Toward a New Balance of Power

Is Germany Pioneering a Global Transformation of the Energy Sector?

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TOWARD A NEW BALANCE OF POWER

IS GERMANY PIONEERING A GLOBAL TRANSFORMATION OF THE ENERGY SECTOR?

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EXECUTIVE SUMMARY

Global electricity markets are in the early stages of a transformation. Conventional centralized, dispatchable, fossil-fuel-based generation is gradually ceding ground to renewable (including intermittent) energy sources and distributed generation. This shift will ultimately have a profound impact on how electricity is produced and consumed. Indeed, its effects are already being felt.

Germany, whose ambitious plan to reshape its energy sector places heavy emphasis on renewable-energy sources, distributed generation, and energy efficiency, is at the vanguard of this transformation. As such, its efforts bear scrutiny.

Germany's move toward renewable-energy sources, distributed generation, and increased energy efficiency will lead to paradigm shifts within the country's power system.

- Growth in power demand will likely cease: most projections call for stagnant demand for the foreseeable future, with rising energy efficiency mitigating the effects of economic growth.
- Simultaneously, Germany's total power-generation capacity will need to increase substantially; capacity could reach more than 250 gigawatts in 2030, compared with 158 gigawatts in 2010, driven primarily by increases in wind and solar photovoltaic (PV) energy.
- Renewables' total share of Germany's power generation will exceed 50 percent in 2030, up from 20 percent in 2011.
- The role of conventional generation will increasingly shift from providing baseload power to serving as backup capacity during periods of limited wind or sunshine.
- As Germany's capacity from renewables and distributed generation increases, its power-supply system will become more diverse,

more modular, more fragmented, more fluctuating, and more flexible.

Distributed generation will become increasingly prevalent in Germany. At the same time, energy self-sufficiency may well become viable for growing numbers of German consumers and communities.

- Current planning scenarios imply that by 2030, approximately 50 percent of Germany's power will come from distributed sources, such as rooftop solar PV installations and wind farms, compared with approximately 15 percent in 2011.
- In 2011, power from rooftop solar PV installations became cheaper for many German consumers than power from the grid.
- The model of Feldheim, a small, rural village 80 kilometers southwest of Berlin that has built its own independent power and heat supply system from local, renewable-energy sources, may prove attractive in other rural areas of the country.

The economic argument for distributed renewable-energy sources in Germany will become increasingly compelling.

- Driven by rising fossil-fuel and carbon-emissions costs, the levelized cost of energy (LCOE)—the price at which a technology breaks even—for power generated by conventional power plants will rise; we expect an LCOE of 7–8 eurocents per kilowatt hour (ct/kWh) for lignite, 7–9 ct/kWh for hard coal, and 7–10 ct/kWh for combined-cycle gas turbine generation by 2020.
- Simultaneously, innovation and declining equipment costs will make the generation costs of numerous renewable-energy sources competitive with those of conventional sources in Germany—the LCOE for onshore wind and solar PV, for example, will drop to 5–6 ct/kWh and 10–11 ct/kWh, respectively, by 2020.

System costs and retail power prices in Germany will climb significantly to 2030; in the very long term, however, the move to a renewables-based system may also have cost benefits.

- In 2030, unit power-supply costs in a renewables-based system will likely be approximately 15 to 35 percent higher than the costs of a conventional, fossil-fuel-based system would be, depending on fossil fuel prices and the costs of carbon emissions.
- Assuming today's pricing mechanisms, retail power prices for residential customers in 2020 in a renewables-based system will be 35 percent higher than in 2010—a significant increase but less than the recent 42 percent increase experienced by residential customers between 2000 and 2010.
- Germany's push toward renewables will ease the country's reliance on imported fuel and may deliver cost advantages to

consumers over the long term, depending on the evolution of fossil fuel and carbon emissions costs.

Germany will need to redesign its power market to support the transition to a power system that places a significant emphasis on renewables.

- The new design will need to ensure the economic viability of backup power plants, offer sufficient investment incentives for climate protection and carbon abatement, improve the cost efficiency of renewable-energy policies, and support the market integration of power demand. It will also need to ensure provision of an upgraded network.

- In the short term, the imperative for policymakers is to improve the cost efficiency of renewable subsidies and institute a strategic reserve to ensure sufficient backup-power-plant capacity; these measures will buy the time required to develop a sustainable, holistic market design compatible with other European power markets.

The ownership of Germany's generation assets will continue to shift away from utilities as more and more new companies enter the power industry.

- Private individuals, cooperatives, industry players, and others are capturing growing shares of power generation assets; in 2010, private individuals owned 47 percent of Germany's wind and solar PV capacity, compared with about 1 percent ownership by Germany's Big Four utilities.

- Infrastructure funds, independent system operators, and other businesses will continue to take growing ownership of electricity transport grids.

The threat to incumbents posed by the paradigm shifts within the power industry is severe and will force them to make hard strategic choices.

- Germany's Big Four utilities will see their business model challenged by a confluence of factors, including the government's mandated phaseout of nuclear energy; the priority given to renewable-energy sources with zero marginal costs and the related decline in wholesale power prices; the falling number of full-load hours of operation for conventional power plants; and the emergence of new competitors that have lower expectations for returns on capital.

- As a result, incumbents' revenues and returns will decline; the return on capital employed in centralized generation, for example, will likely sink from more than 15 percent before 2011 to 8 to 10 percent by 2030 (assuming a yet to be established mechanism that adequately remunerates power plant operators for providing capacity and ensuring security of supply).

- The Big Four, facing business model disruption in their home market, have two viable options: attempt to diversify and become competitive in specific market segments within Germany or focus their efforts outside the country.

Germany's power industry will deconstruct and new business models will emerge.

- The industry's existing one-way value chain (comprising generation, trading, transport, distribution, and retail) will deconstruct, as distributed generation becomes increasingly prevalent and consumers become "pro-sumers," who both consume and produce energy.

- Regulatory pressure, increasing competition, decreasing margins, and new business models will accelerate the transformation of the industry's traditional, vertically integrated value chain into a horizontal, layered architecture with a multidirectional flow of power.

- New business models based on distributed generation and more-flexible power demand will increasingly take center stage.

- The medium- and long-term outlook for Germany's power industry is highly uncertain and will hinge to a large degree on government policy and regulation.

To date, few countries have indicated an intention to closely follow Germany's path.

- Among large economies with traditional power systems, Germany seems to have the most ambitious and far-reaching targets for the adoption of renewable-energy sources.

- Japan seems to be the only country whose emerging energy policy parallels that of Germany—though its choice is largely driven by necessity; the policies of Switzerland and Italy are roughly comparable to Germany's in terms of their stance on nuclear and renewable generation.

A POWER REVOLUTION—LED BY GERMANY?

THE GLOBAL POWER LANDSCAPE is undergoing a profound change. Driven by a confluence of forces—chief among them being environmental concerns, worries over energy security, and advances in technology—countries are beginning to move away from conventional, fossil-fuel-based power generation in favor of renewable-energy sources, distributed generation, and managed demand. Increasingly, they are even rethinking their use of nuclear power—for safety reasons in some countries, for economic reasons in many others. As this trend, which is still in its early stages, broadens and gathers pace, it will transform virtually every aspect of how electricity is generated and consumed, with the long-term potential for a cleaner environment, greater energy security, and increasingly competitive electricity prices.

But the transition away from conventional power generation promises to be rocky for all parties. Grids and system stability will be severely strained as the share of intermittent renewable-energy sources in the energy mix increases. Governments may struggle to ensure that there is sufficient investment to fund the huge necessary expenditures. Retail electricity prices will rise for a decade or two. Conventional utilities, which have long presided over the industry's hierarchy and ensured system stability, will find their revenues and profits under intensifying pressure as their traditional business model becomes less relevant. Indeed, some utilities may be driven to extinction.

Germany, whose government has defined a vision for the country's energy future that strongly emphasizes renewable sources and energy efficiency (see the Federal Ministry of Economics and Technology's *Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply,* issued in September 2010), is at the forefront of this move away from conventional generation. Although Germany's circumstances are unique in key respects—notably the strong stance against nuclear energy and aggressive targets for the adoption of renewable-energy sources—the country's efforts are being closely watched by the rest of the world. If successful, Germany could serve as a model for countries with similar aspirations. For these reasons, it is worthwhile to examine Germany's efforts in some detail.

MASSIVE DRIVERS OF CHANGE IN GERMANY

GERMANY'S ENERGY MODEL IS being fundamentally reshaped. According to the government's mandate, renewable sources and distributed generation, once marginal players in the country's energy scheme, are to meet a substantial and rising share of Germany's energy needs. Conventional generation, in turn, will gradually see its role shift from providing the bulk of generation to offering backup generation for solar and wind during cloudy and windless periods. The end result could be an industry barely recognizable from the vantage point of today.

The development of the German energy landscape is being driven primarily by two powerful forces. The dominant one is government intervention; the other is technological innovation and its attendant cost reductions.

Powerful Government Intervention

As in many countries, the government of Germany considers the energy sector to be a strategic one, and hence it is subject to extensive policymaking. Germany's energy policy is shaped largely by three aspirations: security of supply, cost effectiveness, and, more recently, sustainability. For example, policymakers have done the following: mandated the legal separation of the generation, grid, and retail businesses; established wholesale trading markets for electricity; applied controls on grid owners' returns on capital; given priority to renewable generation and instituted subsidized feed-in tariffs for renewables; and considerably raised taxes and fees on power.

As a result of this legislation, as well as "liberalized" market forces and growing costs for primary energy, power prices in Germany have soared in recent years—by 42 percent for residential customers from 2000 to 2010 on an inflation-adjusted basis. Interestingly, however, higher prices have not caused the public to question policymaking but rather to increasingly lose trust in utilities. Indeed, large utilities, amid record earnings, have been pilloried since 2008.

In this environment, policymakers have continued to think in bold strokes. Take Germany's policy on nuclear energy, which has seen three fundamental shifts over the past ten years. In 2001, the Red–Green coalition government voted to phase out most nuclear generation by 2021; in 2010, the ruling conservative–liberal coalition granted nuclear generation an extension until approximately 2033. Then, following the tsunami-triggered accident at Japan's Fukushima Daiichi nuclear plant in March 2011, the same coalition imposed an immediate shutdown of eight nuclear-power plants and directed the energy industry to fully exit nuclear generation by 2022.

The move away from nuclear energy, which supplied approximately 25 percent of Germany's electricity in March 2011, has not deterred policymakers from pursuing the transformation of the German energy system defined in *Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply.* Policymakers remain committed to the broad vision and its stated goals, in particular that 50 percent of Germany's electricity be provided by renewable sources by 2030 and 80 percent by 2050.

German policymakers will have to remain active to make their vision a reality, since massive challenges remain. These include grid extension and stabilization (which are vital if the electricity supply system is to cope with distributed and renewable generation); defining a market design that ensures sufficient dispatchable capacity to compensate for the intermittent nature of wind and solar photovoltaic (PV) generation; and establishing market-driven investment incentives to encourage climate protection measures and cost-efficient deployment of renewable generation. And the government will have to address these challenges while keeping power price increases manageable for consumers, businesses, and industry alike. An enormously complex task lies ahead for Germany, with little to learn from other countries.

Cost Reduction and Technological Innovation

With its topography ruling out the potential for large-scale use of hydroelectric power, Germany historically has generated a small share of its power supply from renewable-energy sources. By 1990, only 3 percent of its electricity came from renewables. Germany's gradual shift to renewable generation began in the early 1990s with the adoption of wind energy. Since then, the country has continued to actively shift its energy mix away from coal-fired and nuclear generation toward renewables. (See the sidebar, "Germany's Energy Landscape Today.") By 2011, it had installed 65 gigawatts (GW) of renewable-

GERMANY'S ENERGY LANDSCAPE TODAY

To fully appreciate the significance of the transformation taking place in Germany, it is helpful to understand the country's energy landscape as it stands today and its recent evolution.

Energy Mix. In recent decades, Germany's energy mix has relied on a conventional, centralized mix of power sources. In 2010, lignite- and hard-coal-fired generation accounted for 44 percent of overall generation; gas-fired generation accounted for 16 percent, nuclear generation for 23 percent, and renewable generation (from such sources as biomass, wind, solar, and hydroelectric) for 18 percent.

Value Chain. Today's value chain largely follows a traditional one-way model of generation, trading, grid operation at the transport and distribution levels, and sales. Except for the phaseout of nuclear plants, conventional power generation in Germany is unregulated, as are electricity trading and sales. Grid ownership and system operation are controlled by return-regulated geographic monopolies.

Key Players. These include the Big Four incumbents, municipalities, and sales businesses.

- The Big Four—E.ON, RWE, EnBW, and Vattenfall—own a major share of each segment along the entire value chain, excluding transport grids. To date, their generation mix has been dominated by fossil-fuel-fired and nuclear plants. Their returns on capital employed regularly exceeded 10 percent before 2010 but fell in 2011, weighed down by effects from the first phaseouts of nuclear plants, the priority assigned to renewable feed-in, and other factors.
- A few of Germany's approximately 1,000 municipalities own generation assets; more commonly, they dominate

GERMANY'S ENERGY LANDSCAPE TODAY
(continued)

distribution and sales in their local markets. Their returns on capital employed have historically been below those of the Big Four. Given their relatively modest expectations for returns and their local profiles, municipalities see themselves as being advantageously positioned for Germany's transition toward distributed generation.

