early stage to start.

The initial proposal from SENER was for these contracts to have a length of 10-years and encompass any amount of three traded products: energy, CEL, and capacity. Renewable energy developers expressed concerns and requested a longer length for the contracts of 20-years, which is consistent with international practice. The regulation was ultimately published with contracts including commitments for 15-years for capacity and energy, and of 20-years for CELs. This measure will facilitate the transition to more liquid markets in the shortest time, but would also maintain the benefits of an equivalent to the windfall profits of additional five years of CEL.

Mexico called for the first auction in November 2015 immediately after the auction manual was issued, and the first round of contracts were awarded on March 30, 2016. This first auction was issued to purchase a total of 6.3 TWh of energy, 6.3 million CEL, and only 500MW of capacity. Before economic offerings, a total of 352 proposals were deemed technically feasible and paid warranties were requested. SENER has stated that there were up to eight times more offers than originally expected.

With the intention to foster a liquid wholesale market and a competitive environment, long-term contracts will mostly be used to back the future obligations of CELs to be requested by SENER every year. As previously mentioned the CEL obligations or mandate consisted of 5% of the total energy purchased by CFE or any qualified user in 2018, and this auction is intended to cover for most of the expected obligations from CFE.

A special feature of the auction is that the optimization will consider not only the price offers made by the offerors, but also regional differences based on the expected average value of electricity at every node. By doing so, CENACE favors the entrance of clean energy projects, not necessarily where the power output cost is the lowest, but where the economic gains to the system are the largest due to the relative competitiveness between projects affected by the gaps between offers and the expected nodal energy price in the forthcoming 15 years, from 2018 to 2032.

Short-term perspectives on nodal pricing influence long-term perspectives on nodal pricing. A simplified representation of the benchmark against 2015 average nodal prices is presented below in Figure 6 from the PRODESEN 2015.

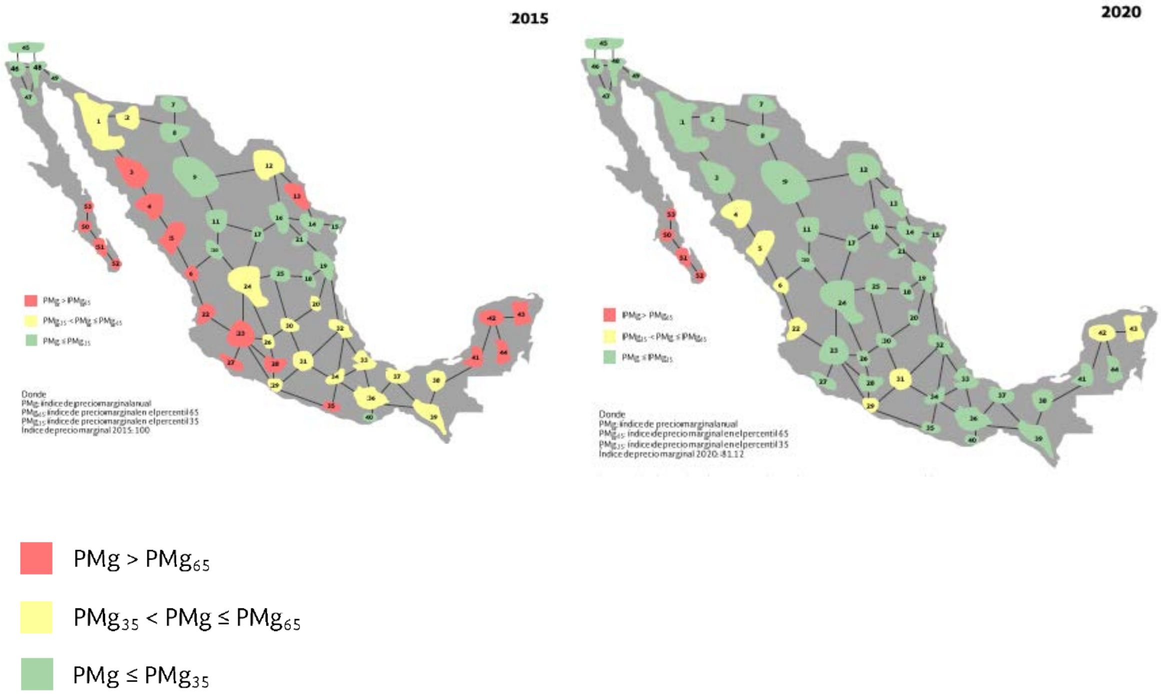

Figure 6. Nodal pricing benchmark in 2015 and 2020 as projected in 2015

Source: SENER (2015)

The actual computation of the auction was finally run by CENACE on March 29, 2016. The process was designed for the possibility of iteration to allow developers to update their economic offers, if there was not sufficient economic surplus to the power system, based on predefined levels. Results were so competitive that this was not necessary.

In total 227 offers from 69 bidders were evaluated, resulting in total 18 winning bids from 11 companies. Among the bidding companies, seven presented solar PV projects and four wind energy project. In total solar PV will provide over 74% of the energy and CEL, while wind will provide only 26%, with no other technology having won a contract. There was a significant price range, from offers below 40 USD per megawatt-hour plus CEL and above 60 USD, with both solar PV projects as the most and least price competitive. The range in prices is a result of the rules regarding nodal pricing which allowed for projects with higher cost per MWh to win contracts when located within the higher nodal pricing. No bidder offered capacity due to low payments offered for this concept by CFE.

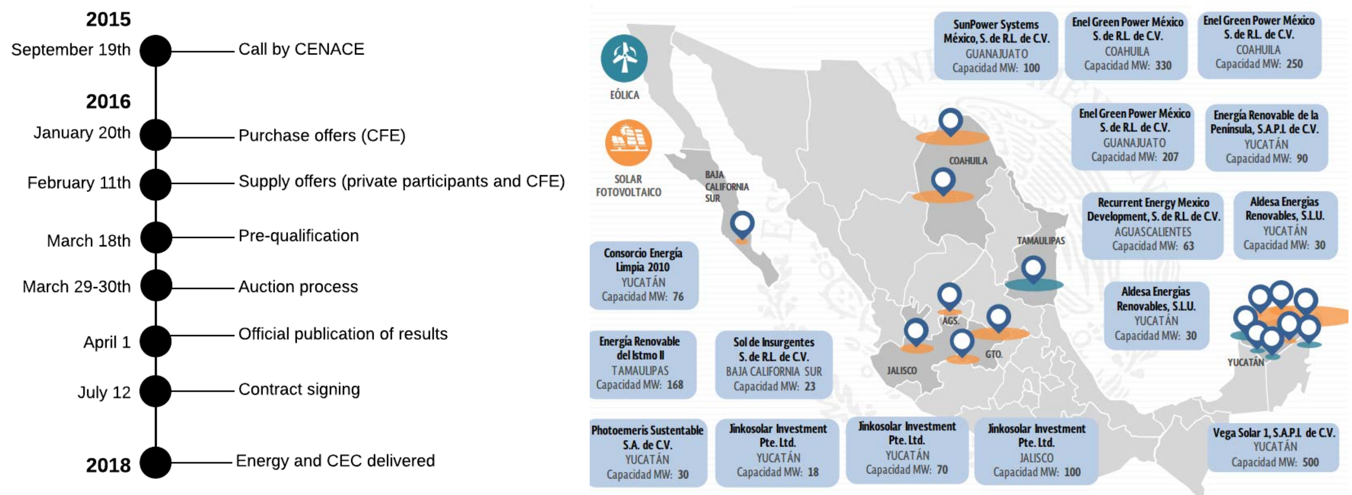

Figure 7. Timeline and location of the projects of the auction

6.3.5 Investment Models for Transmission

The current legal framework establishes that transmission and distribution are under Mexican state control. CFE, which was a vertically-integrated utility previously, is now separated into several "state productive companies". Two of these companies are in charge of transmission and distribution. However, each of these companies can enter into contracts with private companies.

In this new scenario, the development of transmission infrastructure can be carried out via one of the following three options:

- If a project developer wants to invest in transmission infrastructure for connecting his generation or load project, he is allowed to do so at any point in time and is responsible for the financing and development of the project.
- Also, a project developer has the option to propose the inclusion of the needed infrastructure in the annual grid's expansion plan. In this case, the infrastructure is included only if it brings a net benefit to the electric system. The net benefit will be calculated by CENACE, with the CRE's approval.
- Finally, a project developer can make contributions to the transmission or distribution company for the development of the required infrastructure. In this case, the CRE will issue general dispositions in order to determine the terms and conditions under which the contributions will be carried out.

The open season mechanism implemented under the former legal framework will not continue in the current legal framework.

6.4 Key Lessons and Good Practices

Mexico's experience showcases the potential for rapid restructuring that is favorable to the deployment of competitive renewable energy. In 2013, when the precepts of the power sector reform were defined, the country benefited from a rich international experience of market restructuring. The development of domestic institutions and instruments would also become central in the rapid adoption of a wholesale market and clean energy obligations system.

The reform demonstrates the relevance of stakeholder participation, and the importance of creating processes to allow feedback to take place and different stages, through subsequent subsidiary legislation and regulation: for example, from constitutional reform to laws to market rules to market manuals, with more details and precision in each step. The immediate results of the reform provide significant evidence of the benefits of utilizing a suite of tools that foster competition, revealing the true cost of renewable energy, to the great benefit of energy consumers in the country.

Mexican reform, as others before, has been driven primarily under the need and opportunity to reduce the overall cost of energy in the country. But in comparison to other previous market reforms, Mexico has significant long-term climate commitments for 2050, and clear mid-term clean energy goals for 2024. While a consistent political perspective might become the international norm after the Paris COP21, Mexico's robust legal mandates in support of the reform adequately communicated the need to incorporate the energy transition into the core of the new market system.

By interlocking clean energy deployment and the new market institutions, stakeholders will benefit the most from the competitive schemes to achieve reductions in production costs and the expansion of renewable energy portfolio. Clean Energy Certificate mandates and the long-term energy auction were not designed as a by-product or in complement to the reform, but as central elements to it. Subsequently, the development of the grid code, dispatching rules and transmission system planning were already "wired" to allow for the expansion of renewable energy to serve the ultimate objective of providing cheaper energy in the Mexican power system.

7 Clean Restructuring in Denmark

Denmark has a broad-based political vision of an energy system that is fully independent of fossil fuels in 2050. The Danish electricity system plays a key role in achieving this vision. For many years, the system has had a high penetration of renewable generation, and it is well on course for achieving the target of 50% wind power in 2020. It is a political priority for Denmark that renewable energy continues to be integrated into the power system in a cost-efficient manner using market principles. The integration of such high levels of wind power in Denmark has, to a great extent, been possible due to the common Nordic electricity spot market, which is one of the most integrated regional parts of the internal energy market in the EU. The availability of hydropower from Sweden and Norway has previously contributed to reducing the need for coal-fired power production during peak load times and today, it serves as a means to balance the system as it becomes increasingly reliant on fluctuating wind energy. Backup capacity is needed in periods without wind. Meanwhile, Denmark exports large amounts of energy to Sweden and Norway during off-peak hours, allowing them to restrain production of hydro energy. The daily interplay of wind power generation, hydropower production, and CHP that ensures a reliable and affordable supply of electricity is a result of efficient price signals sent through the highly liquid Nordic day-ahead market.

