Chapter 5
Electricity

Overview
In the International Energy Outlook 2016 (IEO2016) Reference case, world net electricity generation increases 69% by 2040, from 21.6 trillion kilowatthours (kWh) in 2012 to 25.8 trillion kWh in 2020 and 36.5 trillion kWh in 2040. Electricity is the world’s fastest-growing form of end-use energy consumption, as it has been for many decades. Power systems have continued to evolve from isolated, small grids to integrated national markets and even international markets.

Economic growth is an important factor in electricity demand growth. Although world gross domestic product (GDP) growth slows in the IEO2016 Reference case in comparison with the past two decades, electricity demand continues to increase, especially among the emerging non-Organization for Economic Cooperation and Development (non-OECD) economies. In 2012, electricity generation in non-OECD countries represented slightly more than one-half of world electricity demand. With continued strong economic growth, the non-OECD share of world electricity generation increases to 61% in 2040 (Figure 5-1), as total non-OECD electricity generation nearly doubles, from 11.3 trillion kWh in 2012 to 22.3 trillion kWh in 2040 (Table 5-1).

In general, the projected growth of electricity demand in OECD countries, where electricity markets are well established and electricity consumption patterns are mature, is slower than in the non-OECD countries. OECD GDP increases by 2.0%/year, less than half the 4.2%/year GDP growth projected for non-OECD countries. OECD net electricity generation increases by 38%, from 10.2 trillion kWh in 2012 to 14.2 trillion kWh in 2040.

The IEO2016 Reference case projections reflect the expectation that economic activity will continue to drive electricity demand growth; however, the rate of growth in electricity consumption continues to become smaller compared to the rate of growth in GDP. From 2005 to 2012, world GDP increased by 3.7%/year, while world net electricity generation rose by 3.2%/year. In many parts of the world, policy actions aimed at improving efficiency will help to decouple economic growth rates and electricity demand growth rates more in the future (Figure 5-2). In the IEO2016 Reference case, world GDP grows by 3.3%/year, and world net electricity generation grows by 1.9%/year, from 2012 to 2040. The 69% increase in world electricity generation through 2040 is far below what it would be if economic growth and electricity demand growth maintained the same relationship they had in the recent past.

Many countries, particularly among the developed OECD nations are pursuing policies and regulations intended to increase the pressure on generators to reduce greenhouse gas emissions from electric power plants by decreasing the use of fossil fuels. As a result, the role of coal as a dominant fuel for electric power plants is being reduced. Since the last forecast cycle, there have been significant revisions to national clean energy policies to reduce emissions, including China’s target of 15% renewable electricity by 2020,164 the European Union’s 2030 Energy Framework objectives,165 and India’s megawatts-to-gigawatts renewable energy commitment.166 The IEO2016 Reference case analysis incorporates many updated targets that reflect the revised regulations

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Electricity and national energy policies that affect renewable energy. (See later sections for region- or fuel-specific revisions.) The effect of the recently finalized Clean Power Plan (CPP) regulations in the United States is not included in the IEO2016 Reference case, but its effects are considered in discussions, tables, and figures throughout the report, based on U.S. Energy Information Administration (EIA) analysis of the proposed rule, which had similar elements.

Given the recent history of renewable energy policy and the scale of current commitments, EIA evaluated the probability that stated targets would be met, based on: (1) data on the countries' prior success in meeting renewable policy objectives, accounting for both the ambition and extent of fulfillment of targets; (2) indicators of the countries’ financial capability to build new projects; and (3) assessments of market pricing to support renewable energy sources. EIA adjusted the probabilities associated with successful implementation, with declining expectations dependent on how far into the future the target was specified.

The IEO2016 Reference case also reflects the impacts of broader policies to constrain energy-related carbon dioxide (CO2) emissions in emerging market countries, such as China and India. In those countries, policymakers have proposed a range of programs that place particular emphasis on the countries’ Intended Nationally Determined Contributions (INDCs) for addressing CO2 emissions reductions as part of the 21st Conference of Parties (COP21) meetings167 held in Paris from November 30 to December 11, 2015. In instances where the objective is clear but specific policy mechanisms are not yet known, judgment was applied to determine the likelihood that the intended outcomes would be achieved without attempting to predict specific actions. New and unanticipated government policies or legislation aimed at limiting or reducing greenhouse gas or other power-sector emissions, which could substantially change the trajectories of fossil and nonfossil fuel consumption, were not incorporated in the IEO2016 Reference case.

Table 5-1. OECD and non-OECD net electricity generation by energy source, 2012–40 (trillion kilowatthours)

<table>
<thead>
<tr>
<th>Energy source by region</th>
<th>2012</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>Average annual percent change, 2012–40</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OECD</strong></td>
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<td></td>
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<td></td>
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<td></td>
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<tr>
<td>Petroleum and other liquids</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
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</tr>
<tr>
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<td>2.6</td>
<td>2.6</td>
<td>3.0</td>
<td>3.5</td>
<td>4.0</td>
<td>4.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Coal</td>
<td>3.2</td>
<td>3.4</td>
<td>3.4</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
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<tr>
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<td>2.3</td>
<td>2.3</td>
<td>2.2</td>
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<tr>
<td>Renewables</td>
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<td>3.4</td>
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<td>2.2</td>
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<td><strong>OECD with CPP</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Petroleum and other liquids</td>
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<td>0.1</td>
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<td>3.5</td>
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<td>1.9</td>
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<tr>
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<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
<td>-0.5</td>
</tr>
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<td>2.3</td>
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</tr>
<tr>
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<td>3.6</td>
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<td></td>
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<tr>
<td>Petroleum and other liquids</td>
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<td>0.6</td>
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<td>0.5</td>
<td>0.5</td>
<td>-1.5</td>
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<tr>
<td>Natural gas</td>
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<td>4.0</td>
<td>4.8</td>
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<td>5.7</td>
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<tr>
<td>Renewables</td>
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<tr>
<td>Petroleum and other liquids</td>
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<td>0.7</td>
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<td>0.6</td>
<td>0.6</td>
<td>-2.2</td>
</tr>
<tr>
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<td>5.3</td>
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<td>8.8</td>
<td>10.1</td>
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<tr>
<td>Coal</td>
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<td>9.7</td>
<td>10.1</td>
<td>10.1</td>
<td>10.3</td>
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</tr>
<tr>
<td>Nuclear</td>
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<td>2.4</td>
</tr>
<tr>
<td>Renewables</td>
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<tr>
<td><strong>Total World with CPP</strong></td>
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<tr>
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<tr>
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<td>3.1</td>
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<tr>
<td>Renewables</td>
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<td>8.3</td>
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<td>10.1</td>
<td>11.1</td>
<td>3.1</td>
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</tbody>
</table>

The national policies represented in the IEO2016 Reference case interact with technology and fuel costs to result in a significant shift in the primary fuels used to generate electricity. Since the late 1980s, coal has consistently met 37% to 40% of world fuel requirements for electricity generation.\textsuperscript{168} In the IEO2016 Reference case, the coal share of total generation declines from 40% in 2012 to 29% in 2040, even as world coal-fired generation increases by 25% through 2040. At the same time, the shares of total generation for both renewable energy sources and natural gas expand: from 22% in 2012 to 29% in 2040 for renewables and from 22% in 2012 to 28% in 2040 for natural gas (Figure 5-3).

**Electricity generation by source**

The worldwide mix of primary fuels used to generate electricity has changed a great deal over the past several decades. Coal continues to be the fuel most widely used in electricity generation,\textsuperscript{169} but there have been significant shifts to other generation fuels. Generation from nuclear power increased rapidly from the 1970s through the 1980s, and natural gas-fired generation increased considerably after the 1980s. The use of oil for generation declined after the late 1970s, when sharp increases in oil prices encouraged power generators to substitute other energy sources for oil.\textsuperscript{170}

Beginning in the early 2000s, concerns about the environmental consequences of greenhouse gas emissions heightened interest in the development of renewable energy sources, as well as natural gas—a fossil fuel that emits significantly less CO2 than either oil or coal per kilowatthour generated. In the IEO2016 Reference case, long-term global prospects continue to improve for generation from natural gas, nuclear, and renewable energy sources. Renewables are the fastest-growing source of energy for electricity generation, with annual increases averaging 2.9% from 2012 to 2040. In particular, in the Reference case, nonhydro power renewable resources are the fastest-growing energy sources for new generation capacity in both the OECD and non-OECD regions. Nonhydropower renewables accounted for 5% of total world electricity generation in 2012; their share in 2040 is 14% in the IEO2016 Reference case, with much of the growth coming from wind power.