- Numerous nationwide "energy-asset lite" businesses have entered the market in recent years, as policymakers have sought to liberalize sales and introduce competition. These businesses source power and gas at wholesale markets and supply them to retail customers. They have struggled to achieve profitability, however.

National Policymaking and Regulation. The industry has been subject to massive policymaking, largely through national legislation. Legislation has targeted a range of issues, including the following:

- *Unbundling.* To foster competition and provide fairer access to grids, the power generation, grid operation, and retail power businesses were required to split into separate legal units, each with independent management, in the first decade of this century.

- *Subsidies for Renewables.* Power generated by renewable-energy sources enjoys priority feed-in to the grid as well as feed-in tariffs that are fixed for the first 20 years of the asset's operation. Costs for subsidies are covered by an apportionment scheme that requires all power consumers connected to distribution grids to pay a certain contribution per kilowatt hour consumed (3.59 ct/kWh in 2012), regardless of whether the power is generated by renewable or conventional sources. The predecessors to today's scheme have been in place since 1991.

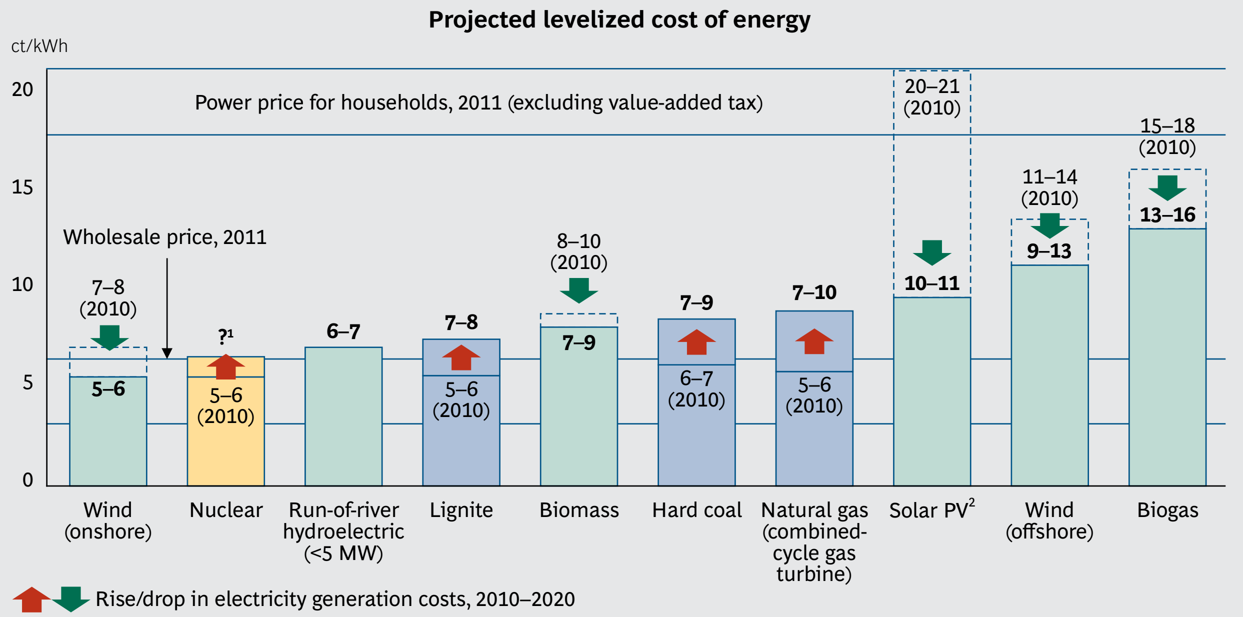
- *Regulation on Returns for Grid Operators.* Both transportation and distribution grids are considered geographic monopolies that fall under so-called incentive regulation. This regulation caps the revenues of grid operators based on the size of the asset base, its efficiency, and the required investment. Essentially, regulators are granting these companies an 8 percent return on capital employed.

European Policymaking and Regulation. European regulation has already resulted in a Europewide carbon-emissions pricing scheme. To date, the European Commission has contemplated a European "supergrid" and power-market integration, although it is too early to predict whether these will come to fruition or what the impact on the German market will be. For the foreseeable future, we expect that European energy policy will continue to be defined primarily at the national level.

generation capacity, which produced about 20 percent of Germany's electricity.

This growth in capacity has been driven largely by an apportionment-based subsidy scheme that makes all power consumers cover today's relatively high costs of renewable generation. But the scale and experience curve effects financed by this subsidy scheme have made some renewables gradually approach the point where their growth will be fueled by their underlying economics rather than by subsidies. Indeed, we expect a number of renewable-energy sources to become cost competitive, without subsidies, with conventional generation by 2020. (See Exhibit 1.) Onshore wind, for example, will likely have a levelized cost of energy (LCOE) of 5–6 eurocents per kilowatt hour (ct/kWh) by 2020, while solar PV will have an LCOE of 10–11 ct/

EXHIBIT 1 | A Number of Renewable-Energy Sources Will Be Cost Competitive with Conventional Generation in Germany by 2020



Sources: German Renewable Energy Act; European Photovoltaic Industry Association; Fraunhofer ISE; International Energy Agency; IRE Universität Stuttgart; BCG analysis.
Note: Estimates include the weighted-average cost of capital, capital expenditures, operations and maintenance costs, and carbon emissions costs. Prices exclude system integration costs (such as the costs of grid expansion and storage capacity). Load hours assume "full capacity": onshore wind, ~2,100 hours per annum (h/a); offshore wind, ~4,200 h/a; solar PV, ~900 h/a; biomass/biogas, ~6,000 h/a; hydroelectric, ~4,800 h/a; all fossil technologies, ~7,000 h/a. LCOE for 2020 calculated for roughly stable and moderately increasing prices for fossil fuels. Carbon costs assumed to increase from €13/ton today to €24.5/ton in 2020.
[1]The effects on prices from increasing safety requirements cannot be reliably estimated.
[2]The economics of solar PV are much better in countries with frequent sunshine.

kWh.[1] These costs compare with projected costs of 7–8 ct/kWh for lignite, 7–9 ct/kWh for hard coal, and 7–10 ct/kWh for natural gas used in combined-cycle gas turbine plants.

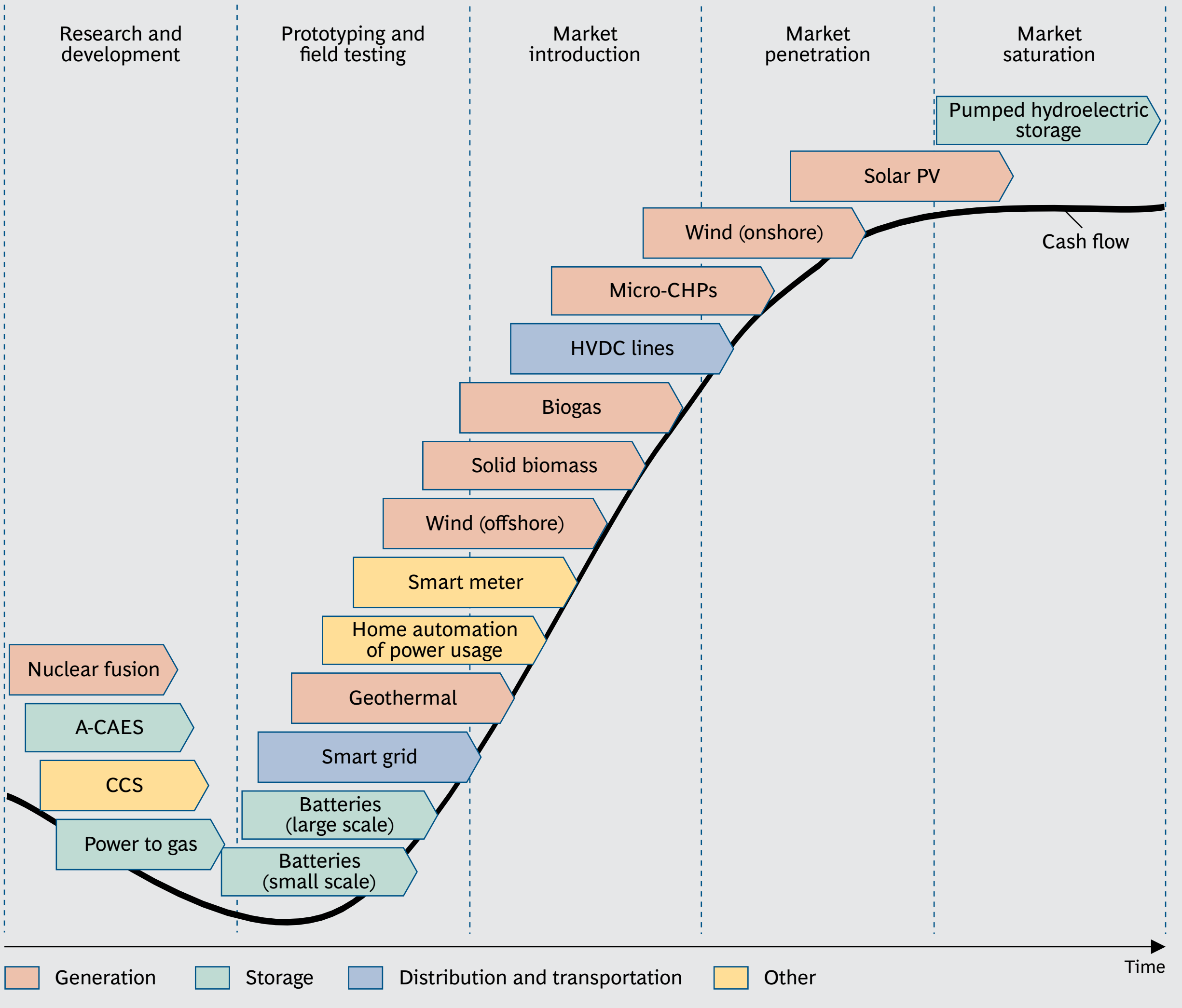
To be sure, the integration of renewables into the power generation system will incur additional costs, such as grid extension and the need for backup capacity. But the trend is clear: most renewable technologies will see their costs continue to fall, with some ultimately expected to reach competitive levels. In contrast, the costs of most forms of conventional generation will likely remain stable or rise, depending on prices for fossil fuels.

Innovation is taking place not just in renewable-generation technologies themselves but also in such related areas as transmission, distribution, and storage. (See Exhibit 2.) Power-to-gas storage technology, for example, which is at a nascent stage of development, allows excess electricity generated from solar PV and wind sources to be used to generate hydrogen or methane, which can be stored in existing gas-storage facilities and transmitted over existing gas pipelines. This gas can subsequently be used as a vehicle fuel or to generate electricity for heating. Power-to-gas storage technology may thus offer a scalable option (albeit one with an efficiency level of only around 40 percent) for overcoming the drawbacks of intermittent renewable-energy sources.

Developing technologies that could preserve or prolong today's centralized business models, in contrast, are problematic. Carbon capture and storage, for example, is unpopular, nuclear fusion is in its infancy, and large hydroelectric plants face site limitations that limit their growth prospects. In fact, the only centralized-generation technologies that may see growth over the next decades are offshore wind and selected conventional (for example, gas-fired) plants that are needed to provide backup capacity.

Exhibit 2 | Widespread Innovation Is a Key Factor Driving the Transformation of Germany's Power Sector

Technologies and their positions in the product life cycle



Source: BCG analysis.
Note: A-CAES = adiabatic compressed-air energy storage; CCS = carbon capture and storage; HVDC = high-voltage direct current; CHP = combined heat and power systems. In Germany, advancement of selected technologies in the product life cycle has been driven by subsidies.

The upshot: most of the innovation taking place in the industry seems to support the growth and integration of distributed renewable generation. This will transform Germany's electricity sector and its prevailing business models. But what will the reshaped industry look like?

NOTE
1. The LCOE is the constant price per unit of electricity that allows a given technology to break even.

NEW PARADIGMS FOR GERMANY'S POWER INDUSTRY

THE TRANSITION FROM CENTRALIZED, fossil-fuel-based generation to a world centered on renewable and distributed renewable generation can deliver a host of benefits to German society. But these benefits may come at the expense of Germany's established energy industry, which will be hit hard by the resulting deconstruction of the industry and declining returns. The transition will also present a cost challenge for residential and industrial power consumers for at least two decades.

Changing Energy Economics

The energy industry's underlying economics will change significantly as Germany moves ahead with its vision. These changes will have a great impact on the industry's investment mix, the design and function of power markets, and power prices for consumers.

