
1. Introduction to the *Handbook on Electricity Markets*

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The electric power industries in all countries have changed enormously over the roughly 140-year history of central station generation/transmission/distribution systems supplying electricity to the public. The evolution has reflected technological change on both the supply and demand sides, exploitation of economies of scale, environmental and other policy constraints, organizational and regulatory innovation, interest group politics and ideology.¹ This handbook focuses on the latest set of institutional changes to electric power sectors around the world that are generally captured by the phrases restructuring, competition, decarbonization and regulatory reform.

The contemporary restructuring of the electric power industry has involved: (1) the separation or unbundling of the previously (typically) vertically integrated – through common ownership or regulated long-term contracts – generation, transmission, distribution and retail supply segments of the industry; (2) the deconcentration of and free entry into the generation segment; (3) the reorganization of the transmission/system operations segment; and (4) the separation of the physical distribution (delivery) segment from the financial arrangements for retail supply of energy. These restructuring initiatives have been designed to enable competition between generators to supply energy, ancillary services and capacity in wholesale markets and to open retail supply to competition. Regulatory reform has been focused on actions to facilitate the efficient evolution of competition, to improve the performance of the remaining regulated monopoly segments of the industry and, most recently, to integrate efficiently intermittent wind and solar generation along with electricity storage, as electric power systems respond to constraints on greenhouse gas emissions.

Government policies and regulation have been particularly important in directing the design of wholesale markets, defining the obligations and behaviour of transmission owners and system operators, improving the performance of regulatory mechanisms that specify how transmission and distribution system owners and system operators are compensated, and guarding against anti-competitive behaviour in the newly competitive wholesale markets and retail supply segments. Policies designed to decarbonize the electricity sector by replacing fossil-fuel generation with zero carbon resources, primarily adding intermittent wind and solar generation along with storage, have created a new set of issues for system operation, wholesale market design, retail rate design, the investment framework for wind, solar and storage, reliability and other considerations. Electric power systems built around dispatchable, primarily thermal generation with capacity constraints are now evolving to manage systems with intermittent wind and solar generation at scale, energy storage and high levels of spot market price volatility as zero marginal operating cost intermittent resources penetrate these systems. Deep

decarbonization is transforming electric power systems from capacity-constrained systems to energy-constrained systems. This transition requires aggressive carbon emissions constraints with network reliability criteria.

Different countries, and even states and provinces within countries, have approached this basic restructuring programme in different ways. The first major initiative occurred in England and Wales starting in 1989.² Restructuring and competition initiatives in the US, Canada, Australia, the EU and other countries proceeded in the late 1990s and early 2000s. In most cases, early reforms have been followed with additional design and regulatory changes in response to problems that emerged during the reform process, lessons learned, new environmental policies, especially policies to respond to climate change, and the evolution of generation supply and storage technologies compatible with these environmental goals – wind, solar, storage, system operations and computing capabilities, energy efficiency and demand response. While the basic architecture of restructuring is similar across countries, states and provinces, there are significant differences in the details. And there are some countries and regions that have not restructured at all and continue to rely on traditional arrangements – for instance, large parts of the US and Canada.

This handbook brings together a wealth of expertise to look at both the current legacy state of power markets around the world (in Part I) and how those power markets can and should adapt to new low and zero carbon generation technologies, energy storage and the policy priorities that are driving their adoption (in Part II). In the rest of this introduction, we briefly summarize some of the key issues covered in the 21 chapters that follow this one.

PART I TAKING STOCK: THE LEGACY

Chapter 2 by Richard Schmalensee discusses the strengths and weaknesses of the traditional institutional arrangements, outlined above, as they emerged following the First World War. The chapter also identifies some of the challenges to wholesale and retail markets and retail pricing associated with deep decarbonization of electricity supply and the associated reliance on intermittent wind and solar generation and energy storage as dispatchable fossil-fuel generation is replaced.