After renewable energy sources, natural gas and nuclear power are the next fastest-growing sources of electricity generation. From 2012 to 2040, natural gas-fired electricity generation increases by 2.7%/year and nuclear power generation increases by 2.4%/year. With coal-fired generation growing by only 0.8%/year, renewable generation (including both hydropower and nonhydropower resources) overtakes coal to become the world’s largest source of energy for electricity generation by 2040. The outlook for coal-fired electricity generation could be further altered in the future by additional national policies or international agreements aimed at reducing or limiting its use. It should be noted that the IEO2016 Reference case does not include implementation of the U.S. Clean Power Plan, which would reduce the use of coal in the United States substantially.\textsuperscript{168}

Excluding the impact of the Clean Power Plan in the United States, which would reduce overall growth by roughly 560 billion kWh, or about 5%, by 2030 according to the EIA report, *Analysis of the Impacts of the Clean Power Plan* (Washington, DC: May 2015), \url{https://www.eia.gov/analysis/requests/powerplants/cleanplan/}

Electricity generation from coal in 2040 is 23% above the 2012 total. China and India alone account for 69% of the projected worldwide increase in coal-fired generation, while the OECD nations continue to reduce their reliance on coal-fired electricity generation. With implementation of the Clean Power Plan, projections for U.S. coal-fired generation are reduced in 2030 by about one-third.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5-3.png}
\caption{World net electricity generation by fuel, 2012–40 (trillion kilowatthours)}
\end{figure}

\textsuperscript{168}International Energy Agency, “Coal statistics” (undated), \url{http://www.iea.org/statistics/topics/coal/}.

\textsuperscript{169}Excluding the impact of the Clean Power Plan in the United States, which would reduce overall growth by roughly 560 billion kWh, or about 5%, by 2030 according to the EIA report, *Analysis of the Impacts of the Clean Power Plan* (Washington, DC: May 2015), \url{https://www.eia.gov/analysis/requests/powerplants/cleanplan/}.

Electricity

Natural gas
Worldwide natural gas consumption for electricity generation grows in the IEO2016 Reference case by an average of 2.7%/year from 2012 to 2040. From 22% of total world electricity generation in 2012, the natural gas share increases to 28% in 2040 in the IEO2016 Reference case. In the United States, natural gas-fired generation is encouraged by low prices and favorable greenhouse gas emission characteristics. Natural gas is the least carbon-intensive fossil fuel; like all fossil fuels, natural gas combustion emits carbon dioxide, but at about half the rate of coal. In addition, natural gas generation technologies are more efficient than coal generation in producing electricity. Thus, natural gas can help in meeting CO2 reduction goals for many countries.

Petroleum and other liquid fuels
The use of petroleum and other liquid fuels for electricity generation continues to decline steadily in the IEO2016 Reference case. The share of total world generation from liquid fuels falls from 5% in 2012 to 2% in 2040, an average decline of 2.2%/year. Despite their recent decline, oil prices are expected to be higher in the long-term projection. As a result, liquids remain a more expensive option compared to other fuels used for generating electricity, and generators replace liquids-fired generation with other fuels where possible. Since June 2014, world oil prices have decreased substantially, falling to less than $40 per barrel in December 2015—a level last observed in late 2008, during the worldwide economic recession. The most notable regional declines in petroleum use for electricity generation are projected for the Middle East, Mexico, and Japan, where policy movements have encouraged the phasing out of oil in the electric power sector.

Renewable resources
Renewables account for a rising share of the world’s total electricity supply, and they are the fastest growing source of electricity generation in the IEO2016 Reference case (Figure 5-4). Total generation from renewable resources increases by 2.9%/year, as the renewable share of world electricity generation grows from 22% in 2012 to 29% in 2040 (Table 5-2). Generation from nonhydropower renewables is the predominant source of the increase, rising by an average of 5.7%/year and outpacing increases in natural gas (2.7%/year), nuclear (2.4%/year), and coal (0.8%/year), even without taking into account the growth in renewable generation anticipated under the Clean Power Plan in the United States. By 2030, the CPP would increase U.S. renewables generation by roughly 396 billion kWh (58%) compared to the IEO2016 Reference case, according to EIA’s analysis of the proposed CPP rule. Solar is the world’s fastest-growing form of renewable energy, with net solar generation increasing by an average of 8.3%/year. Of the 5.9 trillion kWh of new renewable generation added over the projection period, hydroelectric and wind each account for 1.9 trillion kWh (33%), solar energy for 859 billion kWh (15%), and other renewables (mostly biomass and waste) for 856 billion kWh (14%).

In the IEO2016 Reference case, the pattern of growth in renewable electricity generation differs between the OECD regions and non-OECD regions in two ways: the relative rates of increase in generation from nonhydropower renewables and the potential expansion of hydropower capacity. Non-OECD countries surpass OECD countries in their use of nonhydropower renewables for electricity generation by the end of the projection in 2040. OECD net generation from nonhydropower renewables totals 2.3 trillion kWh (or 2.7 trillion kWh with the U.S. Clean Power Plan), compared with the non-OECD total of 2.8 trillion kWh. The difference is primarily the result of ambitious solar targets adopted principally by India and China, and to some extent by other emerging market countries (see “World production of solar photovoltaic modules,” below). In the non-OECD region as a whole, solar generation grows by 15.7%/year on average from 2012 to 2040, nearly twice the growth rates for wind (7.7%/year) and geothermal (8.6%/year). In the OECD region, by comparison, wind, solar, and geothermal generation grow at comparable rates of about 4.5%/year.

Even with the projected strong growth of electricity generation from nonhydropower renewable energy sources in the non-OECD region, hydropower remains an important source of growth in the region’s renewable energy use. Non-OECD hydropower generation increases by 71% from 2012 to 2040, accounting for almost 40% of the total increase in non-OECD renewable electricity generation over the period. The world’s fastest regional growth in hydroelectric generation is projected for non-OECD Asia (see “Plans for hydroelectric generation capacity additions in Southeast Asia,” below). Hydroelectricity production in non-OECD Asia increases by 2.2%/year on average from 2012 to 2040.

Figure 5-4. World net electricity generation from renewable power by fuel, 2012–40 (trillion kilowatthours)

<table>
<thead>
<tr>
<th>Year</th>
<th>Hydropower</th>
<th>Geothermal</th>
<th>Solar</th>
<th>Wind</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2020</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2025</td>
<td>10</td>
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<td>2030</td>
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<td>2040</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: Other generation includes biomass, waste, and tide/wave/ocean.
World production of solar photovoltaic modules

Growth in solar photovoltaic (PV) manufacturing production and the expansion of manufacturing capability have slowed in recent years. From 2006 to 2011, both the world’s total production of PV modules and the combined world capability for production of PV modules grew by an average of 78%/year. From 2011 to 2013, however, their respective annual growth rates fell to 4%/year and 8%/year. In addition, the difference between global PV module manufacturing capability and production has grown in recent years, leading to lower utilization rates of manufacturing facilities. In 2013, global PV module production was 39.9 gigawatts (GW), and global PV module manufacturing capability was 60.5 GW/year. The difference between production and capability in 2013 was 20.6 GW/year, up from 15.4 GW/year in 2011 (Figure 5-5).

In reaction to the slow growth of module production and the excess capacity for PV manufacturing, PV manufacturing companies have been downsizing and consolidating. For example, Germany reported to the International Energy Agency (IEA) that a total of 40 PV companies were operating in that country at the end of 2013, with approximately 11,000 employees, down from 62 companies with more than 32,000 employees at the end of 2008.171 Similar trends were reported by China.