Also, the market has made the economic benefits of increased interconnection with neighboring countries apparent. This has resulted in Denmark increasingly becoming an integral part of a regional northern European power system rather than a national energy system. Interconnectors contribute to cost-effective use of generation capacity through the electricity market in Denmark and abroad, and they reduce the cost of providing a reliable supply of electricity at a reasonable price.

A unique feature of the Nordic electricity market is the successful cooperation of all the different stakeholders, including producers and retailers, the Nordic TSOs, regulators, and political decision makers. The strong political interest, direction, and willingness to compromise on national issues in favor of a Nordic view have been the key to developing and operating an efficient electricity market.

Figure 8 shows the development in the Danish electricity consumption and generation from 1990 to 2025.

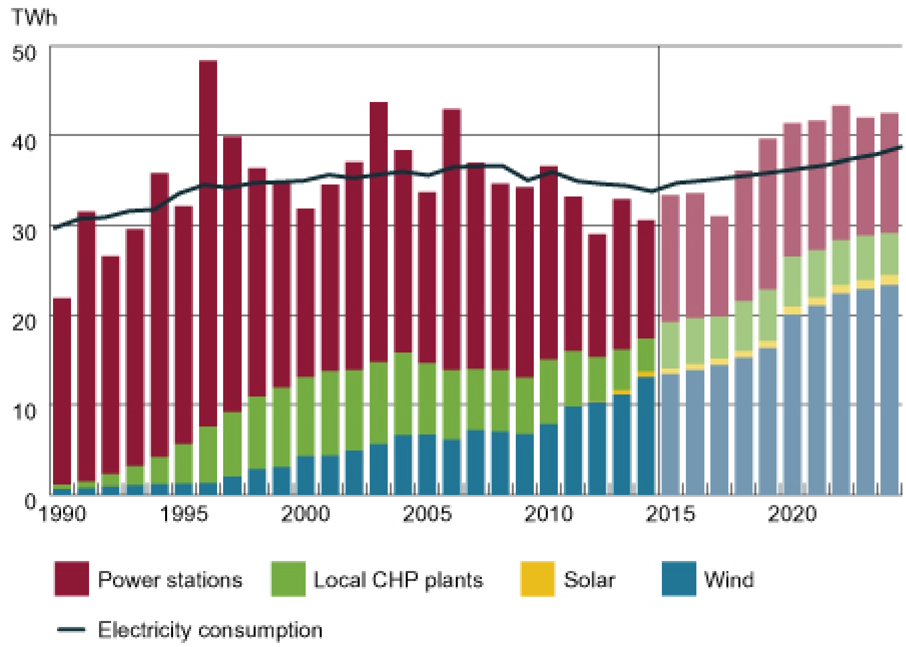

Figure 8. Electricity consumption and generation

Source: Energinet.dk

7.1 Background and Overview of Timeline

- Key features about the Danish electricity market: Denmark has a broad-based political vision to be fully independent of fossil fuels in 2050. Denmark has a long tradition of broad political agreements about energy and climate, which creates certainty for stakeholders and investors in the sector.
- The Danish electricity system consists of two non-synchronous areas: West Denmark (DK1) and East Denmark (DK2). West Denmark is part of the European continental electricity system, while East Denmark is part of the Nordic electricity system, which also counts Sweden, Norway, and Finland. East Denmark and West Denmark were connected by a direct-current link under the Great Belt in 2010.
- In 2014, renewables represented 53.4% of the gross electricity consumption in Denmark, of which wind represented 38.8% (DEA 2016a).

Text Box 1. Combined Heat and Power Plants

Flexible CHP plants[24] help balance the mainly renewable energy-based electricity system. The Danish experience shows the importance of minimum technical requirements for flexibility of load for CHP as well as exposure to market prices and access to several markets (e.g., day-ahead, intraday, and balancing markets) in order to incentivize CHP plants to run according to power system needs.

Generation by CHP plants is regulated according to demand, and the majority of the fossil-fueled plants can also be run in condensing operation mode (i.e., can generate electricity without producing district heating). Condensing operation allows for greater flexibility in the electricity system, in particular in the summer when the demand for heating is low. CHP plants also have low load capabilities, meaning they are very flexible in regard to production load.

Large-scale CHP plants are connected to the transmission grid and provide system stabilizing properties (e.g., inertia and reactive effect), and they thereby maintain the stability of the grid. Small-scale CHP plants are thermal plants connected at medium and low voltage levels, and they typically cannot generate electricity without generating district heating simultaneously.

In recent years, many of small- and large-scale CHP plants have converted to biomass from coal.

Figure 9 shows the composition of electricity generation from renewable energy in Denmark in 2014.

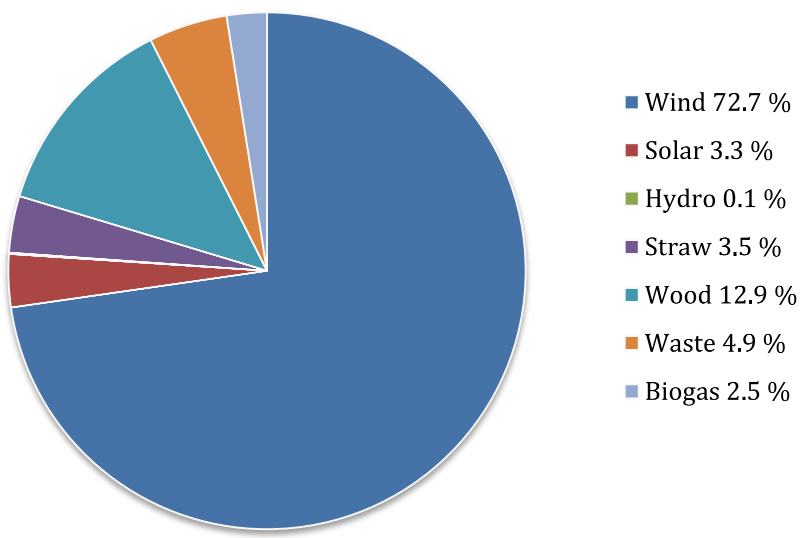

Figure 9. Composition of electricity generation from renewable energy in Denmark in 2014

Source: Danish Energy Agency (2016a)

7.2 Liberalization of the Danish Electricity Market

Historically, the Danish electricity sector consisted of government-regulated monopolies that operated in a geographically defined market. The price of electricity was regulated and suppliers operated in protected markets in exchange for a reliable supply of electricity. Generators had

[24] Legislation related to CHP plants includes the heat supply act (Varmeforsyningsloven, https://www.retsinformation.dk/forms/r0710.aspx?id=165652) and the XYZ (Projektbekendtgørelsen, https://www.retsinformation.dk/forms/R0710.aspx?id=174458).

assured rates of return. Investment risks were allocated to end users in exchange for constant prices.

Since the late 1990s, the Nordic market has gradually been liberalized. The most important step toward the free electricity market was taken in 1999 with an EU directive on full liberalization of electricity markets. This led to the unbundling of the transmission grid from electricity generation. Electricity generation and trade were liberalized, while the grid continued to be a natural monopoly in which all electricity market players have equal opportunity to use the market. As a consequence of the EU liberalization packages, all consumers have since 2002 been able to freely choose the supplier they prefer. As a specific national initiative in Denmark, the DataHub was introduced in 2013 to the Danish electricity retail market. The objectives of the DataHub were to (1) enhance competition through an effective separation of supply and generation activities from network operation ("functional" unbundling) and (2) simplify supplier switching and other market processes for consumers and market parties. Additionally, the DataHub is a prerequisite for the introduction of a supplier-centric model (consumer-centric market design) in the Danish market, which was implemented and fully in action on April 1 2016. The objective of the supplier-centric model is to further stimulate competition. With the clearly defined role of the supplier as the only contact to the consumers, the supplier-centric model clearly distinguishes competitive and regulated players. This leaves the commercial part in charge of the future "packaging" of innovative and differentiated products creating new value propositions to the consumers.

7.3 Primary Challenges in the Electricity Market

Even though Denmark and the Nordic region have come a long way in liberalizing and developing a well-functioning market, there is still room for improvements.

One of the main challenges now is ensuring sufficient generation capacity to safeguard supply. Increased shares of wind and solar power, low coal prices, and low demand have deflated electricity prices in recent years. Consequently, the revenue base for power plants has diminished, reducing incentives to make new investments or reinvest in existing capacity. At the same time, the technical lifetime of existing thermal power plants is eroding and many plants are being decommissioned. This trend is seen not only in Denmark, but it is also a general challenge for most European countries. Germany is also massively expanding its wind and solar capacity, while at the same time decommissioning nuclear power capacity. Sweden is also dramatically expanding its wind capacity. The decline in flexible thermal production capacity has increased the risk of power shortages in Denmark, especially in eastern Denmark in the upcoming years. The market needs to be improved and further developed to ensure investors receive the right price signals in new transmission or production capacity and that they reinvest in retrofit existing capacity. In addition, consumers need to play a more active role in the electricity market in order to ensure a cost effective integration of renewable energy and high security of supply. Demand response has been discussed for many years in the Denmark, and large industrial consumers already have the opportunity of providing demand response to the market. Nonetheless, the volume of demand response is low. To enhance competition in the retail market and increase the consumer incentive to be more flexible, Denmark has decided on several initiatives, including the development of the DataHub, the installation of smart meters, and the implementation of flexible billing systems.

Another current challenge is the bottlenecks in the DK1-DE interconnector between Denmark and Germany. Today, the available southbound capacity (i.e., from Denmark to Germany) is very limited due to internal bottlenecks in Germany. The bottlenecks constrain the trade, and as a result, the Nordic countries have experienced significant socioeconomic losses. TenneT (the TSO in Northern Germany) is currently expanding the internal grid in Northern Germany, and the expansion is expected to be completed in mid-2020. These expansions of the internal grid are expected to solve the immediate problem; however, in the meantime, additional instruments like "redispatching"[25] and countertrading[26] might be needed.

7.4 Regional Interactions with Neighbors

The Nordic countries[27] have a well-established tradition of cooperation and trade between their national electricity systems. The cooperation is formalized at different levels and among different bodies. Figure 10 shows Denmark's current interconnectors and approved links as well as links under consideration.

