

Chapter 12

Energy: Supply, Demand, and Impacts

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Executive Summary

Energy is important to the Southwest United States, where 12.7% of the nation's energy is produced (extracted or generated) and 12.1% is consumed. The region is in the favorable position of having low per-capita energy consumption (222 million BTUs per person) relative to that of the nation as a whole (302 million BTUs per person); nevertheless, disruption of power has significant economic implications for the region (e.g., LaCommare and Eto 2004; Northwest Power and Conservation Council 2005). Climate change itself, as well as strategies aimed at mitigation and adaptation have the potential to impact the production, demand, and delivery of energy in a number of ways.

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- Delivery of electricity may become more vulnerable to disruption due to climate-induced extreme heat and drought events as a result of:
 - increased demand for home and commercial cooling,
 - reduced thermal power plant efficiencies due to high temperatures,
 - reduced transmission line, substation, and transformer capacities due to elevated temperatures,
 - potential loss of hydropower production,
 - threatened thermoelectric generation due to limited water supply, and
 - the threat of wildfire to transmission infrastructure.(medium-high confidence)
- Climate-related policies have the potential to significantly alter the energy sector. A shift from the traditional fossil fuel economy to one rich in renewables has significant implications for related water use, land use, air quality, national security, and the economy. The vulnerability of the energy system in the Southwest to climate change depends on how the energy system evolves over this century. (medium-high confidence)

12.1 Introduction

Energy consumption in the Southwest United States was 12,500 trillion British thermal units (BTUs) in 2009, equal to 222 million BTUs per person (EIA 2010). Any change or disruption to the supply of energy is likely to have significant impacts. For example, a study found that electrical power blackouts and “sags” cost the United States about \$80 billion every year in lost services, industrial capacity, and gross domestic product (LaCommare and Eto 2004).

This chapter provides an objective assessment of the vulnerability of the energy infrastructure of the Southwest to the effects of projected climate change. There are a number of ways in which the Southwest’s energy infrastructure could be affected by climate change, such as by increased peak electricity demand for cooling, damage to energy infrastructure by extreme events, disruption of hydroelectric and thermoelectric generation due to high temperatures or restricted water availability, and evolution of the energy portfolio both in terms of electricity generation and transportation fuel choices (such as moving from fossil fuel-fired electricity generation to utilization of more renewable sources).

This chapter reviews primary energy production and consumption in the Southwest, both past and present, then focuses on potential climate impacts on energy infrastructure, defining for each the exposure pathways, possible extent of impact, adaptation/mitigation options, and data gaps.

12.2 Energy in the Southwest: Past and Present

Energy is an important resource in the Southwest, both in terms of production and consumption. According to the U.S. Energy Information Administration (EIA 2010), primary energy production in the Southwest was 9,200 trillion BTUs in 2009, 12.7% of total

U.S. production. Since 1960, primary energy production in the Southwest has grown 180%. In 2009, consumption outpaced production by 3,300 billion BTUs. However, the per capita consumption in the Southwest of 222 million BTUs per person is significantly below the national average of 302 million BTUs per person. The 2009 consumption level represents a 255% increase since 1960.

Natural gas represents 43% of the primary energy production in the Southwest (Figure 12.1), followed by crude oil (21%), coal (19%), renewable energyⁱ (10%), and nuclear electric power (7%). Since 1960, there has been a strong increase in the production of natural gas, coal, nuclear electric power, and renewable energy, while crude oil production decreased. Significant differences in energy production by state are evident across the Southwest (Figure 12.1). California, Colorado, and New Mexico are among the nation’s top ten energy-producing states, while Nevada is ranked 47th. Colorado, New Mexico, and Utah have significant natural gas production, while California leads the region in crude oil and renewable energy production.

In 2009, 36% of the 12,500 trillion BTUs consumed in the region were associated with the transportation sector, with the remaining consumption spread relatively evenly

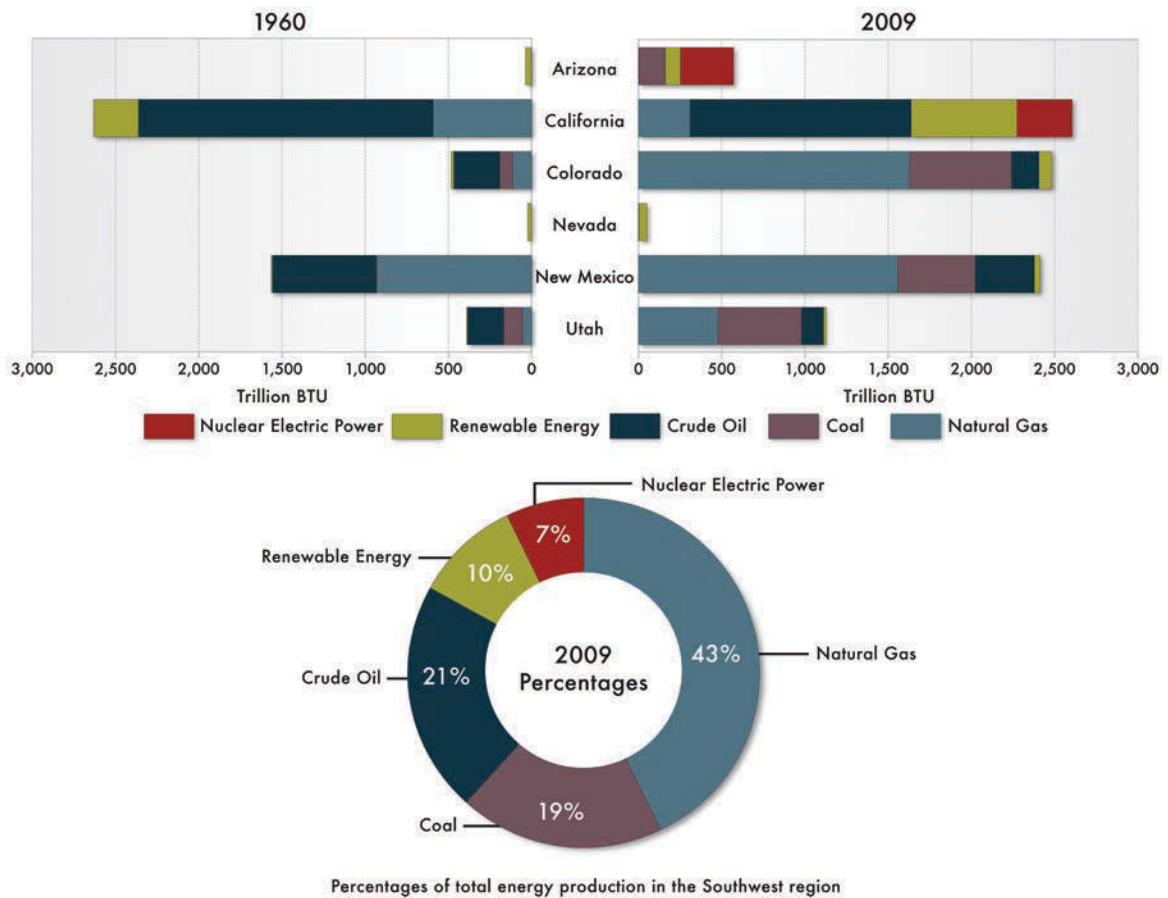


Figure 12.1 Energy production in the Southwest region. Source: EIA (2010).