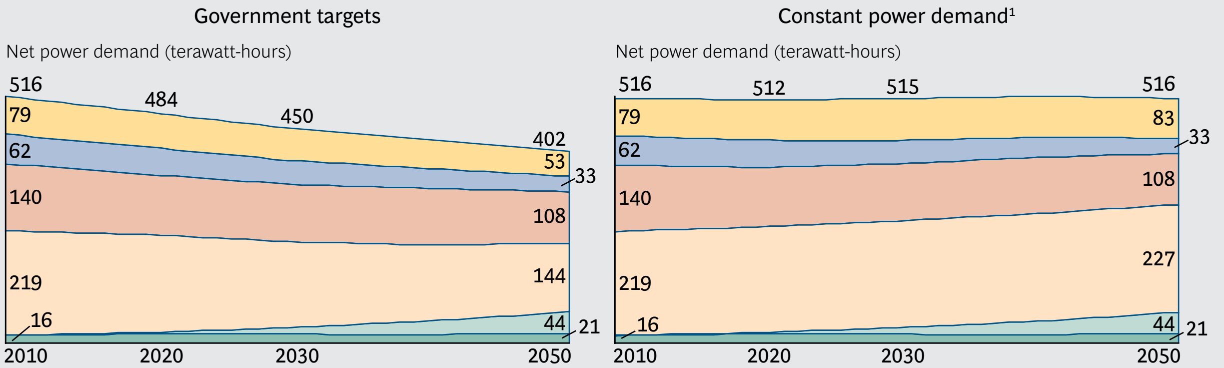
Downward Pressure on Power Demand Resulting from Rising Energy Efficiency. Since 2008, Germany's gross end-user demand for electricity has been essentially stagnant. Going forward, the government's ambition is to actually reduce demand—by 10 percent by 2020 and by 25 percent by 2050 compared with 2008 levels. This goal is based on aggressive assumptions regarding potential annual efficiency improvements in a number of economic segments. It is also based on the expectation of a structural change in the German economy: industrial production will represent a much smaller share of total economic growth in the future. The government assumes that industrial production will grow at a rate of 0.5 percent per year, while German GDP will grow at a rate of 0.8 percent. (See Exhibit 3.)

These assumptions deserve to be challenged. If we assume a constant share of industrial value added and the efficiency improvements indicated on the right side of Exhibit 3, Germany's power demand is much more likely to be stagnant than to decline. Moreover, we believe that Germany can realize its broader ambitions with even a constant demand for power. Assuming that renewables do indeed account for 80 percent or more of generation capacity by 2050, the majority of Germany's power will be "clean," domestically generated (that is, not reliant on imports), and independent of any potentially limited fuels. There is thus no pressing need to limit power consumption by households or industry.

In subsequent sections, we will refer to the two courses depicted in the left and right graphs in Exhibit 3 as the declining power-demand scenario and the constant power-demand scenario, respectively. Though the scenarios differ materially in some of their assumptions, there is one common thread: growth in power demand is expected to end.

EXHIBIT 3 | Constant Long-Term Demand for Power in Germany Is a Reasonable Assumption

Two scenarios for the development of net power demand, 2010–2050



	Government targets	Constant power demand[1]
Annual efficiency gains (electric appliances)	2.4%	1.3% (projected from reference scenario[2])
Annual growth in gross domestic product (real)	0.8%	0.8% (1.4%,1991–2011)
Annual growth in industrial production (real)[3]	0.5%	0.8% (1.4%,1991–2010)
Annual efficiency gains (electricity usage, industry)	1.5%	0.7% (0.4%, 2000–2010)[4]

Households, electric appliances
Households, other
Business
Industry
Mobility, electric cars
Mobility, railway

Sources: Energy Environment Forecast and Analysis; Federal Statistical Office of Germany (Destatis); University of Cologne Institute of Energy Economics, Prognos, and Gesellschaft für Wirtschaftliche Strukturforschung, *Energy Scenarios*, August 2010; BCG analysis.
Note: Apparent discrepancies in totals are due to rounding.
[1]Based on endogenous-demand modeling.
[2]Reference scenario from Federal Ministry of Economics and Technology, *Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply,* September 2010.
[3]Industrial production is defined as gross value added at factor prices (base year, 2000).
[4]Efficiency gains are computed based on gross value added at factor prices (base year, 2005).

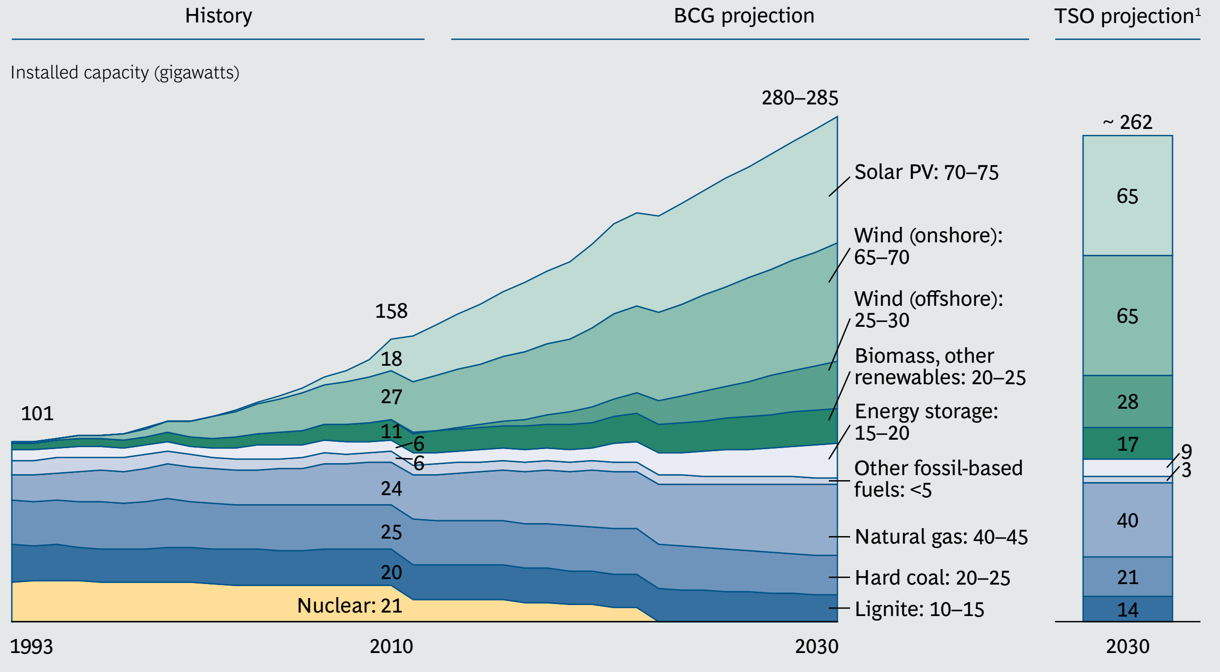
A Diversified, Distributed, Volatile Energy Mix. If Germany is to realize its ambitions, the country's total power-generation capacity will have to increase significantly, from 158 GW in 2010 to more than 250 GW by 2030. Exhibit 4 shows two scenarios—one from BCG and one from Germany's Transmission System Operators—of the potential composition of that capacity. Excluding the target for net power demand, the BCG scenario meets all of the government's objectives, including an 80 percent carbon-emissions reduction (across all sectors) and an 80 percent share of power generation by renewables by 2050.

By generation source, the biggest capacity increases will be in wind and solar PV, making them the technologies with the largest shares of total generation capacity in 2030. Wind and solar PV are intermittent energy sources, so their sizable role in Germany's energy mix will pose challenges to the system as a whole. To ensure an adequate supply of electricity and avoid blackouts when the sun is not shining or the wind is not blowing, Germany will need roughly 80 to 90 GW of dispatchable capacity by 2030 as backup—nearly as much as the total conventional capacity available today. In the short term, lifetime extension of Germany's existing fossil-fuel-fired plants seems an attractive option for ensuring this capacity. In fact, by keeping all of the country's currently installed power plants online until 2022, Germany could close the gap in generation capacity caused by the phaseout of nuclear energy—provided networks are strengthened to cover geographic imbalances. In order to reach the BCG scenario depicted in Exhibit 4, Germany will need to largely maintain its existing conventional capacity while building a renewable-generation-based system "on top."

With this capacity mix, renewable energy will meet approximately 70 percent of Germany's gross electricity demand in 2030—well exceeding the government's 50 percent target. (See BCG's projection in Exhibit 5.) Correspondingly, conventional generation will gradually be crowded out of the energy mix,

EXHIBIT 4 | Germany's Power-Generation System Will Develop and Diversify Substantially

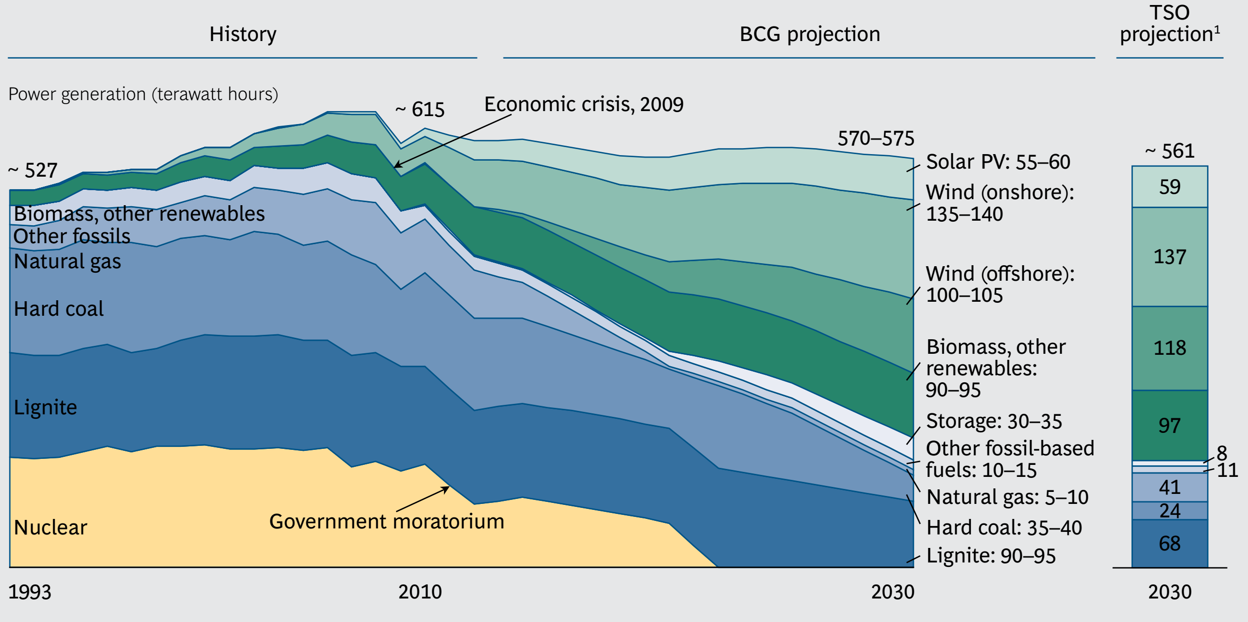
Projected development of installed generation capacity, 2010–2030



Sources: Arbeitsgemeinschaft Energiebilanzen; Federal Network Agency (Bundesnetzagentur); Federal Association of the Energy and Water Industries (Bundesverband der Energie und Wasserwirtschaft); Federal Environment Ministry's Working Group on Renewable Energy Statistics (AGEE-Stat); BCG analysis.
Note: Deviations between total capacities and their components are due to rounding.
[1]German Transmission System Operators, *Netzentwicklungsplan*, 2012.

EXHIBIT 5 | Renewables Will Account for More Than 50 Percent of Germany's Power Generation by 2030

Development of the power generation mix, 1993–2030



Sources: Arbeitsgemeinschaft Energiebilanzen; Federal Network Agency (Bundesnetzagentur); BCG analysis.
Note: Deviations between total capacities and their components are due to rounding.
[1]German Transmission System Operators, *Netzentwicklungsplan,* 2012.

with the total share of generation represented by nuclear and fossil-fuel-based sources falling to 30 percent by 2030 versus 83 percent in 2010. Conventional generation's role will shift from providing baseload power to providing backup capacity.

Exhibits 4 and 5 imply some additional paradigm shifts for Germany's power-supply system:

- *The system will become more modular.* Utility-scale power plants, with several hundred megawatts of capacity, will be complemented by smaller, consumer-scale assets with kilowatts of capacity. The number and types of players in the industry will increase correspondingly.
- *The system will become more distributed—in several ways.* While feed-in has primarily occurred at the transport level of power grids to date, a significant share of electricity in the future will be fed in at the distribution level. The percentage of distributed generation will rise from approximately 15 percent in 2011 to approximately 50 percent in 2030. Furthermore, we will witness the advent of "pro-sumers," who both consume and produce energy, as partial self-supply of energy becomes increasingly viable.
- *The system will become multidirectional.* In the past, power supply followed a one-way paradigm, from power plants to consumers via transport and distribution grids. In the future, the flow of power, and hence value, will be multidirectional.
- *The system will become more fluctuating—and thus need to become more intelligent.* Successful integration of intermittent renewable generation requires an intelligent system control, in particular at the distribution grid level.
- *The system will become more flexible.* "Supply follows demand" has been the ruling paradigm; in light of fluctuating supply, the challenge will be to make demand more flexible.

The Need for Grid Extension. Rebuilding Germany's power-generation system is only viable if the grid is strengthened simultaneously. The growth of distributed generation demands greater capacity and flexibility of distribution grids; transport grids, for their part, require capacity expansion, as a significant percentage of new generation capacity will be built far from the sources of demand. (Onshore and offshore wind capacity will be built predominantly in the northern parts of the country, while heavy industrial consumers are concentrated in the south.) As of late 2012, Germany's Federal Grid Agency was calling for the construction of 2,800 kilometers of new transport lines and the strengthening of an additional 2,900 kilometers.