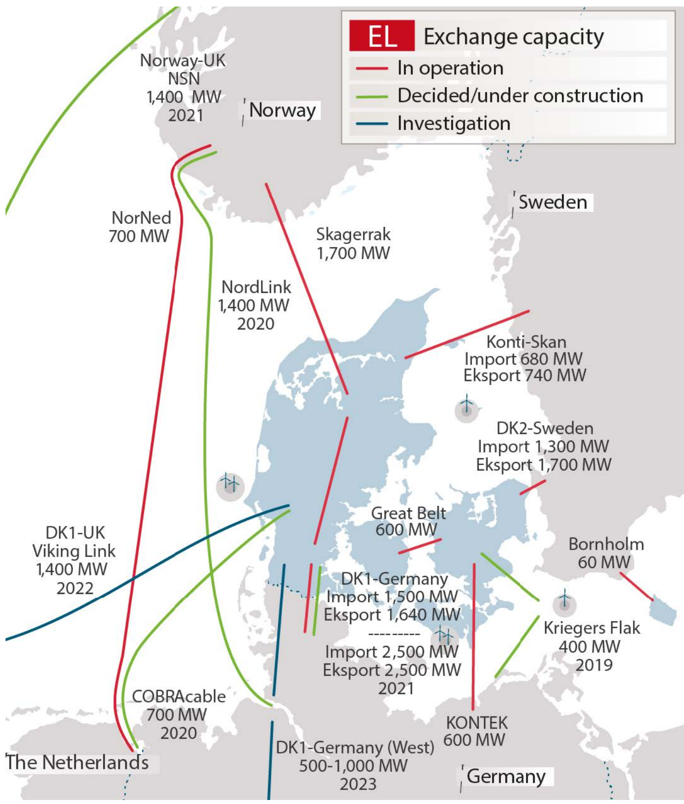

Figure 10. Interconnectors from Denmark to neighboring countries

Source: Danish Energy Agency (2016b)

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[25] Redispatching is a measure activated by one or several system operators by altering the generation, load pattern, or both to change physical flows in the transmission system and relieve a physical congestion.

[26] Countertrading is cross-zonal exchange initiated by system operators between two bidding zones to relieve physical congestion.

[27] The Nordic electricity market comprises the four countries Denmark, Finland, Norway and Sweden. Iceland is also taking part in the Nordic co-operation between the TSOs (Nordel), but is not interconnected to the other countries.

7.4.1 Political Level

The official Nordic cooperation takes place within the framework of the Nordic Council of Ministers,[28] where governments cooperate (Figure 11). In dialogue with parliamentarians from the Nordic countries, the Nordic prime ministers regularly discuss how the Nordic countries can profit from Nordic cooperation. Decisions in the councils of ministers must be unanimous.

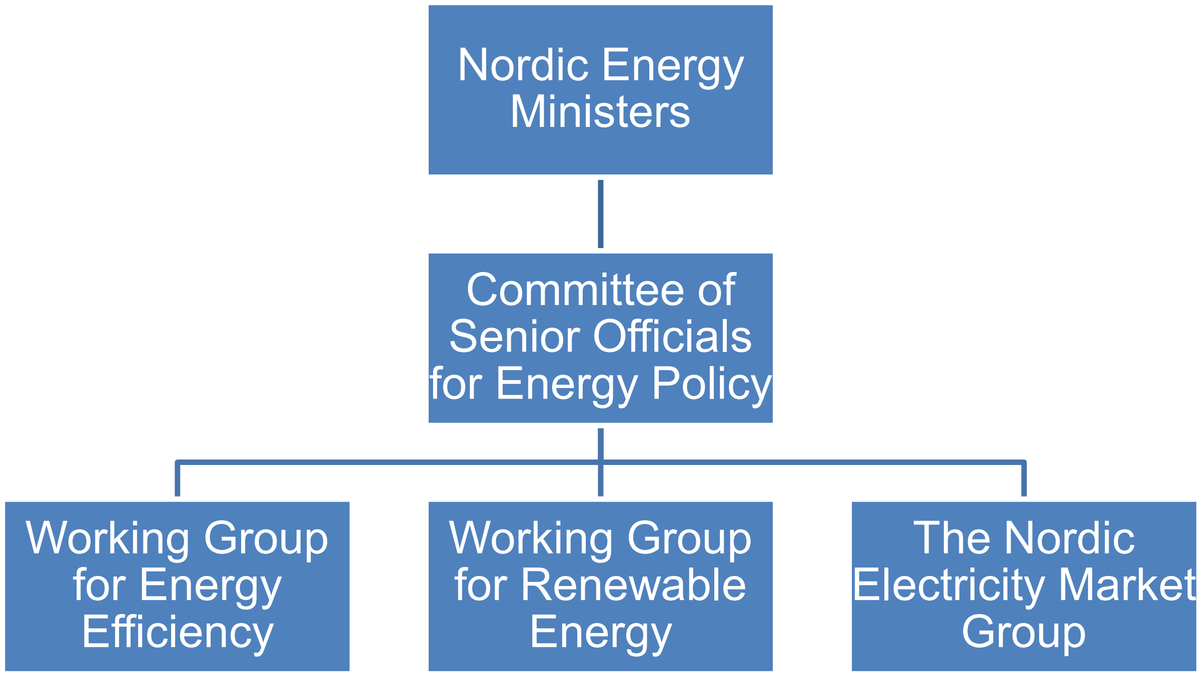

Figure 11. The Nordic setup for political cooperation

7.4.2 TSO Cooperation

Cooperation between the TSOs in the Nordic countries was formalized in 1963 with the establishment of Nordel, whose objective was to create the preconditions for development of an effective and harmonized Nordic electricity market. Nordel was also a forum for contacts between the TSOs and representatives of the market participants in the Nordic countries. Nordel issued advice and recommendations promoting an efficient electric power system in the Nordic region, considering the conditions prevailing in each country. It contributed to international cooperation and information exchange pertaining to the electric power system and the electricity market. The cooperation was formally based on the rights and obligations defined in the Nordic System Operation Agreement. To maintain secure frequency control and power reserves, the

[28] The Nordic Council of Ministers was founded in 1971. Despite its name, it actually consists of several individual councils of ministers. Nordic ministers for specific policy areas meet with their respective council of ministers a few times a year. There are currently 10 constellations of councils of ministers for specific policy areas as well as the council of ministers for the ministers for cooperation (e.g., the Council of Ministers for Business, Energy and Regional Policy). Decisions in all of the councils of ministers must be unanimous. The presidency of the Nordic Council of Ministers, which is held for one year, rotates between the five Nordic countries. Matters are prepared and followed up on by the various committees of senior officials, which consist of civil servants from the member countries (e.g., in the field of energy and climate).

Common Nordic Operation Information System was introduced. On July 1, 2009, all operational tasks were transferred from Nordel to ENTSO-E (ENTSO-E 2016). However, the Nordic TSOs still cooperate closely in many areas such as market development, system operation, and security of supply.

7.4.3 National Regulators

In 2002, the five Nordic energy regulators from the five Nordic countries established the Forum of Nordic Energy Regulators (NordREG) to promote market integration and the development of an efficient Nordic electricity market. In addition, NordREG [prepares joint Nordic views, when appropriate.

7.5 The Nordic Power Market Setup

The Nordic region has a common power market that consists of several specific underlying markets based on a timeline for the bidding offers, as show in Figure 12.

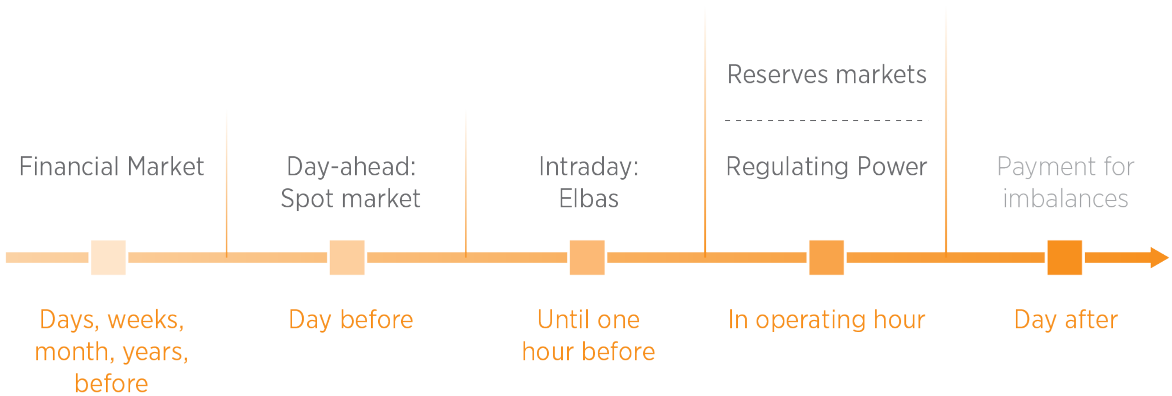

Figure 12. Time frames for markets making up the Nordic market

Source: Ea Energy Analyses (2012)

Text Box 2. The Nordic Market Setup

The Day before the Operating Hour (Day-Ahead Market)

The central Nordic power market is the day-ahead market (Nord Pool Spot), where a daily competitive auction at 12:00 establishes a price for each hour of the next day (24 hours). The trading horizon is therefore 12–36 hours ahead of the operation hour. For each hour, a bid states different prices and corresponding volumes in a certain bidding area. Producers, retailers and some big consumers participate in the day-ahead market. The market price is calculated for each hour as the clearing price that equals sell and buy volumes. In addition to hourly bids, block bids can also be given. A block bid from a producer states the minimum average price the producer must receive during a certain period. Block bids can be suitable when start-up and stopping costs are significant. Almost 90% of total electricity demand in the Nordic countries is traded here.

Up to the Operating Moment (Intraday Market)

If expected supply or demand reported to the day-ahead market changes (e.g., due to power plant failure or changes in wind conditions), the stakeholders can trade in the intraday market, Elbas, to achieve a supply-demand balance. The intraday market is open from 2 p.m. until one hour before the operating hour.

Operating Hour (Automatic Reserves and Regulation Power Market)

In the operation hour, Energinet.dk has sole responsibility for balancing the system through several system services that adjust production. Energinet.dk maintains balance in the system, for example, by buying electricity (upward regulation) or selling electricity (downward regulation) in the regulation power market. Furthermore, grid frequency is stabilized by the automatic reserves in the actual operating moment.

The Day after the Operation Day (Balancing Market)

After completion of the operating day, actual demand and production measurements are collated and compared with the stakeholders' scheduled production and demand. Any imbalances between actual and scheduled demand/production are cleared in the balancing market.