across the industrial, residential, and commercial sectors (EIA 2010). Forty-two percent of this demand was met with petroleum products, 32% by natural gas, 13% by coal, 8% by renewable sources, and 5% by nuclear electric power (EIA 2010). In total, 87% of total consumption was met with fossil fuels. The most notable change since 1960 is the growing share of demand now met with coal and nuclear electric power. Energy consumption also varies significantly by state (Figure 12.2). Consumption is dominated by California, followed distantly by Arizona and Colorado. However, when considered on a per capita basis a very different picture emerges. California has the lowest per capita consumption at 220 million BTU per person, followed by Arizona (220), Nevada (270), Utah (270), Colorado (290), and New Mexico (330), with all but one below the national average. Unlike the other states, California has a disproportionately high use of petroleum (50% of demand) but low use of coal (only 1%). Arizona has the highest proportion of demand met through non-fossil fuels (24%), while Utah has the lowest (2%).

Specific to electricity, 487 million megawatt hours (MWh) were generated in the Southwest in 2009, a 43% increase over 1990 levels. The associated fuel mix for this generation includes 42% natural gas, 30% coal, 13% nuclear, 8% hydroelectric, and 7% other

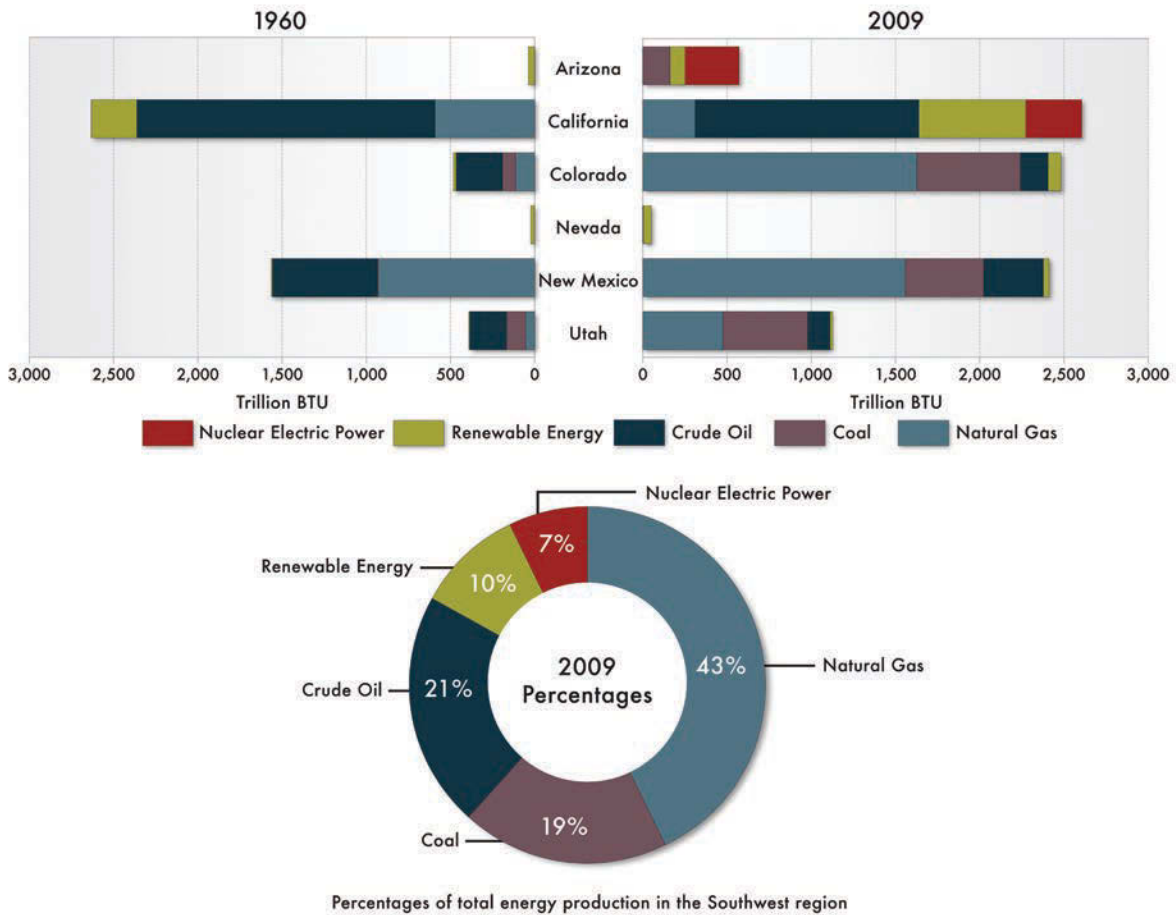


Figure 12.2 Energy consumption in the Southwest region. Source: EIA (2010).

renewable (EIA 2010). Since 1990, significantly less coal has been used to produce electricity, with a commensurate increase in generation by natural gas (Figure 12.3). In 2009 almost 65% of the region's electricity was produced in California and Arizona. Even so, California imported approximately 25% of its electricity, while in contrast Arizona exported 53% of its production. New Mexico, Utah, and Nevada are also net exporters of electricity.

The mix of fuels used to generate electricity differs across the six states (Figure 12.3). Most notable is the sizeable utilization of coal in Colorado, New Mexico, and Utah. California and Nevada make up for their low coal use largely with natural gas. Nuclear electric power is generated only in Arizona and California. In terms of renewables, including large-scale hydropower, California was responsible for 73% of the region's generation (EIA 2010).

