A CONFLUENCE OF FORCES IS placing new, complex demands on the world’s power systems. Principal among these forces is the world’s growing focus on mitigating climate change. This, in turn, has led to rising emphasis on renewable energy and distributed generation, supported by regulation that is fostering their development and deployment, and a higher premium attached to energy efficiency. In concert, technological advances are both enabling new possibilities for the way electricity is delivered and consumed and driving down the costs of many related technologies, particularly in the renewable arena. Additionally, consumers’ expectations are rising, with consumers demanding greater control over their power consumption and holding utilities to higher service standards.

Meeting these new demands will require a substantial transformation of the world’s power systems—and optimizing electrical grids will be a critical part of this. Grids must be made stronger, smarter, more flexible, and more resilient. Making this happen will be a substantial undertaking. It will require new thinking and strategies among stakeholders. It will also require significant investment and, possibly, the development of a new pricing model for the grid. (See “How to Avoid ‘Zombie’ Grids in the Age of Solar Power,” BCG article, April 2016.)

Shifting Conditions and Requirements for Power Systems

Today’s power systems face an operating environment that differs greatly from the one that has prevailed for decades. First and foremost, there is growing commitment by governments to stem global warming, evidenced by the strong consensus on the topic that emerged at the United Nations’ 21st Conference of the Parties (COP21) in Paris in December 2015. Given that power generation accounts for about 40% of the total global carbon emissions produced by the energy industry, pressure is mounting to reduce its output of these gases.
In response, power producers are turning increasingly to renewable technologies to make their generation mix cleaner.¹ In the US, for example, utility-scale solar, rooftop solar, and wind represented more than 50% of the country’s new installed capacity in 2014.² Power production in Europe is following a similar course: in 2014, the European Council set a target of having renewable generation satisfy at least 27% of Europe’s final energy consumption by 2030. Concurrently, distributed generation, such as rooftop solar panels, is becoming more prevalent as the economics of some of these technologies become more compelling. This growth in renewables and distributed generation stands to deliver material benefits over the longer term in the form of reduced carbon emissions. But it poses considerable immediate challenges to power systems that rely on centralized, fossil-fuel-based generation. These include the challenge of integrating intermittent-generation sources, namely wind and solar power, into the system.

Power systems are also being challenged by shifts in climatic conditions. In general, energy infrastructure has been built to function within the known range of historical weather conditions. Increasingly, however, power systems are being tested by the growing frequency of extreme conditions and events, such as hurricanes, severe storms, and drought, which can cause considerable physical damage to power generation and grid infrastructures. They can also sharply limit the effectiveness of specific types of generation. Thermoelectric power generation, for example, can be compromised by rising air temperatures and reduced water availability—conditions that are becoming increasingly prevalent in the Midwest, Great Plains, and southern regions of the US. Hydropower generation can be challenged by reduced snowpack, premature melting, and changes in precipitation patterns.³

Compounding matters, power systems are struggling to meet consumers’ rising expectations. Today’s consumers are increasingly connected to the grid and expect a high degree of reliability. They also expect the provision of sophisticated services and features, such as energy efficiency services and demand management guidance. Furthermore, “prosumers,” or consumers who both consume and produce power through distributed-energy resource systems, also expect the ability to sell back to the system any surplus power that they generate.

Optimized, or smart, power grids are vital for ensuring that power systems can meet these and future challenges. But what will such grids look like?

**Characteristics and Key Benefits of Smart Grids**

Smart grids will possess a number of critical characteristics. They will be fully automated and leverage or enable the deployment of smart technologies, such as smart metering. They will be seamless, enabling multidirectional power flows and transactions among utility distribution companies, power producers, and the wholesale market. They will be open, possessing transparent processes for planning and operations, low barriers for access to physical connections, and more opportunities for value monetization. Their physical and operational qualities will yield improved safety and reliability.

