

THE FUTURE ELECTRICITY GRID

*Key questions and considerations for
developing countries*

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A photograph showing two women in a field of green, leafy plants. The woman on the left is wearing a colorful headscarf and a green and red sari, looking down at the plants. The woman on the right is wearing a white top with orange floral patterns and a white bag, looking towards the right. In the background, several white wind turbines are visible against a clear blue sky.

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A woman in a field reaching for a plant, with wind turbines in the background.

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FOREWORD

Electricity systems around the world are balancing a diverse set of challenges, ranging from energy security and access to environmental and public health concerns. At the same time, the energy landscape is changing rapidly as a result of three trends disrupting the status quo. These include:

- New, more cost effective technologies, including variable renewable energy, energy efficiency, small distributed generation and storage that are being deployed at larger scale.
 - In just over a decade, Solar photovoltaic (PV) energy systems have grown from a meagre 2.6 GW to 177 GW (REN21 2015). And forecasts indicate renewable capacity will continue to grow.
 - Non-hydro renewable energy capacity has increased over 6 times—from 85 GW to 657 GW (REN21 2015)
 - Over the same time period, annual investment in renewables grew from \$40 billion in 2004 to \$329 billion in 2015 (Frankfurt School-UNEP/BNEF).

- New players, like individual homeowners and communities, are being seen as legitimate electricity generators by installing rooftop solar panels and community solar projects. The affordability of renewable energy is leading to growing demand from consumers.
 - About one third of global solar PV's capacity is owned by residential customers (Rickerson et al. 2014).
 - Never before have traditional utilities been faced with such competition from alternative suppliers.
 - This trend will continue as solar panels continue to be more efficient, wind turbine design is improving power output in more locations.

- New policies that support these non-utility generators and aim to increase clean energy use are expanding.
 - Since 2004, the number of countries putting in place renewable energy targets has tripled from 48 to 164 (REN21 2015). These trends are happening in both high income countries and lower income countries.

Electricity sector planners and utilities have important new opportunities to meet economic, environmental, and access goals. This report looks at experiences from Brazil, China, India, and Kyrgyzstan to help electricity planners and utilities become better prepared for the future grid. How governments, energy planners, regulators, and utilities respond to these trends will determine how well they build a future grid to deliver the clean, reliable, and affordable power people need to thrive.



Andrew Steer
President
World Resources Institute



EXECUTIVE SUMMARY

The electricity sector is undergoing a transformation as it transitions from a static sector that is planned and operated by central authorities—regulators, utilities, system operators, and planners—to one that is increasingly driven by a mix of technologies, decentralized operators, and new market mechanisms and reforms. These changes are creating an environment of genuine uncertainty in which many challenges arise, along with new opportunities.

Globally, over the last ten years, non-hydro renewable energy capacity has increased more than sixfold, from 85 GW to 657 GW, and 164 countries have now established renewable energy (RE) capacity targets (REN21 2015). At the same time, the costs of clean energy are much more affordable. To take just one example, solar PV panel costs declined by 80 percent between 2008 and 2013 (IRENA 2014).

Investments in clean energy across the world have been unprecedented, standing at about US\$329 billion in 2015 (Frankfurt School-UNEP/BNEF 2015; BNEF 2016). Investment in other electricity sector technologies is also increasing. For example, the cumulative global investment in smart-grid technologies, including smart-grid-related analytics—that is, software that allows utilities to track, visualize, and predict events relevant to grid and business operations—is forecast to total \$594 billion in the period 2014 to 2023 (Navigant Research 2014). In light of these changes, decision-makers in many countries are navigating a more complex landscape as they seek to deliver reliable, affordable, and high-quality electricity to consumers in all segments of society.

This report focuses on developments in the electricity sectors of four developing countries—Brazil, China, India, and Kyrgyzstan, and two developed countries—Germany and the United States. It also provides an overview of the pace of key global trends based on global datasets and leading global reports. We identify a number of key trends in the sector and examine their likely implications for the electric grid of the future.

- Unprecedented growth and cost improvements in renewable energy sources
- Improvements in new technologies and energy efficiency
- Growing instability in fossil-fuel supply and prices
- Growing support from governments and investors
- Electricity generation by new and different entities
- Technology uptake

We then identify three broad areas on which regulators and policymakers need to focus as they prepare for a more modern grid, though more specific topics for consideration are also suggested. These areas involve: Technology and infrastructure (increased complexities and physical constraints to the grid), institutional arrangements (threatened conventional utility models), and electricity pricing and equity concerns.

Technology and Infrastructure

There will be a need to **overcome technical limitations**. As renewable energy is scaled up, two primary grid infrastructure challenges are emerging: compatibility and interconnection between intermittent RE resources and the grid; and locational disconnects between RE resources and demand centers. A shift toward a safe, reliable, and affordable future grid will require plans for grid upgrades, expansions, and regional interconnections that address these issues in a cost-effective way.

There will also be a need to **ensure system reliability and improve service quality**. Traditionally, the role of the grid has been to provide a reliable supply of electricity to consumers. However, with the proliferation of RE options, consumers may opt for on-site or non-utility generation in the future. These options can be significantly cheaper than current grid tariffs. This trend, combined with growing technical complexity, could greatly affect the way in which electricity providers need to think about grid system reliability and service quality. The grid will be expected to provide power to consumers in the event that distributed sources of generation fail to meet consumer demand. The grid and new generators will have to take on additional challenges related to connecting small-scale distributed on-site electricity generation and consumers, while ensuring safety and reliability.

Institutional Arrangements

The emergence of newer-generation technologies and entities is challenging the traditional utility model and characteristics of the grid, as it moves toward a network involving more decentralized generation in which electricity flows between large numbers of consumers, producers, and

“prosumers.”¹ There will be a need for enhanced institutional capacities, with an increased focus on cooperation across unfamiliar boundaries. This will involve **rethinking institutional frameworks and strengthening sector governance**.

Regulators must consider new problems, such as: who will pay for improvements and innovations in the grid to enable benefits from emerging RE-based projects; how added infrastructure requirements will be financed; and how costs will be distributed. Utilities are faced with new questions concerning how they relate to their customers, who increasingly have alternatives to the grid. Utilities risk losing both market share and high-value customers who represent much-needed revenue, especially in jurisdictions where the grid is not reliable. Solutions are likely to involve both technical options that allow for greater differentiation among the needs of different kinds of consumer, and institutional changes that enable utilities to engage more flexibly with other stakeholders, both consumers and potential funding sources, whether governmental or in the private investment community.

Electricity Pricing and Equity

The rise of renewable energy sources, increased grid complexity, changing consumer demands, and volatile fossil-fuel costs all create new concerns over electricity prices. How should they be set, and how should the costs and benefits of the grid system be equitably distributed? Properly valuing and distributing system costs and benefits among customers will become increasingly important as energy service providers step into new and varying roles. The valuation of these costs and benefits is

also important to ensuring that access to electricity continues to increase in future and that prices remain affordable to the poor.

There will be a need for **rethinking tariffs**. The current tariff determination approach is based predominantly on balancing utility, consumer, and policy considerations, in a system characterized by a relatively simple unidirectional flow of electricity through the grid, from a few generators to a large number of consumers. As net-metering policies pick up and more consumers are both selling to and buying from the grid at different times of day, countries will need a more dynamic tariff policy that attracts and maintains investments to overcome shortages, and improves quality of supply.

In addition, regulators will have to address universal access and affordability issues. Because electricity tariff design directly impacts electricity access and affordability, regulators and utilities will need to explore new tariff and pricing mechanisms to ensure the proper valuation and distribution of system costs and benefits. The goal must be to ensure equitable recovery of fixed costs from the whole spectrum of consumers. These new pricing models could focus on a complete package of grid services rather than on the sale of electricity alone.

This report does not attempt to provide solutions regarding how best to respond to new challenges and disruptions, or how to deliver a future grid that is simultaneously flexible, reliable, sustainable, and affordable. Rather, the aim of the report is to initiate a discussion among sector stakeholders—primarily electric sector regulators and policymakers, but also system operators, planners, and utilities—about the potential opportunities that exist.





SECTION I

INTRODUCTION

Globally, the electricity sector is experiencing a time of unprecedented evolution. Interviews with electricity sector stakeholders in Brazil, China, India, and Kyrgyzstan reveal a number of common trends. Electricity grids are trying to become more secure, less polluting, and more reliable (as an engine of economic development). At the same time, there is an increase in deployment of new and disruptive technologies, including renewable energy, small-scale distributed generation, and storage. New players, such as individual homeowners and communities, are arising as legitimate electricity generators.

Overall market dynamics are changing with increased competition and the introduction of policy support mechanisms for clean energy. With these changes, a new set of questions is emerging regarding the technical, institutional, and economic restructuring that will be necessary to achieve the goals of energy security, universal access, reliability, and environmental sustainability.

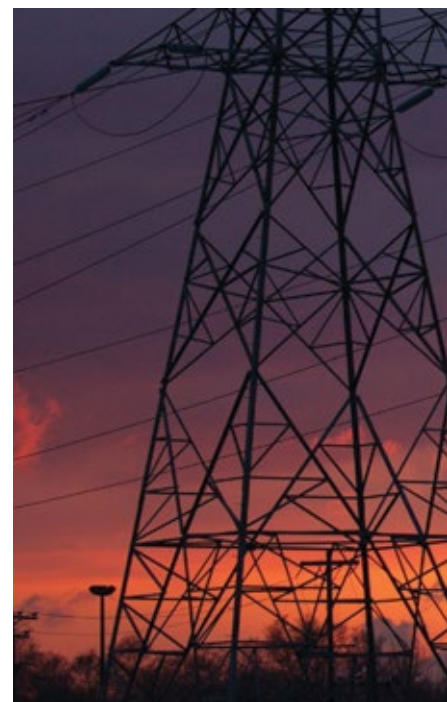
The Future Electricity Grid reviews the pace of key trends globally and examines how these trends are impacting the central electricity grid in four developing countries: Brazil, China, India, and Kyrgyzstan. We also study technologies, costs, and institutional changes in two developed countries: Germany and the United States. The trends we identified are not uniform, and are developing somewhat differently in each of the countries reviewed.

The report focuses on the rapid rise of renewable energy sources, and the implications for the conventional electricity grid. The centralized model is being tested by an extraordinary rate of change in the way markets are organized, and in the range of technologies and generation providers. In Germany, for example, the share of renewable energy (RE) capacity owned by citizens and cooperatives increased to almost 50 percent by 2012 (Morris and Pehnt 2012). In India, the deployment of RE generation capacity experienced a compound annual growth rate of 20 percent between 2002

and 2014, increasing capacity from less than 5 GW to more than 30 GW, or 13 percent of India's total generation capacity (CEA India 2014). Electricity markets are changing in Brazil with the introduction of reverse auctions for RE capacity, and in China with the separation of generation and transmission in 2002 (Ng 2013). Globally, cost reductions in commercially available RE technologies have made RE generation cost-effective in a large portion of world markets (IRENA 2015). Other technologies, such as battery storage, are seeing even more drastic cost reductions (Hockenos 2015).

These trends, along with other important developments, are creating uncertainty in the electricity sector because they have emerged in a short time-frame and affect a sector that is accustomed to planning on a 30–40 year time horizon. Regulators, grid operators, planners, and utilities must now contend with technology changes evolving on a sub-annual basis, while also balancing conventional, pre-existing pressures to increase electricity access, increase the amount and reliability of the electricity provided, and improve the quality of services rendered. We have grouped the changes, and the implications of these changes, into three categories:

- **TECHNOLOGY AND INFRASTRUCTURE:** There are increased complexities and physical constraints to the grid due to the adoption of new, intermittent technologies and distributed generation.



The traditional electricity grid is evolving into a more complex network that is becoming more challenging to design, operate, and manage.

- **INSTITUTIONAL ARRANGEMENTS:** The conventional, central utility model is being challenged by quickening trends toward distributed, on-site, and self-generation. The centralized, top-down approach to operating the grid is being tested and the role of the conventional utility is being brought into question.
- **ELECTRICITY PRICING AND EQUITY:** Electricity pricing and equity concerns are arising, as the scale-up of new generation and grid technologies, and shifts toward new generation models, are raising questions about proper and equitable tariffs, cross-subsidization, and cost burdens.

Evidence from the four developing countries explored suggests that electricity-sector stakeholders in these countries—primarily regulators and policymakers, but also grid operators, planners, and utilities—are only just beginning to understand these trends and their implications.

Numerous reports now document local and global power sector trends, changes, and impacts. Several go beyond providing a portrait of the challenges and opportunities presented by these trends, and explore future potential solutions, scenarios, and pathways that could enable a transition toward a

cleaner grid. These reports include the National Renewable Energy Laboratory’s 2015 “Power Systems of the Future,” Massachusetts Institute of Technology’s 2011 “Future of the Electricity Grid,” The World Economic Forum’s 2015 “The Future of Electricity,” and the International Renewable Energy Agency’s 2014 “Rethinking Energy,” among others. However, there is no single solution or pathway that can be easily copied and pasted from one country’s electricity scenario to the next. For this reason, this report focuses on the global trends that underlie emerging challenges, and provides insights to inform discussions necessary to overcome these challenges.

The report attempts to initiate a discussion among stakeholders in Brazil, China, India, and Kyrgyzstan and in other developing countries by highlighting the impact of key trends on the grid, and identifying important questions that need to be asked to plan proactively for a transition toward a sustainable future grid. Our aim is not to focus on what can be done this year, but to stimulate dialogue about solutions over the next five-to-ten-year period.

1.1 Report Structure

Section 2 outlines the traditional model of the electricity sector, particularly as it has operated over the last two decades in the four developing countries studied: Brazil, China, India, and Kyrgyzstan.



Section 3 describes six major global trends that are currently impacting the electricity sector, with an emphasis on trends in generation technology, consumer and institutional behavior, and public policy.

Section 4 identifies and discusses the implications of these trends in terms of their impacts in the developing countries studied in the report. These implications include: technological and infrastructural changes that increase complexity and create physical constraints on the grid; challenges to the institutional arrangements of the conventional utility model; and electricity pricing and equity concerns.

Section 5 draws on the trends and implications identified earlier to consider a number of key issues that will need to be addressed by electricity sector stakeholders in developing countries. The transition toward a flexible, reliable, affordable, and sustainable grid of the future will depend on pro-active support for the deployment of new technologies, distributed generation, and innovative approaches. The issues highlighted cover a range of considerations the authors believe will require an open discussion among regulators, planners, and utilities.

Concluding remarks are presented in Section 6.

1.2 Methodology

We examined the electricity sectors of four developing countries and their range of experiences with regard to power sector transformation. We also looked at experiences in Germany and the United States—countries that are witnessing a paradigm shift in the electricity sector and are being looked to as reference cases. Brazil, China, and India have great potential to scale up new technologies and are transitioning toward a new paradigm with more distributed generation. Kyrgyzstan is in a relatively nascent stage of system transformation but, like Brazil, is looking to diversify its generation sources in light of unreliable precipitation to fuel the country's hydropower plants.

The analysis for this report is based on primary and secondary research, interviews, and desk reviews. The research team (comprising sector experts in

each study country) developed a framework to guide the research in each country. The framework is based on a commonly agreed “normative vision” that sets objectives for the characteristics of the future grid: it should be a flexible system that provides safe, reliable, and affordable electricity services that enable socio-economic development, environmental sustainability, and public health through the application of good governance practices. This report focuses primarily on the objectives of reliability, affordability, and environmental sustainability.

After finalizing the framework, the research team conducted primary and secondary research at the country level, which included interviews with electricity sector experts such as regulators, utility executives, and policymakers, in their respective countries and markets. (See Annex 1 for a full list of organizations and industry stakeholders interviewed.) The interviews identified challenges and opportunities currently facing the centralized electricity system due to rapid technological changes occurring in the electricity sector in the study countries. The interviews also offered unique perspectives from sector professionals regarding the direction in which national grids are developing, and future requirements.

The country experts compiled their research and developed individual country notes, identifying key trends in their countries. In parallel, we conducted a global study based on commonly cited and credible global studies to identify broader global trends in electricity sector technology changes, innovations, and uptake. This report is a synthesis of the country notes and global research.