China continues to be the largest producer of PV modules, accounting for more than 60% of annual global production in recent years—23 GW in 2012 and 26 GW in 2013 (Figure 5-6). However, China is the sixth-largest market for PV, behind Germany, Italy, ... (continued on page 86)

Table 5-2. OECD and non-OECD net renewable electricity generation by energy source, 2010–40 (billion kilowatthours)

<table>
<thead>
<tr>
<th>Energy source by region</th>
<th>2012</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>Average annual percent change, 2012–40</th>
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</thead>
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<tr>
<td><strong>OECD</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydroelectricity</td>
<td>1,375</td>
<td>1,482</td>
<td>1,532</td>
<td>1,558</td>
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<td>107</td>
<td>121</td>
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<td>270</td>
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<td>324</td>
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<td>1,562</td>
<td>1,596</td>
<td>1,699</td>
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<td>1,592</td>
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<td>489</td>
<td>6.1</td>
</tr>
<tr>
<td>Biomass, waste, tide/wave/ocean</td>
<td>281</td>
<td>395</td>
<td>435</td>
<td>458</td>
<td>483</td>
<td>518</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Non-OECD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydroelectricity</td>
<td>2,270</td>
<td>2,812</td>
<td>3,095</td>
<td>3,258</td>
<td>3,554</td>
<td>3,875</td>
<td>1.9</td>
</tr>
<tr>
<td>Wind</td>
<td>142</td>
<td>506</td>
<td>693</td>
<td>845</td>
<td>995</td>
<td>1,143</td>
<td>7.7</td>
</tr>
<tr>
<td>Geothermal</td>
<td>26</td>
<td>65</td>
<td>118</td>
<td>202</td>
<td>230</td>
<td>261</td>
<td>8.6</td>
</tr>
<tr>
<td>Solar</td>
<td>11</td>
<td>219</td>
<td>352</td>
<td>452</td>
<td>556</td>
<td>638</td>
<td>15.7</td>
</tr>
<tr>
<td>Biomass, waste, tide/wave/ocean</td>
<td>110</td>
<td>296</td>
<td>425</td>
<td>513</td>
<td>622</td>
<td>725</td>
<td>7.0</td>
</tr>
<tr>
<td><strong>Total World</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydroelectricity</td>
<td>3,645</td>
<td>4,294</td>
<td>4,626</td>
<td>4,816</td>
<td>5,146</td>
<td>5,571</td>
<td>1.5</td>
</tr>
<tr>
<td>Wind</td>
<td>520</td>
<td>1,312</td>
<td>1,603</td>
<td>1,863</td>
<td>2,192</td>
<td>2,452</td>
<td>5.7</td>
</tr>
<tr>
<td>Geothermal</td>
<td>68</td>
<td>139</td>
<td>208</td>
<td>309</td>
<td>352</td>
<td>395</td>
<td>6.5</td>
</tr>
<tr>
<td>Solar</td>
<td>103</td>
<td>448</td>
<td>599</td>
<td>722</td>
<td>847</td>
<td>962</td>
<td>8.3</td>
</tr>
<tr>
<td>Biomass, waste, tide/wave/ocean</td>
<td>391</td>
<td>681</td>
<td>857</td>
<td>973</td>
<td>1,107</td>
<td>1,247</td>
<td>4.2</td>
</tr>
<tr>
<td><strong>Total World with CPP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydroelectricity</td>
<td>3,645</td>
<td>4,297</td>
<td>4,631</td>
<td>4,820</td>
<td>5,150</td>
<td>5,574</td>
<td>1.5</td>
</tr>
<tr>
<td>Wind</td>
<td>520</td>
<td>1,352</td>
<td>1,914</td>
<td>2,180</td>
<td>2,488</td>
<td>2,735</td>
<td>6.1</td>
</tr>
<tr>
<td>Geothermal</td>
<td>68</td>
<td>140</td>
<td>209</td>
<td>310</td>
<td>352</td>
<td>395</td>
<td>6.5</td>
</tr>
<tr>
<td>Solar</td>
<td>103</td>
<td>456</td>
<td>652</td>
<td>799</td>
<td>961</td>
<td>1,127</td>
<td>8.9</td>
</tr>
<tr>
<td>Biomass, waste, tide/wave/ocean</td>
<td>391</td>
<td>691</td>
<td>860</td>
<td>971</td>
<td>1,105</td>
<td>1,242</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Japan, Spain, and France. China installed 0.2 GW of solar PV capacity in 2012, bringing its total installed PV capacity to 3.3 GW at the end of the year.

At the end of 2012, global installed solar PV capacity totaled 90 GW. More than 30 countries have established national solar generation capacity targets for 2020, and many other countries have set targets for years before or after 2020. The combined national targets for 2020 total more than 350 GW. Total installed solar PV capacity in the top six countries represented 76% of the world total in 2012 and 61% of the global target total for 2020. At current PV manufacturing capability of 60 GW/year, there is sufficient capability to supply an additional 400 GW of new capacity between 2013 and 2020, well above the aggregated national targets.

It is important to note that national targets do not necessarily correspond with projections of future solar PV market capacity. In the IEO2016 projections, all stated objectives for installation of renewable electricity capacity, including solar PV are not necessarily achieved. Also, most countries continually adjust their targets. For example, India in mid-2015 increased its PV capacity target for 2022 from 20 GW to 100 GW.172

Plans for hydroelectric generation capacity additions in Southeast Asia

The development of hydroelectric power in China—including the world’s biggest hydropower plant at Three Gorges Dam—is substantially larger than planned expansions of hydroelectric power capacity in other countries of Southeast Asia.173 The smaller countries in the region have announced plans to construct a combined total of 78 gigawatts (GW) of new hydroelectric generating capacity by the end of 2020. If those projects are completed, total hydropower capacity in the smaller countries will triple their combined 2012 capacity of 39 GW (Figure 5-7).

Many of the countries in Southeast Asia have access to the immense hydroelectric potential of the lower Mekong River, which flows through or borders China, Myanmar, Laos, Thailand, Cambodia, and Vietnam. Hydroelectric power potential in the Greater Mekong Region (which includes Mekong tributaries) is estimated to be between 175 GW and 250 GW.174 China already has constructed 6 major dams along the upper portion of the Mekong, and as of 2010 another 71 Mekong hydroelectric dams were proposed for completion in other Southeast Asia countries by 2030.175 Vietnam, Indonesia, Bhutan, and Laos already have announced plans for significant additions to hydroelectric capacity in the Mekong region, as well as projects centered on other hydroelectric resources.

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Vietnam has the most ambitious hydroelectric development plan in Southeast Asia, with plans to increase total hydroelectric capacity to 21.6 GW in 2020 and to 27.8 GW by 2030. One of the largest planned projects is Trung Son, to be located on the Ma River in northern Vietnam (which is not a Mekong tributary), with an expected capacity of 360 megawatts (MW).

Indonesia’s goal is to develop 3 GW of new hydroelectric generating capacity, including the 1,040-MW Upper Cisokan pumped storage power facility, expected to be in service by the end of 2018, which would be one of the largest hydroelectric projects outside China.

Bhutan, a relatively small, mountainous country surrounded by India and China, plans to build 10 GW of hydroelectric generating capacity, with much of the electricity to be exported to India, which is funding the projects. Many of Bhutan’s rivers feature high vertical drops over short distances, which are ideal for hydroelectric generation. Three of the proposed facilities, with a combined capacity of 2,940 MW, are currently under construction.

Laos, with existing hydroelectric generating capacity of about 2.5 GW, plans to add more than 6.5 GW by 2020, including 17 projects—with a combined total capacity of more than 4.5 GW—that are in planning stages. More than one-fourth of the planned capacity in Laos is represented by the 1,285-MW Xayaburi hydroelectric power plant, which is the first of 11 planned hydroelectric generating plants along the lower Mekong River. Laos, like Bhutan, expects to be a major electricity exporter.

Despite the strong development and electrification potential of the planned Mekong River projects, there are major concerns about the environmental impacts of damming the Mekong and other rivers in Southeast Asia. An independent Strategic Environmental Assessment prepared for the Mekong River Commission recommended a 10-year delay in the current schedules for hydroelectric projects in the region to address environmental concerns.

Hydropower development potential is much lower in the OECD member countries than in the non-OECD countries, because most of the OECD region’s economically feasible hydroelectric resources already have been developed. Instead, the greatest potential for growth in renewable energy production in the OECD countries is from nonhydroelectric sources, especially wind, solar, and wood pellets (see “World markets for wood pellets,” below). Many OECD countries, and particularly those in Europe, have government policies that encourage the construction of wind and other nonhydroelectric renewable electricity generation facilities.

World markets for wood pellets

Global production of wood pellets has increased significantly over the past five years, and demand in the European Union (EU) has led to international trade in this renewable energy source. In 2013, the EU accounted for 85% of the world’s total consumption of wood pellets for energy production. Wood pellets can be used for heating homes and businesses and as a fuel for small-scale industrial boilers. In the United Kingdom, Belgium, and the Netherlands, they are used predominantly for utility-scale electricity generation.

