Energy 101: Introduction to Renewables

From the CSIS Energy & National Security Program

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According to the International Energy Agency (IEA), renewable energy is defined as "energy derived from natural processes that are replenished at a faster rate than they are consumed." Renewable energy encompasses a wide variety of fuels and other technologies harnessing the power of a variety of sources, including hydropower, biomass, solar, wind, and geothermal. In addition to these relatively developed technologies, there are myriad other frontier technologies being developed, although when or if many of these frontier renewable technologies are ultimately commercially deployed at scale remains to be seen.

Renewables are primarily used for electric power generation; over half of renewable energy consumption is in the electricity sector. Other uses for renewable energy include transportation fuels (e.g., ethanol and biodiesel) and space heating and cooling.

While hydropower and traditional biomass account for the largest share of renewable energy consumption globally (20 percent and 51 percent, in 2010, respectively), solar and wind energy are the fastest-growing renewable energy sources. As a whole, renewable energy is the fastest-growing energy source both in the United States and globally, increasing from under 7 percent of total global consumption in 2000 to 9 percent in 2013 with double-digit growth rates expected through 2035, although this growth is from a small base. The IEA expects renewables to increase their share in electricity generation to 31 percent by 2035, with major expansions in wind and solar generation capacity coupled with more modest increases in hydropower and biomass capacity.

Renewable Costs in Competitive Markets

In restructured electricity sectors, electricity dispatch is determined by market prices, which are set by generators' marginal costs. Renewable energy has challenged the economics of traditional power plants in these markets. In general, renewables tend to have high upfront capital costs and low operating costs (and often zero or near-zero marginal costs); this is in contrast with other types of power plants, which may have lower capital costs but higher operating and fuel costs. This has significant consequences for the financing and operations of renewables generation, and significant implications for renewables and other producers

Renewables are a rapidly growing component of the energy fuel mix, but there are still considerable economic, commercial, financing, technical, and regulatory hurdles inhibiting more widespread adoption and limiting market share. Most notably, in competing with mature alternative technologies, renewables face the barriers of undeveloped infrastructure and higher financing costs. With regards to infrastructure, for example, areas of renewable energy supply (for example, where the wind blows and the sun shines) do not necessarily mirror areas of demand, requiring expensive (and frequently difficult to site) infrastructure to connect the two.

Another challenge for some renewables (primarily wind and solar) is their reliability. Some renewables are intermittent; that is, they produce energy at irregular (and somewhat unpredictable) intervals. Intermittency affects both the operations and the economics of the electric grid. From an operations standpoint, intermittent resources require another source of energy to be available to provide a complement when the sun is not shining or the wind is not blowing—and this need (and therefore the need for other resources) varies by the day, hour, and minute, affecting planning and the cost of operations. Variability can therefore affect cost per unit of electricity output. Intermittency can also be a challenge for the grid from an engineering standpoint; the grid must instantaneously balance supply and demand at all times, and the unpredictability of intermittency makes balancing the system more challenging. While various solutions exist to the problem of intermittency, cost, operational, and scalability issues remain. Nonetheless, renewables growth in the United States and elsewhere remains remarkably strong as regulations, tariffs, financing arrangements, and the technologies themselves continue to evolve to accommodate renewable generation.

Policy can help overcome some of the market and technological barriers and encourage both deployment and generation. Production and investment tax credits, where developers receive a tax credit for investing in and generating electricity from renewable sources, are one example of such policy at the federal level in the United States. At the state level, Renewable Portfolio Standards (RPS) are the most common tool supporting renewable power generation. The standards, which mandate that utilities generate a certain portion of their power generated from renewable sources, often differ on specific design options. For example, RPSs can include carve-outs, or requirements for specific types of renewable energy (often solar), but can also include escape clauses, should renewable energy exceed a certain cost. Other policy incentives for renewables include feed-in tariffs, tax credits, rebates, and mandates.

Finally, while renewable energy is attractive for its environmental sustainability, zero greenhouse gas emissions, and potential to increase energy supply diversity, renewables are not free from environmental impacts. Adverse environmental impacts from renewables range from wind power's interference with bird migration to solar energy's potential use of hazardous materials to land and water use concerns.

Hydropower

Electricity production from water can be traced back to the 18th century. In keeping with this tradition, modern hydropower plants convert the energy produced by either flowing or falling water into electricity. In a run-of-the-river system (flowing water), the natural force of the current provides the pressure to turn the blades of a turbine to generate electricity. In a reservoir system, water is accumulated in reservoirs before being released to a lower elevation; upon release, the falling water turns the blades of a turbine.