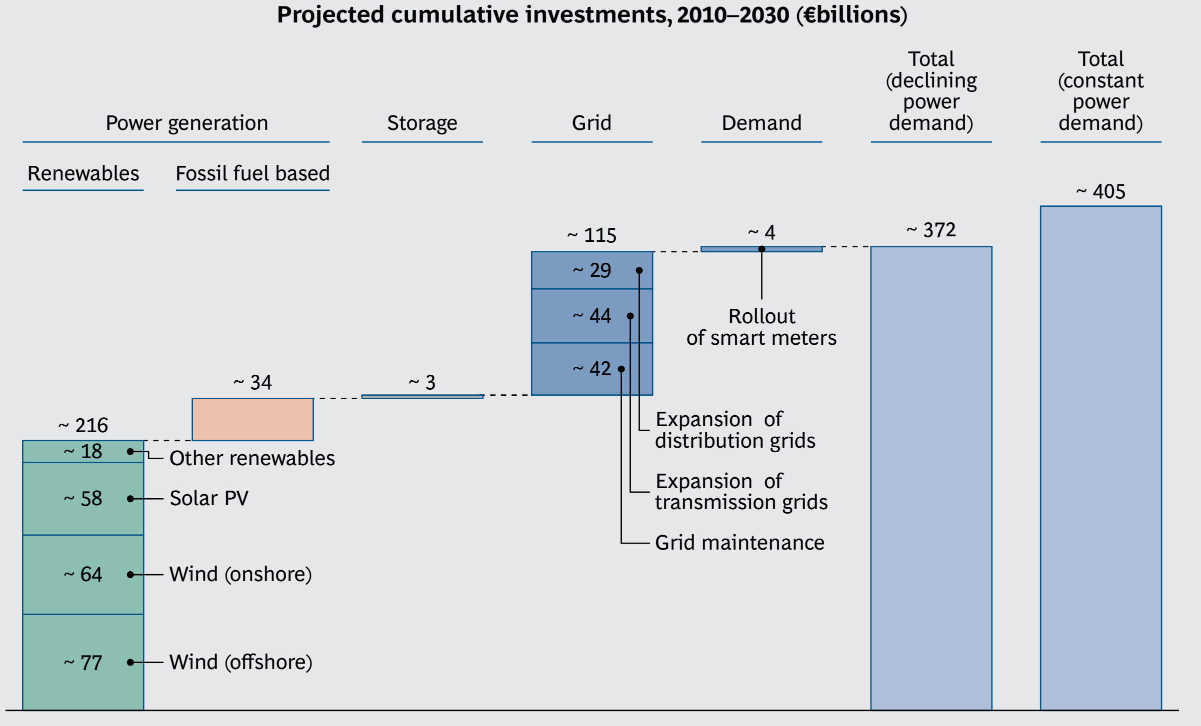
Sizable Investments. We estimate that the minimum investment necessary to ensure that Germany's system can provide reliable power infrastructure and supply will exceed €370 billion from 2010 to 2030. (See Exhibit 6.) Close to 90 percent will go toward grid extension and the buildup of renewables. (Were Germany to pursue a conventional, fossil-fuel-based system, the investment necessary to maintain the current infrastructure and replace nuclear with gas-fired generation would amount to approximately €150 billion over the same period.)

> Conventional generation will shift from providing baseload to providing backup capacity.

Beyond that, there will likely be additional investments in self-supply solutions, with the amount determined by the market's design and power-pricing mechanisms. Solar PV combined with storage, for example, is likely to draw growing interest and investment from residential pro-sumers, because the business case for that technology (based on current regulation) is projected to turn positive sometime around 2017.

Rising System Costs and Power Prices—but an Equally Costly Alternative? How will Germany's transformation affect system costs and, eventually, prices? Exhibit 7 depicts the

EXHIBIT 6 | Germany's Transformation Will Require Sizable Investments in Generation and Grid Infrastructure



Source: BCG analysis.
Note: Based on German Transmission System Operators, *Netzentwicklungsplan*, 2012. Figures include investments in power plants already under construction and estimated maintenance investments from 2010 to 2030. Deviations between total numbers and their components are due to rounding.

potential evolution of the unit costs of power supply to 2020, 2030, and 2050. (Unit costs include the full costs of power generation and the power grid, covering annualized capital expenditures as well as operating expenditures, including fuel and carbon dioxide emissions under the EU's trading scheme.) Unit costs are shown for renewable scenarios with both declining and constant demand for electricity and for a hypothetical fossil-fuel-based system. The fossil-fuel-based system is a reference scenario in which Germany's generation mix remains unchanged from 2010 but includes the phaseout of nuclear energy and its replacement with natural gas. This scenario allows for the comparison of unit costs under the renewables scenarios with the projected costs were Germany to maintain today's fossil-fuel-based power system. Points worth noting about the comparisons include the following:

- In 2010, Germany's unit power costs were around 10 ct/kWh; the capital cost of the existing system, including the grid and all fossil-fuel-based and renewable-generation assets, accounted for about half of those costs.[1] This capital stock declines over time as assets are written off.

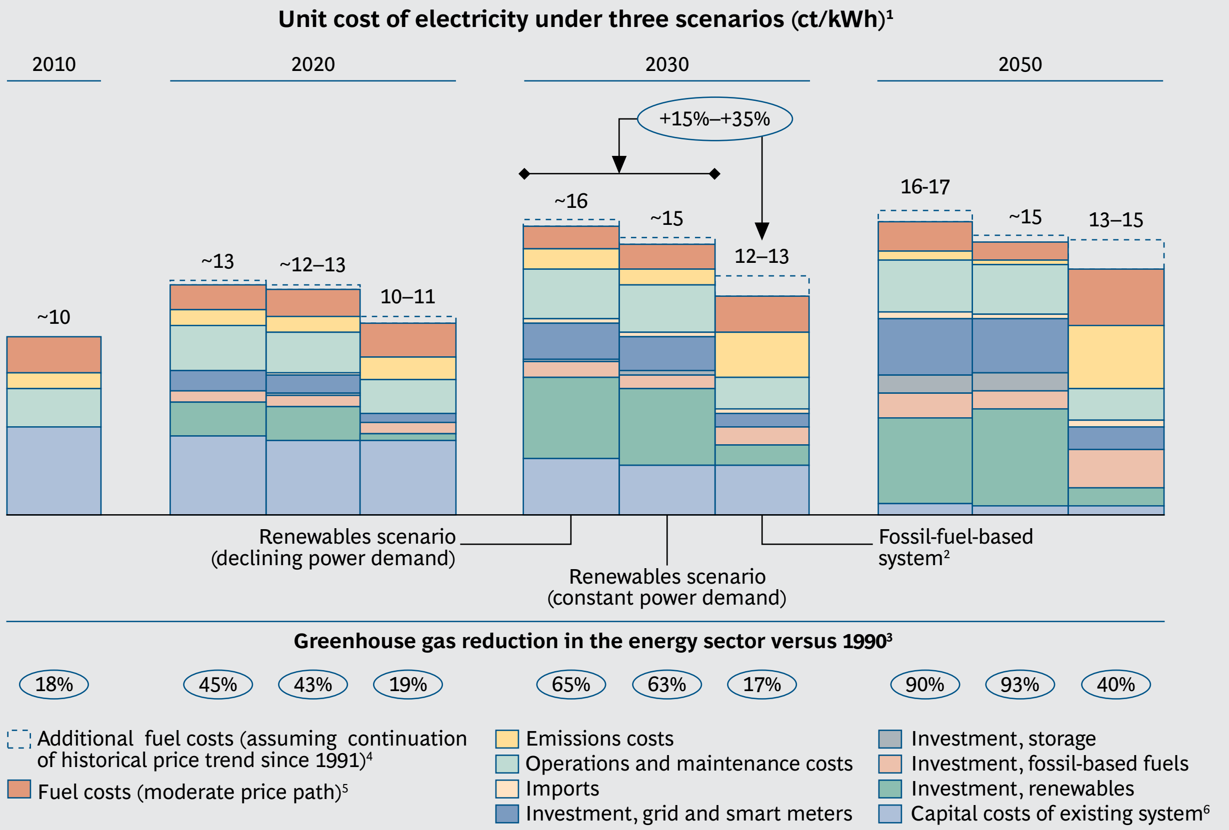
- By 2030, unit costs in the renewables scenarios will increase by 50 to 60 percent.

- Under the renewables scenarios, unit costs in 2030 will be 15 to 35 percent higher than those in the fossil-fuel-based system, depending on fuel and CO_2 prices.

- In the renewables scenarios, the main cost drivers are capital expenditures for renewable generation and the related grid extension.

- Costs for operations and maintenance are also higher in the renewables scenarios, as both a conventional backup infrastructure and a renewables system need to be maintained.

Exhibit 7 | Germany's Unit-Electricity Costs Will Be Higher in 2030 with a Renewables-Based Approach



Source: BCG analysis.
[1]Unit costs include the full costs of power generation and grids and correspond to annual system costs divided by net power demand. The costs of carbon emissions certificates are accounted for in the cost figures for 2010.
[2]A hypothetical system that assumes continuation of today's mix of generation capacities and compensation by new natural-gas power plants for capacity lost as a result of Germany's nuclear phaseout.
[3]Electricity sector, ~90%; other energy-transformation sectors, ~10%.
[4]Price increases until 2050 versus 2010 (real): hard coal, 248%; natural gas, 178%; lignite, 100%.
[5]Price increases until 2050 versus 2010 (real): hard coal, 14%; natural gas, 59%; lignite, 0%.
[6]Assumes that nuclear power plants have already been written off in 2010.

- In the fossil-fuel-based system, the benefits of lower capital expenditures and lower operation and maintenance costs come at the expense of higher expenditures for fuels and CO_2 emissions. In the very long term, rising fuel and CO_2 costs may mean that Germany's move to renewables will deliver cost benefits.

If these projections were to incorporate the full costs of carbon emissions (including the costs of environmental damage), which Germany's Federal Environment Agency (Umweltbundesamt) estimates at €70 per ton, unit costs would be almost equal for all scenarios starting in 2010. In other words, the renewables scenarios would nearly break even today. At a minimum, the renewables scenarios provide a better hedge against dependency on fuel imports and geopolitical risk: in these scenarios, Germany's total imports of natural gas, coal, and oil decrease by around 30 percent to 2050.[2]

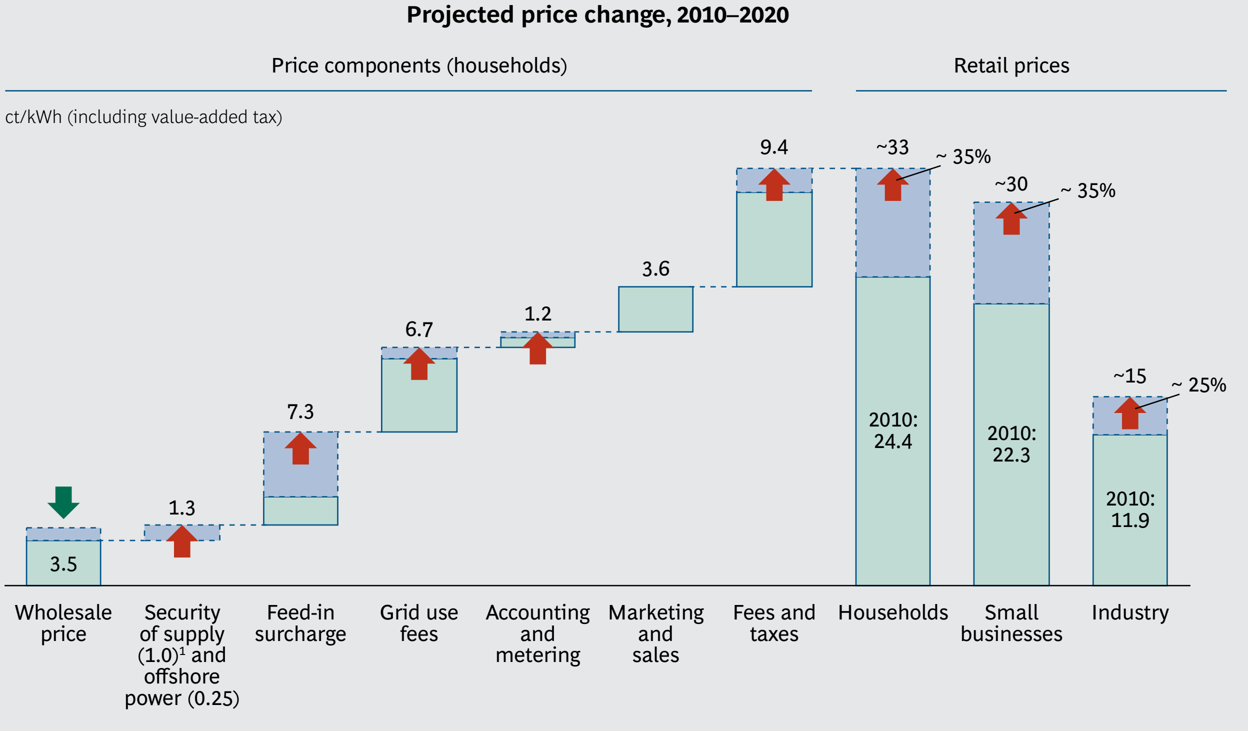
In the medium term, however, increasing system costs for power generation and the grid will translate into higher retail prices for industrial and household consumers. Clearly, pricing mechanisms depend strongly on market design. Therefore it is difficult, if not impossible, to provide projections with confidence.