Financial Market

The big turnover in the day-ahead market means many companies are exposed to fluctuating day-ahead prices. The financial market enables these companies to use risk management strategies and gradually hedge their future income or cost. Contracts can be done for baseload for different time periods up to five years after the present year. The most liquid contracts are the next quarter and the next year. The financial market is operated by NASDAQ OMX Commodities.

The reference price for the financial contracts is the "system price." The system price is an artificial price calculated by Nord Pool that states the common Nordic price that would resulted if there were only one bid area in the Nordic market. The settlement of financial contracts is totally financial against the reference price. There are no physical deliveries contrary to most other commodity markets. A company that wants to hedge its price area risk (the risk that the area price differs from the system price) can use "contracts for differences" (Ea Energy Analyses 2012).

7.6 Bidding Areas

The market in the Nordic region is divided into a number of bidding areas. Denmark is for instance divided into two bidding areas: DK1 and DK2. The different bidding areas help indicate constraints in the transmission systems, and they ensure regional market conditions are reflected in the price. Due to bottlenecks in the transmission system, the bidding areas may get different prices called area prices. When there are constraints in transmission capacity between two bidding areas, the power will always go from the low-price area to the high-price area. This system also ensures no market members are assigned privileges on any bottleneck, which is an important feature of a liberal market. Nord Pool calculates a price for each bidding area for each hour of the following day.

Because building transmission capacity is costly, there will always be situations with congestion. DC-connections are particularly expensive, so congestions will often occur between two different synchronous systems (e.g., between Norway/Sweden and West Denmark, and between West Denmark and East Denmark [Ea Energy Analyses 2012]).

Figure 13. Bidding areas in the Nordic region

Source: NordREG

7.7 Development of the Nordic Power Market and Infrastructure

The Nordic electricity market is one of the most well-functioning electricity markets in the world and regional parts of the internal energy market in the EU. The starting point for the common market in the Nordic region was the Louisiana Declaration in 1995. In it, the Nordic ministers of energy declared that a Nordic electricity market would economically and environmentally benefit all countries and should be developed as soon as possible.

The Nordic electricity market has been developed through a gradual process. First, a common spot market was introduced, and then a common intraday market and finally a common balancing market were introduced. Today, the main focus is on improving the short term markets and developing a closer link between the wholesale and retail markets. This includes balancing responsibilities for all market participants, moving trade closer to the hour of operation, allowing smaller bid sizes in the balancing market, and enabling consumers to actively participate in the market (e.g., smart meters, DataHub, and flexible pricing).

The most important contributors to the well-integrated Nordic electricity market are a suitable energy mix, a long tradition of cooperation between TSOs and National Regulatory Authorities (NRAs), gradual market integration, a liquid market developed through trade at Nord Pool and NASDAQ, and finally a strong political commitment and a common vision on power market development.

7.7.1 Driving Forces for Developing a Market

The driving forces for developing a highly integrated Nordic electricity market were market power dilution and the advantages of connecting the hydropower-dominated systems in Norway and Sweden with the thermal-power-dominated systems in Finland and Denmark. This was expected to result in increased economic efficiency, higher security of supply, and improved environmental performance of the Nordic power system. Market unification would optimize the use of Swedish and Norwegian hydropower, resulting in lower average electricity prices and reduced carbon emissions in the Nordic region as a whole, while security of supply would be increased in dry years through integration of thermal generating capacity in Denmark and Finland.

Table 3. Nordic Generation Capacity (MW) by Type of Power

	Denmark	Finland	Norway	Sweden	Nordic Region
Installed Capacity (Total)	**14,861**	**17,300**	**32,879**	**38,273**	**103,313**
Nuclear power	-	2,752	-	9,531	12,283
Other thermal power	6,989	11,135	1,040	8,079	27,243
Condensing power	-	2,465	-	1,375	3,840
CHP—district heating	1,929	4,375	-	3,631	9,935
CHP—industry	562	3,180	-	1,498	5,240
Gas turbines, etc.	-	1,115	-	1,575	2,690
Hydropower	9	3,125	30,900	16,150	50,184
Wind power	4,809	288	811	3,745	9,653
Sun power	563	0	N/A	43	606

Source: NordREG (2014)

7.7.2 Important Political Agreements in the Development of the Nordic Electricity Market

The electricity market development has for more than 20 years been a prioritized political topic at annual meetings of the Nordic energy ministers. Important political agreements have provided direction and supported the ongoing work of the TSOs and the regulators. One strength of the Nordic cooperation has been the political will to set a clear vision for the TSOs and regulators to pursue with due consideration to the technical, operational, and regulatory possibilities or options at hand. In 2004, the Nordic Council of Ministers for Business, Energy and Regional Policy supported a recommendation from the Nordel on “five priority cuts,” a package of five new interconnectors in the Nordic power system. Under the recommended political agreement, the five projects were to be established if a positive social benefit for the individual interconnector could be demonstrated. This was a major contributing factor in infrastructure development in the Nordic region. In 2008, decisions on developing a common Nordic end-user market were emphasized,[29] and a request for the TSOs to consider further price zones in the Nordic area was taken. In 2010, the ministers reiterated that infrastructure investments that were economically viable and socially benefitted the Nordic area must be implemented, and they agreed that investments where costs and benefits were unevenly distributed between countries would be implemented by TSOs negotiating the allocation of expenses and revenues. Furthermore, the ministers reiterated that they would like to see a development toward price areas that are independent of national borders, where appropriate.

7.7.3 The TSO's Role in the Development of the Market

The Nordic TSOs are mainly publicly owned by the state.[30] The TSOs have been instrumental in the development of the grid infrastructure and the joint Nordic wholesale market. The close TSO cooperation has been important in developing efficient market solutions within the given political framework and conditions. The TSOs collaborate on common grid development plans and own the Nord Pool market together with their Baltic counterparts. Moreover, the TSOs are key actors in system operation through balancing supply and demand in the region, as they procure up- and down-regulation of the power production in close interaction with the market's more than 300 commercial actors. This Nordic regulating power market has been in operation since 2002; in it, an up-regulation bid from Finland can be applied for up-regulation in Denmark. The size and the high liquidity of the Nordic regulating power market have contributed to the majority of bids in the regulating market being voluntary, and only a small part of the regulating market receives any capacity payment. Furthermore, the TSOs are responsible for a well-functioning cross-border balancing market, where the countries have a common method of settlement.

The TSOs submit yearly reports to the Nordic Council of Ministers, which describes the status and developments in the Nordic electricity system market with focus on infrastructure developments, power system operations, and in recent years a status for and assessment of integration of the expected or forecasted amount of renewable energy in the Nordic power system.

7.7.4 From a Regional Perspective to a European Perspective

Due to the increased integration of the Nordic electricity system with the regional systems on the European continent, the focus of the cooperation among the Nordic countries has gradually shifted toward a larger regional or European setting. However, in recent years it has become apparent that despite the ongoing market development and market coupling in the EU there are still significant differences between the common Nordic electricity system and the electricity systems in the adjacent countries to the south. Within the Nordic cooperation, it is possible to focus on the specific Nordic challenges in a smaller country setup than in the context of European cooperation. In addition, the necessary changes in markets that need decision making on EU-level can take place at a slow pace and short-term solutions might be needed during a

[29] The following year, a deadline of 2015 was decided.
[30] The Finnish TSO is half owned by the state.

transitional period. Thus, there are still benefits of and a need for the close cooperation and continued focus on the specificities of the Nordic system.

The TSOs in four countries—Denmark, Finland, Norway, and Sweden—therefore agreed this year that Nordic cooperation supporting the ongoing restructuring of the Nordic electricity markets should be strengthened to ensure integration of the increasing amounts of renewable energy. This renewed cooperation focuses on the challenges and aims to offer solutions that can support an effective transition of power systems with continued high security of supply. It includes the systemic challenges related to planning; market design; market operations; research development and demonstration; and information technology. And, the cooperation is given special emphasis in the following areas:

- Power adequacy (in a system phasing out fossil generation)
- System security (e.g., securing inertia of the power system and thus the systems frequency stability)
- Flexibility (i.e., new sources of flexibility are required with the up and down regulation in relation to variations in wind and sun, for example)
- Transmission links (how to harvest socio-economic benefits for the Nordic region as a whole by strengthening of relations).

Establishing a Nordic "regional security coordination initiative" will further support the operation of the Nordic power system, mainly through coordination of capacity calculations, risk preparedness and common Nordic generation adequacy assessments in addition to the national assessments.

Text Box 3. The Regulatory Framework for Danish TSO, Energinet.dk

The Danish TSO, Energinet.dk, is an independent public enterprise entirely owned by the Danish Ministry of Energy, Utilities and Climate. Energinet.dk is certified as an ownership-unbundled TSO for electricity and gas pursuant to the Danish Electricity Supply Act (Elforsyningsloven) and the Danish Natural Gas Supply Act (Naturgasforsyningsloven). The regulatory framework under which Energinet.dk operates has been in place since 2005. Under the current framework, Energinet.dk operates as a non-profit organization.

The purpose of Energinet.dk is to ensure efficient operation and efficient infrastructure development within electricity and gas transmission. The revenues for Energinet.dk must cover reasonable cost, including a cost of capital to maintain operations and investments. The electricity and gas transmission segment is managed according to a breakeven principle where any excess revenue or deficit for the year is repaid or collected the following year by increasing or reducing the tariffs (paid by consumers). The profitability of all investments is based on a welfare economic assessment. The cost of capital used to measure the welfare economics of the future investments is 4%, according to the guideline from the Ministry of Finance. In accordance with Section 13 of the Danish Act on Energinet.dk, Energinet.dk is not allowed to distribute any profit or equity to the Danish state through dividends or in any other way; any profits are to be used to reduce tariffs.

7.7.5 Cooperation Between Regulators

Efficient cooperation requires well-functioning regional organizations. Formally establishing NordREG to promote market integration and the development of an efficient Nordic electricity market has been a key element of coordination in the region.

Since 2006, NordREG has published a yearly Nordic Market Report, which describes the status and developments in the Nordic electricity market with focus on generation, consumption, transmission, wholesale power market, and retail markets. The report also focuses on the ongoing work within the NordREG working groups.

7.8 Infrastructure

Denmark is situated between the hydro-based power systems of the north and the thermal based power systems on European mainland, and it has a long history as a transit country for electricity from the north. The first interconnector in the Nordic region was built in 1915 between Denmark and Sweden. West Denmark (DK1) is part of the European continental electricity system, while East Denmark (DK2) is part of the Nordic electricity system, which also includes Finland, Norway, and Sweden. East and West Denmark are linked by a DC link under the Great Belt. The connections in the Nordic region facilitate trade throughout the region and provide a solid foundation for the common Nordic electricity market. Denmark has interconnectors to its neighbors in Germany, Norway, and Sweden and is building or planning interconnectors also to the Netherlands and the United Kingdom. The interconnection capacity for the Danish electricity system is 80% of the Danish peak demand.