The handbook then turns to wholesale and retail market design, strengths and weaknesses of different approaches, and adaptations over time in several different countries and regions. There are many similarities between these market models, but also some important differences. The market models have all evolved in response to lessons learned from experience and to changes in public policies. While Part I of the handbook does not cover the market models adopted in all countries and regions, the range of wholesale and retail market design differences and adaptations to imperfections and public policy changes capture most of the variations that we see around the world.

Chapter 3 by Paul Joskow and Thomas-Olivier Léautier presents the basic theory of optimal investment and pricing at the bulk power or wholesale level for systems comprised primarily of dispatchable fossil-fuelled and nuclear thermal generating capacity. This theory can be traced back to the work of Marcel Boiteux, Ralph Turvey and others in the 1950s and 1960s. That work focused on optimal investment and optimal pricing

for a centrally planned monopoly with dispatchable thermal generation at what we would now call the wholesale level.³ However, this basic theory formed the basis for the initial design of competitive wholesale markets, essentially assuming a duality between optimal investment and pricing in a centrally planned system with price formation and investment in competitive wholesale markets. Whether and how this basic theory and its application to wholesale market design must be revised to account for deep decarbonization of the electricity sector with high levels of intermittent wind and solar generation and storage is the focus of Part II of this handbook.

Chapter 4 by Frank Wolak discusses the key design features of successful wholesale electricity markets in general. These include: (1) matching the wholesale market design and resulting generator dispatch and congestion management to the physical attributes of electric power systems; (2) market and regulatory mechanisms to govern the incentives for entry and exit of generators consistent with achieving long-term generation resource adequacy criteria; (3) horizontal market power concerns and mitigation mechanisms; and (4) mechanisms to integrate demand response into wholesale markets. The chapter also discusses issues that arise in small markets and developing country contexts. It concludes with a brief discussion of market design issues associated with the integration of grid-scale and distributed renewables – mainly wind and solar.

Chapter 5 by Stephen Littlechild discusses the development of competitive retail supply markets. The unbundling of physical delivery services (distribution) from the contractual arrangements defining how independent intermediaries can compete to arrange for and are compensated for the electricity consumed by retail customers is truly an innovation that departs from the historical responsibilities of local distribution companies both to deliver electricity and arrange for its supply (and be paid for them in return). Retail competition has been especially valuable for larger customers with interval meters, demand management capabilities and some on-site generation. Competitive electricity retail suppliers can offer contracts that give these customers better price signals and can integrate retail consumption and load management decisions with wholesale markets. Retail competition for residential and small commercial customers has been more controversial, though this may change as smart meters, real-time pricing, smart grid enhancements and individual customer utilization settlements protocols (rather than load profiles) are more widely deployed. The chapter starts by discussing early thinking about restructuring and competition during the 1980s. It goes on to analyse the creation of retail markets around the world during the 1990s and early 2000s. The concerns about and interventions in retail supply markets during the 2010s are presented next. Finally, Littlechild questions whether the concerns are justified and asks what might happen in the future.

The handbook then moves on to in-depth discussions of the details of wholesale market designs in specific countries or sub-regions of countries, their strengths and weaknesses, and their evolution in response to weaknesses and changes in public policies. Chapter 6 by David Newbery discusses the market model initially adopted in England and Wales and how it has changed over time. The chapter provides background information on the pre-restructuring (post-First World War) electricity sector in England and Wales and the motivations for privatization and restructuring for competition. The chapter then turns to a discussion of the post-restructuring ownership structure of generation, the design of the new wholesale market and the horizontal market power problems that emerged.

Dissatisfaction with the performance of the initial industry structure and market design led to deconcentration of generation ownership and major changes in wholesale market design, transforming the initial market into an energy-only market without capacity payments (NETA). We then learn why and how capacity markets and government-mandated procurement of carbon-free resources pursuant to long-term purchased power agreements were reintroduced to support resource adequacy goals and, more importantly, decarbonization goals. The chapter concludes with thoughts on the integration of carbon-free generation resources and potential future reforms.