We can, however, provide some guidance by projecting prices on the basis of today's market mechanisms. In the renewables scenario with constant demand, retail power prices for households will increase by around 35 percent, to 33 ct/kWh, by 2020.[3] (See Exhibit 8.) This is significant but less than the 42 percent increase experienced by Germany's residential customers between 2000 and 2010. The main drivers behind the projected increase are a threefold rise in the costs of subsidies under the country's Renewable Energy Act of 2000 and rising grid tariffs to pay for grid expansion. A security-of-supply component is also factored into our cost projection, reflecting the need to remunerate backup (fossil fuel based) power plants that are suffering from low utilization. We project costs of around 1 ct/kWh to compensate these plants. (See "The Need for a New, Holistic Market Design," below, for a discussion of these effects.)

For retail users, there is thus a steep price tag for a greener energy landscape. The alternative, however, is not much cheaper: due to the potential for rising fossil-fuel prices, retail power prices for households could reach 28 to 29 ct/kWh in 2020, making the renewables scenario only around 15 percent more expensive than today's fossil-fuel system would be through the rest of the decade. This price advantage could be even smaller, of course, depending on the growth rate of fossil-fuel prices.

This assessment of system costs and power prices demonstrates that there is no easy way to determine the precise evolution of the business case for Germany's planned transformation. Clearly, the economics depend heavily on prices for fossil fuels and carbon emissions. While there will not be an explosion of system costs under the renewables scenarios, the path to a greener energy landscape will likely be more expensive than that of the fossil-fuel-based alternative for the next two decades. On the other hand, Germany's economy will be significantly less exposed to fossil fuel price risks. In the long run, higher fuel prices may very well make the business case turn profitable, causing the transformation's breakeven point to be more a question of *when* than *if*. The true challenge

Exhibit 8 | Retail Power Prices in Germany Will Rise by One-Third by 2020 with a Renewables-Based Approach



Sources: Federal Network Agency (Bundesnetzagentur), 2010 values; BCG analysis.
Note: Assumes pricing mechanisms as they were in 2010, with the addition of security-of-supply and offshore components.
[1]The security-of-supply component covers the gap between the costs of conventional power plants and revenues realized in wholesale power markets.

for policymakers, industry, and society will be managing the transition until that point is reached.

The Potential for Achieving Affordability, Security of Supply, and Sustainability

In the long term, Germany's green transformation may give the country the opportunity to fulfill, simultaneously, its three aspirations of affordability, security of supply, and sustainability. The business case for the plan, as noted, could eventually turn positive. Germany's dependence on foreign fuel will fall sharply—gas consumption for supplying power, for example, will fall to 50 terawatt-hours in 2030 from 200 terawatt-hours in 2010. And the country will significantly improve its carbon footprint as it pursues its emissions goals, which include a 55 percent reduction in greenhouse gas emissions from 1990 levels by 2030.

> The current market's design will be challenged by a confluence of effects.

Individual communities may seek to move ahead on their own. Feldheim, for example, a tiny village 80 kilometers southwest of Berlin, claims to have successfully squared the triangle, having built its own standalone power and heat supply based solely on local, renewable forms of energy. Feldheim's system, which supplies two businesses and 145 people in 37 households, comprises 43 wind turbines, 2.25 megawatts (peak) of solar PV modules, a 500-kilowatt-electric biogas-fired combined heat and power plant, and a woodchip heating plant for meeting peak demand. The village even built its own power and heat grid to make the system fully self-sufficient. Feldheim claims a retail power price of 16.6 ct/kWh for its residents, 25 percent less than the price charged by the regional utility. (Participating households must, however, pay a one-time buy-in fee of €3,000, possibly rendering the business case for residents negative from a purely financial perspective.) Feldheim is not necessarily a model for rural areas or the country as a whole. But it demonstrates the pending paradigm shift and possibly a growing will for experimentation.

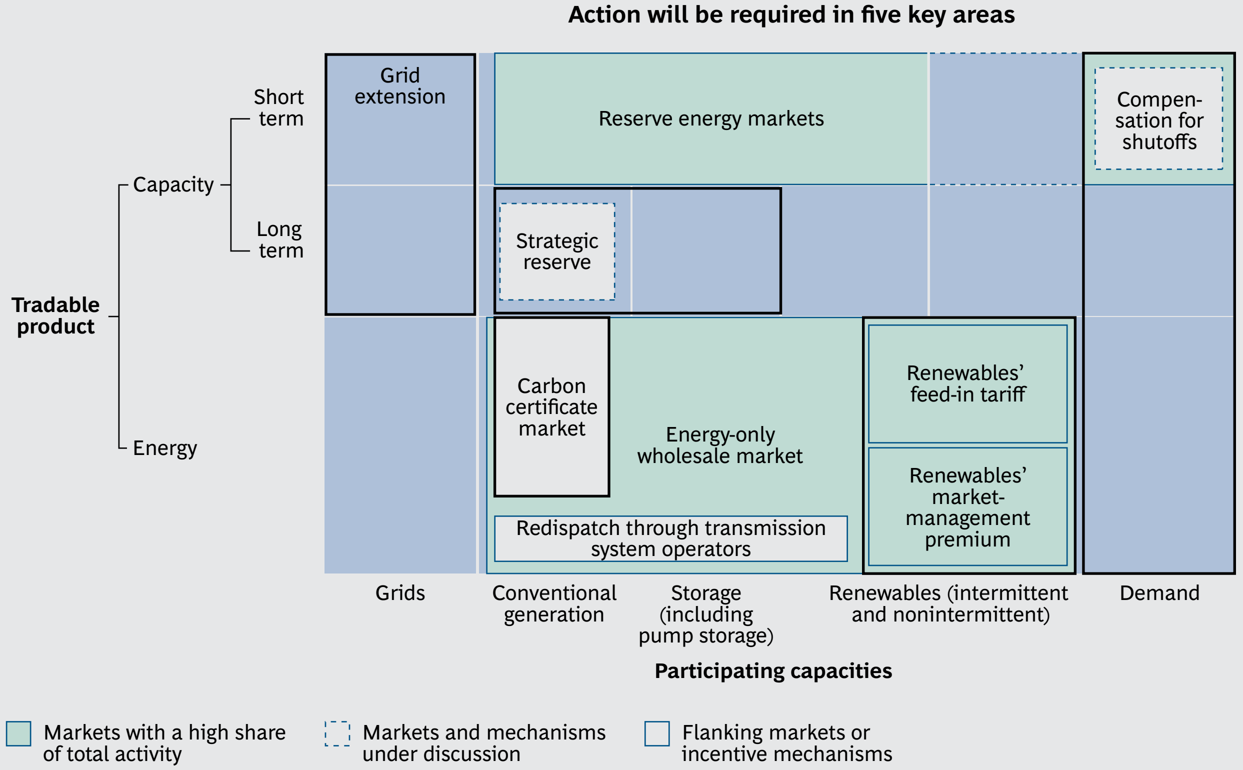
The Need for a New, Holistic Market Design

Germany's transition will have significant implications for energy markets. Some of the effects are already evident. Electricity products that were once highly profitable, for example, are becoming less so, and this will continue as distributed renewable generation becomes more common. Take the sale of peak power. In the past, power covering the peak demand hours of 8:00 a.m. to 8:00 p.m. was significantly more expensive, and hence lucrative for conventional generators, than base power. In 2007, for example, the premium averaged 28 percent. By 2011, however, the price difference had dropped to 12 percent, reflecting the growing prevalence of solar PV panels, which increase the supply of generated electricity during peak daytime demand.

Much more fundamental will be the impact on the design of the power market itself. Currently, Germany has two major markets for energy and capacities. These markets, as well as supporting mechanisms, are illustrated in Exhibit 9. The so-called *energy-only wholesale market* offers trading of electricity volumes based on the short-run marginal costs of power generation technologies. Transmission system operators manage so-called *reserve energy markets,* sourcing capacity (in gigawatts) as well as energy (in gigawatt hours) for the short-term physical balancing of supply and demand. Germany's feed-in-tariff subsidy scheme motivated the installation of 65 gigawatts of capacity by 2011 that would not have been built under the energy-only and reserve energy markets.

This market design will be challenged by a confluence of effects as renewable-energy sources come closer to accounting for 80 percent or more of Germany's generated electricity. As noted, the role of conventional power plants will shift from providing baseload to backup power; supply will become highly intermittent; and the merit order scheme for feed-in to the grid, which is based

EXHIBIT 9 | Germany's Current Power-Market Design Faces Challenges from the Energy System's Transformation



Source: BCG analysis.

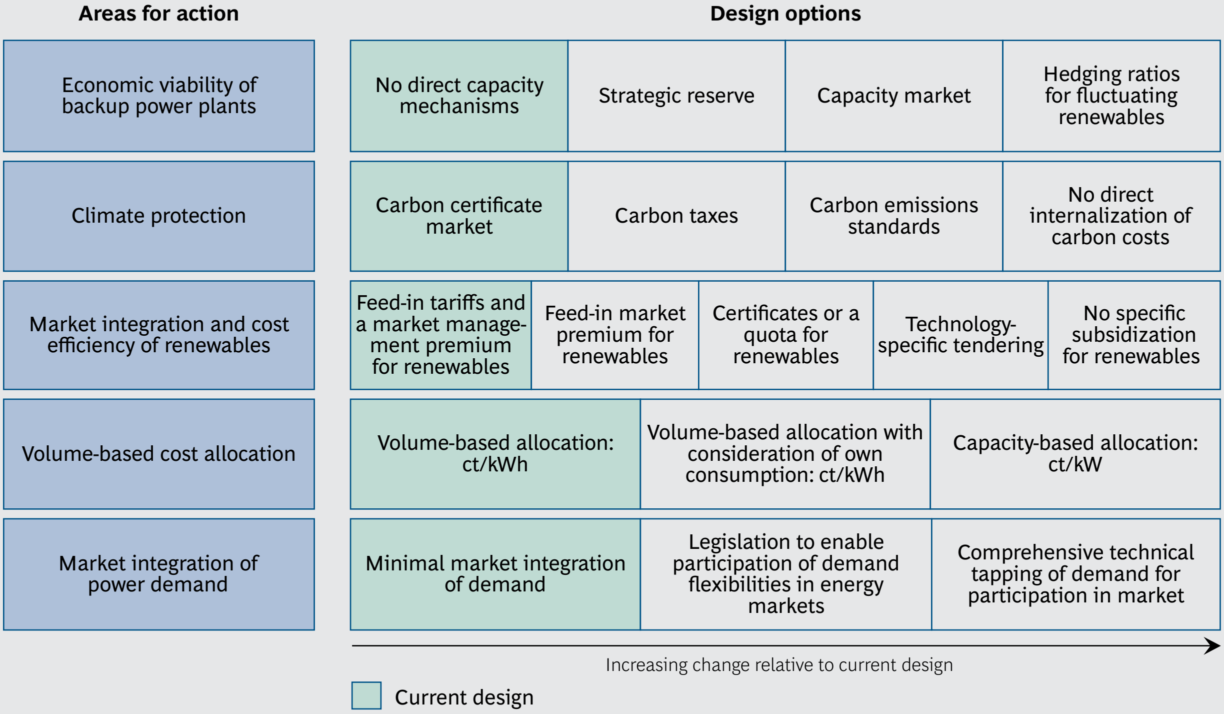
on the short-run marginal costs of power supply, will become increasingly less relevant (since wind and PV are free fuels). At the same time, the levelized cost of energy from renewable sources will become increasingly cost competitive. And given rising retail power prices, self-supply of energy could become an increasingly attractive option for a growing number of consumers.

Overall, these effects will demand a redesigned power market, with a particular focus on five considerations. (See Exhibit 10.)

- *The Economic Viability of Backup Power Plants.* As discussed, the increasing feed-in of renewable energy will reduce the utilization of existing power plants. It will also lower wholesale prices because many renewable-energy sources have negligible marginal costs. This combination of factors will weigh heavily on conventional generators' finances. RWE, for example, reported that it lost several hundred million euros in profit in 2011 owing to these effects. Our analysis shows that the annual economic shortfall for conventional power plants will reach €7 billion by 2030. But conventional plants are far from dispensable, as they will provide the bulk of the capacity necessary to keep the lights on during cloudy and windless periods. Dispatchable capacity, then—critical for providing energy security—will take on increasing value.

The good news is that the capacity provided by existing fossil-fuel-based plants, and by those under construction, is sufficient to cover the capacity lost from the phaseout of nuclear power plants, provided that no fossil plants are decommissioned and grid extension proceeds as planned. A so-called *strategic reserve mechanism* can therefore provide a good interim solution by facilitating payments to existing plants to avoid their shutdown. In fact, the German Federal Grid Agency has already started to contract with several older fossil-fuel power plants during peak winter hours. Such a mechanism would give policymakers more time

Exhibit 10 | Germany Will Need to Redesign Its Power Market, Focusing on Five Key Considerations



Source: BCG analysis.

for an overdue in-depth investigation of more refined and market-driven mechanisms, such as capacity markets or hedging ratios for intermittent renewable-energy sources.