Before finalizing the report, our research was presented at two workshops in India. Attendees included electricity industry experts (utilities, regulators, NGOs, etc.) from Brazil, India, Indonesia, Kenya, Kyrgyzstan, the Philippines, and South Africa. (For a full list of workshop attendees, see Annex 2.) The workshops served as a useful exercise because the discussions validated the common themes of this report, and served as a model for the type of open discussion among stakeholders that this report is intended to facilitate.



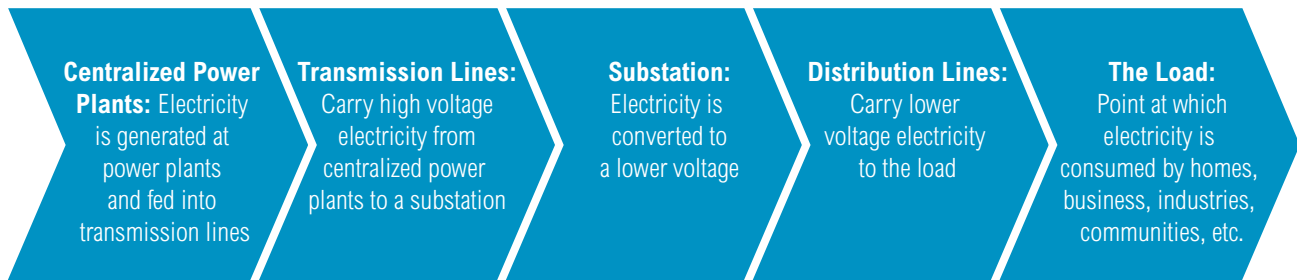


SECTION II

THE TRADITIONAL ELECTRICITY SECTOR MODEL

Generation technology and grid infrastructure have remained relatively constant over the last century. The sector has been structured largely around fossil-fuel generation, large hydroelectric plants, and centralized grid systems. This is true both globally and in the case of the countries assessed in this report. According to the International Energy Agency, four key sources of electricity have dominated generation over the last 40 years: coal, natural gas, large hydro, and nuclear. By 2012, these four sources together accounted for about 90 percent of electricity generation in the world (IEA 2014).

Figure 1 | **The Centralized Electricity System**



The percentage of each fuel used in the electricity sector has remained fairly static worldwide. In the United States, coal-fired generation historically—specifically from 1950 until 2007—provided roughly half of electricity generation (NREL 2013). In China, coal accounted for about 70 percent of total energy consumption from 1980 to 2009 (IEA 2012). Similarly, India has traditionally used coal-fired generation. As of 2014, 59 percent of India’s total installed capacity of 248 GW was accounted for by coal-fired plants (CEA India 2014). Kyrgyzstan has relied mainly on large hydroelectricity, as has Brazil. In 2011, over 90 percent of electricity generation in Kyrgyzstan came from hydro resources (IEA 2011). In Brazil, as of April 2014, hydroelectric resources accounted for 67.6 percent of the country’s total installed capacity of 129 GW (ANEEL 2014).

The structure of the traditional electricity system can be characterized as a network, with a unidirectional flow of electricity from a few centralized generators to millions of consumers. Electricity is transported over large distances through high-voltage transmission and lower-voltage distribution lines from generators to load centers (Figure 1).

Under this structure, the key objective of policy-makers, regulators, and utilities is to ensure access to electricity for all consumers whenever and wherever they need it, in the most reliable and cost-effective manner possible (Box 1). Safety and efficiency of the grid is also a key concern (Small and Frantzis 2010). For these services, under the traditional electric utility business model, utilities earn a guaranteed rate of return on generation, infrastructure, and other investments in the grid and its operation, which is collected through charges on consumer electricity sales. In many developing countries, state utilities are simply mandated to operate regardless of financial viability, and receive public subsidies to make up revenue shortfalls. The traditional sector described here is representative of many developing countries, including the four examined in this report (see below). However, the traditional fuel mix and structure have started to change in recent decades and are doing so at an increasingly rapid pace. Structural changes include various forms of utility restructuring, deregulation and liberalization in wholesale and retail markets.

The Electricity Sector in India

The Electricity Supply Act was enacted in 1948 to encourage electricity development in India. Under this act, vertically integrated State Electricity

BOX 1 | TRADITIONAL PRIORITIES OF THE ELECTRIC GRID

The electric grid maintains a constant balance between supply (generation) and demand (load) while moving electricity from the generation source to the end consumer. The amount of electricity consumed depends on the day, time, and weather and, for the most part, electricity must be generated at the time it is used. To ensure that generation meets demand, electric utilities and grid operators must work together. Traditionally, top priorities for successful grid performance have included: efficiency of transmission and distribution (T&D), reliability of electricity supply, increased technology productivity, and affordability (MIT 2011; NREL 2010).

Boards (SEBs) were established to boost electricity generation capacity in the country and a Central Electricity Authority was set up in 1951 for sector planning. To further encourage capacity addition, the National Thermal Power Corporation (NTPC) and National Hydro Power Corporation (NHPC) were set up in 1975, dedicated to coal-thermal and hydro-generation respectively.

In the 1990s, the Indian electricity sector was liberalized along with the rest of the Indian economy. Liberalization led to an increase in private investments in electricity generation through independent power producers (IPPs). Most contracts with these IPPs were in the form of memoranda of understanding (MoUs) with the state government. However, many of these MoU-based projects were delayed, did not become operational, and thus did little to bridge the growing demand-supply gap.

Since the late 1990s, SEBs have been unbundled into separate generation, transmission, and distribution companies. In 1998, the Electricity Regulatory Commissions Act was enacted. This act defined a framework for instituting Electricity Regulatory Commissions (ERCs) at the state and central levels. The ERCs' role was to evaluate utilities' costs and performance, determine consumer tariffs, and act as an adjudicator in case of any disputes between different utilities. The Electricity Act of 2003 added more power and authority to the ERCs. For instance, the ERCs have the authority to issue distribution and transmission licenses, and license electricity traders.

As a result of these acts and reforms, the current Indian electricity sector is divided between the central and state sectors. Central to India's

generation are the NTPC and NHPC, which produce power and allocate it to states based on their demand and socio-economic needs, such as economic growth. The Power Grid Corporation of India (PGCIL) is the primary central transmission utility responsible for transmission of power between different regions and states. In 2010, PGCIL established the Power System Operation Corporation (POSOCO) for the purpose of power management and efficient operation of the grid. The POSOCO consists of the National Load Dispatch Centre (NLDC) and five regional load dispatch centers, their purpose being to coordinate electricity dispatch across the country.

The central government is not involved in the distribution of power. The Central Electricity Regulatory Commission (CERC) was instituted in 1998, primarily to set tariffs for generation companies owned by the central government. It also sets tariffs for companies that supply electricity to more than one state, regulates interstate generation and transmission issues, and regulates interstate exchanges.

At the state level, generation companies are owned either by the states or by different private entities. States also have their own transmission companies and own the majority of distribution companies in India. Further, the State Load Dispatch Centers (SLDCs) in each state are set up to ensure integrated operation of the power sector in states. State Electricity Regulatory Commissions are responsible for determining electricity tariffs for consumers, and regulating intra-state generation, transmission, and distribution. Currently, key factors affecting electricity sector policy are energy security, significant energy access gaps, and financial viability of the utilities.



The Electricity Sector in China

China's grid system is highly regulated and centralized; power supply, grid infrastructure planning, and electricity prices are determined largely by non-market forces, and state-owned enterprises play a dominant role. The National Energy Administration (NEA) is the key policymaker at national level, administered by the National Development and Reform Commission (DRC). The NEA is responsible for management and supervision of the energy sector, including fossil-fuel energy and non-fossil fuels, and has six regional bureaus and 12 provincial Energy Regulatory Offices. China's power grid is operated by two companies: the State Grid Corporation of China and China Southern Power Grid Company. China Southern Power Grid Company provides service to five provinces with a population of about 230 million people, while the State Grid Corporation serves more than 1.1 billion people in the rest of the country.

China has five state-owned power generation groups, as well as other investors at national and provincial level. By 2014, the five groups accounted for 45.3 percent of national total installed capacity and 45.1 percent of national power generation (Huaneng Techno-Economic Research Institute 2015).

The nation's electricity reform was initiated in the late 1980s and, in 2003, a regulatory agency, the State Electricity Regulatory Commission, was established. The sector is gradually changing, transitioning from a vertically integrated, state-owned monopoly to a market-oriented industry (RAP 2008). However, this transition has been rather long and delayed.

In 2013, the government issued a policy to support private investment in power and other sectors but, in reality, few private capital investments have been made in the power sector. A new National Energy Administration was formed to facilitate market centralization and improve efficiency of regulation and oversight.

On March 15, 2015, the State Council of China issued a notice on "Several Opinions on Further Deepening the Reform of the Electric Power System" (Dupuy and Weston 2015) and, in April 2015, the Chinese Government issued four documents: State Council Document No. 9, National Energy Administration Document on Promoting Clean Energy, NDRC Document on Demand-Side Management Pilot Cities, and NDRC Document on Revenue Cap Pilot Cities. The documents concerned power sector reform in a number of different areas including improving efficiency in the power sector, assisting efforts to integrate renewable energy into the grid, removing conflicting incentives in power



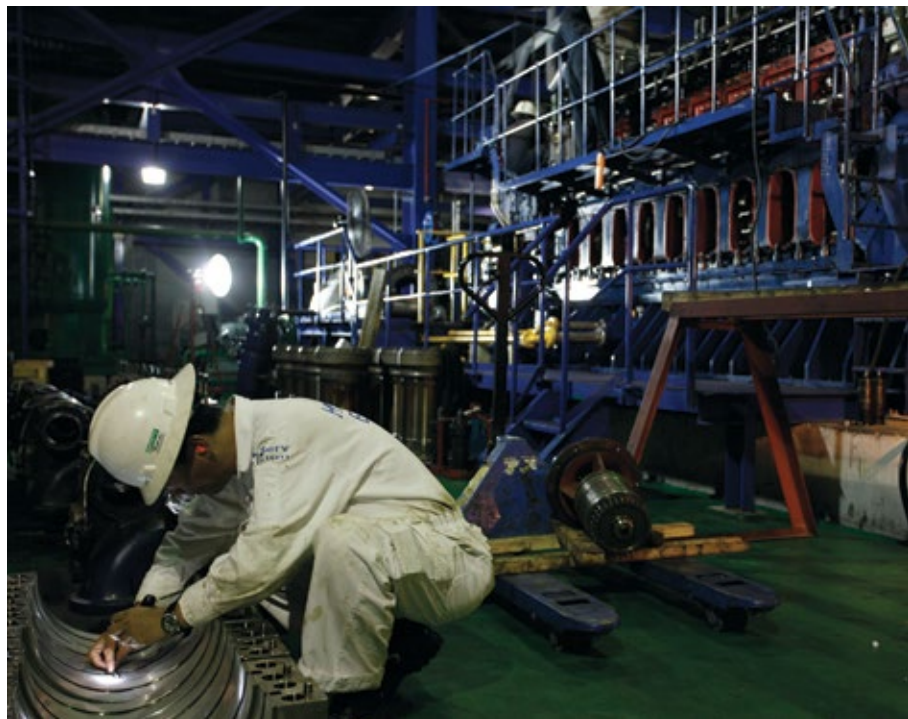
generation, increasing competition, and diversifying supply (Finamore 2015). Presently, the direction of reform is to gradually loosen the central government's monopoly and spur competitive market-based electricity pricing.

The Electricity Sector in Brazil

Brazil's electricity system is operated by a single, independent systems operator, ONS (Operador Nacional do Sistema Elétrico), and a single, national regulatory agency, ANEEL (Brazilian Electricity Regulatory Agency). The sector operates under the concession, authorization, and permission of the State to provide electricity; it is highly regulated. Energy planning is carried out by a planning agency (EPE) under the Ministry of Mines and Energy. Recently, plans have begun to include wind energy (2009) and solar energy (2013) in medium-term projections (REEGLE 2014).

Some states have their own energy plans but they are very limited in the extent to which they can execute their plans because all regulation is centralized. In 2004, the sector underwent major reform to attract investment in power generation and help alleviate shortages. The main goals of the current regulatory system are to guarantee adequate generation, promote reasonable tariffs at lowest cost, and integrate social goals in the sector through a program to provide electricity to every citizen.

In Brazil, some states have their own energy plans but they are very limited in the extent to which they can execute their plans because all regulation is centralized.



Since Brazil's electricity crisis in 2001,² the country has started to diversify its electricity mix, employing different mechanisms to support the penetration of alternative renewable energy sources. These mechanisms consist of a combination of a competitive bidding plus feed-in program, special regulation for wind, small hydro, bioelectricity, and solar PV, and a net-metering system for consumers. The federal government and some states tendered specific auctions for wind and solar PV in recent years (REEGLE 2014).

The first major initiative was PROINFA, an incentive program instituted in 2002 to contract a total of 3,300 MW of new capacity, initially split evenly between bioelectricity, small hydro, and wind sources. This represented a 19.8 percent increment on installed capacity in 2002 from sources other than large hydro. The program included a feed-in type of subsidy. PROINFA ended in 2010 (MME 2015a).

In 2015, the Brazilian federal government released a plan to increase distributed electricity production using renewable energy (RE) sources, mainly solar (MME 2015). The plan sets forth the following targets to be reached by 2030: total investments in RE of \$25 billion, 2.7 small RE-based generators, and an annual RE-based output of 48 GWh. Several financial incentives were introduced or enhanced to achieve these targets, such as new tax exemptions (reduced import duties on solar PV systems, reduction of or exemption from some federal and state taxes), and low-interest financial support from the National Development Bank (BNDES). Recent changes in regulation have permitted new commercial arrangements among consumers, their relationship with utilities, and also with the wholesale electricity market. This plan—ProDG (Program for the Development of Distributed Generation)—is part of the country's 2030 Climate Action Plan presented in Brazil's Intended Nationally Determined Contribution (INDC) during the 2015 UNFCCC Conference of the Parties (COP21) (MME 2015).

The Electricity Sector in Kyrgyzstan

Kyrgyzstan's electricity sector is highly dependent on hydropower, which provides over 90 percent of the country's total electricity output. The power

system includes 18 large power plants, of which 16 are hydro and two are thermal plants (REEEP 2012). Severe droughts experienced in 2008–2009 limited power generation in the country, leading the government to consider thermal power and RE potential (UNDP and Government of Kyrgyz Republic 2012).

Kyrgyzstan began unbundling its vertically integrated state monopoly, Kyrgyzenergo, in 2001 in order to encourage development of the sector and increase attractiveness to investors. In 2005, the State Agency for Energy of the Kyrgyz Republic was eliminated and its functions were transferred to the Agency for Anti-Monopoly Policy of Kyrgyzstan. The Ministry of Energy and Fuel Resources of the Kyrgyz Republic was created in 2007 and the Department for Regulation of Fuel and Energy Complex was created as separate department under the ministry.

Currently, the electricity sector consists of six majority-state-owned generation companies, one transmission company, and four regional grid distribution companies, in addition to a handful of small private power producers and distribution companies. In 2013, the government issued a policy to support private investment in the power sector but, in reality, few private-capital investments have been made. A new National Energy Administration was formed to facilitate market centralization and improve efficiency of regulation and oversight (REEEP 2012).

Despite sector restructuring and efforts to introduce competition, competition in the wholesale market has not yet been achieved in Kyrgyzstan. Almost all of the country's electricity capacity (roughly 98 percent) is generated by one company, the Electric Plants OJSC generation company. The state-owned transmission company, NEGC OJSC, remains a monopoly. Similarly, there is no market competition among Kyrgyzstan's distribution companies, each of which operates in its own territory. While roughly 27 private wholesalers/small distributors were licensed in 2009 to purchase electricity from Electric Plants OJSC and resell it, national policy emphasizes strengthening state control over distribution companies in order to improve management and reduce corruption (REEEP 2012).



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SECTION III

THE CHANGING ELECTRICITY SECTOR: CURRENT TRENDS

“Generating electricity with small, modular, renewable energy units at the point of consumption makes much more sense than the present system in which electricity is produced in centralized large stations (usually based on fossil fuels and nuclear energy) and distributing it to millions of consumers.”

