Congressional Research Service
Informing the legislative debate since 1914

IN FOCUS

June 25, 2019

Variable Renewable Energy: An Introduction

Policy options to increase the use of renewable energy sources for electricity generation have drawn congressional interest. Some renewable energy sources, such as wind and solar, have variable supply. Electricity generators using variable renewable energy (VRE) sources can only produce electricity when weather conditions are right (i.e., when the wind is blowing or the sun is shining).

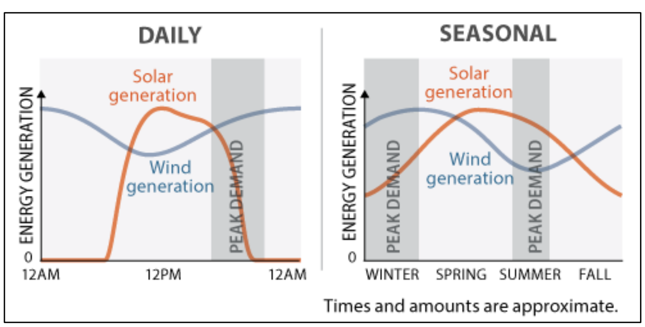
In contrast, conventional energy sources used to generate electricity are typically available when called upon. Frequently, the energy source can be stored on-site, or otherwise be directly accessed by generators. Examples include coal, natural gas, water stored in reservoirs, and nuclear fuel rods. Supplies of these energy sources are typically sufficient to generate electricity steadily for periods of days to months, although supplies are not guaranteed. Extreme weather events or disruptions in fuel transportation networks could potentially create supply shortages. Nonetheless, many consider these conventional energy sources to be more reliable than VRE.

Policy, technology developments, and market forces are leading to an increased use of VRE sources for electricity generation. Members of Congress may be interested in potential reliability issues and possible solutions.

Wind and Solar Variability

Electricity generation from wind and solar sources is weather-dependent, but typical patterns in wind and solar availability exist. **Figure 1** shows typical patterns for U.S.-based electricity generators using wind or solar energy.

Figure 1. Generation Patterns for U.S. Wind and Solar Sources



Source: CRS, based on data from the California Independent System Operator and the U.S. Energy Information Administration.

Notes: The y-axis represents the potential energy generation from each individual source, from a minimum of zero to a maximum defined by the installed capacity of the source. Actual generation from any individual source will depend on its size, local weather conditions, and other factors. Wind seasonal generation patterns vary by region, so the pattern shown here may not apply in all cases. Solar daily generation patterns for photovoltaic panels can vary based on the direction they face.

Over the course of a typical day, generation from any particular wind turbine peaks overnight and during early morning hours, and generation from most solar generators peaks in early afternoon. Over the course of a year, generation from any particular wind turbine typically peaks in winter and early spring, though regional differences exist. Generation from any particular solar generator typically peaks in summer.

Demand for electricity also shows variability, typically reaching a daily maximum point (i.e., peak demand) in the early evening and seasonal maxima during winter and summer.

Potential Reliability Issues

The U.S. electricity system was designed to accommodate conventional sources that can be called upon as needed to generate electricity, barring extreme events or regular maintenance requirements.

The variable nature of wind and solar sources requires changes in electric power system design and operation, in order to prevent damage to system components and widespread power outages. These changes are sometimes referred to as renewables integration. Generation from VRE sources in the United States in 2018 was 8% of total generation, of which 80% was from wind sources. Most reliability indicators used by the North American Electric Reliability Corporation (NERC) were stable or improving in 2018, suggesting that VRE sources are not creating widespread reliability issues at present generation levels.

Over timescales of one second or less, electricity must stay within narrow ranges of voltage and frequency. Conventional sources can support these requirements as a natural consequence of the alternating current (AC) power they produce. Wind and solar sources do not produce the same kind of electricity directly. The electricity they generate is converted to AC power for the grid by a device called an inverter. Federal regulations established since 2016 require inverters to help meet some voltage and frequency requirements of the electric power system.

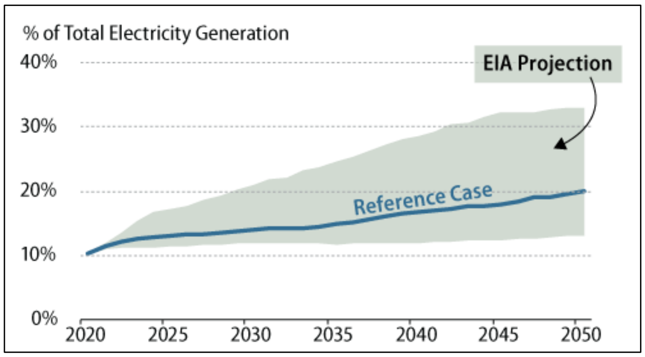
Reliability concerns over timescales of hours to days have been a focus area for Congress. As **Figure 1** shows, maximum generation from VRE sources does not align with typical daily peak demand. Other sources of electricity generation or storage must quickly increase their output to meet demand as generation levels from VRE sources fall (e.g., when the sun sets). The capability to quickly change output is known as ramping. Not all electricity sources are capable of ramping, and some that are may be more costly to use than other sources. In areas of the country with high levels of generation from VRE sources, concern is growing about maintaining sufficient ramping capability.