7.8.1 The Danish TSO's Role in Infrastructure Planning

Denmark has since 2005 had one state-owned TSO (Energinet.dk). It operates as a non-profit organization, financed through tariffs, and the profitability of all its investments is based on a welfare economic assessment. According to the regulatory framework in place, any profits are to be used to reduce tariffs. This organizational and regulatory framework of the TSO has been a key element in the successful expansion in Danish interconnector capacity as well as infrastructure investments internally.

7.8.2 Nordic Infrastructure Planning

The Nordic countries constantly assess the value of strengthening interconnection between and within the Nordic countries. The bidding areas in the Nordic region help illustrate where new connections both internal and cross-border might be needed.

A Nordic grid master plan (the Nordic Grid Development Plan) has been published every two years since 2002. The plan includes the joint recommendations of the Nordic TSO on necessary or advantageous interconnectors from a Nordic perspective. This may include reinforcements across borders as well as reinforcements internal to one country that might benefit the flow of electricity in other parts of the Nordic power system. The projects of the Nordic grid development plan are based on a welfare economic assessment and must be decided nationally, pursuant to the national regulatory framework of the TSOs involved. In 2004, a political agreement ensured a necessary expansion in terms of five important interconnectors that might not all have been built if they had not been a part of a larger package ensuring benefits to the Nordic region as a whole. To avoid unnecessary delays due to the risk of a lengthy political process on new infrastructure projects, the Nordic ministers decided in 2010 that investments that unevenly distribute costs and benefits between countries could be implemented by TSOs negotiating the allocation of expenses and revenues. This decision has contributed to a more flexible approach for many projects and has to a large extent been sufficient. However, to ensure a focus on the Nordic benefit, the Nordic ministers have requested the TSOs include in their

2017 grid development plans recommendations for a possible new package of necessary interconnectors to be considered on the political level.

7.9 Lessons Learned

To have well-functioning regional cooperation, it is important to have:

- A common vision on market development
- Cooperation with a focus on the regional perspective instead of a national one
- Involve all levels in development of electricity markets and market initiatives (e.g., political level, TSOs, stakeholders).

The Nordic electricity market is the most harmonized interstate electricity market in the world. From 1995 to today, it evolved from four national markets to become a joint Nordic market.

The Nordic countries have experience from both valuable regional initiatives and collaborations that has been less successful. In this experience, we can see two main conditions for successful cooperation in general. First, there must be a clear target for the work, with the aim to support all participating countries to achieve their energy policy objectives. Second, the regional cooperation should be developed step by step with a bottom-up approach built on mutual interest and, as much as possible, on a voluntary basis.

The strong political interest, direction, and willingness to compromise on national issues in favor of a Nordic view have been the key to developing and operating an efficient electricity market. A clear political vision of the future market development is a good driver for TSOs and regulators. Having this vision has furthered both infrastructure development as well as development of the retail market. Because Denmark covers two non-synchronous areas (the Nordic and the European continental systems), common Nordic solutions might sometimes pose a dilemma for Denmark if hydro-based solutions are favored over solutions that are more compatible with the continental system. With the further development of interconnectors between the other Nordic countries and the continent, the Nordic cooperation will include a stronger focus on synergies with other European electricity systems on the continent.

Yet another important aspect of the Nordic cooperation is the political will to reassess the vision along the way. This proved necessary for the vision of a common Nordic end-user market to be developed by 2015. On the basis of the annual status report on market development from the regulators, the Nordic Council of Ministers decided in 2015 to continue the work toward a harmonized but not necessarily a common end-user market, recognizing that the Nordic countries although moving in the same direction were not moving at the same pace and that enforcing common Nordic regulation was not appropriate at the time.

A unique feature of the Nordic electricity market is the successful cooperation of all the different stakeholders: producers and retailers, the Nordic TSOs, regulators, and political decision makers. An important principle has been a government focus on the overarching framework combined with great responsibilities for the TSOs to decide on the best solutions for the development and operation of markets.

Under the auspices of the Nordic Council of Ministers, stakeholders are involved through annual power market conferences, recurrent bilateral meetings, and annual reporting to the ministers. Nationally, the Danish TSO, Energinet.dk, initiated in 2014 and 2015 the Market Model 2.0 project in close cooperation with national stakeholders. The objective was to identify challenges in the current electricity market and find solutions for the future electricity market in order to make recommendations for the political system, the system operators, and the commercial actors. The electricity market design is complicated and changes are likely to have different effects on the stakeholders. But due to a thorough and long process with a broad stakeholder involvement, the final recommendations submitted to the political system were to a great extent supported by the participating stakeholders. Energinet.dk also holds regular stakeholder meetings in relation to development and implementation of market regulation. The purpose is twofold: early involvement of stakeholders and continuous orientation in order to explore and incorporate stakeholder views.

8 Clean Restructuring in Germany

The German electricity market has been changing over the last few decades and will continue to pass through a transition phase in the coming years. Renewable energy sources will be expanded further and will take on a greater role in the electricity supply, the use of nuclear energy will end in 2022 in Germany, and the European electricity markets will grow closer. The energy transition (*Energiewende*) is one of the latest iterations of the German electricity market, and not likely to be the last.

The restructuring process of the German power system was initiated in the 1990s. The liberalization of the market progressed with the transition to clean energy, *Energiewende*. With the transition to clean energy emerged the need for a suitable electricity market design for the future. This case study introduces the debate that ensued and the final design of Germany's electricity market 2.0. The study highlights that, in Germany, a liberalized energy-only market can achieve both a market orientation in the electricity sector and a clean transformation of the energy system. The study has been adapted from the official white paper *An Electricity Market for Germany's Energy Transition*, which was published by the German Federal Ministry for Economic Affairs and Energy (the ministry) in July 2015 (BMWi 2015a).

8.1 Overview of the German Electricity System

Until 2005, four major companies—E.ON, RWE, EnBW, and Vattenfall—dominated the German electricity system. With the adoption of the Energy Industry Act of 2005, the German Parliament decided to liberalize the market. Consequently, the previously vertically integrated companies needed to "unbundle" their assets by 2007, meaning that they needed to split generation, transmission, and distribution assets. At the same time, the introduction of the Renewable Energy Act (EEG) and preceding legislation increased the number of independent and small generators as well as the regional distribution of generation assets (see Table 4 and Figure 14).

Table 4. Key Indicators of the German Energy System

Electricity	
Number of companies representing at least 95% of net power generation	> 450
Number of main power-generation companies	4

Source: EU (2014)

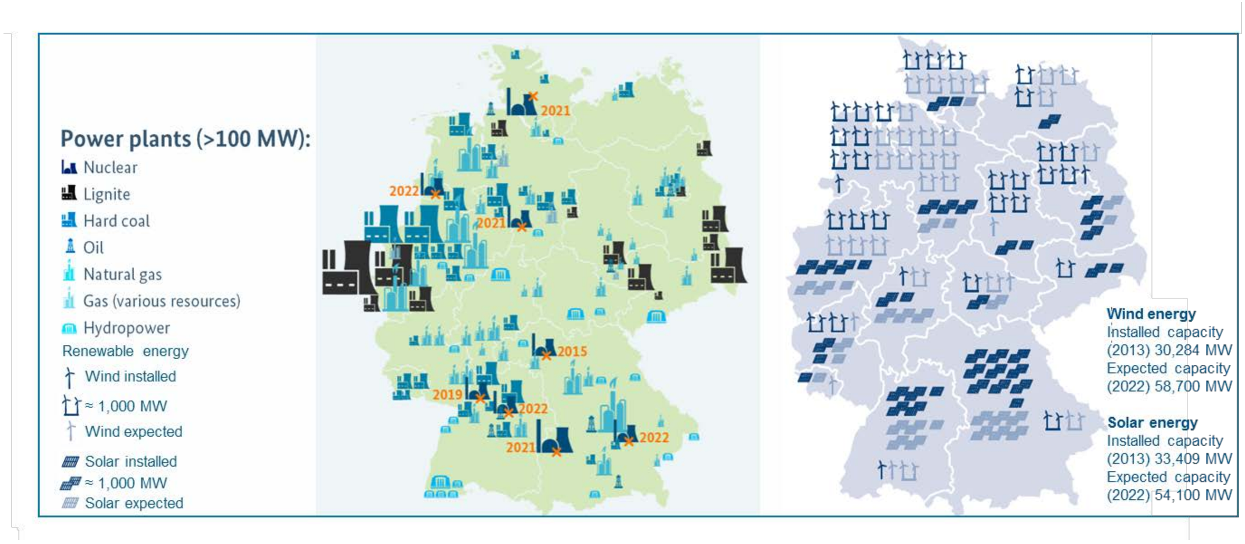

Figure 14. German power generation capacities by region

Source: Ecofys based on BMU (2013); BDEW (2013, 2014); BNetzA (2014); BMWi (2013)

Today, electricity is traded on liberalized electricity markets, either over the counter or on electricity exchanges. There are two power exchanges in Germany: EPEX SPOT for day-ahead and intraday markets and the European Energy Exchange for any forward and future products (see Figure 15). The price on the exchange is set at the point where supply and demand come together. The suppliers with the lowest variable costs are dispatched first (merit order). This minimizes the cost of supplying electricity. In a competitive electricity market, the price of electricity on the exchange corresponds to the variable costs of the most expensive generating installation in use. This installation is the "marginal installation;" the price on the exchange is the "marginal cost price." In the event of high electricity demand, flexible consumers can also match supply and demand based on their opportunity costs. In this case, the demand-side sets the electricity price.