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The increase in consumption of wood pellets in Europe is primarily a result of the European Commission’s 2020 climate and energy plan, which calls for a reduction in greenhouse gas emissions and an increase in renewable energy as a percentage of total energy consumption,184 with individual member states assigned national renewable energy targets. Until recently, the United Kingdom had relied on wood pellets in cofiring or dedicated biomass power plants as part of its compliance plan.185 Approximately 45% of Europe’s demand for wood pellets is met by trade within the EU, and the remainder is met primarily by imports from the United States, Canada, and Russia. The United States currently is the world’s largest exporter of wood pellets, having surpassed Canada in 2012. Total U.S. exports of wood pellets increased by nearly 40%, from 3.2 million short tons in 2013 to 4.4 million short tons in 2014 (Figure 5-8). According to the U.S. International Trade Commission and Statistics Canada, wood pellet exports from the United States and Canada in 2014 accounted for more than $500 million and $220 million in trade, respectively.186 In 2014, almost three-quarters of all U.S. wood pellet exports were delivered to the United Kingdom, mainly for the purpose of generating electricity. The United Kingdom’s renewable energy plan has resulted in plant operators of large coal-fired power plants either retrofitting existing units to cofire with wood pellets or converting them to dedicated biomass plants.187

Data from the United Kingdom (UK) Department of Energy and Climate Change indicate that electricity generation from plant-based biomass (which includes wood pellets) increased by 47%, from 8,933 gigawatthours (GWh) in 2013 to 13,138 GWh in 2014, led by the conversion of the Drax power plant in north-central England from coal to biomass.188 The Drax plant, located east of Leeds, England, has six units that together are rated at nearly 4 gigawatts (GW) of electricity generation capacity. Data released by the Drax Group indicate that the first of six units was converted to dedicated biomass in 2013, and biomass provided 1.8 million short tons of fuel supply in that year.189 A second unit was converted in 2014, and the amount of biomass supplied to the plant increased by more than 150%, providing 4.5 million short tons of fuel. In 2014, wood pellets supplied to the Drax power plant alone accounted for more than 80% of the wood pellets exported to the United Kingdom from the United States and 90% of the wood pellets sent from Canada. Almost 60% of all U.S. wood pellet exports and approximately 54% of all Canadian wood pellet exports in 2014 went to the Drax plant. The United States and Canada are the largest suppliers of pellets to the United Kingdom, providing 61% and 19% of its total supply, respectively, followed by the Baltic countries (10%) and Portugal (9%).

In July 2015, the UK Department of Energy and Climate Change announced that it was cutting subsidies to biomass by removing the grandfather clause in the Renewables Obligation (RO) for new dedicated biomass and cofiring projects. The two converted biomass units at the Drax plant are exempt from the subsidy cut, as the third unit will be when it is built.190 Demand for wood pellets also is increasing in South Korea and Japan, primarily for use with coal in cofiring applications. After the earthquake and tsunami in Japan in 2011 and the resulting closures of several nuclear plants, Japan has tried to close the gap in energy supply by increasing renewable energy generation. In South Korea, the introduction of a renewable portfolio standard in 2012 increased interest in the use of biomass and wood pellets for energy generation. Imports to the two countries come predominantly from Canada, Southeast Asia, and the United States.191 According to Bloomberg New Energy Finance, South Korea’s demand for wood pellets in 2014 was estimated at 2.2 million short tons, equal to approximately 40% of the United Kingdom’s total.192

185Cofiring is the simultaneous combustion of two different fuels—usually coal and biomass. Dedicated biomass plants run completely on biomass.
Electricity

Nuclear power
Worldwide electricity generation from nuclear power increases from 2.3 trillion kWh in 2012 to 4.5 trillion kWh in 2040 in the IEO2016 Reference case, with energy security concerns and limits on greenhouse gas emissions encouraging the development of new nuclear capacity. In addition, world average capacity utilization rates for nuclear power plants have continued to rise over time, from 68% in 1980 to 80% in 2012. In some regions, utilization rates could continue rising in the future. Factors underlying the nuclear power projections in the IEO2016 Reference case include the consequences of the March 2011 disaster at Fukushima Daiichi, Japan; planned retirements of nuclear power plants in OECD Europe under current policies; and continued strong growth of nuclear power capacity in non-OECD Asia (see “Variability in electricity generation capacity factors by region and fuel,” below).

Variability in electricity generation capacity factors by region and fuel
Across the IEO regions, the mix of fuels and technologies used for electricity generation is limited, but the patterns of generator use—measured by annual capacity factors, or the ratio of generation to capacity—vary significantly. Analysis of generating plant utilization from 2008 through 2012 shows wide variability among fuel types and among world regions.

The variations in annual capacity factors can be attributed to a wide range of factors:
• Differences in daily load patterns, which reflect the mix of demand from buildings and industry, among other factors
• Differences in operating costs, which are driven mainly by fuel costs
• Planned outages of units to meet regulatory and maintenance requirements, as well as unplanned outages
• Differences in the efficiencies of generating technologies
• Constraints resulting from resource availability, commonly associated with generators that use renewable resources.

Annual capacity factors also can be affected by partial-year generation effects if the unit was installed within the past year. By convention, the numerator of the capacity factor is the actual generation from the unit, and the denominator is what that generator could have provided, assuming continuous operation for a full year. Projects commissioned in the second half of the year will have only a few months of generation to report, resulting in capacity factors lower than expected for a full year of operation. The data presented here reflect five-year averages ending in 2012, the most recent year for which both generation and capacity data are available for all of the geographic areas discussed (Figure 5-9).

Figure 5-9. Average annual capacity factors for electricity generators by IEO region and energy source, 2008–12 (percent)

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Coal</th>
<th>Natural gas</th>
<th>Petroleum</th>
<th>Nuclear</th>
<th>Hydropower</th>
<th>Solar and wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>66%</td>
<td>26%</td>
<td>13%</td>
<td>90%</td>
<td>40%</td>
<td>27%</td>
</tr>
<tr>
<td>Canada</td>
<td>62%</td>
<td>29%</td>
<td>20%</td>
<td>78%</td>
<td>56%</td>
<td>26%</td>
</tr>
<tr>
<td>Mexico/Chile</td>
<td>64%</td>
<td>51%</td>
<td>40%</td>
<td>73%</td>
<td>37%</td>
<td>23%</td>
</tr>
<tr>
<td>Brazil</td>
<td>44%</td>
<td>29%</td>
<td>28%</td>
<td>85%</td>
<td>56%</td>
<td>24%</td>
</tr>
<tr>
<td>Other Americas</td>
<td>43%</td>
<td>31%</td>
<td>19%</td>
<td>80%</td>
<td>57%</td>
<td>26%</td>
</tr>
<tr>
<td>OECD Europe</td>
<td>51%</td>
<td>39%</td>
<td>53%</td>
<td>77%</td>
<td>40%</td>
<td>18%</td>
</tr>
<tr>
<td>Non-OECD Europe and Eurasia</td>
<td>41%</td>
<td>43%</td>
<td>10%</td>
<td>80%</td>
<td>40%</td>
<td>3%</td>
</tr>
<tr>
<td>Russia</td>
<td>38%</td>
<td>52%</td>
<td>66%</td>
<td>83%</td>
<td>37%</td>
<td>18%</td>
</tr>
<tr>
<td>China</td>
<td>54%</td>
<td>19%</td>
<td>18%</td>
<td>83%</td>
<td>34%</td>
<td>18%</td>
</tr>
<tr>
<td>India</td>
<td>60%</td>
<td>50%</td>
<td>35%</td>
<td>58%</td>
<td>34%</td>
<td>3%</td>
</tr>
<tr>
<td>Japan</td>
<td>62%</td>
<td>44%</td>
<td>26%</td>
<td>48%</td>
<td>40%</td>
<td>15%</td>
</tr>
<tr>
<td>South Korea</td>
<td>82%</td>
<td>40%</td>
<td>43%</td>
<td>88%</td>
<td>25%</td>
<td>16%</td>
</tr>
<tr>
<td>Non-OECD Asia</td>
<td>62%</td>
<td>42%</td>
<td>34%</td>
<td>88%</td>
<td>38%</td>
<td>22%</td>
</tr>
<tr>
<td>Middle East</td>
<td>21%</td>
<td>39%</td>
<td>34%</td>
<td>8%</td>
<td>15%</td>
<td>23%</td>
</tr>
<tr>
<td>Africa</td>
<td>73%</td>
<td>44%</td>
<td>54%</td>
<td>79%</td>
<td>49%</td>
<td>27%</td>
</tr>
<tr>
<td>Australia/New Zealand</td>
<td>65%</td>
<td>31%</td>
<td>33%</td>
<td>--</td>
<td>32%</td>
<td>25%</td>
</tr>
</tbody>
</table>

Note: Solar and wind capacity factors for Russia and the Other Americas region include only wind capacity. Australia/New Zealand has no installed nuclear capacity.