- *Investment Incentives for Climate Protection.* At today's carbon prices of around €8 per ton, investment in climate protection measures is hardly lucrative. To reach Germany's targets for greenhouse gas reduction in a cost-efficient way, a regime that provides long-term, market-driven incentives for low-carbon investments is necessary. It could be that the existing European carbon-certificate trading mechanism is the only feasible option, because other potential solutions, such as carbon taxes or emission standards for power plants, might not be able to receive international agreement. The mechanism could be enhanced by establishing long-term binding targets for greenhouse gas reduction for all participating countries, as well as through a stepwise expansion of the program to other countries.

- *Market Integration and the Cost Efficiency of Renewable Energy.* Germany's Renewable Energy Act has been effective in driving the adoption of renewables, pushing their share of power generation from 7 percent in 2000 to 25 percent in the first half of 2012. For Germany's plan to be viable over the long term, however, renewable energy must also become cost efficient, and related investments should be based on pure economics. To date, the country's technology-specific fixed feed-in tariffs have promoted investments in a number of comparatively expensive generation technologies.

  Short-term approaches to the problem include a full switch from fixed feed-in tariffs to a more market-oriented, feed-in market premium model for all new construction of renewable capacity. Medium- to long-term options include a technology-neutral support scheme, such as a renewable-energy quota system. A further possibility would be both daring and potentially economical. Provided that a long-term binding agreement on CO_2

abatement and a corresponding incentive scheme come into effect, Germany could choose to fully dispose of additional renewable-specific support schemes. From an economic perspective, this might well be the most efficient approach to climate protection.

- *The Viability of Volume-Based Cost Allocation.* Driven by surging retail power prices, partial self-supply of power could become increasingly attractive economically for many Germans. Since 2011, in fact, power derived from rooftop solar PV installations has been cheaper than power from the grid for homeowners in large parts of Germany. In the near future, this will hold true for combined PV and storage solutions as well. However, such "grid parity" can be deceptive. To ensure a secure power supply, each house will have to remain connected to the grid, and grid costs remain the same regardless of how much energy flows. In telecommunications, such costs are covered by connection fees. In the power sector, accounting for grid fees will thus necessitate a (gradual) transition from price per kilowatt hour to price per kilowatt.

- *Market Integration of Power Demand.* Today only a small share of power demand, mostly from energy-intensive industries, is flexible in its consumption pattern and reaction to power prices. Most consumers do not react to time-varying power-price signals. In fact, they cannot do so, because most households and small businesses pay a constant power price per kilowatt hour. In the future, making power demand more flexible could be an efficient measure to balance demand and intermittent supply.

Market design constitutes a fundamental challenge for economists and policymakers alike. Interdependencies in the solution space outlined above are complex.

Dispatchable conventional power plants and intermittent renewable-energy sources share a common challenge: for both, Germany's current wholesale power market, which is based on short-term marginal costs, provides insufficient returns to finance the new builds required to meet Germany's ambitions. For power plants, full-load hours and wholesale prices are too low; for renewables, prices achievable during times of strong sun and/or wind are insufficient. Both conventional power plants and intermittent renewables need supporting investment incentives—or an entirely new market design. Indeed, today's power market seems dysfunctional for an energy mix with a large share of zero-marginal-cost energy forms, such as solar PV and wind.

Change will weigh heavily on energy incumbents, particularly the Big Four utilities.

While a solution is not yet at hand, the immediate next steps seem clear: implement the above-mentioned short-term measures, particularly the institutionalization of a strategic reserve and a reform of the Renewable Energy Act, to buy time to develop a holistic, long-term sustainable solution.

A Hard-Hit Power-Supply Industry

The long-term benefits of Germany's greening of its energy policy could be broad and substantial. But the change will weigh heavily on the energy industry's incumbents, particularly the Big Four utilities (RWE, E.ON, EnBW, and Vattenfall). Indeed, the effects are already being felt.

Value Chain Evolution: Customers Become Competitors. Decentralization will spawn hundreds of thousands of pro-sumers—homeowners with solar PV modules, farmers with wind farms, and communities with biogas assets, for example—who both consume and produce power. Their emergence will have a threefold effect on the industry's value chain.

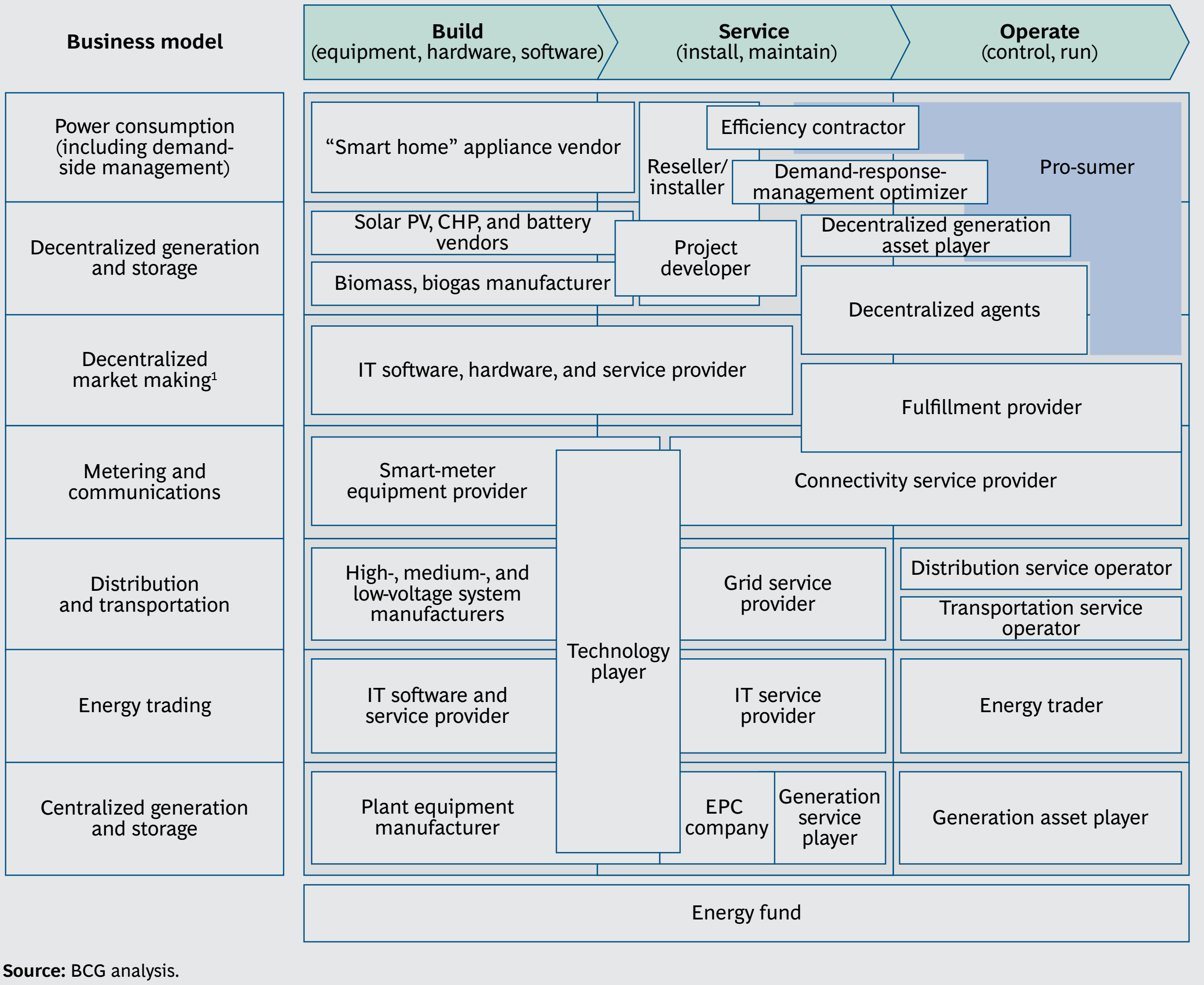
First, as individuals, parts of industry, and communities gain the ability to generate their own power, they will become increasingly self-sufficient. Worse, from the perspective of the utilities, they will feed any excess power they generate back into the grid for sale, effectively becoming competitors.

Second, the rise of pro-sumers will change the structure of the industry's value chain. The current one-way model, comprising generation, trading, transport, distribution, and retail, will become multidirectional in nature, with conventional generators and pro-sumers both acting as generators.

Third, pro-sumers and the multidirectional value chain will generate a variety of new business models and draw new entrants into the market to serve these customers. This will have a particularly strong effect on the distributed parts of the energy industry. Exhibit 11 illustrates a range of prototypical business models that might emerge.

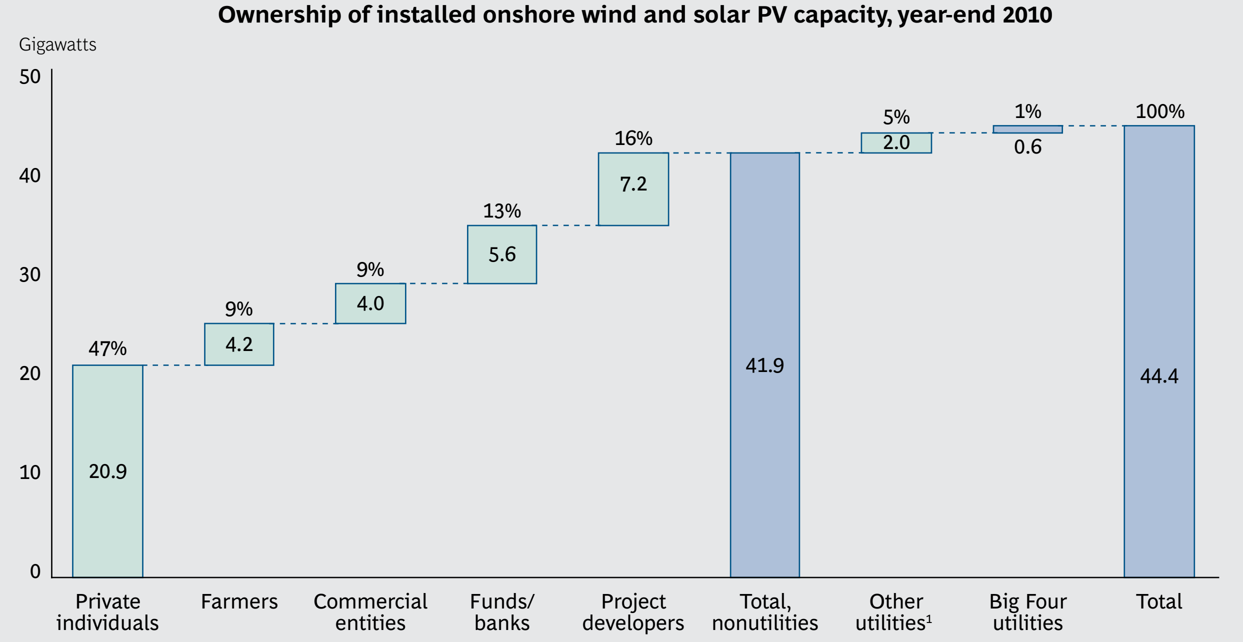
Asset Ownership: Tremendous Shifts. The evolution of the value chain and the new business models that result will be accompanied—and accelerated—by a transfer of influence from incumbents to pro-sumers. This shift is already under way. By the end of 2010, for example, 47 percent of Germany's installed solar PV and onshore wind-generation capacity was owned by individuals. Only 1 percent was owned by the Big Four. (See Exhibit 12.) Ownership of electricity transport grids is undergoing a similar shift. New owners include infrastructure funds and independent system operators. Similarly, distribution grids are being partially remunicipalized.

Exhibit 11 | The Rise of Pro-sumers Will Result in New Business Models in Germany's Power Industry



Source: BCG analysis.
Note: CHP = combined heat and power; EPC = energy performance certificate.
[1]Energy sales.

EXHIBIT 12 | The Transfer of Influence from Incumbents to Pro-sumers Is Already Under Way in Germany



Sources: Klaus Novy Institut, "Marktakteure Erneuerbare-Energien-Anlage in der Stromerzeugung"; Agentur für Erneuerbare Energien, "Investitionen in Erneuerbare-Energien-Anlagen in Dtl. 2000-2010"; BCG analysis.
Note: The apparent discrepancy in the total is due to rounding.
[1]Mainly municipalities.

Incumbents: From Stars to Average. The challenges facing incumbents, especially the Big Four, go beyond the disruptive effects of shifting asset ownership. After years of robust returns on their operations in nuclear and fossil-based generation and strong results in their trading businesses, the utilities face having their earnings wiped out in the German market. Competitors whose business is based on classic business models, such as centralized generation and energy trading, stand to see their revenues plunge, weighed down by a confluence of factors, including the nuclear phaseout, declining wholesale power prices, the "crowding out" of their plants by renewables, a declining spread between daily base- and peak-power prices, regulation of revenues for electricity grids, continued loss of retail customers, and stagnating demand.

For example, returns on capital employed in centralized generation will likely sink from more than 15 percent before 2011 to 8 to 10 percent by 2030, assuming a yet to be established mechanism that adequately remunerates power plant operators for providing capacities and ensuring security of supply; current wholesale markets alone would likely yield negative returns.

The era of double-digit returns for conventional players will thus come to an end. In fact, absent mechanisms that compensate conventional plants for providing generation capacity, returns that have not been written off will probably be negative. And these utilities will likely have no means of driving returns to previous levels. Distributed generation is today effectively a return-regulated business, with returns of about 5 to 8 percent. Even if the industry were to become unregulated, the small scale and intense competition for solar, onshore wind, and biomass assets would yield similar returns for the foreseeable future. Grid operation is also a return-regulated business, with an expected return on capital of about 8 percent. Indeed, the transformation of the energy landscape spells the end of high returns along the entire value chain, with 2010 returns probably representing the high-water mark.