These characteristics will translate into many tangible benefits for both grid operators and consumers. Operators will be better able to do the following:

- Effectively dispatch power as well as balance supply and demand in the system
- Identify outages more quickly and accurately as well as make repairs remotely more readily
- Diagnose potential problems and optimize their preventive-maintenance practices, resulting in a reduced need for remedial action, improved overall maintenance efficiency, extended life cycles for equipment, and, ultimately, greater profitability for the system
- Identify opportunities for improvements to the system
Consumers will experience greater reliability, and the quality of the power supply will improve; they will see fewer, less lengthy blackouts. They will also be able to use smart technologies to gain a greater understanding of their personal patterns of power consumption and usage, and then compare those patterns with hourly power rates. This will allow consumers to potentially reduce their usage or lower their monthly bills by shifting some of their usage to less-expensive times of the day. Indeed, the European Commission estimates that aggressive deployment of smart meters (the European Union aims to replace at least 80% of Europe’s electricity meters with smart meters by 2020), coupled with smart grids, could reduce annual household energy consumption in the EU by roughly 9%, resulting in a reduction of more than 100 megatons of carbon dioxide emissions.  

Smart grids will also help bring about three events that are critical to the establishment of sustainable power systems.

The Integration of Renewable Energy Sources and Distributed Generation. The introduction of renewables—especially intermittent ones, such as wind and solar photovoltaic power—and distributed generation into established power systems brings a host of challenges to those systems. These challenges include unpredictable peaks and valleys in power production and power demand that must be compensated for; two-way flows of electricity (that is, from the grid to consumers and from consumers back to the grid); and the need to maintain and seamlessly deploy reliable sources of backup power. Smart grids should be sufficiently flexible to be able to respond to some of these challenges.

The Enablement of New, Sustainability-Related Business Models. Changes in the energy landscape—including the growing prevalence of distributed generation and the increasing reach of digital technologies, which allow for better monitoring, management, and customization of power generation and consumption—are fostering the development of new business models and applications across the value chain. These include user-friendly applications and services that encourage energy efficiency among consumers, programs that flatten demand during peak hours, and services that optimize the deployment of distributed-energy resources from a cost perspective. Many of these models and applications stand to yield significant green benefits; virtually all will demand smart, flexible, resilient grids.

Industry participants and players along the grid’s value chain will need to tackle the technical challenges associated with enabling these new business models. Working with regulators, they will also need to sort out questions that are likely to arise regarding regulations and the economic framework that will be necessary to support the grid’s optimization. Such questions will include the following:

- **Market Structure.** How can the development of renewable energy sources and distributed generation be encouraged while maintaining the reliability and financial stability of the network? What are the best ways to manage fluctuations in production and demand?

- **Integration Costs.** How are grid companies being paid for investments necessary to enhance the grid? How should the involved costs and incremental benefits be calculated? Who should pay for the additional costs to the system?

- **The Fairness of the Regulatory Framework.** How can the best solution be identified and developed? From a system perspective, would it make more sense to foster utility-scale renewables than distributed generation? Would large-scale batteries managed by the grid be a more economical and sustainable solution than small-scale distributed batteries?

An Increase in the Number of People in Developing Countries Who Have Access to Electricity. Approximately 1.2 billion people worldwide (17% of the global
population), most of whom live in developing countries, are believed to lack access to electricity. Access is particularly limited in many developing countries. (See Exhibit 1.) About 3 billion people rely on highly polluting fuels, such as diesel, for cooking and heating, and on kerosene lamps and car batteries for lighting. Securing grid access for these populations, which would include ensuring the availability of green distributed-energy resources and the ability to cook and generate heat via electricity, could substantially reduce these countries’ emissions—and thus total global emissions. It could also provide these populations significant economic benefits. The International Energy Agency estimates that, for every additional dollar of power sector investment in sub-Saharan Africa, the region’s incremental GDP could be boosted by around $15.