Chapter 7 by William Hogan discusses the market model adopted by PJM Interconnection in the US. PJM covers all or portions of 13 US states located east of the Mississippi River. PJM is a regional transmission organization (RTO), though in the US context it makes sense to use RTO and ISO (independent system operator) interchangeably. PJM manages wholesale energy, ancillary services and capacity markets for most of the investor-owned utilities, generators and transmission owners in this region. Unlike in most European countries, the day-ahead markets are fully integrated with day-of markets and real-time operations. These markets are also fully integrated with the management of transmission constraints by relying on a security-constrained bid-based economic dispatch auction market design for energy and ancillary services dispatch and prices. This mechanism yields locational (nodal) prices that vary from location to location when transmission constraints are binding. The chapter starts with a history of PJM (originally just New Jersey and Pennsylvania), going back to its roots in the 1920s as a centrally dispatched power pool, to the reforms during the 1990s and the ultimate creation of the basic wholesale market framework that defines PJM today. The chapter goes on to discuss many of the details of the PJM market model, whose basic version has largely been adopted by the other ISOs/RTOs in the US. Interestingly, PJM includes states that have fully restructured to rely on competitive wholesale and retail competition as well as those that continue to rely on vertically integrated monopolies.

Chapter 8 by Ross Baldick, Shmuel Oren, Eric Schubert and Kenneth Anderson discusses the market model in the Electric Reliability Council of Texas (ERCOT) (covering most of Texas). The chapter places the restructuring programme in ERCOT in a fascinating historical, political and ideological context. Unlike PJM, ERCOT is a single-state ISO. Nor is ERCOT subject to Federal Energy Regulatory Commission (FERC) jurisdiction but rather to the jurisdiction of the Public Utility Commission of Texas (PUCT). As a result, state policies, ISO policies and market design features can be harmonized more easily than in multi-state ISOs, where each state is a stakeholder and federal and state policies, especially regarding efforts to decarbonize the electricity sector, often differ. ERCOT model also reflects a deep commitment to competition in the electricity sector by Texas policy makers. The chapter reviews the restructuring process in ERCOT, the goals for wholesale and retail markets, the evolution of the design of both and brings us up to date on current issues. Today, ERCOT wholesale markets have many similarities to the other ISO/RTO markets in the US. However, there is an important difference regarding how ERCOT handles resource adequacy. Unlike the other ISO/RTO markets, ERCOT does not have a capacity market or use a centralized market to allocate capacity obligations.⁴ It does not establish forward capacity reserve requirements. Rather, ERCOT is an ‘energy-only’ market, though this simple phrase can be misleading. ERCOT model recognizes that for an electricity market to achieve an efficient long-run

equilibrium and to achieve associated resource adequacy goals, energy prices must be allowed to rise to very high levels to reflect the value of lost load as capacity constraints begin to bind and the market must ration scarce capacity. To do that, ERCOT introduced an administratively determined operating reserve demand curve (ORDC) and associated protocols to manage generating capacity scarcity with a price mechanism. The ORDC is in turn based on assumptions about the value of lost load, loss of load probabilities and other variables. In ERCOT, energy prices can rise to 9000 \$/MWh, the presumptive value of lost load. On the contrary, the other ISOs define capacity needs and use a capacity market to allocate responsibilities for paying for the needed generating capacity or demand response. These markets have price caps in response to concerns about market power in energy and ancillary services supply markets. The price caps are in the range of 1000–2500 \$/MWh. The chapter describes nicely how these market design features evolved and how they work today. Texas also has abundant wind and solar resources and wind generation in particular grew early and rapidly. The chapter illuminates how ERCOT has managed the influx of intermittent generation, as well as a pragmatic application of central planning combined with competitive tenders to choose and select transmission projects to relieve congestion between the major wind generation region and load regions.