Capacity factors for the five-year period are averages, weighted for generators’ annual capacities. For regions with capacity factors missing for some years, only the available capacity factors are used to calculate the five-year weighted average.
Renewable electricity generating plants depend on the availability of renewable resources, such as solar, wind, and water. Because the use of renewable technologies, such as wind and solar, is growing rapidly in many regions—often starting from relatively small installed baselines—reported capacity factors are particularly affected by partial-year generation effects. Solar capacity factors are highest in India and in parts of Africa, where the availability of solar resources is high. Similarly, wind capacity factors are highest in Australia and New Zealand, and hydroelectric capacity factors are highest in Canada and South America.

In the United States, the five-year average solar capacity factor is 15%. In comparison, solar capacity factors in other countries and regions are considerably lower: solar generators in Canada have a five-year average capacity factor of 6%; non-OECD Europe and Eurasia 5%; and the Middle East 8%. Rapid expansion of solar capacity from 2008 through 2012 resulted in partial-year generation effects, contributing to low five-year average utilization. Another explanation for low solar capacity factors in some regions is the common convention of reporting solar photovoltaic (PV) capacity in terms of the direct current (DC) nameplate rating of PV panels, rather than in terms of the alternating current (AC) rating of the grid-tied inverter for the system. Because generation typically is measured and reported in AC terms, and solar PV systems often are designed with lower AC ratings than DC ratings, their apparent capacity factors are lower than they would be if the capacity were reported in DC terms.

In many regions of the world, including the United States, the average capacity factor of wind generating facilities from 2008 through 2012 was approximately 30%; however, the average capacity factor for wind facilities in China during the same period was 18%, primarily because of partial-year generation effects caused by rapid capacity expansion. The 3% capacity factor for wind facilities in Russia is particularly low. Most of Russia’s small-scale wind production facilities are located in agricultural areas with low population densities, and as a result, there are lags in connecting them to the grid.

Capacity factors for nuclear power plants are the least variable. Nuclear plants typically operate throughout the year as baseload generation sources in most countries. However, operational or regulatory requirements can interrupt their production, as in the case of Japan’s 2011 earthquake, which resulted in a low five-year average capacity factor for all nuclear generators in Japan because of the prolonged shutdown of the country’s reactors that followed. In the United States, the baseline average annual capacity factor for nuclear power generating plants from 2008 through 2012 was 90%. In other countries and regions, nuclear capacity factors average 73%, as a result of different operating policies and regulatory requirements. The differences in regulatory and operational requirements between OECD Europe and the United States, including nuclear refueling schedules, contributed to the 77% baseline nuclear plant capacity factor for OECD Europe from 2008 through 2012, which was 13% lower than the U.S. average.

Capacity factors for fossil-fired generators also can vary widely within a single country or region. Coal-fired generation has been the most economic form of fossil fuel generation in many regions, but growing environmental concerns associated with coal-fired generation, as well as competition from natural gas-fired and renewable generation, has recently led to lower capacity factors for coal-fired power plants in some countries. For example, South Korea’s fleet of coal-fired power plants had an average capacity factor of 82% from 2008 through 2012, while the average for natural gas-fired plants and petroleum-fired plants was about 40%. Coal-fired units had significantly higher capacity factors because of significant improvements in efficiency (in 2010, 70% of South Korea’s total coal-fired generation came from highly efficient supercritical units). Also, with the price of coal in South Korea much lower than the price of imported liquefied natural gas, producers generated more electricity from the country’s fleet of coal-fired power plants.

In contrast to South Korea, coal-fired power plants in the United States recorded a 66% capacity factor from 2008 through 2012. The United States reported strong growth in both capacity and generation for power plants using natural gas and renewables, in part as the result of falling natural gas prices and new policies that promoted the adoption of renewable energy. In addition, the U.S. coal-fired generator fleet comprised primarily low-efficiency, aging subcritical units. In 2012, about half of all U.S. coal power plants were at least 40 years old. In addition, the installation and operation of pollution-control equipment required by a range of regulatory and operational requirements between OECD Europe and the United States, including nuclear refueling schedules, contributed to the 77% baseline nuclear plant capacity factor for OECD Europe from 2008 through 2012, which was 13% lower than the U.S. average.

A substantial share of China’s total generating capacity consists of subcritical coal-fired units, and China reported an average capacity factor of 51% for its coal-fired fleet from 2008 through 2012, even as it was aggressively upgrading its coal-fired fleet with more efficient ultra-supercritical units.

For example, a typical solar PV plant might have a DC rating of 10 megawatts (MW) and an AC rating of 8 MW. If the plant produced 14,016 MWh of AC generation per year, its AC-rated capacity factor (based on AC generation) would be 20%, but its apparent DC-rated capacity factor, based on the DC capacity rating and the AC generation, would be only 16%.


Under ideal conditions, an ultra-supercritical turbine cycle system can convert steam into rotational energy at 54% or higher efficiency, supercritical turbine cycles can achieve 50% efficiency, and subcritical turbine cycles can achieve 46% efficiency.

supercritical and ultra-supercritical units. The relatively low capacity factor for coal-fired power plants can be explained by the use of coal-fired units to satisfy peak demand requirements in China, a rapid buildup of new coal-fired capacity, and a large increase in hydroelectric generating capacity during that period.

OECD Europe's relatively low 54% capacity factor for coal-fired generators from 2008 through 2012 can be explained by the combination of lower electricity demand and growth in renewable capacity (65% annual growth in solar capacity and 13% annual growth in wind capacity over the four-year period), driven by Europe's regulatory policies related to power plant emissions, as well as increased penetration of natural gas as a fuel for electricity generation (4% annual growth).

Because natural gas and petroleum prices are typically higher than coal prices in most regions, plants using natural gas or petroleum usually operate during periods of peak and intermediate demand for electricity. Both Mexico and Russia, with high levels of natural gas production, demonstrated relatively high capacity factors for natural gas-fired generation from 2008 through 2012. Similarly, the Middle East, with abundant domestic petroleum resources, maintained a high capacity factor (84%) for its petroleum-fired generating fleet.

Despite significant public opposition to nuclear power in Japan, two nuclear reactors at Sendai were restarted in 2015 under new safety standards put in place after the 2011 Fukushima disaster. In Europe, Germany aims to move from fossil fuel-based electricity generation to a largely carbon-free energy sector while also phasing out nuclear energy by 2022. Among the developed OECD countries, only South Korea has a sizable increase in nuclear capacity (15 GW) through 2040 in the IEO2016 Reference case. However, reductions of nuclear power capacity in Canada, OECD Europe, and Japan more than offset South Korea's increase. As a result, total OECD nuclear power capacity declines by 6 GW from 2012 to 2040.

Almost all the nuclear capacity additions in the IEO2016 Reference case occur in non-OECD countries. In contrast to developments in OECD Europe, nuclear electricity generation grows significantly in Asia, with the strongest growth projected for China and India. In addition, sizeable increases are projected for nuclear power capacity in the Middle East. Average annual growth rates for nuclear electricity generation from 2012 to 2040 in the Reference case include 9.6% in China, 7.9% in India, and 2.9% in the other non-OECD Asia economies. China has the largest projected increase in nuclear capacity, adding 139 GW from 2012 to 2040, followed by 36 GW in India and 8 GW in the remaining non-OECD Asian countries. In the Middle East, nuclear capacity increases from less than 1 GW in 2012 to 22 GW in 2030.