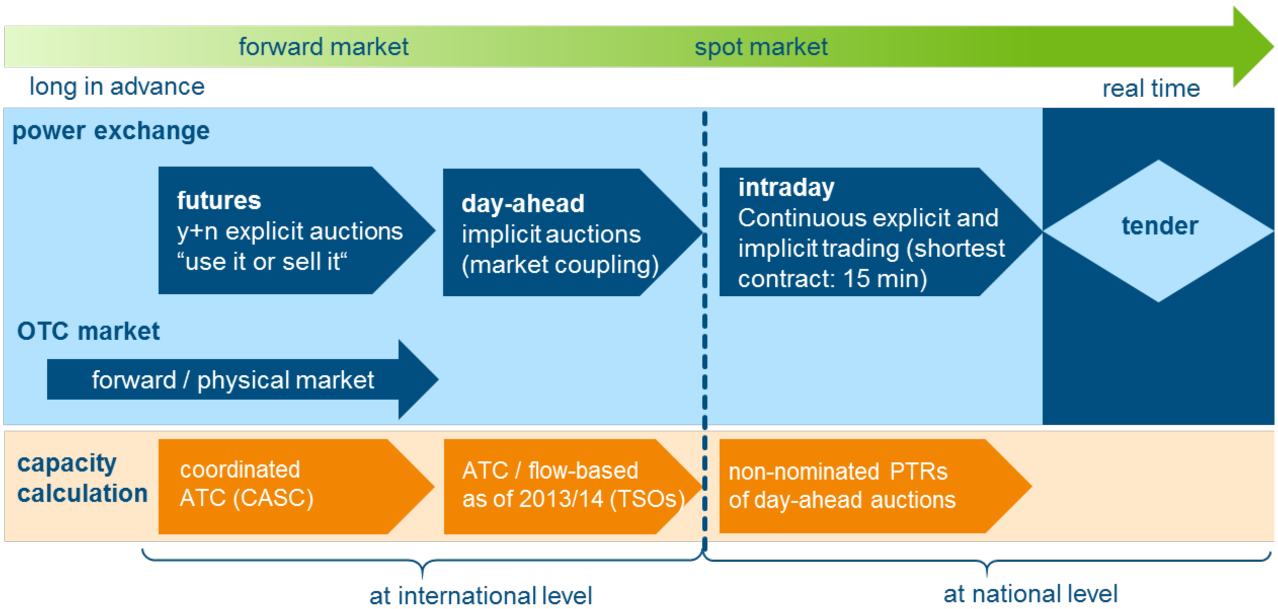

Figure 15. Electricity market segments and products

Source: Ecofys based on ENTSO-E (2012)

Germany has four TSOs. They emerged after the unbundling and have natural monopolies. The German Federal Network Agency for Electricity, Gas, Telecommunications, Posts and Railways (*Bundesnetzagentur*) regulates the TSOs. The TSOs use balancing capacity to balance out any unanticipated differences in demand and supply. The system of balancing groups and imbalance settlement controls synchronization (Bayer 2015). Because of the interaction between these mechanisms, the electricity market provides remuneration for energy and—to a lesser extent—capacity. TSOs rectify bottlenecks in the grid by expanding and upgrading the power grid and, on an interim basis, by using re-dispatch measures.[31]

8.1.1 Generation Mix over Time

Germany has seen a continuous change in its power mix as the share of renewable energy sources continues to increase. Coal still dominates the power generation, but its share is decreasing in favor of renewables. Between 2005 and 2015, the share of renewable energy sources in gross electricity production has increased by 20 percentage points, holding a total share of 30% (see Figure 16). Renewable energy sources have now overtaken each conventional source to become the largest electricity source and are projected to increase further in the decades to come.

[31] It is assumed that the electricity can be transported from the generating installations to the customers. In practice, however, grid congestions are rendering this impossible in a growing number of hours each year. At these times, the TSOs use "re-dispatch" measures. That means they ramp down power stations ahead of the congestion (power stations that won contracts to supply electricity on the electricity market) and ramp up power stations behind the congestion (power stations that did not win such contracts). The power stations ahead of and behind the congestion are compensated for this intervention, and those costs are passed onto the customers via the grid charges.

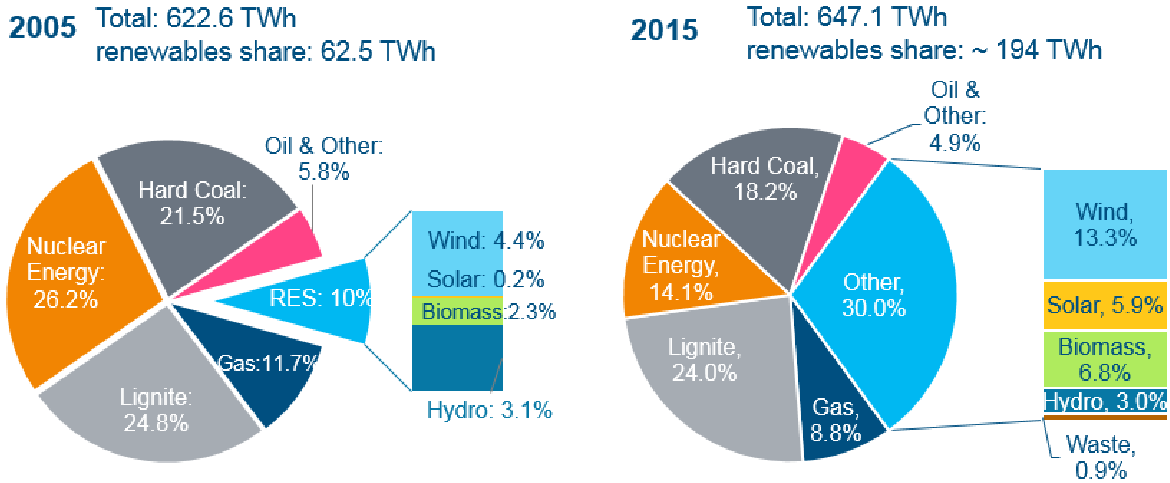

Figure 16. Development in German gross electricity production

Source: Ecofys (2016) based on AGEB (2015)

8.1.2 Regional Interactions with Neighbors

The German electricity market is coupled with the electricity markets of 15 neighboring countries. The exchange price on the day-ahead market is determined jointly for coupled markets. Electricity providers and electricity purchasers submit their bids in their national day-ahead market zones. In an iterative process, the demand for electricity in the market zone is served by the lowest-price offers of electricity from all market areas until the capacity of the connections between the market zones (cross-border interconnectors) is fully utilized. As long as the cross-border interconnectors have sufficient capacity, this process aligns the prices in the coupled market areas. Unfortunately, the capacity of the interconnectors is insufficient to compensate for the overcapacity in the German system caused by exporting electricity.

8.1.3 Political Goals and Drivers

Aligned with European political goals, German energy policies follow three key objectives for the energy supply. It should be secure, cost-efficient, and environmentally compatible. Cost-efficiency considerations mostly drove the liberalization decision. Environmental considerations have driven the continuous support of renewables over the past 25 years (see Figure 17). Environmental, security, and cost-efficiency considerations led to the plan for nuclear phase-out by 2022, which will take roughly 12 gigawatts of generation capacity offline.

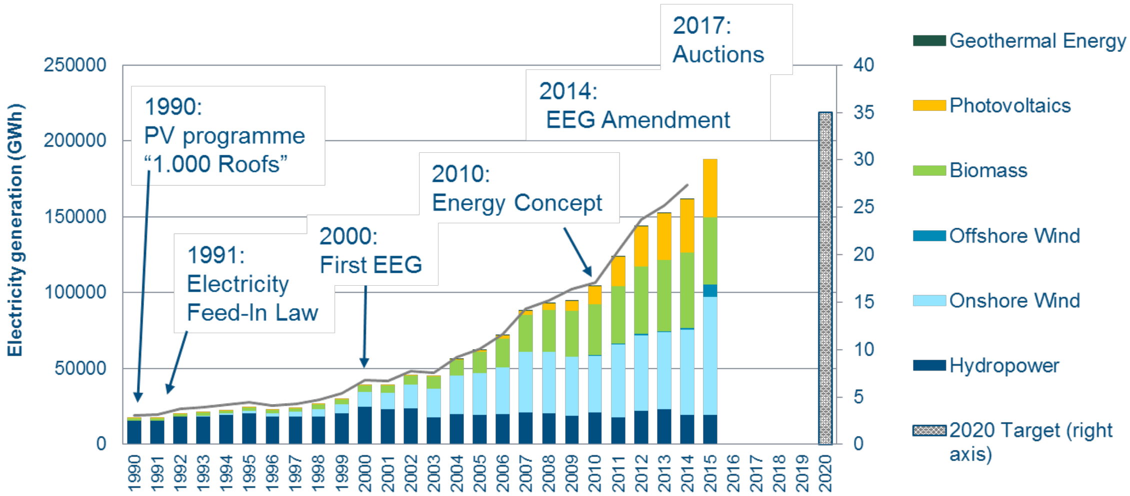

Figure 17. Milestones of the development of renewable electricity generation in Germany

Source: Ecofys based on AGEB (2015); IEA (2015c) AGEE-Stat (2014); BMWi (2015b)

The three goals influenced the debate surrounding the new market design. The consultation process, which the ministry conducted, revealed that for many stakeholders, security of supply was the overriding criterion for the future electricity market design and was seen by many parties as a central aspect of how attractive Germany is for investors. Cost efficiency is another key goal of the new electricity market design, especially the idea that substantial and unnecessary additional costs to consumers should be prevented, and costs due to new subsidies and regulatory risks should be avoided. A holistic approach was taken for the electricity market design to make it environmentally compatible. In particular, the goals of the energy transition—including the expansion of renewables, the new electricity market design, and the federal government’s climate change mitigation strategy—must all be coherent. The energy transition offers the opportunity to support innovation and modernize the industry if a stable long-term policy environment is created.

8.2 Primary Challenges in the Electricity Market

The core of Germany’s energy transition is a transformation from a power system in which controllable power stations follow electricity demand to a system in which a high share of variable generation assets exists, whose output can only be controlled to a limited extent. The goal is to achieve an efficient power system where flexible producers, flexible consumers, and storage systems respond increasingly to the variable supply of wind and solar power.

Four primary challenges culminated in the electricity market 2.0 discussions:

- First, electricity prices had been driven down due to increased competition from the liberalization of the market, which put pressure on existing generation facilities to recover cost.
- Second, the EU internal market accelerated the price decrease. Markets grew and became more interconnected, requiring less spare capacity to cover demand.

- Third, the economic crisis of 2008 led to a decrease in electricity demand; demand has not recovered. Investors overestimated future demand and invested too heavily in new generation assets.
- Fourth, the entry of new generation assets in the form of renewables led to a further increase in overcapacity.

In total, TSOs estimate a "spare capacity" of roughly 10 gigawatts, according to a recent system adequacy forecast for Germany for 2014–2017 (TSO 2014). This capacity is not needed to cover load in Germany. The four factors and the corresponding overcapacity result in low electricity prices on the exchanges, which currently define the market and reduce the economic viability of power stations. In these market conditions, particularly highly flexible peak load generation like gas-powered generation facilities find it difficult to recover costs and may be crowded out; yet, the highly flexible generation assets are exactly those that are needed for a stable and well-functioning system.

System stability requires that production and consumption are aligned at all times. Hence, the power system needs sufficient capacity to meet demand and ensure capacity can be used in times of high demand and low renewable generation as well as dispatched in times of low demand and high renewable generation. Both extremes are present in the electricity market—challenges the market must address in a secure and cost-effective manner. With a high penetration of renewable energy, minimum generation can hamper the cost-effective and environmentally compatible synchronization of production and consumption. Therefore, highly flexible generation assets are needed, and in some cases are the same assets currently at risk of being taken offline because of their higher marginal cost (e.g., natural gas fired power stations).