Chapter 9 by Paul Simshauser discusses the Australian market model. The chapter considers the design features of the National Electricity Market (NEM), retail competition, incentive regulation for transmission and distribution, the regulatory framework and adaptations to the rapid expansion of intermittent renewable energy. Unlike the markets that have been discussed so far, the NEM has no organized day-ahead market, though over-the-counter trades can be arranged day ahead and futures contracts can be bought and sold as well. There are no formal capacity obligations and no capacity market. Accordingly, the NEM is a real-time energy-only market with a high price cap (AU\$15000/MWh 2020). The chapter goes on to discuss the challenges to efficiently integrate intermittent renewable energy supplies and, more generally, to align electricity markets with climate change policies. Recent reforms, their strengths and weaknesses are analysed.

Chapter 10 by Chloé Le Coq and Sebastian Schwenen discusses the Nordic power market that comprises the national markets of the Scandinavian countries. This market also includes trading arrangements with other countries with interconnections (Germany, the UK, the Netherlands and the Baltic countries). The chapter discusses the evolution and design features of Nord Pool, focusing on trading arrangements between the countries that are part of the Nordic market and the harmonization of differences between national markets. The chapter concludes with discussions of the adaptation of the Nordic market to decarbonization goals and security of supply issues.

Chapter 11 by Fabien Roques discusses the market models adopted in EU countries. There is no single market model that covers all the countries in the EU or, more precisely, the European internal market for electricity. Rather, there are a set of national markets with varying design features that follow EU guidance on certain attributes. The chapter explains that the European model for electricity markets has been shaped by successive laws and policy reforms. These have driven a degree of convergence in the designs of the various national (and regional) markets based on EU competition principles for the electricity sector. Beginning in the 1990s, the focus has been on creating an integrated

European market that supports efficient cross-border trade and competition. Unlike the US, where the RTO/ISO markets have ‘centralized’ day-ahead markets, day-of markets and integrated congestion management yielding locational price differences, EU markets typically have decentralized day-ahead markets and transmission congestion management. The chapter then emphasizes how policy priorities changed in the 2000s with the emergence of climate change and security of supply concerns. These changing policy priorities have led national markets to adopt their own rules, reversing the coordination trend. European electricity markets have evolved toward hybrid markets with a number of new features, including: (1) support mechanisms for clean technologies; (2) capacity mechanisms to address security of supply concerns; and (3) new planning processes to coordinate generation and grid development.

PART II ADAPTING TO NEW TECHNOLOGIES AND NEW POLICY PRIORITIES

Part II shifts the focus from the current organization of the electricity supply sector to potential future developments. It does this by discussing the promising new technologies that are emerging and indeed scaling up on the supply and demand side (Chapters 12 and 13), the near- and further-term impacts of renewables and decarbonization on the design of the electricity market and its companies (Chapters 14–17), the potential for electrification of transport and heating (Chapters 18 and 19) and the issues facing the electricity sector beyond the Organisation for Economic Co-operation and Development (OECD) countries (Chapters 20–22).

The electricity system has been undergoing a remarkable technology transition since 2000. Large subsidies to both research and development, and to strategic roll-out, have resulted in more than half of all new capacity additions globally by MW and by value being in renewable electricity in recent years.⁵ This is beginning to change the nature of electricity generation from being characterized by synchronous fossil-fuel generation (from coal, oil and natural gas) to one where both dispatchable renewable (for instance, biomass) and increasingly intermittent renewable (for instance, wind and solar) generation dominate additions of generation in OECD countries.

The nature of these generation technologies is discussed in Chapter 12 by Nils May and Karsten Neuhoff. They discuss the remarkable decline in the cost of both wind and solar generating capacity, which has seen these technologies reach cost parity with fossil fuels (especially with carbon pricing) in many jurisdictions, including in the developing world. May and Neuhoff analyse the prospects for onshore and offshore wind, solar photovoltaics (PV) and concentrating solar power, biomass, geothermal technologies and wave and tidal power within the electricity system. They note that challenges remain if these technologies are to rise to dominate the electricity system. These include local opposition to the siting of facilities, their intermittency (across the day and the season) and their high upfront financing costs. However, there is good reason to be optimistic of continuing technological progress and successful roll-out, especially where this is combined with market expansion, demand flexibility and storage.