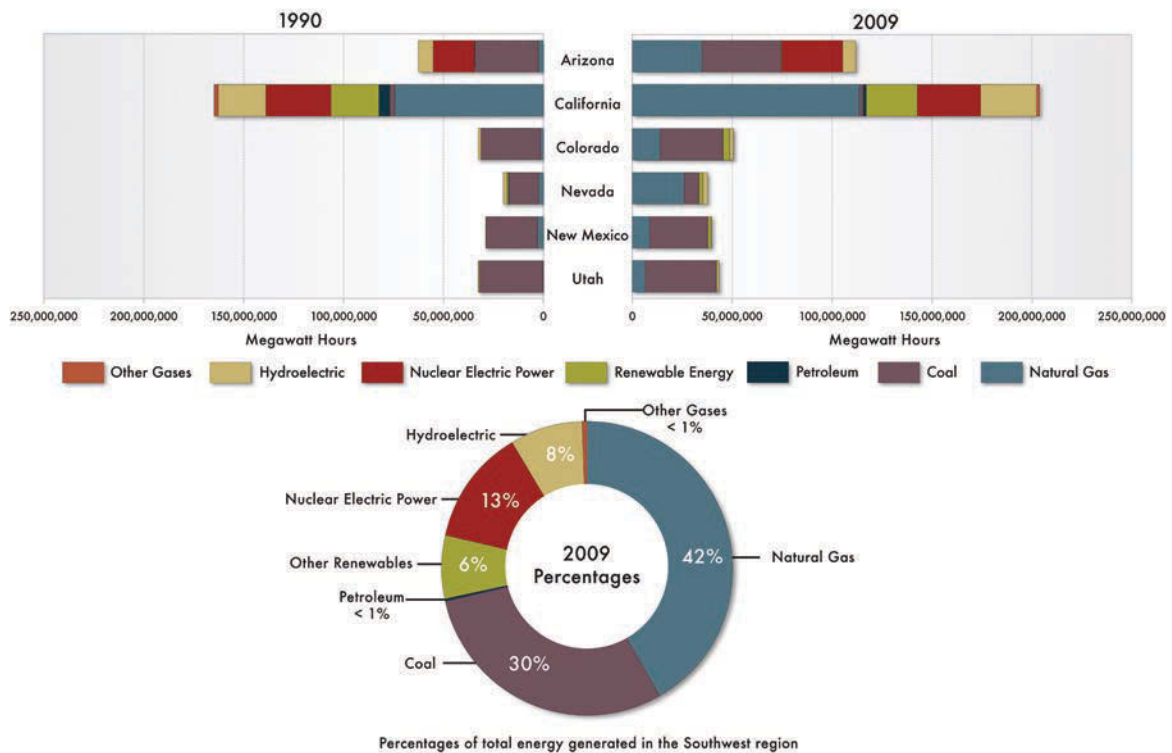


Figure 12.3 Electricity generation in the Southwest region. Source: EIA (2010).

In 2009, total carbon dioxide (CO₂) emission from energy consumption in the region was 728 million metric tons, nearly a third of which was for generation of electricity (EIA 2010). Electricity emissions have grown by 50% over 1990 levels while electricity generation has only increased by 43% over the same period of time. Although California produces 42% of the region's electricity, it is responsible for only 21% of the region's CO₂ emissions from electricity, not counting imports, largely due to generation that favors

natural gas and renewables. However, California alone is responsible for 68% of the region's vehicle CO₂ emissions (217 million metric tons).

Figure 12.4 shows the locations of key energy infrastructure in the Southwest (data taken from EIA 2010). Features shown include power plants (distinguished by fuel type), petroleum refineries, coal mines, and transmission lines (of 345kV or more).

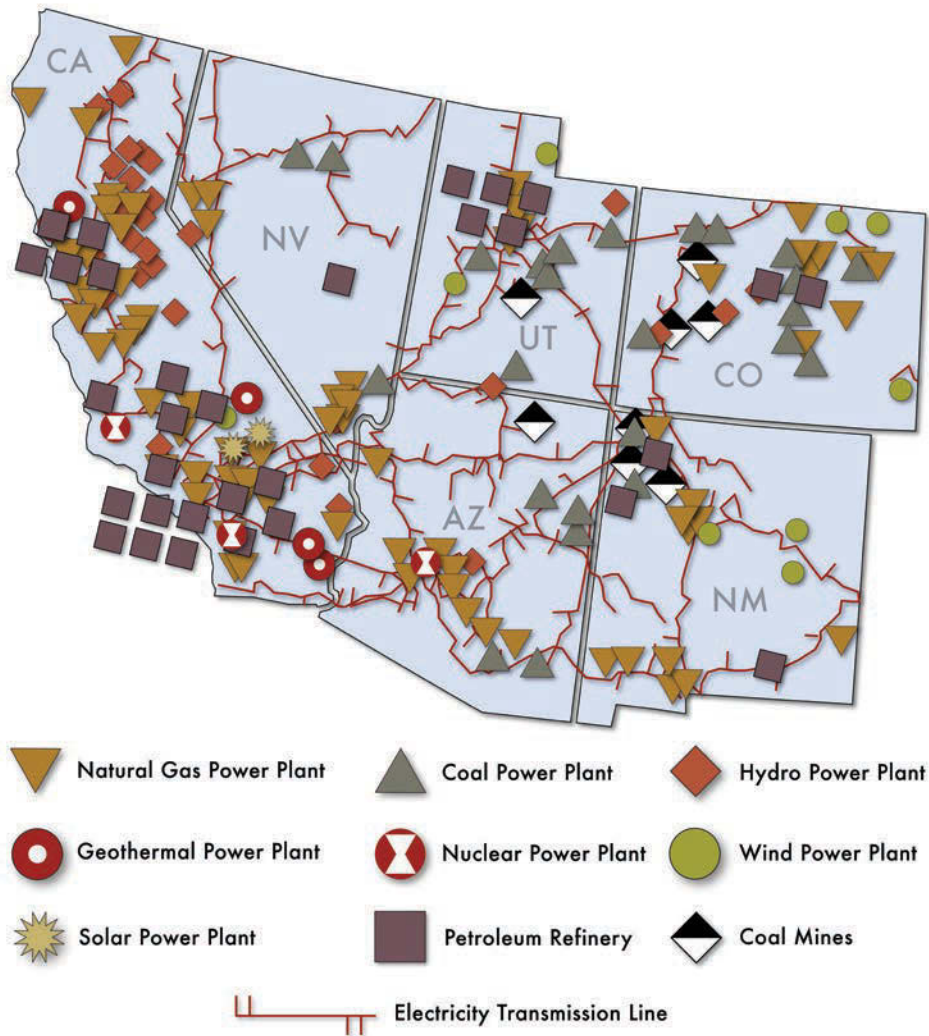


Figure 12.4 Energy distribution in the Southwest region.

Source: EIA (2010).

12.3 Potential Climate Impacts on Energy

This section discusses the energy future of the Southwest, particularly the potential effects of climate change on energy demand, supply, and delivery.ⁱⁱ The potential impacts are organized and discussed according to eight distinct themes: energy demand, electricity generation, electricity distribution, energy infrastructure, renewable source

intensity, evolution of the energy sector, primary energy production, and the cost of climate change. Each theme is explored in terms of linkages to climate change: observed climate-related change; projected range of climate-induced change, mitigation, and adaptation strategies; and related data and knowledge gaps.