Modern hydropower has been deployed for decades and is the most commercially mature and largest renewable component of electricity generation, accounting for 85 percent of the power generated by renewables globally. China, Brazil, the United States, Canada, Russia, India, and Norway together lead in hydropower capacity and generation, accounting for nearly two-thirds of hydropower capacity globally. Beyond the upfront capital costs of building a hydropower facility, the cost of operating a plant is minimal and insulated from fuel price fluctuations.

Nonetheless, both the further deployment of hydropower and existing plants face several challenges. One challenge is water availability; hydropower is highly dependent on yearly precipitation, water availability, and siting. As climate change influences the hydrologic cycle, hydropower generation is threatened in some areas. For example, hydropower accounts on average for about 20 percent of California's in-state power generation, but generated only 10 percent during 2014 as a result of drought. In addition, large-scale dams (generally more than 30-megawatt capacity) have come under increased environmental and social scrutiny in the past several decades. Another challenge is siting. Large dams interfere with natural ecosystems and siting can result in the displacement of both humans and wildlife. Despite these challenges and others, the flexibility and low costs associated with hydropower make it an attractive source of zero-carbon electric generation. Today, most new hydropower plants are in developing countries, with the vast majority of new capacity installed in 2013 by China, Turkey, Brazil, Vietnam, India, and Russia.

In additional to conventional hydropower, researchers are working on novel forms of power derived from water as well, such as hydrokinetic power (power generated from waves and tidal patterns) and ocean thermal energy conversion (using the difference in water temperatures to produce electricity), although such technologies are still in their infancy and their ultimate commercial prospects are unclear.

Biomass

Biomass energy is defined as energy produced from a wide variety of living organisms ranging from wood and waste to crop fuels. Biomass, accounting for 5 percent of U.S. energy consumption and 10 percent of total energy consumption globally, is considered a renewable energy source because plants and crops can be regenerated on a human timescale.

The most traditional form of biomass energy production is the burning of wood and charcoal. Roughly 60 percent of global biomass used for energy was for traditional purposes such as cooking and heating in developing countries. Traditional biomass has been a significant fuel source historically and is still the predominant form of energy used in the developing world today. In the developed world, biomass is burned in the electric sector. However, biomass is considered by some to be a controversial fuel because the burning of wood and other plant materials releases carbon dioxide into the atmosphere, can contribute to deforestation, and can cause adverse health effects in certain instances.

The other major use of biomass is in the transportation sector, where it is often referred to as biofuel. Over 23 percent of renewable energy consumption in the United States is in the transportation sector. Biofuels are derived from crops such as corn or sugar cane and can be used as alternative transportation fuels. Corn ethanol, the primary liquid biofuel in the United States today, is blended with traditional gasoline up to a 10 percent limit for most vehicles (some vehicles, called flex-fuel vehicles, have engines designed to run on gasoline blends of up to 85 percent biofuel). While such fuels generally burn more cleanly than traditional fuels, they have higher evaporative, ground-level emissions that contribute to smog. There are also concerns that biofuel targets result in the diversion of crop production from food to fuel and in higher emissions from changes in land use.

Government mandates in the United States have led to rapid growth in biofuel use in the past several decades. As a result, biofuels make up 4 percent of energy used in the transportation sector today. Globally, biofuel use is driven by policy incentives, with the United States, Brazil, the European Union, China, and India accounting for about 90 percent of biofuels demand.

Other forms of biomass energy production include burning waste to produce heat energy and the use of biogas (or methane gas released from waste as it decomposes). While waste-energy plants are generally more expensive than their fossil fuel counterparts, they have the added benefit of reducing waste buried in landfills.

Wind

Wind energy, or harnessing the wind's kinetic energy through a turbine to generate electricity, is the world's second-largest source of renewable electricity generation after hydropower. Global wind installed capacity has grown 18-fold between 2000 and 2013, increasing from 17 to 317 gigawatts and extending its share of total power generation from 0.2 percent in 2000 to 2.9 percent in 2013 (with most of the growth

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occurring in more recent years). Installed capacity does not necessarily reflect generation (see box).

China has the largest installed capacity (91 gigawatts), followed by the United States (62 gigawatts). Although not the largest producers, several countries generate a larger share of their electricity using wind power (e.g., Denmark). At the end of 2013, at least 85 countries had installed wind capacity.

Capacity additions have been driven largely by policy support in most countries around the world. For example, the drop in installation growth between 2012 and 2013 (46 gigawatts installed in 2012 vs. 35 gigawatts in 2013) is largely attributed to a decline in additions to the U.S. market as a result of policy uncertainties surrounding the production tax credit, the primary federal incentive for the expansion of wind power generation in United States. Similarly, policy has been a catalyst for growth elsewhere. In China, the 11th Five-Year Plan period (2006–2010) was instrumental in spurring renewable energy growth more generally and wind energy growth specifically to its current levels.