8.3 The Electricity Market 2.0

Due to these factors just described, the ministry commissioned several studies to inform the debate regarding the reliance on an electricity market 2.0 versus the need for a capacity market (Energy Brainpool 2013; Frontier and Consentec 2014; Schlesinger et al. 2014; Connect 2015; Frontier and Formaet 2014; Consentec and r2b 2015). In addition to commissioning the technical studies, the ministry decided to launch a public consultation to facilitate an open and transparent debate on options for the country's future electricity market. A multi-step process was carried out, which included the development of a "green paper" that provided a transparent overview of the setup of the two options (electricity market 2.0 and capacity market) and the assumptions and opinions of proponents of the different options (BWMi 2014). The paper was used to facilitate a broad and transparent public discussion on how to organize the electricity market. The guiding questions of the process were:

- What should such a market and corresponding regulatory framework for the electricity sector look like?
- How can we develop the best architecture for the electricity market of the future?

The ministry received over 700 public and private statements, including those from associations, grid providers, state ministries, utilities, NGOs, private individuals, and many others. The following sections summarize the two primary perspectives regarding electricity market 2.0. While many perspectives will be valid in the context of other countries, the specific argumentation and the weighing of the arguments reflect the German context and debate and may need to be adapted to fit to other countries' market reforms.

8.3.1 The Electricity Market 2.0 Perspective

Proponents of maintaining an energy-only market believed that, due to certain market conditions, only the required capacity would need to be remunerated in order to ensure security of supply.

Because of Germany's location at the center of Europe, security of supply in Germany must be approached from a European angle. The German electricity market is already closely linked to the electricity markets of its neighboring countries. The currently available transmission capacity amounts to approximately 20 GW and permits cross-border trade in electricity (r2b 2014). Thanks to large-scale smoothing effects, particularly for maximum peak loads and the feed-in from renewables, security of supply can be achieved less expensively in the European internal market. The joint peak load is smaller than the sum of the national peak loads. Consequently, less capacity (from conventional and renewable power plants, demand side management, and storage) needs to be maintained.

Research also shows that the cross-border trade in electricity will become more important as renewables are expanded (Consentec and r2b 2015). Only the required capacity—not all capacity—must be remunerated in order to ensure security of supply. Few new power stations will likely be needed in the next 10 years. Beyond the power plants currently under construction and the reactivation of a few installations that have been temporarily decommissioned, only a few peak load capacities (e.g., internal combustion engines and gas turbines) will be needed (r2b 2014). According to the cited studies, these flexible installations have low investment costs and can be built quickly. Their operation is profitable even if the periods of utilization are short. At the same time, other flexibility options such as demand side management and back-up power systems will become more important. A simple capacity reserve would be sufficient to safeguard the electricity supply at all times.

The government was also convinced that a further developed electricity market is less expensive than a power supply system with an additional capacity market. Capacity markets can be susceptible to design error, and these errors can result in substantial costs. The electricity market 2.0 could provide the required capacities and the solutions to integrate renewable energy less expensively. This requires undistorted competition between the flexibility options.

The third reason for the decision to opt for the electricity market 2.0 was that the undistorted market price signals, the regulatory framework, and additional instruments could create incentives for new fields of business and sustainable solutions. The government saw the energy transition as an opportunity to modernize the industry and provide a stimulus for innovation and new technologies. Entirely new market opportunities and business models would open up for companies in the energy industry and for small-scale producers, commercial enterprises, and large private-sector consumers as a result of smart grid technologies. Over the last 15 years of liberalization, the energy markets, their products, and the players have already experienced a considerable amount of development. There are various ways to integrate wind and solar power at low costs. The potential from a diverse set of flexibility options is much greater than the actual need. Many flexibility options are already economically viable or will become so with further progress in technology and changed electricity prices. In an electricity market 2.0, the least expensive solutions win in a technology-neutral competition.

8.3.2 The Capacity Market Perspective

The introduction of a capacity market, on the other hand, would have required a significant change in the current electricity market design because an additional market would have to be created. This initially discussed alternative was based on the fundamental assumption that even an optimized electricity market would not provide sufficient incentive for the maintenance of capacity and that an additional market must be introduced. An additional capacity market would provide explicit payment for capacity, and the costs would be redistributed to the electricity customers. Advocates for the option of the capacity market (at least implicitly) make the following assumptions and assessments:

- The level of capacity attained in the electricity market is insufficient.
- Flexibility options, particularly demand side management or back-up power plants, are not sufficiently available or cannot be developed to an adequate extent in the electricity market.
- A strategic reserve that is maintained and then dispatched when the market price hits a certain level does not efficiently ensure a sufficient level of capacity.
- Additional regulatory intervention is necessary; a capacity market must be introduced.
- The higher level of capacity justifies the additional costs (which are redistributed to electricity customers).
- Price peaks in the spot market can be cause for political concern and are therefore not accepted.
- Price peaks are too unreliable to provide investment incentive for market participants because they fear policymakers could intervene with price ceilings. Therefore, investor uncertainties must be reduced through capacity markets.
- The higher level of capacity available means that capacity markets reduce price peaks in the spot market.
- Apart from the reasons in favor of the electricity market 2.0, the following arguments spoke against the capacity market. Due to their complexity, capacity markets are at risk of substantial extra costs for the whole system if optimal parameters are not set or mistakes are made by the system planner. Based on the studies referenced above, overcapacities are commonly found in capacity markets because the administrative requirement can quickly result in an unnecessarily high capacity level, and these costs are transferred to the consumer. Capacity markets need a high degree of coordination and can run the risk of resulting in market power problems and may affect market integration efforts.

In the end, the capacity market concept was finally revoked. Subsequently, the ministry published a white paper in July 2015 with its decision to introduce an electricity market 2.0 (BMWi 2015a). The ministry is currently drafting the corresponding legislation, the Electricity Market Act.

The following sections introduce some details of the electricity market 2.0 reform and overviews what the Electricity Market Act will entail.

8.3.3 Details of Electricity Market 2.0

The electricity market 2.0 policy framework consists of three components:

- Component 1 strengthens the existing market mechanisms so that the market players maintain sufficient capacity and deploy it to the necessary extent.
- Component 2 optimizes the electricity supply at a European level and a national level so that the market players use the capacities more efficiently and in a more environmentally compatible way.
- Component 3 uses a capacity reserve and supply security monitoring to additionally back up the power supply.

The three components build on the tried and tested structures of the liberalized electricity market and are designed to be compatible with European law.

Two preconditions need to be fulfilled to guarantee the necessary capacities in the electricity market 2.0 can be paid via the market mechanism. Electricity pricing must remain free and electricity suppliers must have strong incentives to meet their supply commitments. Free pricing on the electricity market is therefore a core principle of the Energy Industry Act. At the same time, market players get stronger incentives to meet their supply commitments. Overall, the three components split into 20 detailed measures (BMWi 2015a).

8.3.3.1 Component 1: Strengthening of Existing Market Mechanisms

Component 1 strengthens the existing market mechanisms so that the electricity market is able to fulfill its synchronization function and ensure security of supply. It ensures that the market players contract sufficient capacity (i.e., at the level of the expected consumption) and deploy this to the extent necessary. This means that the market mechanisms set the incentives so that the market players will fulfill their supply obligations. This enables the necessary capacities to be refinanced (e.g., on the short-term spot markets and the long-term futures markets) so that sufficient capacity is maintained.

The government identified the need to strengthen the confidence of the market players in competition-based price formation by employing a stable framework on which investors can rely. The law will state that pricing will take place on the basis of competition only. This means that high price peaks are allowed to occur, and the investment incentives of the market mechanisms can take full effect (Measure 1). Also, the Federal Cartel Office (*Bundeskartellamt*) will create greater transparency via its oversight of abuse of dominant positions in electricity generation. Companies will be aware of when they may offer electricity on the wholesale market at prices higher than their marginal costs ("mark-up") (Measure 2). Also, the incentives to uphold balancing group commitments will be strengthened. The Federal Network Agency will revise the balancing energy system and thus strengthen the incentives to uphold balancing group commitments (Measure 3). The law will further state that parties having a balancing responsibility will always bear the cost for balancing energy, even in rare situations of extreme capacity scarcity necessitating intervention by the TSOs (Measure 4).

Measure 1 (guaranteeing free price formation on the electricity market) is of particular interest as it is at the core of the electricity market 2.0. The prices on the electricity market send relevant information to the market players (electricity suppliers, electricity traders, and large-scale industry), and are therefore a key signal for investment and they provide incentives to increase the flexibility of the electricity system. Today, the electricity exchanges have technical upper price limits and in the consultation, some market players expressed a concern that the regulator could intervene in the market in future to prevent high yet needed prices on the exchange. The Electricity Market Act will create confidence among market players. First, the government aims to anchor free pricing as a "target definition" in the body of the law, which means that the principle receives a higher rank in the body of the law. Second, the decision is aligned with and further strengthened by international policies. Germany and its neighboring countries have committed to free price formation in their joint declaration of June 2015. On regional cooperation on security of supply, the declaration stresses that no statutory price caps will be introduced and that national measures that could function as indirect price caps are to be avoided. As the principle is agreed among several states, it is more reliable for investors.

8.3.3.2 *Component 2: Flexible and Efficient Electricity Supply*

The "flexible and efficient electricity supply" component ensures market players will use the capacities in a cost efficient and environmentally compatible manner. This is determined not by the electricity market design in the narrower sense but by the entire regulatory framework for the electricity sector. The measures of Component 2 (Measures 5–16) optimize the electricity supply and anchor the further development of the electricity market at the European level. They thus ensure a flexible, cost-efficient, and environmentally compatible use of capacity and competitive electricity prices. The measures include:

- Measure 5: Anchoring the further development of the electricity market in the European context
- Measure 6: Opening up balancing markets for new providers
- Measure 7: Developing a target model for state-induced price components and grid charges
- Measure 8: Revising special grid charges to allow for greater demand side flexibility
- Measure 8: Continuing to develop the grid charge system
- Measure 9: Clarifying rules for the aggregation of flexible electricity consumers
- Measure 10: Supporting the wider use of electric mobility
- Measure 11: Making it possible to market back-up power systems
- Measure 12: Gradually introducing smart meters
- Measure 13: Reducing the costs of expanding the power grid via peak shaving of renewable energy facilities
- Measure 14: Evaluating minimum generation
- Measure 15: Integrating CHP generation into the electricity market

- Measure 16: Creating more transparency concerning electricity market data.

The measures of Component 2 ensure a flexible and efficient electricity system. They include new fields of cooperation for the European electricity markets, the further development of balancing markets, and the design of the grid fees in order to allow for more market-based demand-side management. One of the most important measures is Measure 6 (opening up balancing markets for new providers).

Balancing markets is important to balance supply and demand in the very short term (i.e., after gate closure on the intraday market). To keep the system stable at all times, the TSOs use balancing capacity to offset unforeseen power plant failures or deviations from forecasts of demand and renewable-based generation.