Climate-induced impacts to peak and annual electricity demand

A potentially important impact of projected climate change would be on peak electricity demand due to changes in peak summer afternoon temperatures. Climate warming in the region is expected to increase peak period electricity demands for summer cooling and possibly increase peak winter heating electricity demand as well if electricity is used for space heating (Wei et al. 2012). Projected climate-induced changes in mean annual and extreme temperatures, including projected changes in cooling degree days, can be found in Chapters 6 and 7.

Using recent data, Sathaye and others (2011) correlated temperatures above 77°F (25°C) with statewide peak loads during the month of August from 2003 to 2009. In California, 90th percentile per-capita peak loads (a measure of extreme energy demands) are projected to increase between 10% and 20% at the end of the century due to the effects of climate change on summer weekday afternoon temperatures.ⁱⁱⁱ Others have also analyzed the influence of increasing temperature on energy demand in California (Miller et al. 2007; Franco and Sanstad 2008). No similar studies have been conducted for the Southwest as a whole, but a similar range of impacts on peak demand is expected. One approach would be to use the projections of Franco and Sanstad (2008) who provide an overview and a simple methodology to estimate annual and peak demand using historical and projected temperature data.

Vulnerability of electricity generation to climate impacts

The areas in which electric power plants are vulnerable to direct climate impacts include reductions in power plant efficiency, loss of hydropower generation, and disruption of thermoelectric production.

TEMPERATURE IMPACTS ON NATURAL GAS TURBINES. A warming climate would decrease the capacity and efficiency of a natural gas turbine in several ways. Warmer air is less dense than cooler air, so the air mass of the turbine at higher temperatures is less for a given volume intake. In addition, ambient, or background, temperature influences the air's specific volume, which in turn influences the work of and the power consumed by the compressor. Finally, the pressure ratio within the turbine is reduced at higher temperatures, reducing mass flow (Kehlhofer et al. 2009).

The relationship between temperature and natural gas power plant performance varies by the type of natural gas power plant, the cooling equipment installed at the plant, and the geographic location of the plant. In many applied studies, the basic power output-to-temperature relationship is assumed linear, such that power plant capacity is decreased 0.25% to 0.5% for every °F increase in ambient air temperature (Sathaye et al. 2012). Maulbetsch and DiFilippo (2006) estimated the relationship between ambient temperature and the capacity potential of natural gas power plants. They found that combined-cycle power plant capacity drops 0.15% to 0.25% per °F and air-cooled

Box 12.1

Compounding Impacts of Drought

Delivery of electricity may become more vulnerable to disruption due to climate-induced extreme heat and drought events as a result of:

- increased demand for home and commercial cooling,
- reduced power-plant efficiencies due to high temperatures,
- reduced transmission-line, substation, and transformer capacities due to elevated temperatures,
- potential loss of hydropower production,
- threatened thermoelectric generation due to limited water supply, and
- threat of wildfire to transmission infrastructure.

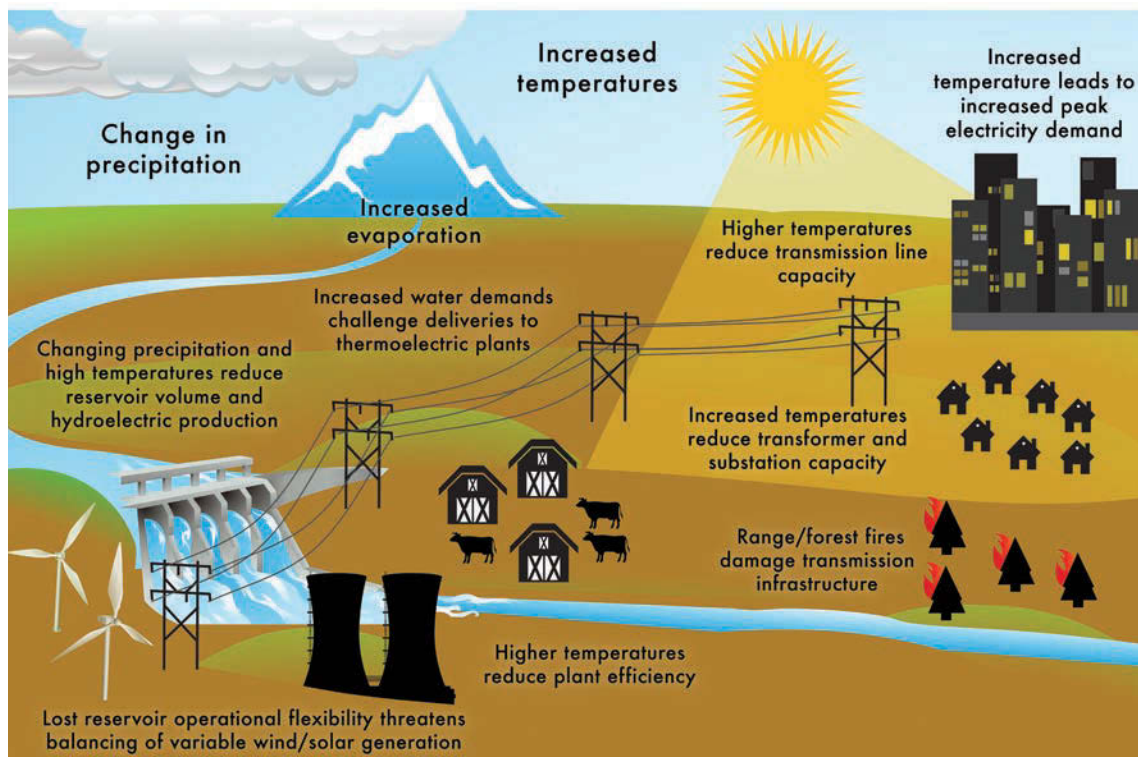


Figure 12.5 Compounding impacts of drought on energy.

combined-cycle power plant (dry cooling) capacity drops 0.35% per °F rise in ambient temperature. Using these assumptions, climate change projections suggest natural gas thermal power plant capacity in California could drop on average between 2% and 5%, and as much as 6% during hot summer afternoons by the end of the century. During peak load periods, reserve margins can be low and natural gas power plants are running near capacity.

Similar studies of climate change impacts on power plants in other Southwestern states have not been undertaken. However, the temperature increases simulated for those states match or exceed temperature simulations for California and a similar impact on power plant performance should be anticipated for those plants as well. Nevertheless, additional research is needed to estimate temperature impacts on different types of electricity generating capacity and on power plant performance outside of California. Types of electric power plants that may be affected by climate warming include coal power, nuclear power, wind, solar, bio-power, and geothermal plants as well as natural gas-fired plants.