Nearly all installed capacity to date has occurred onshore, although placing wind turbines offshore takes advantage of the stronger and more consistent offshore wind resources. In spite of technological advances, offshore wind is not yet commercially deployed at the same rates as onshore wind due to high costs (in part attributable to the high cost of grid connection). While still dwarfed by onshore wind, 1.6 gigawatts of offshore capacity was added in 2013 for a total of over 7 gigawatts, almost all of which is located in the European Union.

Wind has enjoyed enormous growth and is economically competitive in many markets, but challenges to further deployment remain. In order to take advantage of strong and consistent wind, turbines are frequently located in remote areas, requiring the build-out of transmission lines to bring the electricity to population centers. Intermittency remains an issue. Further, wind turbines have come under criticism for their obstruction of scenic landscapes, noise, intermittency, interference with birds, and land use.

Capacity and Generation in the Electricity Sector

There are two ways to measure renewables deployment in the electricity sector: installed capacity and generation. Installed capacity is the amount of power a generator can produce under ideal conditions, if it is running at its maximum output. Generation, by contrast, is the amount of electricity actually produced in a given period of time. Some electric generators, such as nuclear power plants, generate an amount of power very close to their installed capacity (the ratio of generation to installed capacity is called the capacity factor). Others, such as natural gas plants and renewables, may have a large discrepancy between capacity and generation (a low capacity factor).

When measuring renewables deployment, installed capacity may differ significantly from actual generation for a variety of reasons, such as economic factors relating to dispatch, transmission availability, and intermittency.

Solar

Solar energy can be harnessed in two primary ways: solar photovoltaic (PV) and solar thermal/electric. Solar thermal/electric (also called concentrated solar power, or CSP) involves concentrating the sun's rays to heat water and produce enough steam to turn a traditional electric turbine. By contrast, solar PV utilizes individual photovoltaic cells to convert sunlight directly into electricity through the photoelectric effect. Photovoltaic cells are grouped together to form modules, which in turn can be grouped together to form a solar array, generating large amounts of electricity. PV cells can be scaled up or down, from use in a calculator to the solar panels placed on individual residential homes to large-scale solar power plants.

In addition to the distinction based on the way solar energy is converted into electricity, PV solar can also be classified as “distributed” (projects smaller than 1–5 megawatts) or “utility-scale” (larger than 1–5 megawatts). For example, PV solar can be used on a small scale (e.g., distributed generation with several panels placed on the roof of a house) or on a large scale (e.g., concentrated PV in which hundreds of panels are put together to form a “solar farm” or “solar plant”). Utility-scale solar accounts for most solar in the United States and globally.

Solar energy’s share in the global energy mix has increased rapidly in recent years as a result of favorable policies and falling installation costs, although from a very small base. While Europe accounted for the majority of solar deployment until 2012, recent years have seen rapid expansion elsewhere, notably in China, Japan, and the United States. Overall, 2013 was a record year for solar installation globally, with 39 gigawatts of added capacity, resulting in a total global capacity of 139 gigawatts. Nonetheless, solar only accounts for less than 1 percent of world energy consumption globally.

Despite rapid growth, obstacles to further market penetration remain. One of the primary challenges is solar energy’s intermittency: the sun only shines for part of the day and varies based on cloud cover resulting in a varying amount of electricity produced. As with other forms of intermittent inputs, this variability can also present challenges for grid management, although these can be managed with proper oversight. Further, solar PV is not very efficient (the most efficient panels currently convert about 35 percent of sunlight into energy) and thus requires a larger surface area to produce quantities of energy comparable to those of other generation sources. This presents particular challenges for utility-scale electricity. Notably, many such large solar facilities are located in remote locations such as deserts to maximize their access to the sun. The build-out of infrastructure to connect these facilities to the grid requires additional upfront capital costs. Nonetheless, costs for PV solar have fallen dramatically in the past few years and are projected to continue falling rapidly. There is significant regional cost variation, but the average cost for utility-scale PV dropped almost 50 percent between 2010 and 2013 to $0.11 per kilowatt-hour, sinking below the average U.S. electricity price of $0.12 per kilowatt-hour.

Geothermal

Geothermal energy production takes advantage of the earth’s naturally occurring heat to generate electricity. Geothermal plants pump water down a well where the heat in the earth’s crust naturally converts it to steam. That steam then rises and propels a turbine. The United States is the leader in geothermal energy production, but it is still a relatively small source of energy (0.4 percent of total U.S. electricity generation). The Philippines is the country with the largest share of geothermal energy, where it accounts for over 15 percent of power generation. Geothermal energy is not impacted by weather or climate change and can act as a stable, low-cost base load energy for power generation, but requires high upfront exploration costs and availability varies greatly by location. In the United States, six states (California, Nevada, Utah, Hawaii, Oregon, and Idaho) had geothermal power plants in 2013, with California accounting for 78 percent of geothermal electricity production.

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