Since the oil crisis of the 1970s, energy conservation and efficiency have been a policy priority in many jurisdictions. Recent developments with renewables on the supply side

has refocused attention on demand side technologies to not only reduce demand (relative to business as usual) but also to make it more flexible. This is the focus of Chapter 13 by Fereidoon Sioshansi. Annual and peak electricity demand are now below peak levels in many OECD countries, partly because of slower industrial demand growth, the impact of more energy-efficient appliances, low-energy lighting and more recently the diffusion of prosumers – that is, consumers that self-generate (part of) the electricity they consume by typically installing roof-top solar. Sioshansi discusses how self-generation, rising numbers of electric vehicles (EVs) and distributed batteries could add further – often behind-the-meter – flexibility to the electricity system and allow it to better match demand to intermittent electricity supply. He documents several nascent technologies such as ground source heat pumps and remote digital control technologies, which offer promising sources of local energy and supply and demand matching. While the timing of any mass take-up of demand-side technologies remains highly uncertain, it is clear that in densely populated cities, such technologies seem much less likely to be significant than in more sparsely populated regions where prosumagers – that is, prosumers with their own storage – might make economic sense.

Next, the attention turns to future changes to the market context in which electricity systems will be operating. A major driver of new technologies in electricity are policies that explicitly or implicitly promote decarbonization of the sector. This is the subject of Chapter 14 by Kathryn Cleary, Carolyn Fischer and Karen Palmer. The authors introduce and compare a range of policies that governments have been using to promote decarbonization. These include carbon taxation and trading mechanisms, renewables subsidies and portfolio standards, energy efficiency measures and policies targeting nuclear and coal. As the authors point out, these policies have very different levels of efficacy if the ultimate goal is decarbonization (early phase-out of existing nuclear power plants by pro-renewables governments, for instance, is a pro-carbon policy). Often, governments enact a range of policies simultaneously that conflict with one another and would benefit from policy rationalization (cap-and-trade plus renewables subsidy can result, for example, in more expensive decarbonization than is necessary). The authors conclude that putting a price on CO₂ emissions remains the most efficacious policy for decarbonization, while recognizing that other market failures such as those arising from myopia may justify policies to help investments in capital-intensive renewables and energy efficiency.

What impact will renewables have on the operation of electricity markets? The nearer-term effects of this are discussed in Chapter 15 by Richard Green. Green analyses how the rise in renewable energy supply (RES) will affect electricity market design. First, context is important. While some jurisdictions have seen large rises in their RES share in total production, globally low carbon electricity supply is dominated by hydro and nuclear. Biomass is also significant. However, it is the rise of intermittent RES that poses new challenges for the electricity system by shifting supply to when the wind and the sun are available. Rising intermittent supply will impact prices that will encourage demand to be more flexible. In turn, this will provide incentives for electrical energy storage investments and further investments in transmission interconnection capacity. Green suggests that in the medium term there is plenty of scope for the existing market design to accommodate rising RES shares in many jurisdictions.

Market design for electricity markets is not just about matching aggregate electrical energy supply and demand, it is about maintaining power quality at every node in real

time as well. Thus, power markets must also procure voltage and constraint management services. This is the focus of Chapter 16 by Michael Pollitt, who discusses the extent to which increasingly distributed electricity generation from intermittent RES and locally flexible electricity demand (in the presence of storage and EVs) can be accommodated within the two benchmark market designs that we currently see in Europe and in the US (as exemplified by PJM). He discusses two contrasting visions of the future (drawing on ideas from Fred Schweppe and Ronald Coase, respectively): one where more use is made of spot granular power prices at the nodal or device level; and one where the system operator makes more use of longer-term flexible control contracts. Reflecting on the experience of the pricing and rationing of the Internet, he suggests that at very high levels of intermittent RES, a new future market design that combines price signals with non-price rationing of intermittent renewables that match device demand in priority order would seem to be more acceptable within many regulatory systems than pure price-based rationing.