Smart Grids: Progress and Investment Requirements

A number of countries and regions have already made considerable progress toward grid optimization. And much additional investment is planned: agencies and analysts estimate that around $5 trillion will be spent on distribution grids, and $1.8 trillion on transmission grids, around the world from 2014 to 2035. Progress in the US has been particularly noteworthy. (See Exhibit 2.) This has been aided significantly by the $4.5 billion in funding awarded by the government, through the American Recovery and Reinvestment Act (ARRA), to the US Department of Energy (DOE) in 2009 to modernize the country’s power grids. Under ARRA’s largest program, the Smart Grid Investment Grant, the DOE and the electricity industry have jointly invested $8 billion in roughly 100 projects with the goals of modernizing grids and improving their security and interoperability, as well as collecting and studying data on smart grids’ operation and benefits.

Europe’s ambitious “20-20-20” targets for its energy sector will require sizable improvements to, and investments in, the region’s grids. Since 2002, European countries have invested more than $3.5 billion in more than 450 smart-grid projects. This rate of investment will not be sufficient to meet the Continent’s green agenda, however, including the goal of having renewables satisfy 27% of Europe’s energy consumption by 2030. Indeed, the European Commission estimated in 2015 that the EU will need to invest around €400 billion by 2020 in the modernization of its transmission and distribution grids to reach its goals. So far, France, the UK, Germany, Italy, and

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**EXHIBIT 1 | Access to Electricity in Many Developing Nations Is Limited**

SHARE OF POPULATION WITHOUT GRID ACCESS

Note: 2012 data.
Spain are leading the way, with strong pushes on smart-meter deployment, grid automation, or both. In Spain, for example, the vast majority of the country’s high-voltage substations are already automated, and a number of grid operators are exploring pilots to increase the level of automation. In the UK, incentives introduced by Ofgem, the government regulator of electricity and downstream natural gas markets, are fostering the launch of pilots utilizing new technologies that will help further automate and modernize the country’s grids.

Elsewhere, China is making an aggressive push to modernize its electricity infrastructure and develop a reliable smart grid. In 2014, the country became the world’s largest market for smart-grid spending, surpassing the US. India is also expected to make massive investments in grid updates in the coming years: the country’s Ministry of Power estimates that India will need to invest about $50 billion on that front.

It will also require setting policies that push development in the right direction and demand cooperation, collaboration, and new ways of thinking among industry players, regulators, and other stakeholders. But the rewards of optimization, including vastly enhanced chances of achieving the environmental targets established at COP21, will more than compensate for the effort.

This article is the third in a series on the effects of COP21 on the energy sector. The first article, published in May 2016, was “Will Natural Gas Demand Soar as Emissions Reduction Intensifies?” The second article, published in August 2016, was “Is COP21 a Win for Europe’s Power Producers?”

Notes
1. The International Energy Agency calculates that realization of the Paris agreement’s targets will require investment of more than $13 trillion in clean-energy and energy efficiency technologies during the next 15 years.
2. According to the US Department of Energy and the US Energy Information Administration, coal’s share of US electricity generation has fallen from roughly half in 2005 to approximately one-third
today. Total emissions from the country’s power sector are now about the same as those from its transportation sector.


4. The International Energy Agency estimates that total carbon dioxide emissions in 2013 for the EU were 1,215 megatons, with an average emission factor of 0.38 megatons of carbon dioxide per terawatt hour.

5. For more examples, see Smart Energy: New Applications and Business Models, a report by The Boston Consulting Group in collaboration with the Energy Chair of Orkestra, April 2015.

6. The Boston Consulting Group is a supporter of the Oil and Gas Industry Energy Access Platform, an effort launched by the OPEC Fund for International Development, the World Petroleum Council, Total, and Shell International in support of the Sustainable Energy for All (SE4ALL) initiative led by the United Nations. The platform was developed to help foster universal access to sustainable energy.

7. Many of these people live in rural areas. For them, microgrid solutions that utilize distributed-energy sources are often the best solution, both environmentally and economically. Such solutions could include solar photovoltaic cells with battery storage that are connected through a local grid that optimizes generation and consumption at the local level.


9. Policymakers aim, by 2020, to have reduced Europe’s carbon dioxide emissions versus 1990 levels by 20% or more, to be meeting 20% of Europe’s energy consumption with renewable generation, and to have achieved a 20% increase in energy efficiency.

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