Regional electricity markets in non-OECD Asia

In non-OECD Asia, with some of the world's fastest-growing economies, electricity demand is expected to grow strongly as standards of living rise, and as demand for lighting, heating and cooling, and electric appliances increases. Non-OECD Asia remains the fastest-growing region in the world, with projected GDP growth of 4.7%/year through 2040. Many of the key non-OECD Asia economies (including Hong Kong, Indonesia, Singapore, and Taiwan) rely heavily on exports, both to China and to OECD nations. For these export-dependent Asian countries, slower economic growth in China and the OECD at large is likely to lower their own GDP growth in the near term.

In view of increasing pressure to reduce greenhouse gas emissions, the likely responses of the non-OECD Asia subregions are reflected in projections for coal-fired shares of total electricity generation. In particular, the most significant reduction in coal-fired generation among the non-OECD Asia regions in the IEO2016 Reference case is projected for China (Figure 5-10).

China

Despite some moderation in its projected economic growth, China remains one of the world's fastest-growing economies in the IEO2016 Reference case. As a result, its total net electricity
generation nearly doubles from 4.8 trillion kWh in 2012 to 9.4 trillion kWh in 2040, at an average annual growth rate of 2.5%. The impact of China’s continued rapid economic development on the environment has become a primary concern among environmental policymakers in China and also for the general public. In particular, China recently introduced a number of policies and proposals to address heightened concerns about air quality. In a joint statement in November 2014, both China and the United States committed to actions designed to ensure long-run reductions in emissions, with China targeting a reduction in CO2 emissions beginning by 2030. 203 China is moving to generate more electric power from nuclear power, renewables, and natural gas to address environmental concerns and to diversify its electricity generation fuel mix toward energy sources with lower or zero emissions of greenhouse gases.

In June 2015, China outlined the specific steps needed to achieve a decline in its CO2 emissions beginning in 2030. The government’s INDC policy includes the following energy-related targets for China:

- Lower carbon intensity (CO2 per unit of GDP) by 60% to 65% compared with 2005 levels
- Increase the share of nonfossil fuels in the primary energy mix to approximately 20%. 204

At the time of the announcement of its commitment to peak emissions in 2030, China’s government officials estimated that to achieve that target it would be necessary to build 800–1,000 gigawatts of non-emitting generating capacity by 2030, thus offering a comparative benchmark for projections. 205

In adapting assumptions regarding China’s announced multisector policies to achieve emissions reductions in the electric power sector, IEO2016 combines the application of broad policy levers to alter the use of fossil generation in the projection with detailed analysis of renewable targets, including assessment of their timing and achievement up to 2030.

In recent years, the cost of renewable technologies has continued to decline, with the greatest cost reductions recorded for solar technologies. However, clean energy policy goals also play a major role in the adoption of renewable energy sources in China. Renewables policy targets include both the stated specific national-level goals formally included in various Five-Year Plans and an interpretation of the implications of general policy commitments to additions of renewable generating capacity (for example, capacity growth resulting from the preservation of renewables market share after the deadlines for achieving renewable targets have passed). The 12th Five-Year Plan (2011–15) includes a target to increase nonfossil energy sources (including hydropower, nuclear, and renewable energy) to 11.4% of total energy use (up from 8.3% in 2010). In addition, the plan sets a 15% overall target for the renewable share of total electricity generation in 2020.

China’s renewable energy outlook in the IEO2016 Reference case reflects the policy effects of identified Chinese government targets for specific renewable fuel types from 2015 to 2020, the results for previous Five-Year Plans, and the economic outlook for growth in the electric power sector through the next decade. Projected renewable energy capacity additions are on track to achieve a combined 622 GW of total installed hydroelectric, wind, and solar generating capacity in 2020 (Figure 5-11). At that rate, renewables and nuclear power would fulfill their part in China’s INDC to increase the share of non-fossil fuels in the primary energy mix to approximately 20% by 2030. Strong growth in both wind and solar installed generating capacity supports the projected growth in China’s renewable energy use, with installed solar capacity increasing from 3 GW in 2012 to 184 GW in 2040 and wind energy capacity increasing from 61 GW in 2012 to 350 GW in 2040.

In 2012, coal’s share of China’s total electricity generation was estimated at 75%. Assuming the phase-in of various government policies through 2030 in the IEO2016 Reference case, the coal share declines to an estimated 53% in 2030 and to 44% in 2040 (Figure 5-12). Overall, renewable electricity generation increases by an average of 3.8%/year and nearly triples, from 1,004 billion kWh in 2012 to 2,878 billion kWh in 2040. Solar is China’s fastest-growing energy source in the IEO2016 Reference case, with annual growth averaging 15.4% through 2040.

Another rapidly growing energy source in China’s electric power sector in the IEO2016 Reference case is nuclear power generation. Net electricity generation from the country’s nuclear power plants grows by an average of 9.6%/year, from 93 billion kWh in 2012 to 1,212 billion kWh in 2040. In addition, although natural gas previously has not played a significant role

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204 World Resources Institute, “CAIT Climate Data Explorer: China” (last updated July 1, 2015), http://cait.wri.org/indc/#/profile/China.

in China’s electric power sector, natural gas-fired generation grows at a comparable rate of 9.9%/year from 2012 to 2040 in the Reference case. As a result, the natural gas share of total electricity generation increases from 2% in 2012 to 12% in 2040. A major factor in the expanding role of natural gas in electricity generation is an increase in sources of natural gas supply, including contracts with Russia for large-scale construction of natural gas pipelines between the two countries, financed by China, with the first stage calling for a pipeline with the capacity to carry 1.3 trillion cubic feet per year.206

**India**

India’s need for energy continues to increase as a result of its economic growth and modernization over the past several years. With nearly a quarter of its population having no access to electricity, a significant component of progress for the Indian economy lies in the prospects for electrification.207 As a result, India has one of the fastest-growing electricity sectors in the world. Between 2005 and 2012, India’s net electricity generation increased by an average 6.6%/year (Figure 5-13). In the IEO2016 Reference case, net electricity generation in India increases from 1,052 billion kWh in 2012 to 2,769 billion kWh in 2040; at 3.5%/year, this is the fastest growth of any IEO2016 region over the projection period.

With a large-scale domestic production potential, coal is India’s primary source of energy for electricity generation. However, as electricity demand has risen sharply, a widening gap between coal demand and supply has emerged, with coal shortages contributing to blackouts in India. In response to rapid demand growth, India has increased capacity and upgraded efficiency of its transmission grid, which has helped to reduce electricity losses. However, most of the country’s remaining transmission and distribution losses are the result of theft (see “Electricity transmission and distribution system losses in India,” below).

**Electricity transmission and distribution system losses in India**

India’s state-owned utilities have a history of large losses of electricity from their transmission and distribution (T&D) systems, resulting from both technical inefficiencies and theft. For example, in fiscal year (FY) 2001 nearly one-third of all the electricity generated by the utilities did not reach the intended customers.208 Since FY 2001, the government’s efforts have cut the country’s total T&D losses to about one-fifth of the electricity generated and delivered to the power grid.

India’s T&D losses are among the highest in the world (Figure 5-14). High loss levels have contributed to electricity supply outages throughout the country—including, in 2012, the largest power outage in the world.209 They also have led to financial bailouts of the country’s utilities by the central government in FY 2001 and FY 2011.210 In FY 2014, average annual electricity demand exceeded the amount of electricity India’s electric utilities could supply by 3.6% (and by 4.7% during periods of peak demand).211 India’s

(continued on page 94)
Central Electricity Authority, which is responsible for overall development of the power sector, expects a total electricity shortage of 2.1%, and a peak demand shortage of 2.6%, in FY 2015. Improving T&D losses by even a few percentage points would help lower the country’s electricity shortages and help reduce the number of outages.

Technical losses are caused by the resistance of wires and equipment, when the electricity passing through them is converted to heat. Normal T&D losses—generally between 6% and 8%—can be reduced by upgrading transmission lines and power transformers and by improving electric power dispatch planning. T&D losses also can be reduced by improving operation and maintenance practices; upgrading power lines, transformers, insulation, voltage, and thermal monitoring systems; and modernizing metering systems.

Recently, India has increased the capacity and upgraded the efficiency of its transmission grid. On February 25, 2009, the National Load Dispatch Center began supervising regional load dispatch centers, scheduling and dispatching electricity, and monitoring operations of the national grid. In December 2013, the country’s five regional grids were interconnected to operate at a synchronous frequency to transfer power more efficiently from generation sources to load centers. In addition, Powergrid—the government agency in charge of national grid construction—has been developing high-capacity transmission corridors. Since 2002, the mileage and capacity of India’s high-capacity/high-voltage direct-current lines, which reduce transmission losses over long distances in comparison with alternating-current lines, have more than doubled.