A variety of adaptive measures may be taken by utility planners to offset the impact of climate change on thermal power plant performance, such as installing new types of cooling equipment or simply expanding the existing capacity in anticipation of future losses.

CLIMATE IMPACTS ON HYDROPOWER GENERATION. Hydropower generation depends on such factors as total runoff, timing of runoff, reservoir operations, and the profile of electricity demand, each of which is vulnerable to climate change. Projected changes in runoff due to potential decreased precipitation and increased evaporation (Chapter 6) means less water for hydropower production. Earlier snowmelt (Chapter 6) and shifts in the frequency of extreme events (Chapter 7) could lead to important changes to the timing of streamflow and thus reservoir storage. Climate change could also impact water-demand regimes downstream of the reservoir, such as with urban (Chapter 13) and agricultural (Chapter 11) uses. Hydropower production could be compromised as reservoir operations are adjusted to address changing patterns of reservoir storage coupled with changes in competing water uses for in-stream flow requirements, flood control, water supply, and recreation (National Energy Education Development Project 2007). Also, the way in which hydropower is utilized for electricity production may change in the future (for example, with increased use to balance intermittent loads), so that changes in water availability may have different impacts than they do today.

Since 1990, hydroelectric power has satisfied about 11% of the Southwest's total electricity demand (46.9 gigawatt hours [GWh]), of which, as mentioned earlier, California supplied about 34.3 GWh (73%) (EIA 2010). Hydropower production in the region varied widely year to year, ranging from 31.1 GWh (8% of regional demand) to 66.7 GWh (16% of regional demand). Similar variability was noted in the California production record. A unique feature of California hydropower is that much of it (greater than 70%) is generated by a fleet of more than 150 small, single-purpose reservoirs located high in the Sierra Nevada that depend on snowmelt (Madani and Lund 2009). These reservoirs have little storage capacity and thus are uniquely vulnerable to shifts in streamflow that might result from climate change (Vicuña et al. 2008).

Recent droughts provide insight into climate-related impacts on hydropower production. Severe drought in California and the Pacific Northwest significantly reduced hydroelectric power generation in 2001, contributing to tight electricity supplies and high prices (the crisis was enhanced by market manipulation). While significant outages were largely avoided, there were financial impacts due to the large increase in prices (BPA 2002). The Northwest Power and Conservation Council (2005) estimated the total regional economic impact of the drought to be between \$2.5 and \$6 billion. Impacts

of the drought were intensified by energy-water interdependencies linking the California coastal basins, Columbia River Basin, and Colorado River Basin (Cayan et al. 2003). These cross-basin linkages provide the opportunity to compensate hydropower losses if, during dry conditions in one basin, the others experience wetter conditions, or to intensify the effects if two or more basins are simultaneously drier (as was the case in 2001).

Over 70% of hydropower production in the Southwest is associated with the Colorado River and with high-elevation dams in the Sierra Nevada (EIA 2010). Several studies suggest that both systems are vulnerable to future climate change. Specifically, a recent water-budget analysis showed a 50% chance that minimum power pool levels in both Lake Mead and Lake Powell will be reached under current conditions by 2017 if no changes in water allocation from the Colorado River system are made. This would impact over 3,700 MW of generating capacity on the lower Colorado River (EIA 2010). Such a result would be driven by a combination of climate change associated with global warming, the effects of natural climate variability, and the current operating status of the reservoir system (Barnett and Pierce 2008).

Numerous studies have explored potential future climate impacts on Sierra Nevada hydropower production. Harou and others (2010) used geologic evidence suggesting two extreme droughts occurred in California during the last few thousand years, each 120 to 200 years long, with mean annual streamflows 40% to 60% of the historical average. They used an engineering-economic simulation model to evaluate impacts under such conditions to power production, irrigation, and environmental resources, based on projected demands in 2020. Under current operating rules, a 60% reduction in hydroelectric power generation was projected for low-elevation hydropower units that traditionally contribute about 30% of the hydropower generation in California (Phinney et al. 2005). Another study investigated the impact of increased air temperatures of up to 11°F (6°C) on mean annual streamflow, peak runoff timing, and duration of low-flow conditions. Vulnerabilities to these three flow characteristics were found to differ by region and hence their susceptibility to altered hydropower production (Null, Viers, and Mount 2010). Other studies have used climate data from multiple general circulation models (GCMs) under different greenhouse gas (GHG) emissions scenarios to investigate potential impacts on California hydropower production (Madani and Lund 2010) and adaptation options (e.g., K. P. Georgakakos et al. 2011; A. P. Georgakakos et al. 2011). For scenarios resulting in reduced annual streamflow, hydropower production is reduced but to a lesser extent than revenues, reflecting the ability of the system to store water when energy prices are low for use when prices are high. The opposite was true when projected annual flows increased (Vicuña et al. 2008).

Opportunities to mitigate the impact of climate change on hydropower production include expansion of hydropower resources (DOE 2010). According to preliminary estimates from the Electric Power Research Institute (2007), the United States has additional water power resource potential of more than 62,000 MW (or about 79% of current conventional hydroelectric capacity). This includes efficiency upgrades at existing hydroelectric facilities and development of new low-impact facilities. Issues of cost, environmental impacts, and suitability of construction sites are potentially limiting factors. Adaptation opportunities also exist, primarily in the form of altered reservoir operations. Several of the studies noted above for the California Sierra Nevada reservoirs have shown that climate impacts could be mitigated through adaptive management strategies (Harou

et al. 2010; A. P. Georgakakos et al. 20011). However, identifying “optimal strategies” that balance multiple objectives (hydropower, water supply, flood control, recreation, and instream flow) is problematic as it would require agreement among stakeholders to change longstanding operational rules.

Two key data gaps are apparent. First, there has been relatively little effort to directly quantify potential climate change impacts on hydropower production in the Colorado River Basin; however, a recent study by the U.S. Bureau of Reclamation (2011) should help to fill this gap. The second gap is in evaluating the broad implications of climate change for the entire, interconnected West, including evaluating concurrent impacts on hydropower and thermoelectric production and on shifts in electric power demand.

CLIMATE AND DROUGHT IMPACTS ON THERMOELECTRIC GENERATION. Thermoelectric generation can be limited when power plant water supplies are threatened, such as when the surface of a water supply drops below intake structures of the generating plant (NETL 2009b), when access to water is limited by priority of power plant water rights (Stillwell, Clayton, and Webber 2011), or when water discharge temperatures exceed environmental limits (Averyt et al. 2011).