At current levels of generation from wind and solar sources, seasonal variability has not generally presented reliability issues. A main reason is that many other conventional sources are available that can generate electricity when output from wind and solar sources is relatively low.

Projections over the coming decades generally agree that, given current policy and market trends, more wind and solar sources will come online and many conventional sources will retire, increasing the share of total electricity generation coming from VRE sources in the United States.

For example, the U.S. Energy Information Administration (EIA) projects that wind and solar could comprise 13%-33% of total electricity generation in 2050 (**Figure 2**) depending on economic growth, technology development, and other factors. Seasonal variability of VRE sources could present greater reliability challenges moving forward if the share of generation from these sources increased.

Figure 2. Projections of Share of Total Electricity Generation from Wind and Solar Sources, 2020-2050



Source: CRS analysis of data in EIA, *Annual Energy Outlook 2019*, https://www.eia.gov/outlooks/aeo/data/browser/.

Notes: Dark line represent EIA's reference case. Shaded area represents the range of outcomes in EIA's side cases. Assumptions for EIA's cases are described in the *Annual Energy Outlook 2019*.

Potential Solutions

As noted above, current levels of generation from VRE sources have not created widespread reliability issues. Sufficient backup capacity is usually available, and system operators and participants are developing new practices to address the variability of wind and solar sources.

Policy options to address reliability issues that could arise in the future have drawn congressional interest. Some frequently discussed potential solutions are described below. Implementing any of these might require significant infrastructure investment. How such investment should be funded and what other potential costs and benefits would be associated with such investment could be key considerations. Other concerns, such as environmental impacts, cybersecurity, and data privacy, may be of interest as well.

Transmission System Expansion

The transmission system is the network of over 700,000 miles of high-voltage wires and supporting equipment that moves electricity over long distances. Some regions experience transmission congestion when electricity cannot be moved to where it is needed because of insufficient transmission capacity. Congestion increases overall electricity costs for consumers, and it can create hurdles to balancing generation from VRE sources, particularly over daily timescales.

Expanding the transmission system could potentially support renewables integration by alleviating transmission congestion. It might address seasonal variability by allowing electricity generated during periods of high output to be delivered to more areas.

Smart Grid Upgrades

Smart Grid describes, in part, upgrades to the transmission and distribution systems that could support renewables integration. Some Smart Grid upgrades could support integration of large-scale wind and solar projects connected to the transmission system. Other aspects of the Smart Grid could support integration of small-scale projects connected to the distribution system, the network of 6.5 million miles of wires, supporting equipment, and meters that deliver electricity to most end users.

Smart Grid components include phasor measurement units (PMUs) that can monitor reliability status over timescales of microseconds (current technology makes measurements over a few seconds); advanced metering infrastructure (AMI), sometimes known as smart meters, that can communicate with the grid in almost real-time (current technology does not communicate with the grid); and data communication and data processing components.

Energy Storage

Electricity is essentially generated as a just-in-time commodity. Some technologies can store electric energy in some form and then release it back to the grid, potentially saving electricity generated during periods of high supply and delivering it during periods of low supply. Energy storage can be located on the transmission system or the distribution system. Pumped hydro, in which water is pumped to a reservoir during periods of high electricity supply and then released to generate electricity during periods of low electricity supply, is a form of energy storage that has been used for many years. Other technologies are attracting increasing interest. These include batteries, compressed air storage, and fuels like hydrogen. Energy storage could potentially be used to address variability over multiple timescales, though most energy storage technologies deployed today are usually capable of balancing over timescales of minutes to hours.

Additional Analysis

For more information about VRE sources, potential reliability issues, and possible solutions, see CRS Report R45764, *Maintaining Electric Reliability with Wind and Solar Sources: Background and Issues for Congress*, CRS Report R45156, *The Smart Grid: Status and Outlook*, and

CRS Report R42455, *Energy Storage for Power Grids and Electric Transportation: A Technology Assessment*.

Ashley J. Lawson, Analyst in Energy Policy

IF11257

Disclaimer