Industry Architecture: Deconstruction, Fragmentation, and Stacking. And so we are witnessing the industry's third, and potentially final, era of deconstruction. During the 1980s and 1990s, large, vertically integrated businesses and local municipalities dominated the industry, most often as geographic monopolies. In the first decade of this century, in an attempt to initiate competition, policymakers called for legal unbundling and "liberalization": essentially, power generation, grid businesses, and power sales were split into separate legal units, each with its own management. Competition was introduced, grid access was granted to third parties, a wholesale market was created, customers were allowed to choose their power supplier—and the industry began to deconstruct.

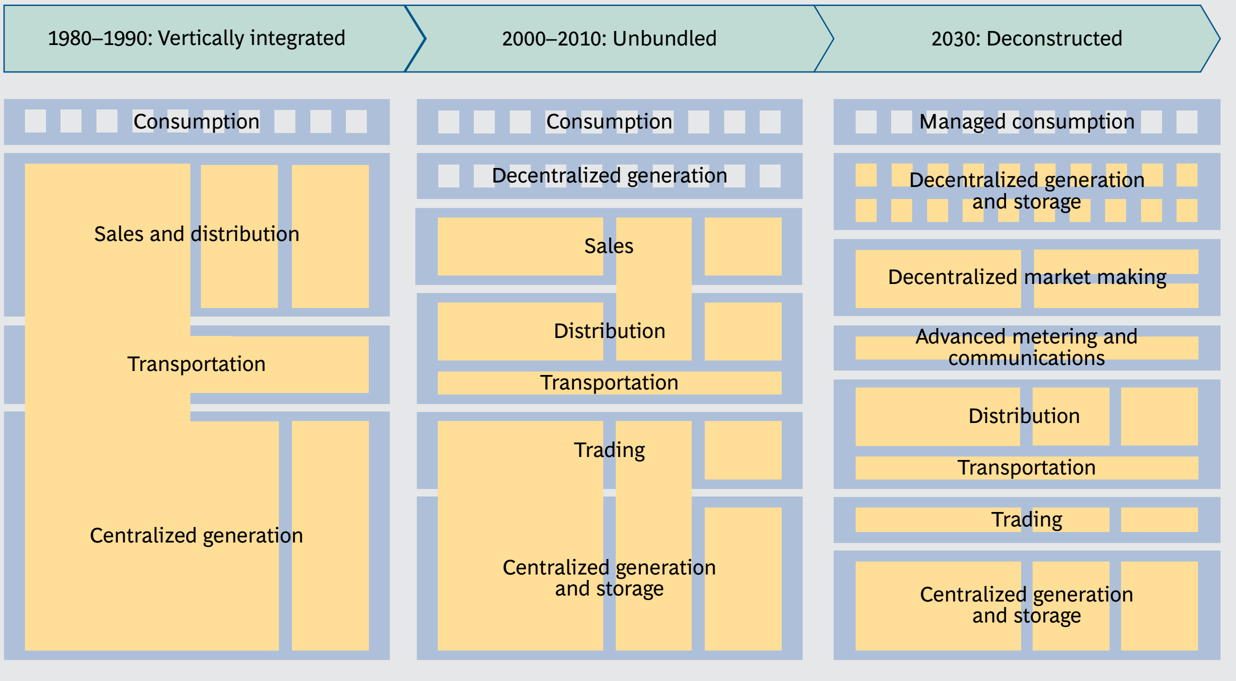
Now additional forces of deconstruction—declining margins, increasing cost pressures, business model disruption, and fragmentation of asset ownership—are beginning to take effect. Ultimately, these forces may transform the industry's architecture from one of vertically integrated monoliths to horizontal, stacked layers of revenue pools. (See Exhibit 13.) This will change the bases of competitive advantage, putting a premium on specialization, scale, standardization, and business model innovation.

While this seems a natural evolution for the market, similar to that of other industries, it is by no means a given. Market design and business models, and hence industry structure, are strongly dependent on policymaking and regulatory conditions—and uncertainty regarding future developments here is high. One conceivable scenario is a "renaissance of liberalization," in which policymakers succeed in setting up a truly competitive power market. Another possibility is the nationalization of systemic players—essentially, the wheel would turn back to preliberalization times—which would place state-owned companies in key parts of the value chain.

Imperatives and Opportunities for Stakeholders

The reshaping of Germany's energy landscape will force action on the part of all stakeholders. For some, it will offer potentially lucrative opportunities. For others, the primary focus will be on avoiding the negatives and managing the effects of the disruption.

Exhibit 13 | Germany's Energy Industry is Evolving from Vertical Integration to Stacked Layers of Revenue Pools



Source: BCG analysis.

Utilities: be agile and experiment. Germany's established utilities, including the Big Four, are in a period of unprecedented uncertainty and face some hard strategic choices. But attempting to deny their predicament or forestall the inevitable is futile. Instead, incumbents, and in particular the Big Four, need to acknowledge the new reality and move from lobbying against the transformation to leading it. This will demand adaptiveness, agility, and experimentation in the years ahead.

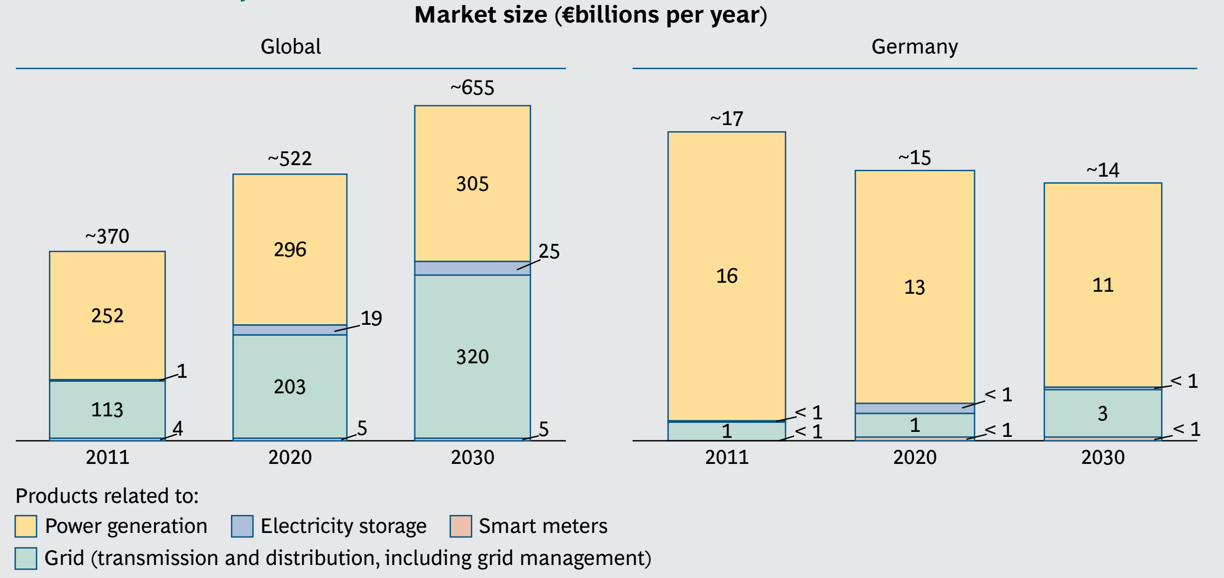
Essentially, the Big Four have two major options. First, they can attempt to penetrate developing segments of the market within Germany, such as distributed wind and solar power, combined heat and power (CHP), and biogas. Doing so, however, will entail accepting lower returns—probably of less than 10 percent on invested capital, compared with the double-digit returns of the past. A second option is to seek to replicate their current business model internationally, an option that some utilities are already exploring. E.ON, for example, is entering markets in Brazil, India, and Turkey, partly through joint ventures with local players.

The Big Four could also, at least in theory, seek to diversify into other industries. This would be a high hurdle, however, given the shortage of cash currently being experienced by these businesses and their lack of suitable capabilities.

Technology companies: review the product portfolio. Germany's shift toward renewable and decentralized generation offers tremendous opportunities—and challenges—for power technology vendors. Exhibit 14 provides an overview of the revenue potential for the German and worldwide power-technology market.

By far, the greatest revenue opportunities to date from the massive required investment have resided with cost-competitive vendors of renewable-generation technologies. Indeed, Germany's push toward renewables has been a significant driver of the global increase in production capacity of solar and wind technology and of the industry's rising cost competitiveness with conventional forms of energy. (For individual technology companies, however, the results so far have been mixed: hot competitive markets have led to overca-

Exhibit 14 | The Global Power-Technology Market Will Grow Strongly to 2030, While Germany's Market Has Already Peaked



Sources: International Energy Agency; U.S. Department of Energy; BP; European Photovoltaic Industry Association and Greenpeace; Bloomberg; German Wind Energy Institute (DEWI); Global Wind Energy Council; Institute of Economic Structures Research (GWS); German Institute for Economic Research (DIW); European Wind Energy Association; International Renewable Energy Agency; BTM Consult; Pike Research; Photon Research; Visiongain; Federal Office of Statistics (Statisches Bundesamt); Federal Ministry of Economics and Technology (BMWi); BCG analysis.
Note: Estimates for the German market are derived from the BCG and German Transmission System Operators scenarios shown in Exhibits 4 and 5 and include refurbishment and replacement efforts; worldwide figures are based on technology-specific market forecast studies. Apparent discrepancies in totals are due to rounding.

pacity and the fallout of some of the industry's pioneers. Revenue opportunities are no guarantee of profits.)

There are signs, though, that the market for renewables in Germany may have already peaked: 2010 and 2011 were record years for solar PV, in particular, and a gradual slowdown from this point is likely. However, revenue opportunities for vendors will remain, especially since existing renewables will eventually have to be replaced. In fact, investment to replace existing renewables will account for a signicant share of the projected €13 billion in generation-related revenue in Germany in 2020. The power-grid-technology market will also benefit substantially from Germany's energy transformation, with annual revenues growing from around €1 billion in 2011 to around €3 billion by 2030.

Beyond the pure sale of technology products, some technology companies may have opportunities to pursue integrated strategies with companies positioned elsewhere on the value chain. Vaillant, for example, a vendor of micro-CHP systems, is partnering with RWE and E.ON to sell heat- and power-generating devices to residential consumers. Nontraditional competitors will also see increasing opportunities as industry boundaries start to blur. Telecommunications giant Deutsche Telekom, for example, has entered the distributed-energy business, offering a solution based on the use of CHP devices to municipalities seeking to move toward distributed generation.

The industry's local small-business artisans stand to capture the lion's share of revenues from the installation and maintenance of decentralized generation assets, a market that should reach €2 billion to €3 billion by 2020. These players' established service coverage and relationships, cheap cost structure, and low expectations for returns will make it hard for potential competitors, such as utilities and other industrial companies, to compete against them effectively.

Startups: expect challenges in achieving scalability. We expect startups to develop innovative and partly disruptive business models, primarily for servicing and operations at the distributed end of the energy industry. Entelios and Next Kraftwerke, for example, are pursuing the direct marketing of flexible, decentralized power generation and consumption.

But startups face two challenges. First, they must establish a new business model, often positioned between classical utilities and prosumers, as decentralized market participants. Second, they must find a way to achieve profitability and scalability with a business model that generally requires a service force to install and maintain equipment at partners' or customers' locations.

Policymakers: recognize that the challenge is still ahead. Germany's policymakers have set the goals for the transition to distributed and renewable generation. But the bulk of their work remains ahead of them. Policymakers will have to drive and support the development of critical technology and infrastructure enablers, such as grid extension.

Above all, the challenge of policymakers will be to make immediate adjustments, as necessary, as well as develop long-term solutions for a sustainable and stable power-market design. And policymakers will have to do this while taking great care to find a balanced allocation of the costs associated with the transformation.

NOTES

1. Capital expenses are annuitized over the asset's lifetime, with a weighted-average cost of capital of 7 percent for renewable generation, 12 percent for fossil-fuel-based generation, and 9 percent for grids.
2. This reduction refers to total final energy consumption, including the transportation (mobility) sector.
3. Due to the complexity of the large array of regulations, we cannot discuss in detail the likely trends in energy prices for industry in this report. However, the government has ensured global competitiveness for power-intensive industries through exemptions and special price regulations, and we expect this commitment to continue in the future.

FOLLOWING GERMANY'S PATH

Germany has taken the lead in transforming its energy-supply system from a conventional paradigm to a renewable and more distributed one. Are other countries likely to follow in Germany's footsteps? If so, what are the key imperatives for stakeholders?