—*Prof. José Goldemberg, Energy and Environment Institute,
University of São Paulo*

Since the mid-1990s, the electricity sector has seen rapid changes in fuel mix and overall structure. Dominant among these changes has been the rapid rise of renewable sources of energy and clean technologies such as smart grids, storage technologies, and energy efficient products. Globally, the costs of renewable technologies are decreasing rapidly, the operating efficiency of clean technologies is improving, government support for clean technologies is expanding, and consumer uptake of these technologies has increased.

These trends have resulted in major shifts in the shares of key fuel sources for energy in general and for electricity generation in particular. Utilities, regulators, and planners are pushing toward even greater diversity in their fuel mix in order to protect against price swings and to capture benefits from new market trends.

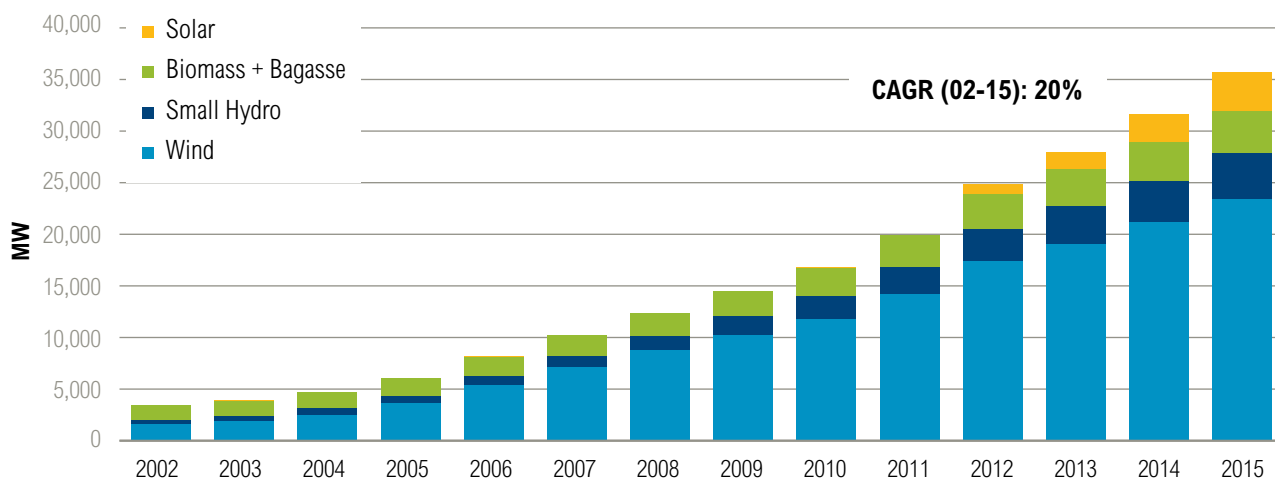
For example, in the early 1990s, renewables were a minor source of energy in Germany; by 2014 they accounted for 31 percent of net electricity consumption (Wirth 2015). Similarly, in India, renewable electricity grew from roughly 4,000 MW installed capacity in 2002 to over 30,000 MW in 2014, accounting for 13 percent of India’s total generation capacity (see Figure 2).

These changes have created uncertainty about how rapidly future technology uptake will occur, and what this uptake will mean in terms of grid changes, and complexity in the regulatory, utility, and policy decision-making processes.

This section highlights six global trends, based on a review of numerous global studies on clean energy, clean energy technology, consumer interactions with new technologies, and the political landscape for clean energy. These trends are:

- Unprecedented growth and cost improvements in renewables
- Improvements in new technologies and energy efficiency
- Growing instability in fossil-fuel supply and prices
- Growing support from governments and investors
- Electricity generation by new and different entities
- Technology uptake

Figure 2 | Renewable Electricity Capacity Additions in India, 2002–2015



Source: Prayas Energy Group (2015).

Note: CAGR refers to compound annual growth rate.

3.1 Unprecedented Growth and Cost Improvements in Renewables

In 2013, global installed electricity generation capacity from all sources was 5,950 GW (IEA 2014). New sources of electricity are being deployed very rapidly. Between 2004 and 2014, non-hydro RE capacity increased more than sevenfold worldwide, from 85 GW to 657 GW. During the same period, global installed wind energy capacity increased from 48 GW to 370 GW. Similarly, global solar photovoltaic (PV) capacity grew from 2.6 GW to 177 GW, and ever-increasing annual capacity additions are forecast (REN21 2014; REN21 2015).

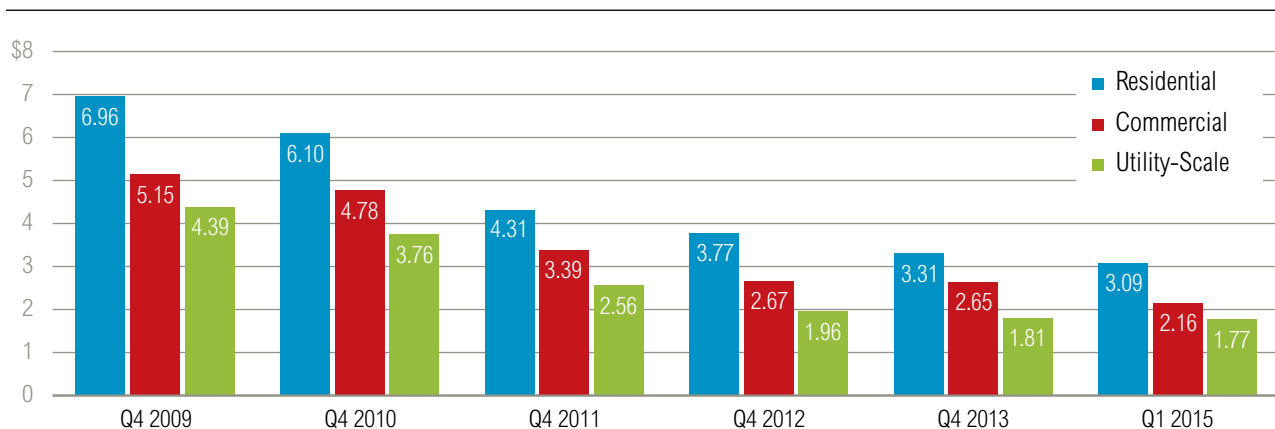
The share of these generation sources in national generating capacity has become significant in some regions. In India, RE generation capacity experienced a compound annual growth rate of 20 percent from 2002 to 2014, increasing from less than 5 GW to more than 30 GW; it accounted for 13 percent of India’s total generation capacity in 2014 (CEA India 2014). By 2013, total installed RE generation capacity in China reached 435.8 GW, accounting for 32.1 percent of total power capacity—up from 22.4 percent in 2006 (CNREC 2015). Perhaps the best example is Germany, which increased its share of RE from near zero in the early 1990s to 31 percent of net electricity consumption in 2014 (Wirth 2015). Changes in the shares of fuels in the overall energy mix have happened in the past, but the current pace of change is rapid and more complex.³

Wind and Solar

Both wind and solar technologies have seen drastic price reductions since 2008 and are now widely competitive with conventional technologies. The International Renewable Energy Agency (IRENA) reports that, between 2009 and 2014, prices for solar modules fell 75 percent (IRENA 2015). IRENA’s 2015 study further acknowledges that the most competitive utility-scale solar PV projects are now delivering electricity at costs between US\$0.06 per kilowatt-hour (kWh), where excellent resources and low cost financing are available, and at \$0.08/kWh without financial support (IRENA 2015). This compares with a range of \$0.045 to \$0.14/kWh for fossil-fuel power plants (IRENA 2015). It is estimated that at least one third of new small- to mid-sized solar energy projects in Europe are being developed without direct subsidy (IRENA 2014).

Prices continue to drop, and some of the more recent solar deals in Dubai and the United States were signed at prices near or below \$0.05/kWh. For instance, in Dubai, 100 MW of solar capacity was auctioned by the Dubai Electricity and Water Authority at \$0.0584/kWh in 2015 (Mittal 2015). In the United States, NV Energy, a Berkshire Hathaway-owned utility company, signed a power purchase agreement (PPA) to purchase electricity from the 100 MW power plant at \$0.0387/kWh (Brown 2015). Figure 3 demonstrates a decline in installed solar PV prices for residential, commercial and utility scale systems in the U.S. between 2009–2015.

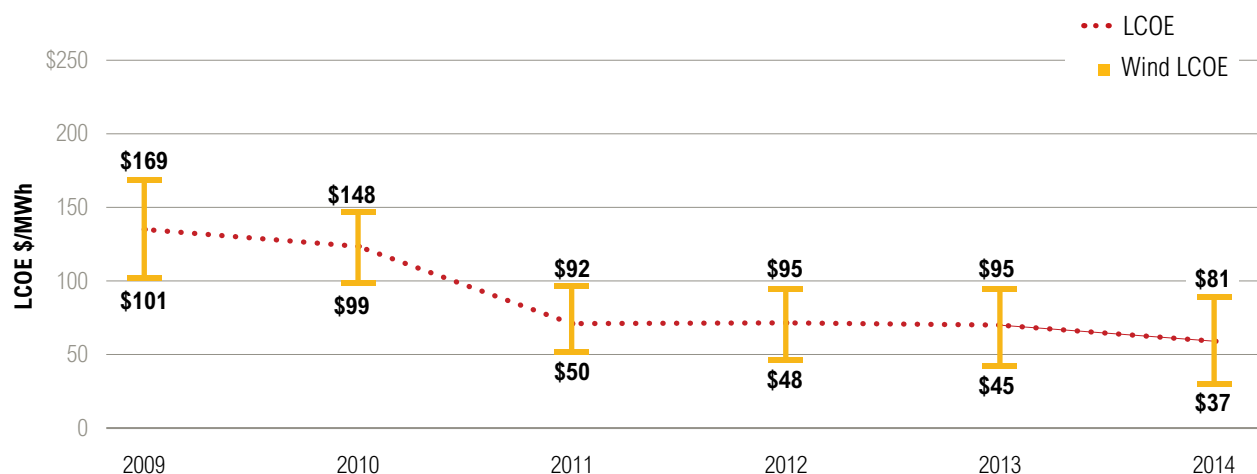
Figure 3 | **Benchmark Residential, Commercial and Utility Scale Solar PV Installed Prices in the U.S. Q4 2009–Q1 2015**



Note: Prices are NREL calculated benchmark prices that include module, inverter, balance of system hardware and labor costs.

Source: Chung (2015).

Figure 4 | Reduction in U.S. Levelized Cost of Onshore Wind



Source: Lazard (2014).

Similar price trends are seen for another main-stream RE technology, onshore wind, which is projected to continue price declines of 15 to 40 percent from 2012 out to 2030 (Lantz et al. 2012). Onshore wind has seen a particularly significant drop in the United States since 2009, with a levelized cost of energy (LCOE) more than 50 percent lower in 2014 than 2009 (see Figure 4).

Geothermal, Offshore Wind, and Ocean

Technology, deployment, and cost trends around other RE generation technologies are also notable because these technologies may be viable generation options, depending on the local context and/or future technological advances. Geothermal power generation, specifically, is a mature, commercially available option for providing low-cost base load capacity with a levelized cost of energy (LCOE) as low as \$0.04/kWh, competitive with the LCOE of fossil-fuel power (IRENA 2015). However, geothermal power is cost-competitive only “in areas with excellent high-temperature resources that are close to the surface” (IRENA 2015). In 2013, about 530 MW of geothermal capacity came online globally, bringing the global installed capacity to just over 12,000 MW. This represents the most geothermal capacity to come online in a single year since 1997. Another 12,000 MW of geothermal energy are in the pipeline, and 30,000 MW are under development (Matek 2014).

Offshore wind is another RE generation technology with increasing installed capacity. By late 2014, the total global installed capacity of offshore wind was 8,759 MW with 1,713 MW installed in 2014 alone; over 90 percent of global offshore wind capacity is installed in Europe (GWEC 2015; REN21 2015). The relatively high cost of offshore wind is the greatest challenge to further development. Offshore costs generally are about 50–60 percent higher than onshore costs, and range from about \$204/MWh (including transmission infrastructure) to \$170/MWh in European markets (REN21 2015). Studies suggest that the levelized cost of offshore wind will reduce significantly in coming years, making offshore wind cost-competitive. In the United States, for example, the levelized cost of offshore wind is expected to drop 50 percent by 2050 (USDOE 2015).⁴

Marine (or ocean) energy systems also suffer from high costs—roughly \$0.35/kWh to 0.57/kWh,⁵ but they represent tremendous potential. Estimates of technically achievable electricity production range from 20,000 terawatt-hours (TWh) to 80,000 TWh of electricity per year, which is 100–400 percent of current global demand for electricity (Mofor et al. 2014). By 2014, global installed ocean energy reached 530 MW, primarily from tidal technologies, with significant projects on the horizon (REN21 2015).

Challenges and Opportunities Presented by Rapid Growth and Deployment of Renewable Energy Sources

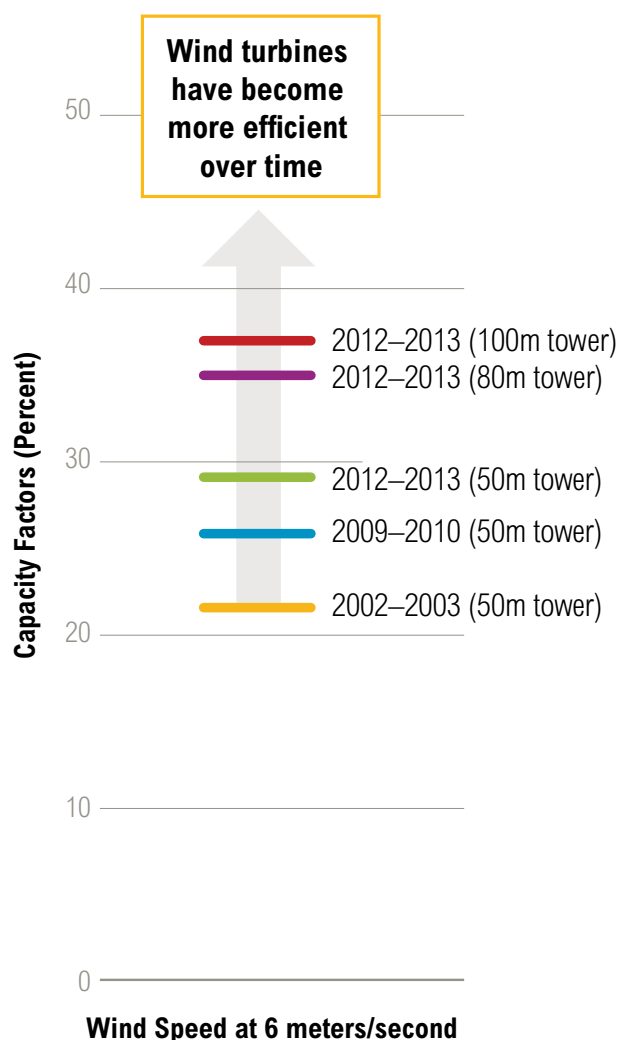
The rapid pace of deployment of clean technologies presents technical challenges to the grid. It also raises important governance questions about institutional roles, transparency, and coordination. At what point should developing countries start worrying about stranded assets in generation and transmission infrastructure? How can planning systematically account for stranded asset risk and ensure that transmission upgrades are made prudently? Who will pay for improvements and innovations in the grid to enable benefits from emerging RE-based projects? Who will pay for added infrastructure requirements? And how will costs be distributed?