There are no examples from the Southwest where drought has threatened thermoelectric power production. However plants have been shut down in other regions due to drought, including the Alabama Browns Ferry facility in 2007, 2010, and 2011 (Nuclear Regulatory Commission [NRC] 2007, 2010, 2011); the Exelon Quad Cities, Illinois, plant in 2006 (NRC 2006); the Minnesota Prairie Island plant in 2006 (NRC 2006); and plants in France in 2003 (De Bono et al. 2004). All these cases involve nuclear plants whose production was limited by effluent temperatures exceeding regulated discharge limits. In contrast, the 2011 drought in Texas threatened to impact a variety of thermoelectric power plants there due to limited water availability (e.g., Galbraith 2012).

There are several studies that have assessed power plants’ vulnerability to drought. Each utilized different criteria to assess vulnerability and each focused on different subsets of the electric power industry. A study by NETL (2009a) identified five plant sites in four western states with a total capacity of 3,284 MW as vulnerable on the basis of shallow intake structures (NETL 2009b) and historic severity of local drought measures. In a study focused on coal-fired generation, twenty-six power plants in the Southwest region were identified as vulnerable based on eighteen unique indicators of water demand and supply (NETL 2010). A recent study by the Union of Concerned Scientists (2011) identified twenty power plants in the Southwest that discharge cooling water at a maximum temperature that exceeds 90°F (32°C), most of which is into streams with high biodiversity. Taking a slightly different approach, Sovacool (2009) identified Denver, Las Vegas, and San Francisco as places where water resources are likely to be scarce or declining due to growing and competing demands for thermoelectric and non-thermoelectric water supply. Based on these studies it is difficult to assess exposure of thermoelectric power production to drought/climate change as none of the studies consider the existence and robustness of contingency plans that individual plants may have in place.

Mitigation of drought vulnerability can be achieved through integrated water-energy planning (e.g., Western Governors’ Association 2010, 2011) or utilization of non-potable water sources.^{iv} Adaptation measures can be achieved through contingency planning and include options such as allowing power plants to lease water from farmers with senior

water rights in times of drought or developing backup groundwater sources. Dry cooling (which uses air rather than water to cool a power plant's working fluid) is another option that is already utilized to generate 4,150 MW in the intermountain West (Cooley, Fulton and Gleick 2011). However, dry cooling is more costly, requires additional land, and results in reduced generation efficiencies on hot days. Dry-cooled plant capacity declines on hot days more than water-cooled plant capacity, but hybrid units are also available. In some cases, dry-cooled plants lose 0.5% of their capacity for every 1°F increase in peak temperature—roughly twice the loss of wet cooled plants (Sathaye et al. 2012).

To fully evaluate the vulnerability of thermoelectric power production to drought will require assessing local hydrologic conditions together with plant-level operational characteristics and institutional controls. Plant contingency plans must also be reviewed in terms of their robustness in the context of future climate extremes.

Vulnerability of electricity distribution to climate impacts

This section discusses the vulnerabilities of electricity distribution infrastructure to direct climate impacts, specifically the temperature impacts on electric transmission line capacity (220 KV and higher) and on substation/transformer capacity.

TEMPERATURE IMPACTS ON TRANSMISSION LINE CAPACITY. Transmission lines incur incremental power losses as the temperatures of conductors increase (IEEE 2007). In general, higher temperatures increase the resistance of a conductor, which decreases the carrying capacity of the transmission line and requires additional generation to offset the increased resistance over the lines. Climate change is expected to increase mean and peak period temperatures across the Southwest, thereby increasing demand for electricity while at the same time increasing the resistance of transmission lines and decreasing their carrying capacity. One study of the impact of a 9°F increase in ambient air temperature suggests that while climate warming would cause very little resistance loss, capacity losses might be more significant, amounting to an additional 7% to 8% of peak (Sathaye et al. 2012).

The potential for climate change-induced line capacity losses should be researched further, including identification of operating practices that minimize loss and of new design parameters (e.g., underground transmission lines). Also, utilities generally count on the presence of at least 2 feet per second of wind on hot days. If a “zero-wind” condition should happen during extremely high temperatures, conductor temperatures may rise into the “emergency” range (i.e., above 212°F [100°C]), where continued operation may cause excessive conductor sag, permanent damage, and even lead to wildfires. Further investigation into the effects of climate change on the probability and duration of no-wind conditions on hot days is necessary to more accurately evaluate the impacts on transmission capacity (Sathaye et al. 2012).

One option for coping with the impacts of climate change on the transmission system is decentralized generation: producing a larger fraction of the power at or near the end-use reduces the line capacity requirements. Examples of such generation are low-pressure methane to support local industry (Welsh et al. 2010) or even utilization of traditional windmills to circumvent electric-powered groundwater pumping. Another option for avoiding the impacts of higher temperatures would be to place transmission lines underground.

TEMPERATURE IMPACTS ON SUBSTATION/TRANSFORMER CAPACITY. Major substations contain clusters of transformers that allow alternating current voltage to be “stepped up” or “stepped down” between various components of the power system. A number of studies have looked at the performance of transformers under different operating conditions, including changing ambient temperatures (Lesieutre, Hagman, and Kirtley 1997; Swift et al. 2001; Li and Zielke 2003; Li et al. 2005; Askari et al. 2009). Higher ambient temperatures reduce the peak-load capacity of banks of transformers in substations.^v High minimum temperatures can affect transformer performance as well as high peak temperatures. For example, in some extreme cases, excessive hot spot conductor temperature within the transformer can lead to catastrophic failure of the transformer, so improved methods to monitor these internal temperatures are proposed (Lesieutre, Hagman, and Kirtley 1997).

Other studies have quantified the general relationships between air temperature and transformer lifespan and capacity (Swift et al. 2001; Li et al. 2005). The basic relationship of power capacity to temperature used in most studies is linear, with some research suggesting that transformer capacity decreases approximately 0.35% for each 1°F of higher ambient temperature (Li et al. 2005).

One study indicates that substations in California could lose, on average, an additional 1.6% to 2.7% capacity by the end of the century (Sathaye et al. 2012). Other parts of the Southwest with similar or higher temperature increases from climate change would face similar substation capacity losses as well. Judging by the spatial distribution of the simulated change in the number of days with maximum temperatures greater than 95°F (35°C), the southern and eastern parts of the Southwest are more at risk to lost substation peak capacity than areas in the region’s north and west.

Utility planners may take several adaptive measures to offset future losses to substations and increase their capacities, including proactively installing new types of cooling.

Vulnerability of infrastructure to indirect climate impacts

This section looks at two key indirect vulnerabilities from climate change: risk of wild-fire to electric transmission lines and the effects of sea-level rise and coastal inundation on power plants and substations.