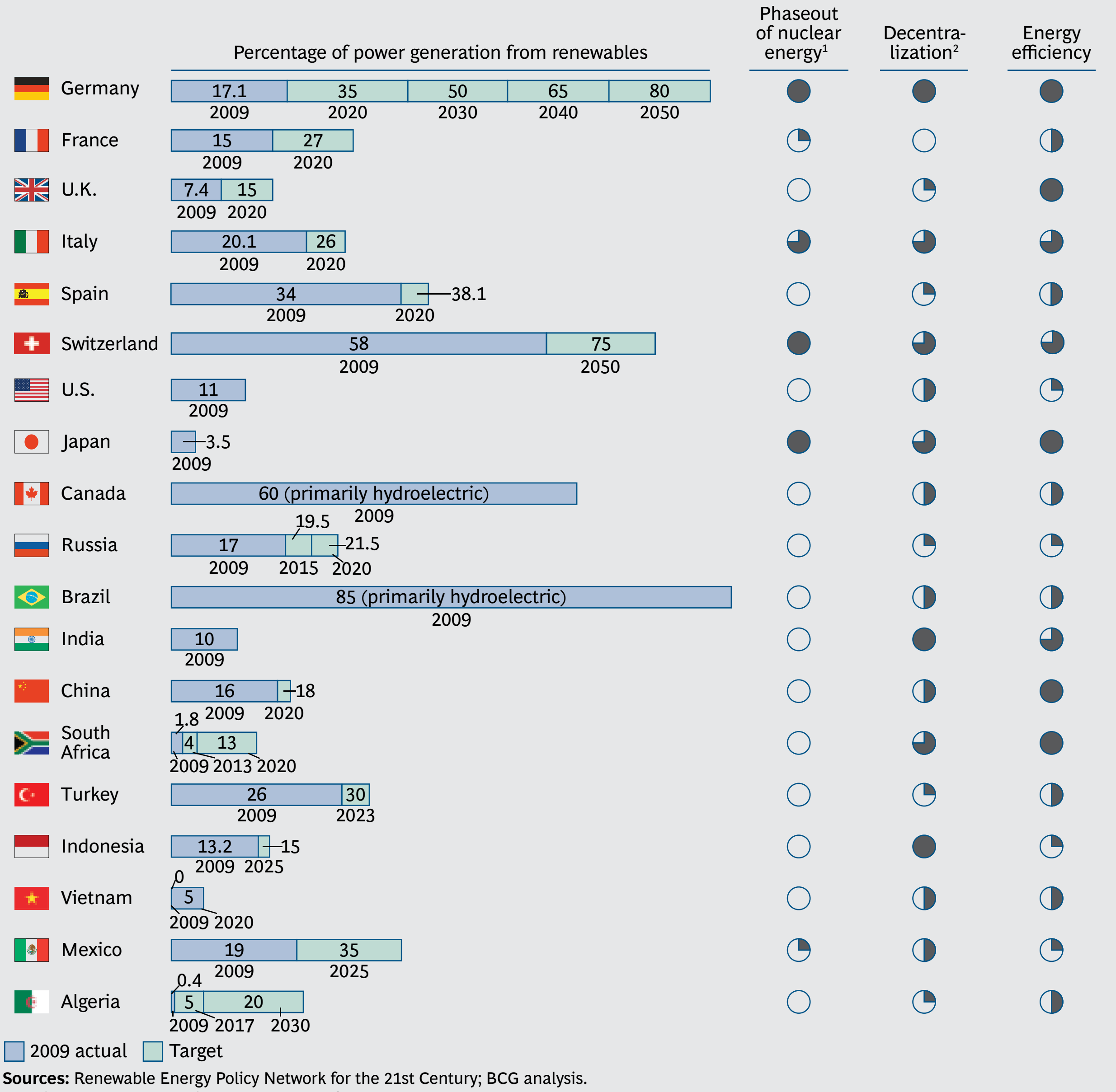
Role Model or Special Case?

Not surprisingly, countries are pursuing a range of different energy policies, reflecting their distinct geographic, political, and economic conditions. (See Exhibit 15.) Currently, Japan seems to be the only country whose emerging policy is comparable to that of Germany, although its choice is largely driven by necessity. As a result of the government's extended freeze on domestic nuclear generation following the crisis at the Fukushima Daiichi plant in 2011, Japan is heavily reliant on imported fossil fuels and is battling an energy deficit of approximately 10 GW, which has triggered painful restrictions on energy consumption in the private and public sectors. Renewable and distributed generation offer potential solutions that the government may choose to pursue. However, logistical considerations, namely a lack of space for centralized, large-scale wind and solar projects, may limit the government's options.

Other countries are pursuing elements of Germany's policy and face comparable challenges, particularly with regard to nuclear energy. In Europe, Switzerland is apparently targeting a phaseout of nuclear by 2034, when the country's youngest plant will have reached 50 years of age. As the country gradually takes nuclear capacity offline, it will need to replace it with generation from other sources (nuclear energy represented 38 percent of Switzerland's electricity generation in 2010). Similarly, Italy, which closed the last of its nuclear reactors in 1990 and confirmed its antinuclear stance in a 2011 nationwide referendum, has had to aggressively pursue other sources of energy to make up for the shortfall. It has turned, in particular, to solar PV. Driven by high feed-in tariffs for the technology to 2010, Italy's installed solar PV capacity is now the world's second largest, trailing only Germany's.

Notwithstanding its similarities with these countries, Germany seems to be on a special path. Most countries continue to embrace nuclear energy and largely conventional, centralized generation. The U.S., fueled by the goal of energy self-sufficiency and the presence of abundant shale-gas reserves, which are complemented by large-scale solar and wind projects, continues to rely on conventional sources. The majority of non-European countries also seem likely, for the foreseeable future, to continue to pursue strategies based on centralization and conventional sources. Among major markets, this also applies to China and Russia, both of which have direct

Exhibit 15 | Countries are Pursuing a Wide Range of Energy Policies



Sources: Renewable Energy Policy Network for the 21st Century; BCG analysis.
[1]Phasing out or not resuming development of nuclear energy.
[2]Implicit or explicit pursuit of a distributed power-supply system.

access to fossil fuels, vast spaces available for big, centralized infrastructure projects, and soaring energy demand. Similarly, South Africa will likely continue to rely predominantly on coal—even though cheap solar and offshore wind power offer attractive and potentially disruptive solutions to the country's long-term energy-shortage challenge. Brazil, for its part, will continue to rely on centralized hydroelectric power.

But there are forces that could ultimately steer more countries down Germany's path. One is the economic argument for renewable generation in specific countries. For those that are rich in sun and wind, for example, and those in remote locations where the costs of imported fossil fuels are high, the pure financial argument for a shift to renewables is very attractive—indeed, much more attractive than it is for Germany. Second, there is a similarly strong business case in many countries—especially developing countries with a need for greenfield electrification of rural areas—for decentralized generation for residential consumers. Instead of investing in expensive grid infrastructure and centralized power plants, governments in Africa, India, and Indonesia, for example, could provide power to remote locations via small rooftop solar PV installations, batteries, and rarely used backup diesel generators. (See Exhibit 16.) The use of distributed generation and island grids for electrification would parallel the role that wireless technology played in bringing telecommunications to such regions. Third, an increasing number of countries and regions have set ambitious energy-efficiency targets—and renewables and distributed generation will be critical levers in meeting those goals.

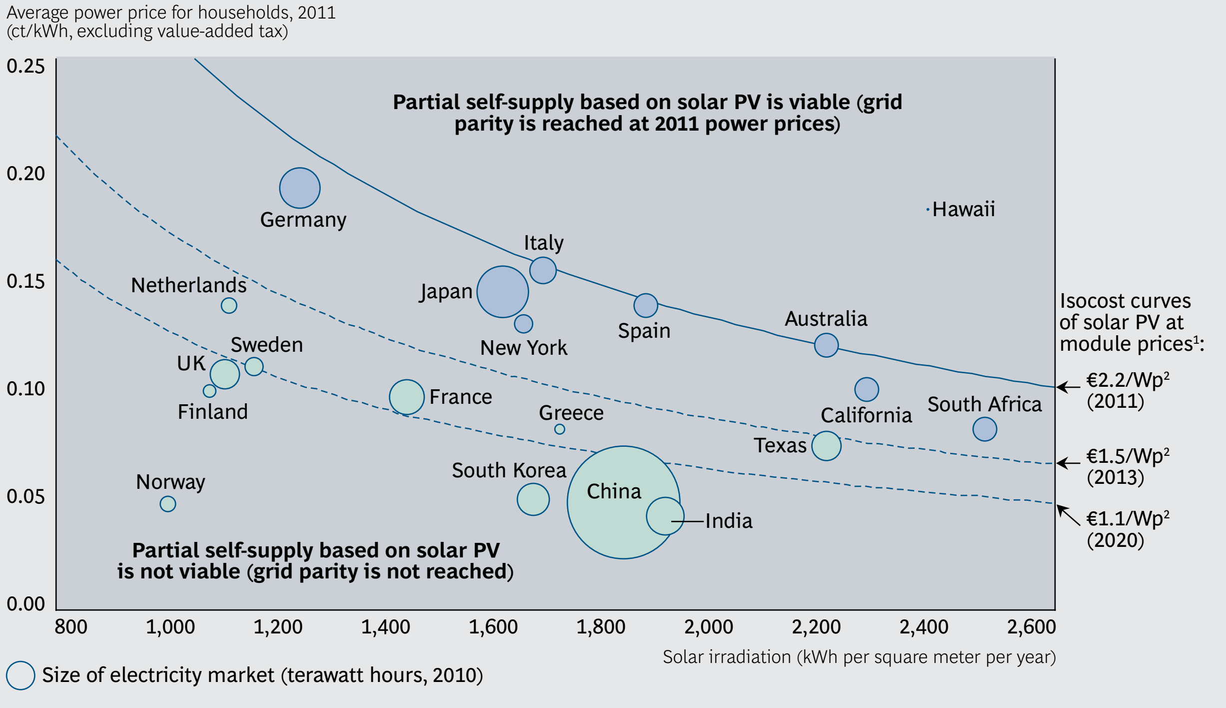
Mandates and Opportunities for Global Stakeholders

To date, then, it appears that Germany is essentially marching to its own drummer. But its experiences and lessons learned can provide valuable guidance to stakeholders in other countries.

Utilities and technology companies: prepare for business model changes. Established utilities that rely on conventional, centralized business models face significant risks from the rise of renewable and distributed generation. Incumbents should be prepared to diversify their generation portfolios early on—and this includes the possibility of entering the distributed- or renewable-generation arenas themselves. True, with the exception of large hydroelectric plants, these businesses may currently offer comparatively low returns on capital. But their economics will improve considerably over time and may ultimately be superior to those of more traditional forms of generation.

As markets evolve, utilities may also have to experiment with new business models in order to ward off competitive threats from private individuals, cooperatives, telecommunications players, and other third parties. Potential options include acting as corporate venture-capital investors and investing in technology vendors and in companies with

Exhibit 16 | Falling Costs for Solar PV Will Make Partial Self-Supply of Power Viable in Some Locations



Sources: Research Centre of the European Commission; BCG analysis.
[1]Isocost curves show all possible combinations of factors at a constant cost. Prices are as of year-end for a large rooftop installation without storage and assume the following: 85 percent efficiency of the PV module; 20-year economic lifetime; 8 percent cost of capital; annual operating expenditures 1 percent of initial investment cost; €1 = $1.30.
[2]Wp = watt-peak (a measurement of peak power).

strong capabilities in distributed-asset management—or acquiring such businesses outright.

For technology companies, the large investments accompanying the shift to renewable and distributed generation are a tremendous opportunity. For many, however, the trend toward distributed generation changes the structure and economics of their market. While focusing on large-capital-expenditure power plants and networks is an attractive option today, smaller-scale generation in solar and wind, distributed storage, and intelligent-network and consumption management will be important markets and control points tomorrow. Many technology businesses may find their conventional-technology and large-project-management expertise, as well as their utility-focused offering and sales channels, increasingly ill suited to emerging-market opportunities. As fundamental capabilities and business models are challenged, the necessary changes will be disruptive and require bold strategies and rigorous change processes.

Policymakers: shape the opportunities. There are few areas in which regulators assert more influence on fundamental market dynamics than the energy sector. Politicians should reinforce their commitment to facilitating the market's transformation by reconsidering the business case for renewable generation. Rather than viewing renewables as expensive technologies whose primary advantage is their impact on greenhouse gas emissions, policymakers need to remind themselves that the argument is increasingly about economics. A move to renewable generation means growing independence from fossil fuels and related price volatility. Last but not least, the rebuilding of the energy infrastructure necessary to accommodate a growing emphasis on renewable generation could provide a tremendous stimulus to the larger economy. While many countries do not seem ready to embark on a path as aggressive as Germany's, most would arguably benefit from a significant increase in renewables' share in the energy mix.

In effect, a country's energy policy today will help determine its industrial competitiveness 10 to 20 years from now—and renewable generation can be a weapon that should be leveraged to its fullest potential. This is particularly true for countries that have relatively advantageous geographic conditions. The southern part of Italy, for example, has nearly double the solar radiation of Germany. South Africa has even more, and it also has considerable open space that could accommodate wind parks as well as very favorable conditions for offshore wind generation. Governments need to be aware of such national assets and take steps to exploit them—in order to shape a new balance of power.

FOR FURTHER READING

The Boston Consulting Group has published other reports and articles on alternative energy that may be of interest to senior executives. Recent examples include:

Trend Study 2030+: An Economic Assessment of Germany's Energy Turnaround
A report by the German Industry Association and The Boston Consulting Group, February 2013

Toward a Zero-Carbon World: Can Renewables Deliver for Germany?
A Focus by The Boston Consulting Group, June 2012

Toward a Distributed-Power World: Renewables and Smart Grids Will Reshape the Energy Sector
A White Paper by The Boston Consulting Group, June 2010

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