3.2 Improvements in New Technologies and Energy Efficiency

Technology Improvements

The global deployment and reduced costs of new technologies are primarily driven by technical improvements. Wind electricity generation systems, for instance, have experienced major technological improvements since the mid-2000s. The trend has been toward taller towers, longer turbine blades, and increased power capacity. In 2012, the global average rated power capacity of new grid-connected turbines was roughly 1.8 MW, up from 1.6 MW in 2008. Such improvements have pushed up capacity factors considerably (Figure 5) (Philibert and Holttinen 2013). In the United States, average tower height for new wind turbines in 2013 was 80 meters, representing an increase of 45 percent between 1998 and 2013. Similarly, the U.S. average blade length (rotor diameter) in 2013 for new wind turbines was 97 meters, up 103 percent since 1998–1999, translating to a 310 percent increase in swept area (Wiser et al. 2014). Wind turbines are also increasingly being designed for low wind-speed environments, which allows for installation closer to areas of demand and away from areas of public and environmental controversy. Together these trends have led to an increase in average wind farm capacity factor (Philibert and Holttinen 2013).

Figure 5 | Capacity Factors of Selected Wind Turbine Types



Source: Philibert and Holttinen (2013).

Solar PV technologies have also experienced significant technological improvements in recent years. Crystalline silicon (c-Si) solar panels, a technology that makes up 90 percent of the solar PV market (Philibert 2014), started with cell efficiencies below 15 percent in the late 1970s (NREL 2015). They had achieved efficiencies of more than 25 percent by 2014 (Bullis 2014). The average efficiency of commercial silicon modules (or panels) themselves has improved over the last ten years by roughly 0.3 percent per year, reaching 16 percent efficiency in 2013 (Philibert 2014).

Solar inverters, necessary to convert the DC output of solar panels to AC, have also improved over the same period (2004–2013), decreasing the material needed for a solar installation from 12kg/W to 2kg/W. Continued technology improvements in solar PV technologies are likely to be the main factor in future PV cost reductions (Zheng and Kammen 2014).

This is not to say that improvements and innovation in technologies are not occurring in other, more conventional, technologies. Today, for example, it is cheaper to get natural gas out of the ground from more locations than ever before. Prices for natural gas and oil have been dropping since 2014, while technology has been improving. The average lateral length of drills increased over 114 percent between 2011 and 2015 (less than five years). At the same time, drilling costs/lateral lengths (\$/foot) and prices came down 71 percent over the same time period, from \$1,200/foot to roughly \$350/foot (Liebreich 2015).

Efficiency Improvements

Experts interviewed for this study raised the potential impact of energy-efficient technologies and measures as an issue that merits particular attention. Measures such as appliance and equipment standards and labels, building codes, reducing outdated industrial practices, and national energy savings targets, to name a few, are expected to lead to energy savings that will change load profiles, and might reduce the need for investments in generation and grid operations. For instance, the energy efficiency of major appliances in countries that have adopted standards and labels for energy efficient appliances have improved at more than three times the underlying rate of technology improvement, which is between 0.5 and 1 percent per annum. A 7 percent improvement in the efficiency of refrigerators in the European Union was recorded in the first year following the introduction of mandatory energy labeling in 1995 (IEA and SEAD 2015).

Technology improvements for general service lighting continue to develop and grow as countries ban inefficient incandescent lights. The market for LED lighting is growing globally. Not only is

average lighting efficiency increasing, but the cost per LED light bulb is also decreasing (USEIA 2014). The U.S. Energy Information Administration projects that, by 2020, LEDs will produce more than 150 lumens per watt, compared with 16 lumens per watt for a typical incandescent bulb, and will be cost-competitive with incandescent bulbs by 2025 (USEIA 2014).

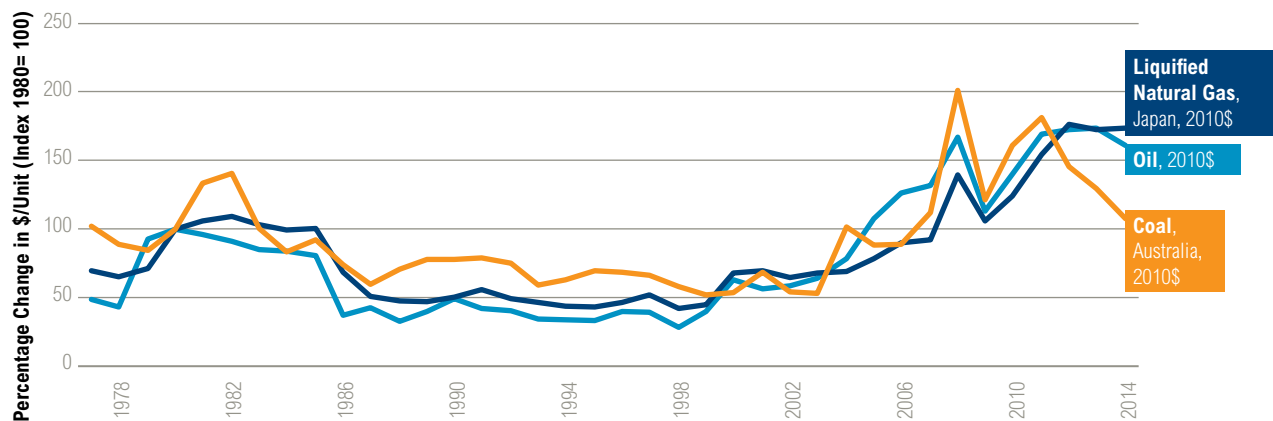
Demand-Side Technologies

Demand-side technologies such as smart grid technologies, electricity storage devices, and energy efficient technologies (including energy efficient appliances and LEDs), which help with integration of variable renewable energy generation, are also starting to see significant deployment, as well as technology and cost improvements. In 2013, investments in smart grid technologies reached \$45 billion, up from \$33 billion in 2012 (IEA 2014a). These investments cover applications such as transmission upgrades, information and operation technology, and smart meters. In 2013, global penetration of smart meters reached 20 percent, and the IEA projects it to reach 55 percent by 2020 (IEA 2014a). By 2014, 145 GW of large-scale storage capacity was in place, 97 percent of which was pumped-hydro storage (IEA 2015). Between 2005 and 2014, there was a large increase in the deployment of batteries for storage, mainly to deal with the challenge of integrating intermittent renewable energy sources. Large-scale battery storage capacity rose from 120 MW to 690 MW (IEA 2015). In 2014 alone, the cost of lithium-ion batteries fell 20 percent and is expected to fall another 15 percent in 2015 (Hockenos 2015).

Challenges and Opportunities Presented by Improvements in Technology and Energy Efficiency

Improvements in energy efficient and demand-side technologies will help consumers do more with less energy consumption. How will consumers benefit from this? How will energy efficient consumption change the consumer preference for the types of generation resources they might use? The impacts of declining renewable energy costs, combined with more efficient consumer behavior, is something electricity stakeholders need to track closely.

Figure 6 | Trends in Prices of Coal, Crude Oil, and Natural Gas, 1977–2014 (2010 US\$)



Source: World Bank 2014, DataBank Global Economic Monitor Commodities.

Note: In order to compare the evolution of prices for oil (\$/bbl), coal, (\$/mt) and LNG (\$/mmbtu) over time, prices have been scaled using a baseline index of 1980=100. This allows for the various metrics used (bbl, mt and mmbtu) to be normalized and compared measuring percentage change over the given time period. Australian coal and Japanese LNG prices are used because they are the best reflection of 'world' prices.

3.3 Growing Instability in Fossil-Fuel Supply and Prices

Rapid and dramatic swings in fossil-fuel prices—increasingly apparent since the 1970s—are one of the main drivers of change in the electricity sector. Fossil-fuel resources often experience price jumps (or declines, e.g., U.S. shale gas) due to various supply or demand shocks, particularly because these resources are traded in an international market. Changes in the prices of these resources affect the cost of electricity from fossil-fuel-powered plants. Figure 6 shows the high level of price volatility experienced by fossil fuels since the 1970s, and particularly in the late 2000s.

Fossil-Fuel Prices

McNerney (2011) notes that the total cost of coal-generated electricity remained low and stable, with minor fluctuations in developed countries, between 1902–1970, increased from 1970–1990, and then leveled off until 2011. Because of the historic resource availability, cost-effectiveness, stability, and maturity of coal-based technologies, they became the primary option for electricity generation in newly industrializing economies such as China and India in the late 1990s/early 2000s. The resultant growth in global demand for coal-based generation has led to significantly higher and more volatile global coal prices (Figure 6). In general, higher coal prices have led to higher costs for coal-generated electricity since the turn of the century.⁶

The limited availability of adequate domestic fossil-fuel supplies has impacted some national economies, for example, that of India. The increased demand for, and limited supply of, coal and natural gas have led to a significant increase in imports. Coal imports for India's electricity sector increased by about 510 percent between 2007/2008 and 2012/2013 (Sreenivas and Bhosale 2014). This resulted in the share of India's current deficit accounted for by coal rising from 5.8 percent to 7.8 percent over the same period (Sreenivas and Bhosale 2014). Similarly, India's net import bill for natural gas increased by 25 percent every year between 1989/1990 and 2010/2011 (WISE 2014). Cumulatively, this has led to the cost of India's energy imports accounting for 5 percent of national GDP, which is one of the highest in large economies (WISE 2014).

Challenges and Opportunities Presented by Volatile Fossil-Fuel Prices

These trends suggest that developing country policymakers must take into consideration fossil-fuel price volatility, and no longer assume that prices will be stable for longer-term planning. At the same time, decision-makers need to consider trends in falling prices of RE (particularly, solar and wind).⁷ Lower capital costs, and relatively rapid improvements in the performance of these technologies, suggest that developing country policymakers should search for the right balance

between existing generation assets and investments in new technologies, so as to avoid ending up with stranded assets.⁸ This issue could develop into a major problem for developing countries because the costs of stranded assets are borne by consumers and/or tax-payers, and significantly impact electricity tariffs.

3.4 Growing Support from Governments and Investors

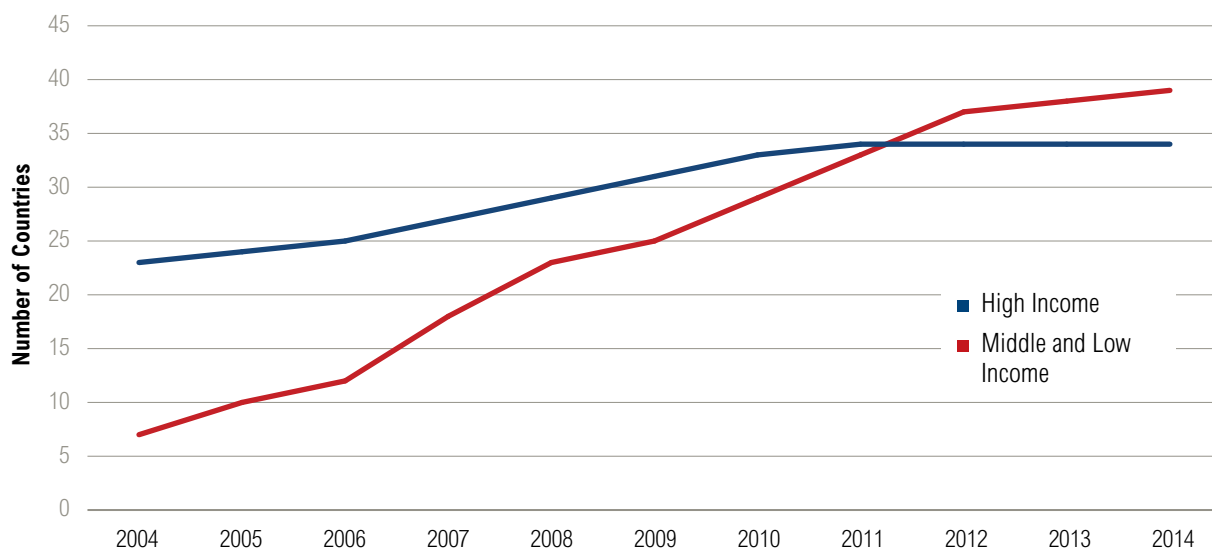
There has been rapid growth in the number of countries and regions that support renewable energy through a range of policies. According to REN21 (2015), only 15 countries (mostly high-income) had any RE support policies in 2005 but, by 2015, 145 countries in all income categories had implemented some sort of RE support policies at either the national or sub-national level. Figure 7 demonstrates the rise in countries by income group that have enacted Feed-in Tariff (FIT) policies since 2004. By 2012, the number of middle and low income countries that enacted such policies surpassed high income countries. These policies vary significantly in scope and design, and new policies

targeting technologies such as electric vehicles, stationary storage, smart meters, and more, continue to develop around the world.

At the same time, the investment community has grown annual renewable energy investments sixfold over the last decade (2004–2015), from \$40 billion to \$329 billion worldwide (Frankfurt School-UNEP/BNEF 2015; BNEF 2016). Over the 2013–2014 timeframe, several major investment firms, including Citi, Barclays, HSBC, Ceres, UBS, JP Morgan, and Goldman Sachs, produced detailed analyses of the potential implications of the growth in RE for fossil-fuel assets and investments, signaling their increased attention to RE.⁹

Government subsidies in the form of quotas and portfolio standards, feed-in tariffs, and tax credits have also been widely used to help drive down costs and support the growing use of renewable energy. The IEA (2014) estimates that the value of renewable subsidies worldwide totaled \$121 billion in 2013. This was \$16 billion, or 15 percent, higher than in 2012. In 2013, solar PV attracted \$45 billion in subsidies, followed by wind power at \$28 billion globally.¹⁰

Figure 7 | **Cumulative Number of Countries Enacting Feed-in Tariff Policies by Income Group, 2004–2014**



Note: The number of countries included in this graph only include countries that have enacted national level feed-in policies, and do not include countries where only state and provincial level feed-in policies have been enacted. Countries are classified by income group using World Bank. 2015. World Bank Data Country and Lending Groups. Online at: <http://pubdocs.worldbank.org/pubdocs/publicdoc/2015/11/187611446669202793/Pnk-1115.pdf>. Feed-in tariff is a policy that typically guarantees renewable generators specified payments per unit (e.g., USD/kWh) over a fixed period.

Source: REN21 (2015).

Challenges and Opportunities Presented by Increased Government and Investor Support

Government support, increased investment, and technology improvements could be aligning to further increase adoption of renewable electricity and this is something that electricity sector stakeholders need to watch closely.

3.5 Electricity Generation by New and Different Entities

Technological changes are giving many electricity consumers a cost-effective alternative to the grid for the first time. The traditional structure of the electricity sector provides consumers with essentially one choice for meeting their electricity needs: the grid. In areas of low reliability, commercial and industrial customers have had to self-generate backup power, often through on-site diesel generation, but this has typically been done as a supplement to grid electricity and at additional cost.

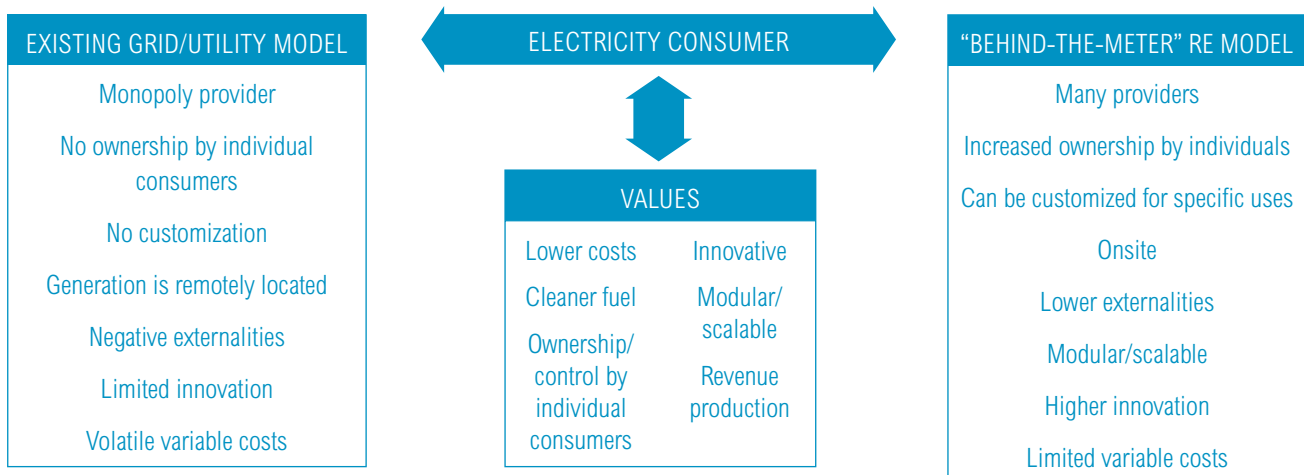
“Behind-the-Meter” Generation

The behind-the-meter model is fundamentally different from the centralized generation model. In this new model, consumer characteristics, values, and needs determine which consumers adopt which combination of services (generation + storage + management) and from which provider. Figure 8 presents the contrasting attributes of the two models: the unidirectional conventional grid model and the behind-the-meter model. The

“Individual consumer choice can make a big difference... Analysis of consumer behavior will be extremely important.”
M. Sivasankar, Chairman, Kerala State Electricity Board

behind-the-meter model represents a scenario where renewable energy generation supplies electricity at the point of demand without first interacting with the grid. The most common examples to have been installed since the mid-2000s are residential, commercial, and industrial solar PV systems (Ryor and Tawney 2014).