Although improvement and expansion of the national grid have helped reduce electricity losses, most of India’s T&D losses are the result of theft. Thefts occur in two ways: when energy consumed is not accounted for (as a result of consumers rigging lines to bypass their electricity meters or directly tampering with their meters) and when customers avoid paying for some or all of the electricity they consume (often by bribing utility meter readers or billing agents). Illegal power lines are above ground and easy to detect, but utility staff have been bribed or attacked while attempting to remove them.

Utilities have not always received adequate reimbursement for providing state-mandated, subsidized electricity to the agricultural sector and to the poor, mainly because of poorly managed accounting systems. According to India’s 2005 National Electricity Policy, the high levels of technical and commercial T&D losses and poor management of utilities have led to unsustainable financial operations. In addition, subsidies paid to utilities by the central government to keep the utilities operating have risen to unsustainable levels. The latest reported data show that subsidies made up 12.8% of revenue from power sales in India’s FY 2012.

Collection efficiency issues also have contributed to T&D losses in India. Collection efficiency is a measure of the share of billed revenues that a utility is able to collect from its customers. For example, if the utility bills a customer for 100 MWh of electricity it has provided but is able to collect only 90 MWh, the collection efficiency is 90%, and the utility has lost 10% of that revenue. Collection efficiency is a measure of the share of billed revenues that a utility is able to collect from its customers. For example, if the utility bills a customer for 100 MWh of electricity it has provided but is able to collect only 90 MWh, the collection efficiency is 90%, and the utility has lost 10% of that revenue. Collection efficiency is a measure of the share of billed revenues that a utility is able to collect from its customers. For example, if the utility bills a customer for 100 MWh of electricity it has provided but is able to collect only 90 MWh, the collection efficiency is 90%, and the utility has lost 10% of that revenue.

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efficiency is 80%. According to the Indian government’s Power Finance Corporation, Ltd., collection efficiency among all utilities selling directly to consumers in FY 2013 was about 94%, suggesting that an average of 6% of the potential total utility revenues nationwide were instead financial losses.

Collection inefficiency has led the Indian government to institute plans to reduce aggregate technical and commercial (AT&C) T&D losses,\(^{223}\) which represent the percentage difference between electricity generation available for sale (adjusted for transmission losses and trading) and electricity sold (adjusted by the collection efficiency factor). In 2001, the government launched its Accelerated Power Development and Reform Program (APDRP), with goals of strengthening the subtransmission and distribution network and reducing AT&C losses to 15% in five years. After failing to achieve that target, the Ministry of Power launched a Restructured APDRP (R-APDRP) in July 2008 specifically to reduce AT&C losses.\(^{224}\) Loans and grants were used to establish baseline data, to set up information technology-based energy accounting and auditing systems and consumer service centers, and to strengthen and upgrade the subtransmission and distribution network. The goal was to reduce AT&C losses by 3%/year for utilities with AT&C losses greater than 30% and by 1.5%/year for all others, with supervisory control and data acquisition systems installed to monitor energy flows through power lines and substations.

After the 2011 government financial bailout of state distribution companies (Discoms), India’s government approved a utility restructuring plan for state Discoms, providing financial rewards to companies that surpassed targets for lowering AT&C losses. In March 2012, a National Electricity Fund was established to promote investment in the power distribution sector.\(^{225}\) The $1.3 billion fund provides interest subsidies on loans disbursed to both public and private Discoms to improve the distribution network for areas not already covered by rural electricity initiatives and for R-APDRP project areas. Eligibility for the loans is based on the undertaking of reform measures prescribed at the state level, and many of India’s state governments have now adopted new regulations and technologies to improve tariff billing and collection practices.\(^{226}\) The amount of the interest subsidy is linked to progress in achieving the reform measures.

Since 2014, the Indian government has initiated more programs to improve grid operation and reduce losses. The Integrated Power Development Scheme (IPDS) was approved in November 2014, with a budget allocation of $3.8 billion from the national government.\(^{227}\) The IPDS is intended to further strengthen subtransmission and distribution networks in urban areas by using information technology-based systems to meter distribution transformers, feeders, and urban consumption. In 2015, a new National Smart Grid Mission was established—with a budget allocation of almost $51 million—to work with Discoms and other financing agencies in planning smart grid projects to be implemented as funding is secured from public and private sources.\(^{228}\) AT&C losses in India have trended downward since FY 2003 (Figure 5-15). When the Ministry of Power released its latest evaluation of 40 power distribution entities in August 2015,\(^{229}\) it announced that 21 power distribution companies had shown improvements in their AT&C loss levels from FY 2013 to FY 2014. Eight utilities were able to achieve reductions in AT&C losses greater than 20%, while 10 utilities showed increases greater than 10%.

\(^{223}\) AT&C losses represent the difference between energy available for sale (MWh), adjusted for transmission losses and trading in energy, and energy realized (MWh). Energy realized is the energy billed, adjusted for trading in energy (MWh), factored by the collection efficiency. Collection efficiency is an index of efficiency in realization of billings for current and previous years, focusing on the year-to-year movement of receivables.


While trying to accelerate economic growth, India also is attempting to address concerns about the environmental effects of rapid development. In October 2015, India issued an Intended Nationally Determined Contribution which set the following national goals to address climate change:

- Reduce CO2 emissions intensity by 33% to 35% from 2005 levels by 2030
- Nearly triple renewable energy capacity from 2012 levels by 2022
- Increase the share of zero-carbon electricity generating capacity to 40% of the total by 2030.230

In 2012, 72% of India’s electricity was generated at coal-fired power plants; that share falls to 55% in 2040 in the IEO2016 Reference case. According to the International Energy Agency, a shortage of coal and natural gas supplies for power generation is a pressing issue for India’s power sector. Domestic natural gas production is also declining.231 In the IEO2016 Reference case, natural gas production increases by an average of 1.3%/year from 2012 to 2040.

In an effort to diversify its electricity generation portfolio and limit emissions from fossil fuels, India’s government is promoting renewable energy use. In total, renewables constituted 15% of India’s electricity generation in 2012; in the IEO2016 Reference case, the renewables share increases to 28% in 2040. Net electricity generation from hydroelectric and other renewable sources increases from 160 billion kWh in 2012 to 764 billion kWh in 2040. India was the world’s seventh-largest producer of hydroelectric power in 2012, with 125 billion kWh generated.232 Hydroelectric generation increases in the Reference case to 405 billion kWh in 2040. In addition to renewables, India seeks to accommodate its swiftly growing power demand with increased nuclear generation. In the IEO2016 Reference case, India’s nuclear power generation increases by 7.9%/year from 2012 to 2040, and the nuclear share of the country’s total electricity generation rises to 9% in 2040.

**Vietnam**

Vietnam is expecting a significant transformation of its electric power generation mix, with plans to modernize its agrarian economy over the next two decades and become a more industrialized nation. Demand for electric power in Vietnam has increased over the past five years at annual growth rates of 10% to 12%. The Vietnamese government also is pursuing an enhanced level of energy security to support the country’s economic transformation. Its National Strategy on Energy Development to 2020, with an outlook to 2050, lists “Policy to ensure national energy security” at the top of the energy policy agenda.233

**Figure 5-16. Installed electricity generation capacity in Vietnam, 2014 (gigawatts)**

Vietnam’s interconnected electrical system relies heavily on hydroelectric power generation, and the 2005 Plan for Power Development (PDP) called for the installation of 17 GW to 18 GW of hydroelectric generating capacity between 2006 and 2015. However, as a result of environmental problems and concerns over social displacement, only about 4.1 GW has been developed so far.234 To accommodate the expansion of its industrial sector, Vietnam is diversifying its installed generation capacity to include a larger share of coal- and natural gas-fired power plants235 and is planning to build the first nuclear reactors in Southeast Asia and to complete the first offshore wind farm in Asia.236

The predominant energy sources for installed electricity generation capacity in Vietnam vary by geographic region—coal in the northeast, hydropower in the central and western areas, and natural gas in the southeast (Figure 5-16). Most of the country’s electricity grid is concentrated around the capital (Hanoi) in the north and around Ho Chi Minh City (Saigon) in the south.