WILDFIRE RISK TO ELECTRICITY TRANSMISSION. Fire is a natural component of ecosystems in western North America, and its occurrence is strongly correlated with climate variability. Weather-related effects on fire include behavior (wind conditions), fuels (combustible material), and ignitions (lightning). Wildfires are also greatly affected by moisture availability, as influenced by temperature, precipitation, snowpack, and other meteorological factors, all of which may be impacted by climate change.

Increases in the size and frequency of wildfires in the Southwest will increasingly affect electricity transmission lines (see Box 12.2). Transmission line-related impacts from wildfires are not restricted to the actual destruction of the structures (Aspen Environmental Group 2008; personal communication, Fishman and Hawkins, CAISO [California Independent System Operator Corporation], 2009). In fact, only smaller lines may be directly destroyed in a wildfire, because these types of power lines are typically built with wooden poles. But the transmission capacity of a line can be affected by the heat, smoke, and particulate matter from a fire, even if there is no actual damage to the

Box 12.2

Transmission Line Exposure to Wildfire

The most recent study of fire risk in California suggests that most transmission lines in the state will be exposed to an increased probability of fire risk across a range of different climate models, emission scenarios, and time periods (Sathaye et al. 2012). This figure summarizes changes by the end of the century in the length of lines exposed to areas of either increasing or decreasing burned area, the latter being more common. At the end

of the century some key transmission lines crossing between California and Oregon and between northern and Southern California may face a particularly high fire risk. Certain areas will be less at risk. For example, transmission lines passing through the desert areas in southeastern California are projected to see reduced exposure to wildfires in the future, in part due to changes in vegetation projected for the future.

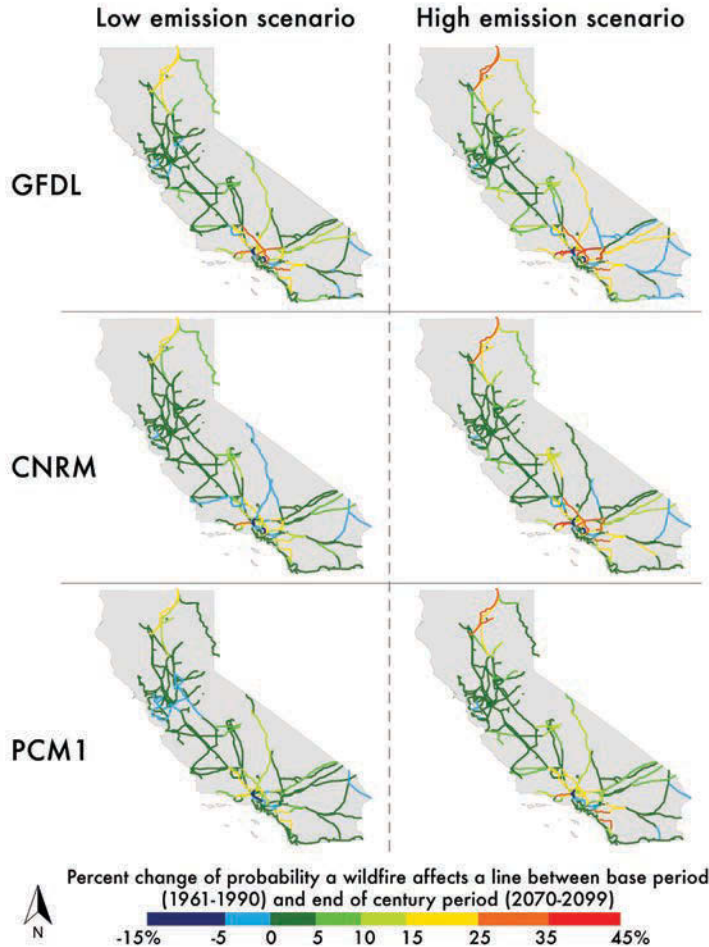


Figure 12.6 Transmission line exposure to wildfire.

The probability of damage is taken as the product of the probability fire and the relative length of the line in a given region. Used in this study are the GFDL (Geophysical Fluid Dynamics Laboratory), PCM1 (Parallel Climate Model), and CNRM (Centre National de Recherches Météorologiques) GCM, and the high- and low-emissions scenarios as defined by the Intergovernmental Panel on Climate Change (IPCC) (Nakićenović and Swart 2000). Modified from Sathaye et al. (2012).

physical structure. The insulators that attach the lines to the towers can accumulate soot, creating a conductive path and causing leakage currents that may force the line to be shut down. Ionized air in smoke can act as a conductor, causing arcing either between lines, or between lines and the ground, that results in a line outage. Finally, even if the lines are protected from fire, the effects of firefighting can also negatively affect transmission operation, such as by aircraft dumping loads of fire retardant that can foul the lines or through preventive shutdowns for safety measures.

Several studies have shown that climate change will increase the size and frequency of wildfires in California, which leads the region in wildfire-related economic losses (Flannigan et al. 2000; Lutz et al. 2009; Westerling et al. 2009). Of the ten largest wildfires in California's history, seven have occurred since 2001 (CDFFP 2009). Texas, Arizona, and New Mexico have all experienced record-breaking wildfire seasons in recent years as a result of increasing temperatures and advanced evaporation (Samenow 2011).

Many adverse effects of wildfire risk to the transmission grid can be avoided by careful planning, increasing fire corridors around transmission lines, building excess transmission capacity, and using new transmission line materials that provide better protection against the effects of soot and heating.

There are no studies of fire risk to the transmission grid in the Southwest, outside of California. Since fire frequency and cost due to climate change are likely to be particularly high, studies of this issue across the Southwest are recommended. (For further discussion of the effects of climate change on the occurrence of wildfires in the Southwest, see Chapter 8, Section 8.4.2.)

PROJECTED IMPACTS OF SEA-LEVEL RISE AND COASTAL INUNDATION ON POWER PLANTS AND SUBSTATIONS. California is the only state in the Southwest region facing impacts from sea-level change (see a detailed discussion in Chapter 9). Mean sea level along California's coast has risen at a rate of about 8 inches (20 cm) per century for several decades—a rate that may increase (Cayan et al. 2009). Mean high water, which poses an even more significant threat, is increasing at an even faster rate (Flick et al. 2003). Extreme surge events at high tides, often provoked by winter storms, are also expected to increase (Cayan et al. 2009). The confluence of these three trends puts increasing amounts of coastal energy infrastructure at risk: recent studies of sea level along the California coast indicate that twenty-five to thirty power plants—including thirteen located in the San Francisco Bay Area—are at risk of impact from what would be currently a 100-year flood (which will become more frequent) caused by a 4.6-foot sea-level rise (Figure 12.7) (Sathaye et al. 2012).^{vi} Many of the plants shown to be at risk, though, are likely to be retired over the next few decades.