The future of the electricity supply industry is not just a function of technology or market design but is also importantly determined by the success of the business models that the companies within it adopt. The future of various electricity business models is the focus of Chapter 17 by Jean-Michel Glachant. Glachant unpacks and distinguishes a range of different business models within both the competitive and regulated parts of the electricity supply sector. These include the business models being pursued by generators in onshore and offshore wind (for the many and for the few), solar PV at utility scale and on rooftops. These new business models also involve aggregators moving from retail into wholesale markets, peer-to-peer bypassing of conventional utilities and the emergence of behind-the-meter territories. In this changing environment, grid companies are facing regulatory pressures to adapt their business models. These include the need to focus on the cost-effectiveness/competitiveness of grid capacity additions and strong revenue incentives for quality of service. The author argues that this fundamentally changes their business model from 'fit-and-forget' asset owners to companies engaged in seeking asset-light innovations.

What are the prospects for the electrification of transport? This subject is addressed in Chapter 18 by Bentley Clinton, Christopher Knittel and Konstantinos Metaxoglou. Transport consumes a considerable amount of the world's fossil fuels and much of surface transport could in theory be electrified. The authors focus on the prospects for electric vehicles. Passenger cars consume 50 per cent of surface transport vehicle energy demand and recent technological developments have seen a take-off in sales of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). EVs have substantial challenges to overcome such as the current price of the batteries (around \$200 per kWh storage in 2019), their range and the time taken to charge them. The authors show that many electricity systems could likely cope with 100 per cent penetration of BEVs in the time frame over which such a rise in penetration is likely (to 2040) but that EV life cycle economics remains challenging over the next ten years. Beyond passenger cars, electrification of buses and trucks remains at least as difficult in part due to the much higher battery capacity required. A key issue raised by transport electrification is the need to replace the lost transport fuel tax revenue.

What are the prospects for the electrification of residential and commercial heating and cooling? This is the issue discussed in Chapter 19 by Mathilde Fajardy and David Reiner.

The authors outline the scale of the heating challenge. Current global non-electrified heating demand is twice as much as current electricity demand: thus, the electrification of heating would significantly increase the demand for electricity. Worse than this, peak heating demand can be five times higher than peak electricity demand. Technologies do exist to decarbonize heating and cooling, including electric heat pumps, district heating, PV, green hydrogen from renewables via electrolysis or with blue hydrogen from natural gas with carbon capture and sequestration, and the use of biomass and biomethane. On the demand side, building energy efficiency and heating and cooling appliance efficiency can be increased. However, none of these routes to decarbonization are cheap or quick to implement. The authors conclude by showing that all major possible opportunities come with associated challenges (for example, more use of peak load pricing to encourage energy consumption shifting and storage poses challenges in public acceptability given energy poverty concerns).

We go on to examine the issues facing the electricity sector beyond OECD countries. Chapter 20 by Ignacio Pérez-Arriaga, Divyam Nagpal, Grégoire Jacquot and Robert Stoner focuses attention on the problem of how to achieve universal access to electricity. Despite extensive efforts to improve electricity access, 840 million of the world's population lacked access to electricity in 2017. The authors argue that the key to promoting electricity access is to empower local distribution grids, via what they call an integrated distribution framework (IDF). The chapter notes that traditional grid extension, mini-grids and stand-alone electricity systems can all play a role in providing access. The IDF approach is all about ensuring that the appropriate mix of access provision (and associated revenue recovery mechanisms) is employed within a local distribution company area to achieve near total electricity access, especially when the unserved are in increasingly difficult-to-reach areas. Countries such as Sierra Leone and Uganda are successfully extending access in this way. The authors conclude by suggesting that the IDF approach can improve on the current projection (in 2019) that 650 million people will still be without access to electricity in 2030.