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230 World Resources Institute, “CAIT Climate Data Explorer: India,” (last updated October 1, 2015), [http://cait.wri.org/indc/#/profile/India](http://cait.wri.org/indc/#/profile/India).
Ten main rivers and five main river basins supply Vietnam’s existing hydropower system, with resources concentrated in the north, the central highlands, and the lower south central coast.237 In 2014, Vietnam consumed 54.1 TWh of electricity generated from hydroelectric plants, a 1.3% increase from the 2013 total.238 The country’s slow growth in hydropower generation coincided with relatively weak 2.0% total world growth in hydropower production from 2013 to 2014.

The majority of Vietnam’s coal-fired power plants are in the north. The country’s proved reserves of anthracite and bituminous coal total 150 million metric tons,239 concentrated primarily in Quang Ninh province, directly east of Hanoi. In 2014, Vietnam produced 41.2 million metric tons of coal, an increase of 0.5% from 2013. In comparison, coal consumption in 2014 was up by 20.6% from the 2013 level of 15.8 million metric tons, primarily as a result of industrial sector expansion.

Over the past decade, increases in foreign investment have supported wider exploration for natural gas in Vietnam, which has increased its proved natural gas reserves significantly. At the end of 2014, Vietnam held 21.8 trillion cubic feet (Tcf) of proved natural gas reserves after producing an annual total of 361 billion cubic feet (Bcf) of marketed natural gas, all of which was consumed domestically. Both production and consumption of natural gas in 2014 increased by 4.7% from the 2013 levels.240 Although Vietnam currently is self-sufficient in natural gas, PetroVietnam predicts a potential supply gap, particularly in southeastern Vietnam, as consumption outpaces domestic production. liquefied natural gas (LNG) regasification terminals are already in the planning stages.

The Mekong River Delta and southeastern Vietnam contain nearly all the country’s installed natural gas-fired electricity generation capacity. Most of the natural gas reserves are located offshore, southwest from the tip of the Mekong Delta. In addition, ExxonMobil Vietnam recently announced a large discovery off the central coast and is partnering with PetroVietnam to determine potential locations for a thermal power and natural gas treatment complex in central Vietnam.241

Although Vietnam currently has no nuclear generation capacity, deposits of uranium ore (U3O8 content greater than 0.015%) in the northern and central regions are estimated at 660 million pounds.242 Vietnam’s nuclear fuel-cycle policy calls for survey and exploration of its uranium reserves to determine whether domestic uranium can be used to produce fuel for nuclear power plants.

Economic transition

Vietnam is developing its industrial sector, with the intention of pursuing a larger share of Asia’s export market for manufactured products. Bloomberg News reports that, among the Association of Southeast Asian Nations (ASEAN), Vietnam was the largest exporter to the United States in 2014. The gain is attributable to Vietnam’s comparatively young workforce and relatively low wages.

Vietnam entered the World Trade Organization (WTO) in 2007 and became an early negotiating partner in the Trans-Pacific Partnership (TPP) in 2010. Vietnam’s gross domestic product (GDP) growth was estimated at 6.4%/year in 2014, and it is projected to remain above 5.0% through 2030.243 Rapid economic growth, along with industrialization and export market expansion, has spurred domestic energy consumption. The nation’s General Statistics Office (GSO) projects annual increases in commercial sector electricity demand, from 169.8 billion kWh in 2015 to 289.9 billion kWh in 2020 and 615.2 billion kWh in 2030. The GSO also forecasts increases in electricity generation, from 194.3 billion kWh in 2015 to 329.4 billion kWh in 2020 and 695.1 billion kWh in 2030 (Figure 5-17).244

239 BP, BP Statistical Review of World Energy (June 2015). A metric ton, or tonne, is equal to 1,000 kilograms, or approximately 2,204.6 pounds (1.10 U.S. short tons).

Figure 5-17. Electricity demand in Vietnam, 2010–30 (billion kilowatthours)


**Future electricity generation**

PetroVietnam is seeking to import 11 million tons of coal per year starting in 2017 to supply the domestic power industry, according to a PetroVietnam Power and Coal Import and Supply Company official quoted by Reuters.245 The coal imports would supply three power plants—two in the southern Mekong Delta and the third in the northeastern province of Quang Ninh.246

Vietnam’s 2011 Gas Master Plan includes initiatives to promote natural gas in the primary energy mix, targets for natural gas production and consumption, and detailed infrastructure construction plans for natural gas gathering systems, pipelines, and processing facilities.247 In addition, the government has considered importing LNG in the southern part of the country to meet growing demand for natural gas. PetroVietnam Gas, a subsidiary of PetroVietnam, has signed a memorandum of understanding (MOU) and a front-end engineering and development (FEED) contract with Tokyo Gas Company to develop the Thi Vai LNG terminal in the Vung Tau province, which is expected to be operational by 2017. Also, in March 2014 PetroVietnam Gas signed a natural gas sales and purchase agreement with Gazprom of Russia. Under the agreement, PetroVietnam Gas will receive 48 Bcf/year via the Thi Vai LNG terminal.248 A second terminal, Son My LNG, is planned to open in 2018, although its construction has not been started.

Vietnam also plans to build the first nuclear reactors for power generation in Southeast Asia. In 2010, Russia’s Atomstroyexport agreed to build two 1,000-MW reactors on the Nin Thuan 1 site at Phuoc Dinh. Japan followed in 2011 with an agreement to build Nin Thuan 2 at Vinh Hai. However, the 2011 Fukushima accident delayed construction plans for both projects. Safety concerns contributed to a postponement of the construction start for the Nin Thuan 1 project until 2020. Vietnam continues to work closely with the International Atomic Energy Agency (IAEA) to develop its nuclear infrastructure and to address issues such as siting, stakeholder involvement, industrial involvement, and environmental protection.249

Vietnam also plans to build Asia’s first offshore wind farm. In March 2015, the United States Trade and Development Agency (USTDA) awarded a feasibility study grant for Phase III of the Bac Lieu Wind Farm, located in a submerged coastal area of the Mekong Delta. Phase I of the project, rated at 16 MW, was completed in May 2013; the scheduled 2016 completion of Phase II, rated at 67.2 MW, will result in a total capacity of 83.2 MW. Phase III, still in the conceptual and early planning stages, has a proposed capacity of 300 MW.250 The USTDA grant will help Vietnam address the technological challenges of implementing Phase III, which include wind assessments, permitting and land control issues, and electrical grid interconnection.251 In addition to the Bac Lieu project, the Tay Nguyen Wind Farm broke ground in March 2015. The facility, located in the central highlands, has a design capacity of 120 MW and an estimated cost of $279.62 million (U.S. dollars). The GSO estimates that hydropower will represent a smaller share of Vietnam’s power generation mix as other technologies come online (Figure 5-18).

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\text{Figure 5-18. Vietnam electricity generation capacity by fuel, 2015–30 (gigawatts)}
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In the IAEA 2013 Vietnam Country Nuclear Power Profile, Vietnam reported that its generation capacity mix will change significantly by 2030, with coal-fired generation projected to dominate the country’s total installed capacity. GSO projections indicate that coal-fired capacity will increase from 36% of Vietnam’s total net generation capacity in 2015 to 56% in 2030, hydropower capacity will decrease from 33% of the total in 2015 to 16% in 2030, oil- and gas-fired capacity will decrease from 25% in 2015 to 13% in 2030, and nuclear power plants will provide 8% of total generation capacity in 2030 (Figure 5-19).

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\text{Challenges}
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Vietnam faces several challenges to its planned electric power system transformation. The state-owned utility, Electric Vietnam (EVN), is pursuing the dual challenge of installing additional capacity while modernizing the country’s transmission and distribution (T&D) infrastructure. In addition, EVN must deal with the effects of the monsoon...

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246 IHS Energy (subscription site), “Vietnam raises coal imports to supply ballooning power capacity” (February 12, 2014).


Electricity season, which brings 8 to 10 severe storms annually, with wet foliage, flash floods, and mudslides threatening the reliability of the country’s interconnected power system. Another challenge facing Vietnam’s electric power sector is attracting the capital needed to finance projects that require large upfront capital expenditures and long lead times to complete, such as the planned Ninh Thuan nuclear power plant project. Developing the necessary T&D infrastructure, creating a stable economic environment to support large projects with longer cost recovery periods, and securing international investment will be critical to Vietnam’s ability to achieve its goals of industrialization and energy security.