Figure 8 | Two Models for Meeting Electricity Needs: Traditional Grid vs. Behind-the-Meter RE



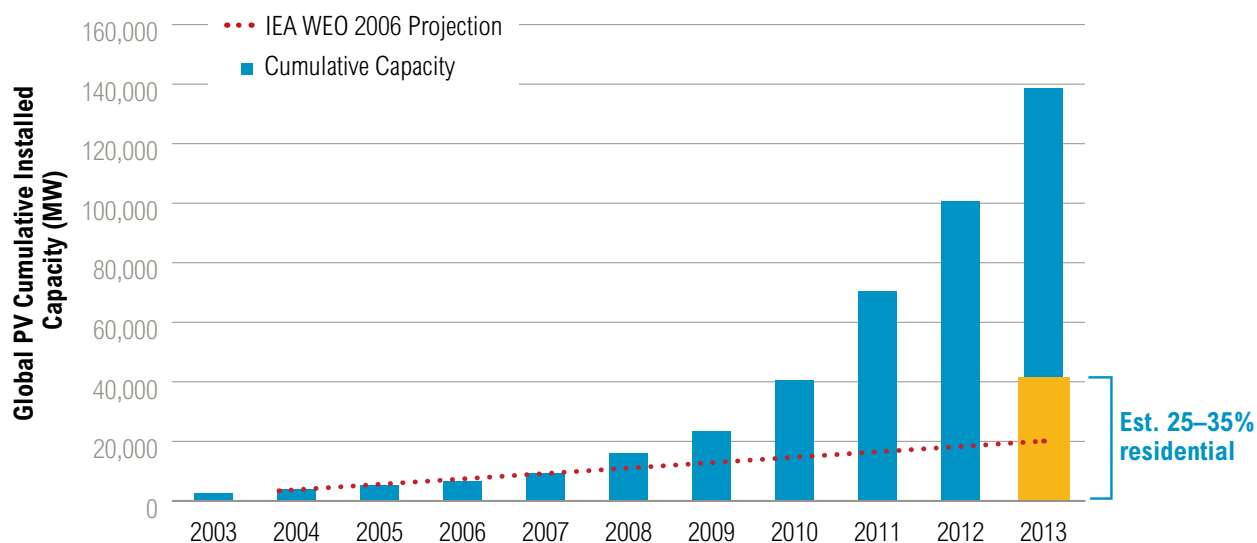
The behind-the-meter model is similar to earlier commercial and industrial models where diesel generation provided backup power. However, there are three main differences. First, behind-the-meter generation is a significant source of electricity supply, whereas diesel generation usually supplies only backup power. Second, technology improvements have led to price reductions, which have made the behind-the-meter model cost-competitive with grid electricity in many places. And third, when connected to the grid, the behind-the-meter model allows customers to provide electricity to the grid.

Under the behind-the-meter model, consumers who are still connected to the grid, and can produce their own electricity and supply any excess to the grid, are known as “prosumers.” Prosumers are distinct from both consumers who simply reduce their dependence on the grid through on-site generation and consumers who are not connected to the grid. Residential prosumers have a greater understanding of how electricity is consumed and awareness of the link between production and consumption. They have more direct control over the electricity they produce and tend to adopt energy efficiency and conservation practices (Rickerson et al. 2014).

Globally, prosumers have become increasingly involved in the RE market. A significant share of global PV capacity, for example, has been installed behind the meter at the residential level. The IEA estimates that, in 2013, 25–35 percent of the global cumulative installed capacity of PV was owned by residential entities (Fig. 9). Reasons for growth in the prosumer market are varied and include: technology performance improvements and innovations that allow for greater consumer choice; RE systems cost reductions (including system installation, operation and maintenance, and system financing); availability of subsidies; and increasing retail electricity tariffs (Box 2).

Both Germany and the United States have seen steady growth in prosumer entities. In the United States, installed capacity of rooftop solar photo-voltaic systems (PV) on residential, commercial, and industrial facilities has steadily increased in recent years, from 585 MW installed in 2010 to 1,904 MW installed in 2013. This has occurred especially where “net metering” and in-state incentives exist, and leasing models are allowed (Munsell 2014). Since the beginning of 2011, over 60 percent of installed residential rooftop solar PV capacity in the United States has come online through some sort of leasing model (Munsell 2014). In Germany, it is

Figure 9 | **Global Cumulative Installed PV Capacity**



Source: Rickerson et al. (2014).

Note: Global residential share estimated only for 2013.

BOX 2 | INCREASING ELECTRICITY TARIFFS AND GROWTH IN DISTRIBUTED GENERATION

An important consideration for consumers and producers alike is how cost-effectively consumers meet their electricity needs. Among other choices, consumers can now weigh tariffs for grid-based electricity against distributed generation (DG) alternatives. Increasing retail electricity tariffs worldwide are an observed factor in the growth of prosumer-led DG.

In the case of Brazil, electricity prices have risen to a record high, in part because low rainfall has led to a fall in hydropower dam reserves (Orihuela and Lima 2014). At the same time, prices of solar PV have been dropping steadily, and the LCOE of solar PV is expected to reach parity with residential grid prices in the near future (Pérez et al. 2014).

In Germany, retail electricity tariffs have risen by 50 percent since 2002. Increases in retail tariffs and the high feed-in tariffs have contributed to an increase in the number of homeowners installing small,

behind-the-meter solar PV systems (Morris and Pehnt 2012). On-site PV has enabled consumers to avoid high daytime grid electricity costs of approximately \$0.32/kWh, and instead to supply PV electricity on site for approximately \$0.15/kWh (Rickerson et al. 2014). German rate increases have been caused in part due to the increasing number of consumers reducing their demand from the grid. (See Chapter 4.3 on pricing and equity concerns.)

In the United States, retail electricity tariffs have decreased with the advent of cheap natural gas, but are expected to rise in the longer term because of a backlog of capital spending needed to improve reliability and an aging infrastructure. The U.S. Energy Information Administration's most recent Annual Energy Outlook projects that average retail electricity prices will increase by 18 percent from 2013 to 2040 (USEIA 2015). Larger consumers are considering other electricity and heating supply options

that reduce their exposure to these price future increases (Adam 2013). One such electricity option, commercial-scale PV systems, has experienced huge technology-cost reductions.

In India, solar energy prices have dropped significantly in the last five years, from 17.90 INR per unit in 2010 (Government of India 2015) to bids as low as 5.05 INR per unit as of July 2015 (Jai 2015). Rooftop solar PV has already reached grid parity in 12 states for certain consumer categories, including industrial and commercial electricity (Bridge To India 2016). Electricity tariffs vary widely from state to state but, on average, from FY2009–10 to FY2013–14, residential (“domestic”) tariffs increased by 15 percent and commercial tariffs rose by 16 percent—an annual increase of roughly 5 percent (Government of India 2014). Falling prices of solar PV and rising consumer tariffs will only widen the price differential in the years to come.

Note: Costs for onsite PV were expressed as €0.29/kWh, and €0.14/kWh in the original publication and have been converted into US\$ based on 2014 \$/EUR exchange rates.

estimated that citizens and cooperatives owned almost 50 percent of RE capacity in 2012 and that “energy cooperatives,” or community-owned renewables projects, have leveraged a total of \$870 million¹¹ in investments from more than 80,000 private citizens (Morris and Pehnt 2012).

Similar trends are starting to arise in developing countries. In Kyrgyzstan, the number of prosumers is rising, with consumers installing residential solar PV systems as a complementary electricity source (UNISON 2014). In addition to behind-the-meter installations, many states in India have allowed open access, where large consumers with a connected load of 1 MW and above have a non-discriminatory provision for the use of the grid, which frees them of their obligation to purchase power from any single distribution utility. And in China, future growth in distributed generation is expected to come from the residential sector. The Chinese government has published new regulations to promote the development of distributed solar PV,

committing to a goal of 7 GW of distributed solar generation, 3.15 GW of which is to come specifically from rooftop solar PV in 2015 (Ayre 2015).¹² As of September 2015, 1.58 GW of distributed solar PV has been installed (CNEA 2015).

Challenges and Opportunities Presented by Unconventional Generating Entities

The emergence of prosumers as viable electricity generators raises questions concerning the need for new regulatory processes and policies. These will include setting appropriate tariffs for behind-the-meter or independently generated electricity, ensuring that electricity consumers are not disproportionately burdened by grid defectors, and regulating new players appropriately in a system that traditionally has been accustomed to regulating centralized utilities. Tariff design and tariff structures might allow the grid to be compensated for services (back-up, storage, voltage support) that go beyond the mere provision of electricity. Further complexities arise in terms of operating the existing

“Most mainstream projections did not predict the extraordinary expansion of renewables that was to unfold over the decade ahead. Scenarios from the renewable energy industry, the International Energy Agency, the World Bank, Greenpeace, and others all projected levels of renewable energy for the year 2020 that were already well exceeded by 2010.”
REN21 (2014)

grid system. There will be a need for improvements in forecasting demand and generation from renewable sources, scheduling, and more efficient balancing of resources.

3.6 Technology Uptake

It is difficult to predict the future rate of change in the electricity sector. However, recent changes have occurred in a shorter timeframe than can be accommodated by traditional planning in the sector; this is particularly true of the rapid adoption of renewable energy. Traditional models have systematically underestimated the potential penetration of renewables globally. Most recent IEA projections have been substantially revised. Figure 10 demonstrates that, by 2012, the level of renewable capacity was already as high as the maximum potential level in 2030 that had been projected by the IEA a few years earlier.

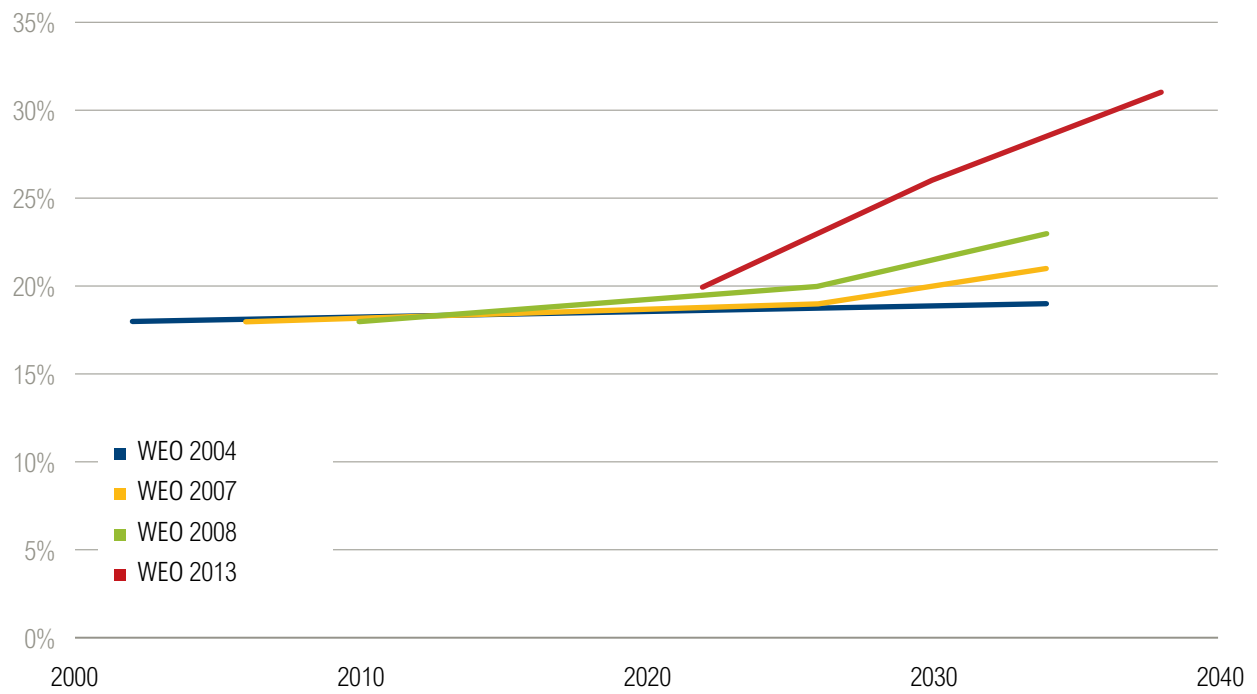
This means that policies can have unintended consequences, or leave too short a time to prepare for the consequences. For example, the German RE feed-in-tariffs led to the rapid build-out of rooftop solar PV, which caused an unintended, sustained dip in wholesale electricity prices. This made some conventional generation unviable because wholesale prices were too low to fully recover costs.

Challenges and Opportunities Presented by Rapid Uptake of New Technologies

Regulators, policymakers, utilities, and other sector players must now ask questions such as: “How quickly will these changes occur?” and “what impacts could these changes have?” because there may not be enough time to fully understand the implications, or develop and implement appropriate responses to mitigate all detrimental consequences.

Electricity sector stakeholders who must plan for the future need a thorough understanding of current trends and rapid changes such as declining cost trends in new technologies, improvements in performance, changes in consumer behavior, increased investor and government support to new technologies, and the implications of these trends and changes for centralized grid systems in the countries examined in this report. These implications are discussed in the next chapter.

Figure 10 | **Global Projections and Share of Renewables in Electricity Generation**



Source: IEA's Reference Scenarios in World Energy Outlook (WEO) 2004, 2007, and 2008, and the New Policies Scenario in WEO 2013.

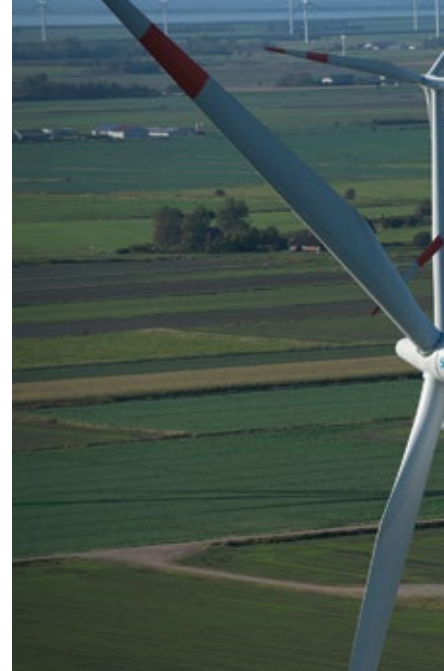




SECTION IV

IMPLICATIONS FOR THE FUTURE GRID

The electricity sector trends described in Section 3 concern technology costs and improvements, consumer preferences, and public policy. These trends have proven disruptive, in ways both positive and negative. They have brought new generation and system technologies, market structures, and generating entities to the grid, and they have increased the complexity of design and operation in an already complex electricity system.



These changes represent major challenges to countries worldwide. Countries are experiencing different levels and rates of disruption but, as changes inevitably unfold, all countries must face the implications for their ability to move toward a grid that is reliable, economically viable, and environmentally sustainable.