China has emerged as the world's electricity super-power. In 2019, more than 27 per cent of the world's electricity was produced in China, only slightly less than the US and Europe combined. China's electricity sector has grown spectacularly since 2004, but it remains a state-owned and heavily regulated sector. Chapter 21 by Xu Yi-chong discusses the recent history of the Chinese electricity industry and its prospects for reform. The short-lived State Power Corporation (SPC) was broken up in 2002 to form two grid companies – State Grid Company of China (SGCC) and China Southern Grid (CSG) – five generation companies and four power service companies. While both final prices and generator prices remained heavily regulated following the 2002 reform, there were strong incentives to build new assets for both generators and grid companies. This underpinned the rapid growth of the sector. By 2015, this system had given rise to high costs and high prices, causing the government to embark on a new round of reform, introducing pilot provincial wholesale electricity markets and large reductions in the regulated prices. Recently, China has also sought to internationalize its electricity sector by buying up overseas electric utilities and by building power plants abroad, in line with its 'One Belt, One Road' initiative. The author concludes that the current contradiction between China's desire to participate in global electricity markets and its slowness in creating a domestic electricity market, is a function of China's unique history and the

considerable influence of the Chinese Communist Party within the state-owned electricity system.

The final chapter focuses on Africa, where over half the population lacks access to electricity and consumption per capita is very low (although electricity production and consumption vary enormously between countries). Chapter 22 by Vivien Foster, Anton Eberhard and Gabrielle Dyson discusses the prospects for the electricity sector across Africa. The chapter begins by noting that things have been changing in the final years of the decade to 2020: Chinese investment in the power sector has been significant (in line with the previous chapter) and the prospects for solar power have improved enormously. Nonetheless, there are still great opportunities to improve regional power pools via more extensive transmission interconnection, in part to exploit the huge regional RES potential; in addition, access to electricity is on average still rather low – it was around 60 per cent in 2017 – because many choose not to connect to the grid due to cost, unreliability and lack of demand. Although some countries have shown notable improvements – Kenya went from an access rate of 22 per cent to 75 per cent between 2010 and 2018 – the lack of effective power sector reform often represents a key barrier to development. A lack of competition, private ownership and industry restructuring persists in many countries, leading to low prices (for those lucky enough to receive on-grid electricity), under-investment and poor quality of service. The authors suggest that low-cost renewable technologies combined with innovative business models might allow poorly served African countries to avoid the need for expensive centralized grid expansions, spurring electrification despite (or indeed, because of) a lack of reform.

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Together, the chapters of the handbook offer a global tour of an industry on which much of the world's hopes for decarbonizing the global energy system depend. We are very grateful to our authors for writing their chapters specifically for this book and hope their efforts provide food for thought and inspiration for what might be possible by way of power market developments in the coming years.

NOTES

1. For good histories of early developments in electricity supply, demand, organization and regulation for several countries, see Caron and Cardot (1991), Hughes (1983) and Klein (2008).
2. Chile, which unbundled generation, transmission and distribution in 1982, is sometimes identified as the first system to adopt these reforms. However, while Chile restructured and unbundled generation, transmission and distribution, its system remained highly regulated with relatively little real competition. The Electricity Act of 1982 has been amended three times (1999, 2004 and 2005) after major electricity shortages.
3. Optimal scheduling and the derivation of shadow prices for water stored behind dams in hydroelectric stations were developed in parallel.
4. California Independent System Operator (CAISO) is another exception since it has relied on a murky resource adequacy requirement protocol that requires load-serving entities to meet resource adequacy criteria specified by the California Public Utilities Commission.
5. See REN21 (2019, p. 33).

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