In Germany, the balancing market remunerates the *availability of capacity* at short notice and is open to generation that meets certain flexibility standards. To facilitate more competition and thus to cut costs, the balancing markets should be open to as many providers as possible. Also, greater participation in the balancing markets can reduce the minimum generation from thermal power plants; in certain situations, thermal power plants will no longer be needed to cover the demand on the electricity market. The Federal Network Agency is therefore opening the balancing markets to permit new, flexible providers to participate. It has started a procedure to stipulate the auction rules before the end of 2015. If there are shorter ramp-up times and smaller products, providers such as storage units, flexible consumers, and renewable energy can play a greater role in the balancing markets. System stability will continue to be the priority when the balancing markets are opened up to new providers. In the long term, the "Leitstudie Strom" expert report proposes calendar-day procurement with one-hour blocks (Connect et al. 2015).

Other measures that ensure a flexible and efficient electricity system include new fields of cooperation for the European electricity markets, the further development of balancing markets, and the design of the grid fees to allow more market-based demand-side management.

8.3.3.3 *Component 3: Additional Security*

The measures of Components 1 and 2 strengthen existing market mechanisms and ensure a flexible, efficient electricity supply. The measures of Component 3 provide additional security of supply. The monitoring process will continuously survey the security of supply. The measures of Component 3 include:

- Measure 18: Monitoring security of supply
- Measure 19: Introducing a capacity reserve
- Measure 20: Continuing to develop the grid reserve.

The key measure here is Measure 19, which introduces a so-called capacity reserve. By creating a capacity reserve, Germany aims to provide further backup for the electricity market 2.0. Power stations that receive payments under the capacity reserve will be used only if—despite free price formation on the wholesale market and contrary to expectations—supply does not cover demand at a particular time. The capacity reserve ensures all consumers can still obtain electricity in such a situation.

The key justification of Measure 19 is that it is possible that, in unforeseeable situations, supply and demand will not match. Unlike the “capacity market,” the capacity reserve consists solely of power stations that do not participate on the electricity market and therefore do not distort competition or pricing.

Regarding its setup, the capacity reserve will maintain technically suitable reserve power stations. Following an auction, TSOs will enter into contracts with power stations whose technical characteristics make them suitable to provide the reserve timely and targeted capacity. It looks likely that power stations will only participate in the auction if they can no longer be commercially operated on the electricity market. They will remain the property of their operators. The TSOs will only control their dispatch. The capacity reserve will only be deployed if there is a capacity deficit. In the unlikely event that, on the day-ahead market, despite free pricing, insufficient electricity is offered on the electricity exchange in order to cover demand, the TSOs will call on power plant operators to place their installations “on stand-by.” The power stations will ramp up to their minimum partial load and await further instructions from the TSO. On the following day, the short-term, intraday trading takes place. The TSOs will only intervene if this intraday trading is also unable to fully cover the demand, despite free pricing. First of all, they will use the available balancing capacity. If this proves insufficient, the TSOs will call on the reserve power plants to cover the remaining demand.

Besides the capacity reserve, there is also a grid reserve in Germany; yet, the instruments are different and separate. The capacity reserve safeguards the electricity supply in the unlikely event the market is unable to balance supply and demand. In contrast, the grid reserve secures the functioning of the grid when there is regional congestion. Until the congestion in the grid has been removed, the grid reserve will retain power stations in southern Germany so that they can be used for re-dispatch in the case of grid congestion. While the capacity reserve will be introduced nationwide and without a time limit, the grid reserve has a regional, temporary task that largely depends on the progress made on expanding the grid. The grid reserve can be closed down as and when key grid expansion projects are completed and reserve power plants are no longer needed for secure grid operation.

The capacity reserve therefore complements the existing instruments in Germany. It ensures security of supply without distorting the market.

8.4 Next Steps and Remaining Challenges

Germany’s energy transition will continue to place new challenges on the design of the electricity market and the interaction with neighboring countries:

- The EU Member States have already taken important steps on the path toward a liberalized, integrated electricity market. This development is to be continued and intensified in coming years.
- The electricity supply system must integrate the rising share of renewable energy sources in a secure and cost-efficient manner. Meanwhile, an appropriate policy framework is needed to reduce the support requirement for renewable energies.
- Conventional power plants will remain an important means of ensuring security of supply. However, they will assume a new role in the supply of electricity; whereas in the

past, these base load power plants were the backbone of the electricity generation system, providing a continuous supply of electricity, their future role will be to supplement the fluctuating supplies from wind and solar energy.

- With the continued expansion of renewables, it is increasingly important to link the electricity, heating, and transport sectors. If there is demand for electricity at market prices in all sectors and electricity is thus also converted to heat and mobility in response to market demand, the targets for reducing carbon emissions in the transport and heating sectors can be achieved at lower cost. The electricity market design must therefore take into account the entire regulatory framework of the electricity sector.
- The focus of the electricity market design is shifting; besides addressing the goals for the electricity sector, the electricity market design must in the future take greater account of the other goals targeted by the energy transition, such as boosting energy efficiency.
- Coordination between the power grids and the electricity market is vital. For example, greater interaction between the electricity, heating, and transport sectors can have an impact on the power grids.

In summary, the current decision in favor of the electricity market 2.0 is a landmark design, yet it is unlikely to be the last time that fundamental electricity market design questions need to be addressed. New challenges will emerge to which new solutions will need to be found.

8.5 Lessons Learned

Germany provides an example of a country in which a restructuring of the power system was driven by the decision to liberalize the market and, more recently, by a clean energy transition. Hence, the electricity market 2.0 decision is an example of a key decision along the way of a clean restructuring of the power sector. Three major lessons can be learned:

1) A clean transition affects the electricity market design. While debates in the 1990s in Germany focused on the support of renewables as such, their increasing share affects the functioning of the electricity market and the power sector fundamentally. In other countries, too, market design issues will likely become more important as the share of renewables becomes higher.
2) Liberalization and a clean restructuring can go hand in hand. It is not necessary to revoke a liberalization decision to guarantee security of supply in a system with high shares of renewables. In Germany, the arguments for having an energy-only market outweigh the arguments for a capacity market.
3) Markets that let the price signal be formed more freely can incentivize the development of flexibility options and innovative solutions for the integration of renewables and thereby support the clean transition. Capacity markets, on the other hand, are prone to regulatory failure and may hinder innovation.

A transparent and inclusive restructuring process allows the identification and solution of unprecedented issues while increasing public acceptance of the restructuring. When the energy transition (*Energiewende*) and the power system liberalization started, not all challenges could possibly be foreseen. Throughout the process, a variety of studies, and expert and public consultations were conducted. Consequently, an informed public debate emerged that allowed the solutions to be identified that best suit the political goals at this particular time.

9 Conclusions

Countries interested in clean energy restructuring can take advantage of lessons learned in liberalized power markets that have recently experienced rapid growth in clean energy resources. Although power markets have unique local considerations, policy objectives, operational practices, and physical characteristics (e.g., grid infrastructure, generation mix), international experience can help inform paths forward toward clean energy restructuring.

In recent years, power markets in a variety of regions have addressed changes in generation mix, and the increase in variable generation resources, by revising all facets of power systems, including: 1) generation planning and procurement practices, 2) market design and operations, and 3) grid planning processes, interconnection procedures, and grid codes. These experiences are documented in the detailed case studies and examples included in this report. Collectively, these experiences suggest the following key considerations for jurisdictions considering electricity market transformation in light of expected growth in clean energy resources.

Generation Planning and Investment

- Case studies featured here indicate that incorporating forward-looking flexibility and resource adequacy assessments and analysis into planning processes can be beneficial for markets that expect significant penetrations of variable clean energy sources. The exact nature of flexibility and resource adequacy issues will be distinct for each power system.
- Under certain circumstances, revenue sufficiency concerns may arise for existing and new generators in the market. Planning and procurement processes can, to some extent, address these issues by promoting appropriate levels of new capacity deployment, reducing occurrences of over-generation, and striving to maintain the bankability of new infrastructure projects.

Market Design and Operation

- The design and implementation of unit commitment and dispatch rules can significantly impact the ability to manage variable renewable generation on the system; dispatch rules have implications for the economic viability of renewables as well. Short dispatch increments, and the ability to revise bids during the day based on updated forecast data, can enable markets to more effectively utilize available renewable generation resources. Other considerations for the viability and integration of clean energy sources are the structure of imbalance penalties and rules for curtailing generation for balancing.
- In the case studies included in this report, integration of forecasting into market operations has been important for continuous system balancing as well as planning for extreme weather events to avoid system outages. Adequate data from generators can help system operators ensure accuracy of system level forecasts, which could be instituted as a condition of interconnection.
- Newly restructured markets can consider market design elements that alter the way that ancillary services are provided to the system, and include provision of these services by clean generation sources. Modifications may need to be made to load following, frequency responsive reserves, inertial response, and reactive power support.

- New market products, such as ramping products, may be helpful for achieving the additional system flexibility needed to address the variability and uncertainty introduced with variable renewable generation.
- Demand response can be an important component of cost-effective system flexibility.

Grid Infrastructure, Interconnection, and Grid Codes

- For network expansion and investment in a restructured environment, the signature policy and regulatory task is to appropriately allocate the cost and risk of network expansion among developers and ratepayers in accordance with policy goals. Case study experiences indicate that this is particularly true for power systems with more geographically dispersed clean energy sources that may not be easily located on the existing transmission grid or near load centers.
- Streamlining the interconnection process for resources applying to connect to the network can reduce barriers to entry for new resources (including clean energy) in terms of the time and cost of the application process.
- With higher levels of VRE on the system, updating grid codes to reflect technologies with different operating characteristics can help ensure that all resources contribute to system reliability as feasible. For variable generators, grid code modifications may be needed for: power control, reactive power and voltage control, frequency and inertial response, and voltage and frequency ride through.

Three case studies from Power Partnership countries—Mexico, Germany, and Denmark—illustrated individual pathways for power sector reforms that enable the integration of clean energy, but also presented more universal insights on clean restructuring in practice.

- Strong stakeholder engagement processes in all of the three areas discussed above helped create a truly competitive market environment and a level playing field for various market actors, including clean energy resources.
- Mechanisms for ongoing political and institutional support for clean restructuring efforts, especially those of a transnational nature, can also provide a long-term and stable policy environment within which markets can operate.
- Particular elements of clean restructuring may be phased in over time, especially as the levels of clean energy in the power sector gradually increase. Similarly, market elements and rules can also be implemented that anticipate future growth in clean energy.

While optimal solutions for transforming power markets will vary by jurisdiction, these common considerations from global experience can help inform the direction and types of changes that may be needed in power systems of the future with expanded adoption of clean energy resources.

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