In the four developing countries studied for this report—Brazil, China, India, and Kyrgyzstan—the authors conducted research to identify country-level trends that are impacting electricity generation, transmission and distribution technologies, generating entities, markets, policies, and institutions. The country-level research was supplemented by global analysis of trends in sector transformation. We identified challenges that affect all the many different stakeholders involved in the sector; these challenges can be grouped under the following three categories:

- Technology and infrastructure
- Institutional arrangements
- Electricity pricing and equity

These categories are interconnected. They impact the sector as a whole and are relevant to all sector stakeholders, including electric utilities, sector regulators, planning bodies (national/central and state/provincial), grid/system operators, policy-makers, and consumers. For example, the need for grid network expansions or modifications to accommodate new technologies will require significant investments by the government, system

operators, generators and/or utilities. Though some of these investments could be recovered from efficiency gains, the remaining costs will need to be recovered through either consumer tariffs or taxation, meaning that they will also have new pricing or equity implications. While these interconnections exist, some challenges will of course be more pertinent to some stakeholders than others.

4.1 Technology and Infrastructure

Large- and small-scale distributed RE generation is being added by numerous entities, including individuals, commercial business owners, and cooperatives, among others. This development presents **increasing technical complexities** and causes **physical grid infrastructure constraints**.

On-site RE generation can bring several benefits, such as reduced power line losses, lower transmission and distribution investment, and improved emergency power supply if placed close to areas of consumption. However, high penetration of distributed RE generation systems can pose issues related to grid management such as voltage rise, reactive power needs, and frequency regulation.

Reliable Supply Depends on Overcoming the Problem of Intermittency

The inherently variable nature of solar and wind resources presents obstacles to reliably delivering electricity for grid operators and utilities in countries worldwide. In the case of a traditional grid, electricity-generating power plants are often



powered by fossil fuels or hydroelectricity, where the output can be easily and accurately scheduled ahead of time, compared to output from wind and solar generation. This arrangement, coupled with relatively predictable load patterns (historically), made centralized dispatch of electricity comparatively straightforward. However, an increase in the rate of deployment of large-scale solar, wind power, and small-scale decentralized renewable energy could lead to several complexities in terms of load balancing. These primarily arise due to variability in supply/demand caused by weather patterns on a diurnal and seasonal scale. We have already seen in China how the rapid growth of wind energy systems has posed issues for these systems' integration with the grid. While large numbers of wind turbines have been connected to the grid (in 2013, roughly 14.5 GW of wind power capacity was added to the grid (CREIA 2014)), its variability has caused balancing problems for system operators. In East Inner Mongolia, where wind power accounted for more than 30 percent of the local system capacity in 2014, system balancing has been dealt with by curtailing a large proportion of wind generation.¹³ This is leading to large financial losses for wind project developers. High levels of wind curtailment have been associated with a lack of grid infrastructure connecting load centers in the south to wind resources in the north. In 2012, the Chinese Wind Energy Association estimated that wind curtailment equated to financial losses of \$1.6 billion for that year (Qi 2013). A recent report from the Comptroller Auditor General of India notes high levels of wind curtailment in

Tamil Nadu. The report found that, during the period of 2007–2014, the portion of wind power curtailed was 6,018 million units (MUs), with the highest losses occurring in 2012–2013 (1,155 MUs) and 2013–2014 (3,419 MUs). This resulted in loss of revenue of Rs. 2,040 crore (over \$305 million) during the seven-year period (Union Government Ministry of New and Renewable Energy 2015).

New Energy Sources Must be Integrated with Legacy Grids

As countries seek to meet renewable energy targets and look to connect more renewable energy projects to the grid, the grid faces two primary infrastructural constraints: **a disconnect between generation resources and demand centers and compatibility and inter-connection of distributed generation with the grid** (Ballesteros et al. 2013). Good resource sites that are available tend to be in remote areas, far from load centers and grid connection points. How costs of grid extension and new generation connections are handled will impact how the economic impacts of bringing on new renewable energy capacity are distributed.

In China, 3,940 MW of wind capacity was connected to the grid in 2013 in the northwest of the country, in provinces including Xinjiang, Gansu, Shaanxi, Tibet, Ningxia, and Qinghai (NEA 2014). This region accounted for 26.3 percent of the total wind capacity installed that year; however, the region is home to only 10 percent of the country's

population. The location and speed at which wind power has been developed in the country has created a burden on grid expansion and the transmission of electricity in the country. New transmission lines are being constructed, including a high-voltage transmission grid. However, lengthy transmission networks are expensive to build and operate for the State Grid Corporation. Kyrgyzstan faces a similar problem: a geographic divide exists between the majority of hydro reserves in the south and most of the load in the north. The country also faces hydro reservoir constraints due to droughts and low water levels, while simultaneously it must deal with increased demand for electricity (UNISON 2014). This situation has resulted in investment for the construction of new and costly transmission infrastructure, namely the 500Kv Datka-Kemin transmission line and substation, to provide power supply to the country's capital city, Bishkek (Kyrgyz Republic 2009).

In developing countries, in general, these challenges are aggravated further because transmission systems are less developed (Madrigal and Stoft 2011). For example, India started integrating its major regional grids in 2003 and transitioned to a single frequency national grid in 2013. This grid expansion comes at a time of increased electricity demand, as access to electricity improves, GDP increases, and electricity is demanded to meet development goals (Prayas 2014). A report by the Indian Forum of Regulators (FoR) indicates that this new, larger grid is already challenging grid operators in India, due to the large variation in load and generation (Power Grid Corporation of India 2012).

Electricity consumers and prosumers alike would like electricity supply on demand, regardless of whether renewable resources are generating power at any given time. This requires the utility or grid operator to provide balancing services to balance generation with demand (load) sources across various time horizons and physical constraints, in addition to moving the power from the generation sources to the customer. These necessary services are both complex and expensive, but they are surmountable. Germany's experience shows that it is possible to decrease balancing reserves while

increasing variable RE. Between 2008 and 2015, wind and solar capacity tripled, yet balancing reserves were reduced by 15 percent and costs by 50 percent (Hirth and Ziegenhagen 2015).

Integration also requires decisions to be made about when grid extensions are appropriate for connecting new and emerging generation projects, who makes those decisions, and who is tasked with developing and paying for new infrastructure. Failure to make such decisions will lead to sub-optimal outcomes. For instance, in Brazil, RE generation has been growing rapidly since 2005. Installed wind capacity in operation increased from 1.4 GW in 2010 to 4.7 GW in 2014, with an additional 10 GW already contracted to come online through 2018 (Mello 2014). This translates to more than 140 wind power projects as of mid-2014. However, 48 of these operational projects were not connected to the grid at that time because there were no transmission lines planned, let alone built, to receive this power (Jornal Nacional 2014). As of October 2015, 6.75 GW of wind power capacity existed in Brazil, representing 4.4 percent of the country's electricity generation capacity. Of this, roughly 60 MW have yet to be connected to the grid, primarily due to lack of transmission infrastructure (ANEEL 2015; Ambiente Energia 2015).

In coming years, adoption of newer technologies, including other distributed RE systems, on-site generation, and storage technologies will lead to the connection of even greater numbers of entities. These issues, in addition to existing grid-related problems common in developing countries, such as poor existing grid infrastructure, lack of access, and low supply quality (such as unreliable supply and unplanned disruptions), could pose a challenge to the operation and management of the grid.

4.2 Institutional Arrangements

The emergence of newer-generation technologies and entities is challenging the traditional utility model and characteristics of the grid. It is moving toward a network with more decentralized generation, leading to bidirectional flow of electricity between large numbers of consumers, producers, and prosumers. There will be a need for enhanced institutional capacities, with an increased focus on training and knowledge.

The electric utility industry in developed countries, once thought to be a low-risk sector for investors, has recently faced declining credit ratings. The most notable examples are declining stock prices of Germany's Big Four Utilities and the decision of E.ON, Germany's largest utility, to split itself up and focus on creating revenue through renewables (The Economist 2014), as well as the downgrade of the entire United States electricity sector's credit rating by Barclays in early 2014 (Trabish 2014). Barclays believes that rapid technology advances, especially in solar and electricity storage, will leave "regulators and utilities...constantly trying to respond to a moving target, which is precisely the environment where slow-moving incumbents can fall behind." Ultimately, "[Barclays] expect[s] the net effect to be higher grid power costs (thereby exacerbating the consumer shift to solar + storage), lower average credit quality for regulated utilities and unregulated power producers, and increased recognition of the long-term threat to grid power" (Wile 2014). S&P and Moody's, on the other hand, foresee stable credit ratings for U.S. utilities in the near and long term, due to a continued focus on regulated operations and improving state regulatory environments (EEI 2014).

Big Utilities Face a Declining Share of Generation...

These new pressures facing the electric utility industry are epitomized by the shift in generation ownership in Germany. By 2012, renewable energy

made up 20 percent of Germany's electricity capacity. Of that 20 percent, private individuals and farmers owned 45 percent, while Germany's four largest utilities—RWE, E.ON, Vattenfall, and EnBW (the "Big Four")—owned less than 11.9 percent (Trendresearch 2013). These four utilities, which had previously dominated the generation market, have failed to capture 88.1 percent of the market for renewable energy generation, and roughly 20 percent of the total German electricity generation market (Richter 2013). This has had financial ramifications for these utilities. RWE posted a loss of nearly 3 billion Euros (roughly \$3.3 billion) in 2013 due, in part, to "4.8 billion euros (roughly \$5.2 billion) in write-downs on power-generation assets" (Morris 2014a).

...And are Losing Customers and Revenue

The new pressures facing electric utilities are not exclusive to developed economies; and their impact is likely to be much harder on the financially strapped utilities in many developing nations. In India, distribution utilities are coming under financial pressure with the implementation of open-access provisions, which enable large customers to procure electricity from outside their local distribution utility, as well as the growing movement of large consumers to self-generation, due in part to the cost-competitiveness of RE systems. Utilities are beginning to lose some of their highest-paying customers because of the move to RE. Both open access and self-generation have led to a slow-



BOX 3 | TRADITIONAL TARIFF STRUCTURE LEAVES FIXED COSTS UNRECOVERED

The most common electricity tariff structure, consisting of both fixed costs and energy costs (charged per kWh), can create cost-recovery problems for utilities. Electric utilities and private generators recover part of their fixed costs (either investment costs or network costs) from the energy charges. This structure has the potential to impact utilities and grid operators' ability to provide the necessary level of fixed-cost services required for affordable and reliable electricity. This is due to the fact that fixed costs can go unrecovered in this structure, especially if electricity sales (kWh) fall, thus lowering the level of revenue available to pay for fixed costs. The choice of some customers to move toward distributed resources may exacerbate this problem. With fewer people paying for energy (kWh), or any costs, utilities will have trouble covering their fixed cost with lower energy sales; grid service may suffer and energy prices for remaining customers will rise.

down in commercial and industrial demand growth across the country. Commercial and industrial customers are particularly important in the Indian context because they pay the highest electricity tariffs in order to subsidize low-income and agricultural customers.

In the western Indian state of Maharashtra, electricity tariffs vary across different consumer categories. The levelized tariff (cost) of rooftop PV for 2015 was around Rs.7/kWh (roughly \$0.11/kWh), which is cheaper than the price paid by about 50 percent of consumers (without fixed costs, but including electricity duty and Fuel Adjustment Charges). While the costs for rooftop PV are expected to fall further, consumer tariffs are expected to rise, making rooftop PV an even more attractive option for an increasing number of consumers (Prayas 2014). In the southern state of Tamil Nadu, the net revenue loss attributable to open access in the fiscal year 2012–2013 was about 35 percent of the total revenue gap (the difference between costs and revenue) for the utility. Such developments will test current utility business models in the coming years (Prayas 2014).

Regulators will need to anticipate these types of losses, account for these types of changes, and identify governance processes in order to find equitable solutions to mitigate adverse impacts related to the loss of a utility's customer base. Solutions might involve redesigning the structure of retail electricity tariffs to better value the services the grid is providing in support of the customer move to renewables. Regulators and utility managers alike will need to rethink institutional frameworks in order to develop stronger and more flexible sector governance.

4.3. Electricity Pricing and Equity

Increased grid complexity and managing complexity create new concerns over electricity prices and the equitable distribution of system costs and benefits. Properly valuing and distributing system costs and benefits among customers will become increasingly important as energy service providers step into new and different roles. The valuation of these costs and benefits is also important to ensure increased electricity access and maintain affordable prices.

Encouraging Renewables Can Undercut the Financial Viability of Utilities

Setting electricity tariffs is an important part of ensuring the equitable distribution of system costs and benefits across customers. Many factors affect the ability of electricity tariffs to achieve these objectives. One important factor is whether fixed costs and energy costs are each set at a level that allows utilities to recover both types of costs fully, particularly as customers move to distributed generation and policies such as gross-metering and net-metering are introduced. Electric utilities and/or system operators may be unable to provide proper grid services or affordable prices if they are unable to recover both these costs (see Box 3).

“Net-metering” policies, which have encouraged renewable energy deployment in the United States, involve the utility paying distributed generators (prosumers), typically at the retail or wholesale electricity rate, for any excess generation they produce that is provided to the grid at the end of each month. This has been a matter of significant public and sector debate due both to the exponential rise in distributed solar PV installations in the United

States since the mid-2000s and the loss of utility electricity sales represented by distributed solar PV customers (Kind 2013). The debate surrounding net-metering concerns the appropriate rate of compensation—the retail, wholesale, or other price. The appropriate rate should depend on the system, location, and valuation methods used for energy and other factors (reduced power line losses, reduced need for transmission investment, investment in distribution system upgrades to manage the changing power flow, etc.).

Another important factor is the presence of feed-in tariffs (FiTs), which can increase electricity prices to customers. Electricity tariffs and tariff instruments have been used for decades to incentivize alternative energy systems and fuel diversity.¹⁴ They set special tariffs for energy produced by particular types of electricity generation sources. The price differential between the normal electricity tariff and a FiT can be funded through two primary mechanisms: distributing the surcharge in customers' electricity bills, or public funding. The pros and cons of both funding mechanisms need to be considered before designing and implementing any FiT (Ballesteros et al. 2013), but the choice essentially concerns who pays for these special tariffs: the taxpayer or the electricity customer. In the case of public funding, questions of a country or region's fiscal stability should be kept in mind. In the case of electricity customers, questions about how additional costs are distributed should be addressed.

In a country like Kyrgyzstan, where policymakers are looking to diversify energy sources due to water stress in a country with high dependence on hydro-power, existing low electricity tariffs and growing electricity demand are pushing policymakers and regulators to consider subsidies like FiTs. Consideration of FiTs is already a legal obligation in Kyrgyzstan, but estimates of the additional surcharge needed to fund a FiT are relatively high compared to current household tariffs. Tariffs in 2012 were around \$0.015/kWh, whereas estimated additional surcharges range from \$0.04 for small hydro to \$0.17 for solar (Hasanov and Izmailov 2011).

Policy approaches aimed at supporting RE, like net-metering and FiTs, have particularly large implications for the poor and may affect their ability to pay for electricity, if tariffs are not distributed

BOX 4 | UTILITY REGULATORS AND ELECTRICITY TARIFF-SETTING

Electric utility regulators play a crucial role in valuing and distributing costs and benefits because they are tasked with balancing customer, utility, and private investor interests in line with public policy. One way in which regulators balance the interests of these groups in regulated markets is through the setting of electricity tariffs. Traditionally, tariffs are set at a level which: maintains the financial and operational health of the utility; attracts private investment; meets growing demand; and minimizes outages and maximize reliability. Tariffs must also be set low enough to promote continued economic growth, protect the interests of low-income populations, and prevent utilities and private investors from making undue profits. The electricity sector can suffer from artificially high or low tariffs in regulated markets without appropriate tariff regulations, as is the case in Kyrgyzstan. This makes it hard for utilities and generators to recover all of their costs with low tariffs and creates windfall profits for utilities that overcharge customers with high tariffs.

Note: For an overview of electricity tariff fundamentals, see Reneses et al. (2013).

appropriately and if utilities are unable to provide electricity at affordable rates to these customers. For this reason, it is important that regulators structure tariffs fairly, and adjust payback rates that factor in additional components including the economic value of adding RE to the grid, and the financial impacts of RE adoption on all customers, not just homeowners who can deploy solar on their roofs, for example (Kind 2015).

Pricing Policies Must Balance Utility Investment Concerns and Equity

Regulators and governments often require utilities to offer subsidized prices to some customer classes. This is done in order to maintain the “affordability” of electricity services and for other economic and social reasons (see Box 4). The financial strain caused to utilities and customers by customers reducing their consumption from the utilities—through self-generation in both India and Germany, net-metering policies in the United States, and FiTs in several countries—are all examples of how

new system complexities create new concerns over electricity prices and the equitable distribution of costs and benefits.

In India, utilities have mandates, or are subject to political pressure, to protect low-income customers through a “cross-subsidy” approach that charges some customers higher tariffs in order to subsidize lower tariffs for low-income customers. As discussed, the higher tariffs, as well as issues of power quality and reliability, provide incentives for large industrial and commercial consumers to opt out of buying electricity from the utility and invest in their own generating systems, powered either by diesel or RE. Diesel-based generation in India is used primarily to address issues of reliability and not to reduce purchases from the utility. This is because diesel generation is costlier than utility-purchased power. The difference with RE is that RE generation is much cheaper than diesel, and also offers long-term stability of price and generation cost.

It is important to carefully consider and evaluate the tariff methodology, which was based primarily on a unidirectional flow of electricity from generator to consumer, and payments from consumer to the utility. The fundamental assumptions made in designing tariffs may need to be reviewed.

Therefore RE is used more to reduce purchases from utilities and not to mitigate poor reliability of the grid.

In Germany, by mid-2013, roughly 16 percent of companies produced a percentage of their own power on-site, according to the German Chamber of Commerce (Hromadko 2014a). German companies are seizing the opportunity to avoid high electricity prices that have resulted, in part, from the 22 percent government-mandated electricity bill surcharge used to fund renewable energy sources. On-site power not only shields these companies from the government surcharge, but also makes them eligible for subsidies designed to encourage energy efficiency and so-called green electricity. As of 2014, companies in Germany that avoid the surcharge and receive subsidies may be able to cut their electricity bills by around 50 percent (Hromadko 2014a).

Grid electricity defection not only affects utility revenues, it can also disproportionately affect ratepayers who stay behind. As customers exit and electricity tariffs typically increase, utilities and state budgets may be less able to provide low-cost electricity to low-income households and agricultural consumers. As the German experience suggests, surcharges on tariffs meant to promote energy efficiency and renewable energy may be associated with negative effects in the medium to long term. It is important to carefully consider and evaluate the tariff methodology, which was based primarily on a unidirectional flow of electricity from generator to consumer, and payments from consumer to the utility. With multiple generators using the grid as a vehicle to supply electricity to consumers (many of whom are prosumers), the fundamental assumptions made in designing tariffs may need to be reviewed.





SECTION V

CONSIDERATIONS FOR DEVELOPING COUNTRY STAKEHOLDERS

“Technical issues can and have all been overcome where there is the political will to do something. Consumers can potentially help drive this political will.”

—*Dr. Pramod Deo, former Chairperson,
Central Electricity Regulatory Commission, India*

The previous section outlined some of the major challenges and opportunities that face countries as they seek to adapt their national grids to a more complex world. The grid increasingly needs to account for factors such as distributed generation, intermittency in generation and load, electricity storage, energy efficiency and management, increased open access, on-site generation, and more. These multiple factors make grid planning and management more complex.

Managing this complexity involves more than considering technical adaptation and changing the physical infrastructure. It entails a shift in approaches to grid planning, moving beyond simply planning for future demand to planning for a grid that is flexible and adaptable to new technologies, new patterns of supply and demand, and new customers (see Box 5). Future management will entail identifying new roles and operating models for traditional stakeholders in the sector. It will also require rethinking tariff structures and pricing models, and incorporating adequate governance mechanisms in the planning processes.

In addition to these requirements, a variety of skills and qualifications will be necessary at multiple levels. For example, skills will be required to develop regulatory and tariff designs that take into consideration the economic and social impacts of scaling distributed renewable generation. Technical skills will be required for maintenance of systems and for ensuring system dispatch and balancing as more variable renewables penetrate the system.

This section revisits the challenges and opportunities identified in Section 4 and highlights a number of questions that merit consideration and discussion among regulators, planners, and electricity sector decision-makers in developing countries.

5.1. Technology and Infrastructure

The emergence of new energy actors adding distributed RE generation to the conventional grid is presenting increasing technical complexities and causing physical grid infrastructure constraints. A high penetration of distributed RE generation can pose grid management issues that need to be considered and addressed by system operators.

BOX 5 | TRADITIONAL PLANNING APPROACHES IN INDIA

Planning in the electricity sector has traditionally focused on meeting annual electricity demand; this has meant building enough generation capacity to meet peak demand and ensuring adequate fuel supply to operate power plants. While the goal of planning approaches is still to meet annual demand, this goal will need to involve a greater number of variables and constraints in coming years. Planning approaches are going beyond traditional criteria, and are shifting toward more holistic, coordinated, and transparent practices in order to account for increased RE and new energy technologies (Dixit et al. 2014).

Existing institutions are often focused on dealing with immediate, urgent issues, and are unable to envision and engage in

long-term planning for the grid. In India, meeting the existing supply-demand gap is a priority. The country is faced with severe short-term supply challenges that impact long-term grid planning. Close to 400 million people in India still lack access to electricity. Transmission and distribution (T&D) losses in India, as of May 2013, were about 22.69 percent (ISGF N.d.) as compared to 6 percent in China and the United States and 8 percent in the UK. T&D losses in India are related to inadequate investments in the T&D system and contribute to Indian utilities' continued financial duress (Bhalla 2000).

Considerations such as possible changes in supply and demand patterns in the future due to increased demand-side measures, new storage or variable RE

technologies, or interdependencies between different sectors, may not be factored into planning for the grid. For example, the Indian National Electric Mobility Mission Plan (Government of India 2012) projects about 6–7 million electric vehicles in use by 2020, which will have implications for grid planning and operations. The success of this policy and increased adoption of electric vehicles will require widespread improvement in the charging infrastructure offered by the grid, as well as consideration of how the grid will cope with changing load patterns from charging infrastructure. However, these considerations are not adequately taken into account, hampering the sector's preparedness for the future (Prayas 2014).

Overcome Technical Limitations

With the scale-up of RE, two primary grid infrastructure challenges are emerging: compatibility and interconnection between intermittent RE resources and the grid, and locational disconnects between RE resources and demand centers (Ballesteros et al. 2013). A shift toward a safe, reliable, and affordable future grid will require plans for grid upgrades, expansions, and regional interconnections that address all these issues.

Providing timely, efficient, and economic transmission and distribution services remains a major challenge because grid-planning practices can result in long delays and can be costly (Madrigal and Stoft 2011). Construction lead times for RE technologies are often shorter than for most conventional power sources and therefore require faster delivery of transmission infrastructure. For this reason, decision-makers in many countries are planning for grid expansion and modernization, and investments in the grid are increasing. Grid modernization studies, and intra- and inter-regional grid expansion plans are being developed to increase system reliability, improve service quality, and integrate new-generation technologies and sources into the grid. In India, the Ministry of New and Renewable Energy, together with the Power Grid Corporation of India, released a report on Green Energy Corridors that outlines how the transmission network in the country needs to be strengthened to integrate large-scale renewable energy. The corridors will comprise both inter-state and intra-state infrastructure for evacuation of an additional 40 GW of renewable energy by 2020, primarily in the RE-rich states of Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Himachal Pradesh, and Rajasthan. The total cost of developing Green Energy Corridors is estimated to be \$7 billion (Saikia 2013). In 2015, the Government of India revised its RE target to 175 GW by 2022 (MNRE 2015), which includes significant contributions from rooftop solar PV (40 GW) (Government of India 2015), transmission planning, grid investments and operation, all of which will need to be considered as part of grid integration strategies.

As intermittent RE and distributed generation technologies scale up, technical complexities are becoming more apparent. Information and Communication Technologies (ICT) may improve

grid system efficiency, flexibility, reliability, and safety as new and decentralized generation systems develop. There is a need for better technical understanding of these ICT measures, and of new transmission technologies that need to be deployed to enable improved reliability with increased distributed RE. There is also a need for better strategic understanding of how long new infrastructure requirements will take to develop, and at what cost. The future grid will have to develop increasing capability to handle intermittency in generation and to modify grid operation protocols accordingly.

Ensure System Reliability and Improve Service Quality

Traditionally, the role of the grid has been to provide a reliable supply of electricity to consumers at the lowest possible cost. However, with the proliferation of RE options, consumers seem likely to opt for on-site or non-utility generation in the future. This trend, combined with the technical complexities described above, could greatly affect the way in which electricity providers need to think about grid system reliability and service quality.

Electricity consumers and prosumers alike will continue to expect reliable power supply from the grid. As a result, in the coming decades, we can expect a diversification in the role of the grid (Electric Power Research Institute 2014). First, the grid will be expected to provide power to consumers in the event that distributed sources of generation fail to meet consumer demand. This is especially important given that many distributed energy systems are likely to be powered by renewable energy, which varies considerably with changes in weather. Second, the grid and new generators will have to take on additional challenges related to connecting small-scale distributed on-site electricity generation and consumers, while ensuring safety and reliability. While a consumer's on-site generation system can help supply electricity during normal operation, it is the grid that provides maximum starting power for a reliable start without voltage fluctuations. Third, because the grid does not have to adjust to localized demand needs, it will be necessary to help distributed energy systems to run at their optimal level. This is important, because systems not connected to the grid will not be able to ramp their output up or down to match varying load demand.



These emerging system-balancing services will become even more complex for the utility or grid operator, which must manage generation and electricity demand (load) sources across various time horizons and physical constraints, in addition to moving the power from the generation sources to the customer. These additional services are both complex and costly. As noted earlier, the grid operator in Germany had to increase its interventions in the system in order to maintain system balances and uninterrupted power supply. The total duration of nationwide balancing measures more than tripled between 2010 and 2011, and their costs more than tripled also (Adam 2013a).

These issues need to be considered not only in terms of current scenarios but, more importantly, in light of future scenarios that could include, for example, a 30–50 percent increase in behind-the-meter generation. Stakeholders will need to understand how load profiles will change, how this will impact system balancing and flexibility requirements, and how costs and benefits of these behind-the-meter systems will be valued.

5.2. Institutional Arrangements

Enhanced institutional capacities are necessary to manage a more decentralized system involving new generation technologies and entities.

Rethink Institutional Frameworks and Strengthen Sector Governance

The rapid deployment of clean technologies not only represents technical challenges to the grid, it also raises important governance questions about institutional roles, transparency, and coordination.

Current institutional frameworks and governance structures will have to change in coming years. The existing approach to electricity sector governance is one where regulators or similar agencies oversee the sector, provide for public hearing processes to enable consumers and the public to give input, and provide reasoned decisions. Decision-making in the electricity sector happens to a large extent in silos. Because regulators are traditionally not accustomed to RE and siting transmission projects, the emerging set of generation and ownership models raises questions about how regulatory processes will change. Management at big utilities will also change; utilities have not been accustomed to dealing with a variety of generating entities and customers who demand more choice of energy providers.

As noted earlier, factors such as variability of generation and load, energy storage, energy efficiency and management, increased open access, and on-site generation are expected to make grid operation and planning more complex. Managing this complexity will mean more than just changes to the physical infrastructure. It will entail a shift in the grid management paradigm through an increased emphasis on understanding the management of complex systems. There is, therefore, a serious need for education, training, and skill enhancement for building up human capacity at all levels to manage such complex systems. Stakeholders need to consider specific institutional capacities that will be required to address some of the challenges. This will be required not only for sector planners, regulators, and utility managers, but also for system operators and operation-level utility staff.

Regulators are being faced with questions: Who will pay for improvements and innovations in the grid to enable benefits from emerging RE-based projects? Who will pay for added infrastructure? How can planning systematically account for stranded asset risk and ensure that transmission upgrades are made prudently? And how will costs be distributed? Given the pace of technology development across different sectors that could affect electricity planning in the country, current institutional capacity and arrangements may be inadequate to handle it. For example, do traditional electricity sectors have the capacity to anticipate

the growth in electric vehicles, which will impact electricity planning with regard to generation and load profiles, among other factors?

Utilities are faced with questions of how they relate to their customers, who increasingly have cost-effective alternatives to the grid. Utilities risk losing market share and high-value customers who represent much-needed revenue. Traditional demand loads may change with improvements in energy efficiency unrelated to RE sources. Solutions are likely to involve both technical options that allow for greater differentiation among the needs of different kinds of consumer, and institutional changes that enable utilities to engage more flexibly with other stakeholders such as consumers and potential funding sources, whether governmental or in the private investment community.

As generation becomes more distributed, electric utilities will need to develop new roles and new business models in an attempt to address new pressures, such as the increasing number of prosumers, adapt to new pricing requirements, and take advantage of funding opportunities, all of which can contribute to maintaining healthy finances. Electric utilities will be expected to provide certain minimum services to support the scale and pace of prosumer uptake. These services are not fundamentally different from their current operations, but they represent a change in focus. Prosumers will expect the electric utility to continue to provide power in the event that self-generation fails to meet demand. For all customers, the electric utility has the responsibility of ensuring the overall safety and reliability of the grid that connects these distributed generators. As part of that responsibility, electric utilities and grid operators will need to optimize the grid with both centralized and decentralized generation (Prayas 2014).

5.3. Electricity Pricing and Equity

As generation based on small and large scale RE and increased grid complexities rise, policy makers and regulators will need to identify new tariff structures and properly distribute systems costs and benefits among customers.

Rethink Tariffs

The introduction of new technologies and expanded infrastructure brings new investment concerns and priorities. Furthermore, distributed generation, open access, and the rise in self-generation mean that utilities are increasingly threatened by the loss of consumers, especially large corporate customers, and therefore loss of revenue. At the same time, consumers will be less dependent on grid generation but will still require the “grid service” of power on demand; intermittent, RE systems will not necessarily generate power at all times required by the customer.

Regulators and policymakers need to rethink the current tariff determination approach, which is based predominantly on balancing utility, consumer, and policymaker considerations in a system characterized by a unidirectional flow of electricity through the grid, from a few generators to a large number of consumers. As net-metering policies pick up and more consumers are both selling to and buying from the grid at different times of day, countries will need a more dynamic tariff policy that attracts and maintains investments, apportions costs fairly among a wide variety of consumers, and improves quality of supply.

In addition, regulators will have to address universal access and affordability issues in a system that will now have prosumers, consumers, and households without grid access. Tariffs and pricing will therefore need to be reconsidered in at least two ways. First, tariffs will need to be fundamentally reviewed and unbundled to enable grid operators to maintain reliable levels of grid services, for example, wheeling,¹⁵ ancillary services, supply of last resort or backup power, scheduling and forecasting, and transmission redundancy. Second, tariffs and pricing must address equity concerns, to ensure that those who are not able to self-generate or use open access are not burdened with excess costs caused by grid defectors. Regulators and utilities will need to explore new tariff and pricing mechanisms to ensure the proper valuation and distribution of system costs and benefits, as well as to ensure equitable recovery of fixed costs from all types of consumer. These new models could capture the impacts of open access and on-site generation on consumers still connected to the grid, and focus on a complete package of grid services rather than on the sale of electricity alone.



SECTION VI

CONCLUSION

The electricity sector is undergoing a transformation, transitioning from a sector that is statically planned and operated by central authorities, to one that is increasingly driven by a mix of variable technologies, decentralized operators, and new market mechanisms and ownership models.

These trends are increasingly challenging the traditional way in which the grid operates, with implications for regulators, planners, utilities, and individuals alike. While these challenges can be seen as a threat, they also present many opportunities if they are considered and planned for accordingly.

The emergence of RE, as well as other clean energy technologies and applications, will mean changes in the technical landscape, as well as in consumer behavior, ownership patterns, and institutional arrangements. Our conclusion is based on the assumption that the trends described in this report are sustained: the rapid rate of deployment of renewable energy and distributed generation will continue as the cost of these technologies continues to fall, technology improvements will advance, fossil-fuel prices will fluctuate, clean energy support policies will be maintained, and significant numbers of individuals will express a preference for clean energy.

These trends are increasingly challenging the traditional way in which the grid operates, with implications for regulators, planners, utilities, and individuals alike. Challenges such as increased complexity and physical constraints on the grid, challenges to the conventional utility model, and price and equity considerations, are increasingly putting pressure on all of these stakeholders. While these challenges can be seen as a threat, they also present many opportunities if they are considered and planned for accordingly.

This report does not attempt to provide solutions on how best to respond to these various challenges or how to deliver a future grid that is simultaneously flexible, reliable, environmentally sustainable, and affordable. Rather, the aim of the report is to initiate a discussion among sector stakeholders—regulators, system operators, planners, utilities, and policymakers—about key issues to consider as developing countries plan for their future grids. Stakeholders in Brazil, China, India, and Kyrgyzstan need to proactively address some of these challenges and opportunities from a longer-term perspective.



GLOSSARY

Ancillary markets: Electricity markets for services additional to energy and power capacity, e.g. frequency regulation

(Reverse) auctions: Competitive bidding process to fill specific generation or grid requirements with the lowest bid winning

Behind-the-meter: Used to describe electricity generation sources connected on the consumer side of the electricity meter (i.e. connected “on-site”) and not directly to the grid

(Generation) capacity: The maximum rated or “nameplate” output that can be produced by a single (or multiple) generation source(s); typically much greater than actual output

Capacity Factor: The ratio of actual output over a period of time to theoretical maximum output if the generation source were able to operate at full nameplate capacity continuously over the same period of time

Capital (spending): Upfront costs associated with electricity generating sources; for electricity customers, electricity is not usually associated with this type of cost

Conventional technologies: Thermal electricity generation plants, as well as nuclear technologies, which have been the main source of electricity generation over the latter half of the 20th century

Credit ratings: A measure of the “credit-worthiness” of a business that affects its borrowing power and indicates the likely risk of investing in its business

Cross-subsidy: Broadly, any circumstance in which one party (usually the customer) is paying more for the service it is consuming/providing in order to allow (subsidize) another party to underpay; in India, this approach is explicitly taken to provide electricity to poor and agricultural consumers

Decentralized technologies: Small-scale generation or other technologies that feed directly into the local distribution grid

Decoupling: A rate adjustment mechanism that breaks the link between the quantity of energy a utility sells and the revenue it collects to recover the fixed costs of providing service to customers

Demand-side management: A combination of technological and behavioral energy efficiency strategies deployed by consumers to reduce electricity costs and/or electricity use

Deregulation (liberalization): Separation of the traditional electric utility (in part or wholly) into the constituent elements of electricity generation, transmission, and/or distribution. Wholesale markets for electricity generation and retail choice for consumers are two common characteristics

Dispatchable/Flexible capacity: Power capacity that can be provided to the grid on request or demand; typically associated with traditional thermal plants as well as new concentrated solar power plants and batteries

Distribution grid: The low-voltage portion of the grid that is typically responsible for final delivery of electricity to the consumer

Distribution utility (DISCOM or DISCO): An electric utility company that solely owns and operates the distribution network

Electricity planners: All stakeholders (policymakers, regulators, utilities, etc.) involved in short- or long-term planning of the grid

Energy cooperative: Community-owned electricity generation source or utility; In Germany, many cooperatives own renewable energy projects

Feed-in tariffs (FiTs): Special tariffs for energy that is produced by particular sources of electricity generation

Frequency regulation: Near real-time balancing of the grid to adjust for changes in both supply and demand

Fuel/Generation mix: The combined share (percentage) of electricity generation sources (the “power/generation portfolio”) and associated input fuels connected to a particular grid

Good governance practices: As defined by the Electricity Governance Initiative, they include the principles of transparency, accountability, participation, and capacity

Grid: The centralized electricity system, including both transmission and distribution networks; these may be described separately as the “transmission grid” and the “distribution grid”

Grid congestion: The effect of either too much electricity supply on a given section of the grid or too much electricity demand, or both

Grid dispatch protocols: The order of operation in which electricity generation sources are dispatched and grid infrastructure is used

Grid/Electricity services: The delivery of electricity, including the balancing of generation and electricity demand (load) sources across various time horizons and physical constraints (e.g. backup power, frequency regulation, etc.); also the movement of power from the generation sources to the customer, exclusive of any physical or infrastructure services such as repairs or system upgrades

(Grid) integration: Connecting and balancing new generating sources onto the grid

Grid interconnection: The connection of two independent, non-synchronous grids via one or more points of connection

(Grid) penetration: Either the increased generation of a given electricity generation source on the grid or the current level of a given generation source on the grid in comparison to other sources

Grid-related analytics: Software that allows utilities to track, visualize, and predict events relevant to grid and business operations

Gross-metering: Under a gross-metering arrangement, all electricity generated is exported to the grid

Load: A location that has a demand for electricity, measured by its peak demand in a day

Load/Demand centers: Geographical locations in which a high amount of electricity demand is concentrated; typically large cities or industrial sites

Load shape/profile: Electricity demand on a grid over a day, which may change seasonally or with other trends

Micro-generators: Electricity generation source with capacity less than 100 kW

Net-metering: A policy that requires utilities to pay (or credit) prosumers for the electricity they provide to the grid; the rate of compensation is usually the retail rate

New network technologies: Include forecasting, ICT systems, storage, grid efficiency, among others. A combination of technologies and measures applied on both the supply side (utility/system operator) and demand side (customer) that involves both soft infrastructure (e.g. software, data analytics) and physical infrastructure (e.g. upgraded power lines, smart meters)

Open access: Used generally to describe any non-discriminatory law, regulation, or other measure allowing access to the grid for given generation sources and/or customer classes

Open access provisions: In India, large consumers with a connected load of 1 MW and above have a non-discriminatory provision for use of the grid, which frees them of their obligation to purchase power from any single distribution utility

Peak hours: The hours of highest electricity demand on a grid

Power plant curtailment: A management decision that is made when power produced is surplus to requirements and cannot be supplied to the grid; a specific power plant must be shut down and electricity wasted

Prosumers: Consumers who can produce their own electricity

Re-dispatch: The reallocation of electricity generation on a grid

Renewable energy (RE): Electricity generation technology powered by a renewable input source such as wind, solar, geothermal, and biomass/biogas

Reserve margin: Extra generation capacity on a grid that is not operating, but is ready to respond in case of changes in supply or demand, or system faults

Retail electricity rate/tariff: The price, usually per kWh, paid by end-use electricity consumers for the electricity they use

Retail electricity sales: The sale of electricity to end users, including residential, commercial, industrial, and agricultural consumers, among others.

Revenue gap: The difference between utility costs and revenue

Smart grids: Vaguely used to describe any grid deploying new network technologies or approaches

Smart meters: Advanced metering systems that can communicate more effectively with consumers and system operators

Solar inverters: A device that converts the direct current (DC) output of solar PV panels to alternating current (AC) used on the grid

Spinning reserves: Generation capacity that is on-line and is ready to respond within 10 minutes to compensate for generation or transmission outages.

Stationary/Centralized storage: Electricity storage devices connected at a specific point on the grid (centralized) or load which range technologically from traditional batteries and pumped storage to flywheels and compressed air

Stranded assets: Electricity generation sources or other grid infrastructure that becomes unused due to technological, operational, regulatory, or other changes in the electricity sector

System operators: May take various roles, but typically are responsible for day-to-day operation of the grid, including dispatching generation, balancing loads, managing system faults and outages, etc.; utilities and independent bodies (e.g. load dispatch centers in India) may play this role

Third-party financing options: A party other than the owner, operator, and/or lease partner who provides loans or other financial support for an electricity generation project

Traditional utility: Vertically integrated electric utility company with all three business functions (generation, transmission, and distribution) regulated by a local commission or other authority as a monopoly

Traditional utility business model: Typically predicated on the fact that traditional utilities earn a rate of return on investment through charges on consumer electricity sales, linking utility revenues and electricity sales. Utilities can earn a guaranteed rate of return on generation, infrastructure, and other investments in the grid and its operation

Ultra/Extra-high voltage lines: Transmission lines carrying electricity at voltages higher than typical transmission infrastructure in order to increase efficiency and reduce losses over long distances

Utility service area: The geographical footprint within which a utility provides electricity to all customers

Variable energy sources: Electricity generation sources with variable output due to variable inputs, such as wind and solar; can also apply to traditional generation sources with supply problems

Wheeling: The transfer of electrical power through transmission and distribution lines from one utility's service area to another

Wholesale market: Electricity generation and other services are sold before transmission and distribution to end-use customers

ANNEX 1. LIST OF ORGANIZATIONS AND SECTOR STAKEHOLDERS INTERVIEWED

Brazil

- Directors and Senior Executives, NeoEnergia, Brazil
- Prof. R. Lamberts, University of Santa Catarina
- Prof. R. Ruther, University of Santa Catarina
- Dr. O. Soliano, CBEM Centro Brasileiro de Energia e Ambiente

China

- Deputy Director, State Grid Energy Research Institute
- Senior Advisor, Natural Resources Defense Council (NRDC)
- Deputy Division Director, Energy Research Institute (ERI), NDRC
- Division Director, National Center for Climate Change Strategy and International Cooperation (NCSC)
- Research Associate, Energy Research Institute (ERI), NDRC
- Deputy Secretary-General, Chinese Renewable Energy Industries Association (CREIA)
- Director of Policy Research, Chinese Renewable Energy Industries Association (CREIA)
- Project Manager of Wind Power, Shenhua Guohua Energy Investment CO., Ltd
- Project Manager of Solar Power, Shenhua Guohua Energy Investment CO., Ltd

India

- Mr Gireesh Pradhan, Chairman, Central Electricity Regulatory Commission (CERC)
- Mr Srinivas Murthy, Chairman, Karnataka Electricity Regulatory Commission (KERC)
- Reji Kumar Pillai, President, India Smart Grid Forum
- Ajit Pandit, Director, Idam Infrastructure Advisory Pvt Ltd
- Mahesh Vipradas, Head, Regulatory Affairs, Suzlon
- Ravi Pandit, Co-founder, Chairman and Group CEO of KPIT Technologies Ltd
- Rahul Walawalkar, Executive Director for India Energy Storage Alliance and Vice-Chair for the Global Energy Storage Alliance; Head, Emerging Technologies & Markets, Customized Energy Solutions
- Sudhir Chella Rajan, Professor, Humanities and Social Sciences, IIT Madras
- Ashok Jhunjunwala, Professor, Department of Electrical Engineering, IIT Madras
- Bindoo Srivastava, Consultant: Leveraging Digital Infrastructure to Transform Power Utilities into Smart Entities
- Tobias Engelmeier, Director and Founder, Bridge to India

Kyrgyzstan

- Director, Ak-Trans Company (solar thermal product supplier)
- Simakov Yuriy, Professor, Kyrgyz-Russian Slavic University
- Consultants, KyrSEFF (Kyrgyz Sustainable Energy Financing Facility, EBRD-EU-funded program)
- Kazatbek Attokurov, Chief Specialist, National Electric Grid Company
- Kanat Mirshakirov, Chief Specialist, State Department for Regulation of the Fuel and Energy Complex under the Ministry of Industry and Energy

ANNEX 2.

Two workshops were held on “The Future of the Grid” in Bangalore, India. The first was on November 19, 2014 and the second on August 25, 2015. The purpose of these workshops was to discuss preliminary findings of the paper, as well as create dialogue among regulators, utilities, academia, and civil society around the challenges presented in the paper and potential solutions to those challenges.

Participants in the workshops included representatives from: Andhra Pradesh Electricity Regulatory Commission (APEREC); Auroville Consulting; Bangalore Electricity Supply Company Limited (BESCOM); Brazilian Electricity Regulatory Agency (ANEEL), Brookings India; Calcutta Electric Supply Corporation (CESC); Center for Study of Science, Technology and Policy (CSTEP); Central Electricity Regulatory Commission (CERC); Central Power Research Institute (CPRI); CLEAN Network India; Customized Energy Solutions (CES); Civic Action Group (CAG); Energy Regulatory Commission of Kenya; Development Academy of the Philippines; Energy Regulatory Commission of the Philippines; Gujarat Electricity Regulatory Commission (GERC); Gujarat (State) Load Dispatch Center (GLDC); India Energy Storage Alliance; Indian Institute of Technology (IIT) Bombay; Indonesian Institute for Energy Economics (IIEE); Institute for Essential Services Reform, Indonesia (IESR); Kerala State Electricity Board (KSEB); Kerala State Electricity Regulatory Commission (KSERC); Karnataka State Load Dispatch Center (KSLDC); Karnataka Regulatory Commission (KERC); MP Ensystems Advisory Pvt. Ltd.; National Load Dispatch Center (NLDC); Ministry of Energy and Mineral Resources, Indonesia; New Ventures, India; People’s Monitoring Group on Electricity Regulation (PMGER); Rajasthan Electricity Regulatory Commission (RERC); Regulatory Assistance Project (RAP); River Research Centre; Schneider Electric India Pvt. Ltd.; Shakti Sustainable Energy Foundation; SELCO Foundation; South Africa Faith Communities Environment Institute; State Load Dispatch Center (SLDC); University of Campinas, Brazil; UNISON Foundation, Kyrgyzstan; World Resources Institute; and WWF Kenya.

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ENDNOTES

1. Prosumers are end-use consumers of electricity who also produce their own electricity at the point of consumption, either to supply their own electricity needs or to export electricity to “the grid” (the electricity system), or some combination of the two. Simply, prosumers are electricity consumers interacting with the grid by generating some amount of electricity.
2. In 2001, severe droughts caused power shortages and energy rationing, which lasted until May 2002.
3. Wood was the primary source of energy in the world until the discovery of coal as a viable source in the middle of the 19th century. Within a relatively short period of 30–40 years, coal accounted for more than 50% of global energy use, reaching shares exceeding 80% by the early 20th century. (Channell et al. 2013). As the share of coal increased rapidly, new sources of energy—oil, natural gas, and hydro—also started to become commercially viable. By 1973, oil (~46%) had overtaken coal (25%) as the largest source of primary energy supply. As of 2012, coal provided ~29%, oil ~31%, and natural gas ~21% of global primary energy supply; together accounting for over 80% of total energy supply (IEA 2014).
4. Levelized cost analysis does not include costs such as subsidies and environmental impacts, or social effects such as employment. If these external costs were accounted for in the levelized costs of different generation options, the cost of renewable-based generation would be lower, and the cost of fossil-fuel generation would be higher. That is because, in the case of renewable-based generation, many of these external costs, such as environmental costs, would be negative (Siemens AG 2014).
5. Costs for marine energy systems were expressed in Euro at €0.32/kWh to €0.52/kWh in August 2014.
6. Note: Coal prices have fallen since 2011. The price of coal in Australia reached \$52.2/mt in October 2015, down from \$96.4/mt, the annual average for 2012 (World Bank Commodities Price Data, 2015).
7. In the U.S. State of Minnesota, the utility Xcel Energy’s Northern States Power Co signed an agreement for a 100 MW solar power project. The solar project competed successfully with three natural gas proposals after it was found that solar was a better deal for the utility (Walton 2014).
8. Stranded assets in the power sector refers to a situation in which investments in new generation squeeze out profits of existing generation plants, reducing the average expected lifetime of these plants (or assets) faster than previously anticipated.
9. For example: Citi Group’s “The Age of Renewables is Beginning—A Levelized Cost of Energy,” and HSBC’s “The Rise of Renewables.”
10. Note that, in 2013, global subsidies for fossil fuels amounted to over four times the value of subsidies for RE and more than four times the amount invested in EE improvements (IEA 2014).
11. Total number of investments leveraged was expressed as €800 million in original publication and has been converted into US\$ based on 2012 conversion rates.
12. As of 2013, China had a total installed capacity of 19.9 GW of solar PV (REN21 2014).
13. Personal communication with a Research Associate at the Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC) in discussion with Dr. Wang Tao, July 22, 2014.
14. As of 2015, FIT policies were in place in 73 countries at the national level, and in 35 states and provinces (REN21 2015).
15. Wheeling refers to the transfer of electrical power through transmission and distribution lines from one utility’s service area to another.

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Shakti Sustainable Energy Foundation works to strengthen the energy security of India by aiding the design and implementation of policies that support energy efficiency and renewable energy.

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