The vulnerability of power plants to flooding is very site-specific and more information should be gathered on a site-by-site basis. It should be noted that in addition to increasing flood risk, sea-level rise may accelerate shoreline erosion and destabilize coastal power plants and related infrastructure. Further studies are needed to evaluate the risk posed by soil erosion to energy infrastructure along the coastline.

Adaptive measures may be taken to protect power plants against flooding and destabilization from sea-level rise. For example, new power plants should be constructed at higher elevations, farther from the ocean, and out of reach of tidal flooding. In addition, existing plants may be protected by building higher levees.

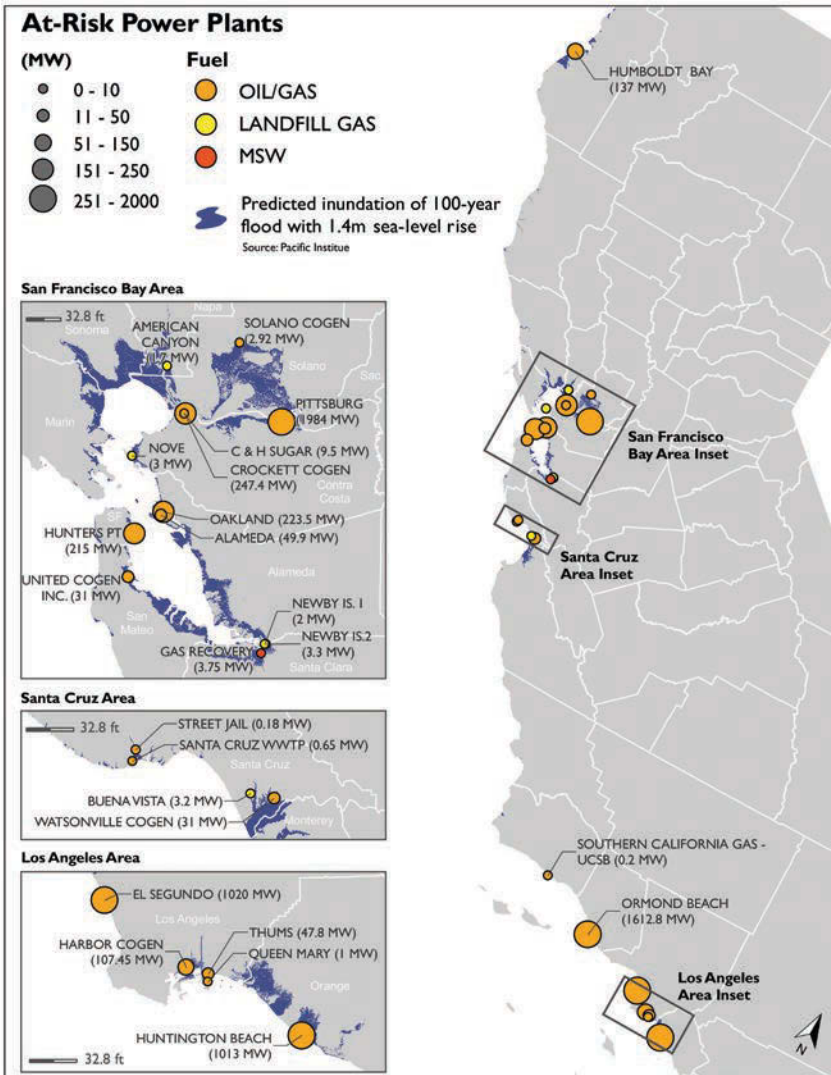


Figure 12.7 Power plants potentially at risk to a 100-year flood with 1.4-m (4.6-ft) sea-level rise. Reproduced from Sathaye et al. (2012).

Climate impacts on renewable source intensity

To estimate the potential impacts of climate change on renewable sources of energy, spatial details are needed on how the electricity system would evolve. For example, if climate change causes shifts in wind regimes, areas now suitable for wind farms may be less suitable in the future and new areas may become an attractive option for wind energy development. Few studies, however, have been published on this topic for the Southwest.

WIND POWER. Some research suggests that wind speeds in the United States as a whole are declining, based on the 50th and the 90th percentile wind speeds from 1973 to 2005 (Pryor et al. 2009; Pryor and Ledolter 2010). However, for the Southwest region no significant changes in wind speeds are reported (Pryor and Ledolter 2010).^{vii}

Pryor and Barthelmie (2011) estimated potential changes of wind-energy density (the mean annual energy, in watts, available per square meter of the area swept by a turbine) for the conterminous United States using results from outputs from a handful of regional climate models (with spatial resolutions of about 31 miles [50 km]), driven by the outputs from atmospheric-ocean global climate models. The reported changes in wind-energy density for the next fifty years are not beyond what could be expected from natural variability. This implies that current and planned wind power facilities likely are not in danger of experiencing reductions in their ability to generate electricity, and areas that are presently suitable for wind-power generation would not be affected by climate change at least for several decades.

Rasmussen, Holloway, and Neme (2011) attempted to estimate the potential impacts of climate change on three California sites with significant installed wind capacity: Altamont Pass (562 MW), San Geronio Pass (710 MW), and Tehachapi Pass (359 MW). The authors used the same outputs from the regional climate models as did Pryor and Barthelmie (2011). Rasmussen, Holloway, and Neme (2011) reported wide disagreement between the regional climate models on how wind resources would be affected. This may be explained in part by the fact that the 31-mile spatial resolution of the regional climate models are much wider than the relatively narrow passes where wind resources in California are located (i.e., the models cannot resolve the topographic features in these passes that contribute to the acceleration of the wind). Mansbach and Cayan (2012) used a different approach, developing a statistical model that relates large-scale atmospheric features that are supposed to be adequately modeled by the global climate models with local wind speed at three California wind farms. Their results were mixed, precluding any conclusions about the potential impacts of climate change on wind farms.

In summary, no trend in wind-energy density has been observed in the Southwest and it seems likely that wind power will continue to be a viable resource in the Southwest. However, further analyses and modeling studies are needed to resolve the current discrepancy between model results and to address the deficiencies with the existing studies.

SOLAR POWER. Climate change can affect the amount of solar irradiation reaching ground level mainly via its effects on clouds. Unfortunately, the simulation of clouds remains one of the main sources of uncertainty in the projections of future climate regimes (IPCC 2007). Global and regional climate models are implemented at geographical resolutions too coarse to allow for the simulation of clouds directly from physical principles. Instead, they use statistical relationships (parameterizations) developed using historical data. For this reason, caution is in order with the interpretation of estimated ground-level solar radiation information generated by global and regional climate models.

Crook et al. (2011) used the results from two atmospheric-ocean global climate models developed in the United Kingdom to estimate the impacts of climate change on the future of photovoltaic (PV) and concentrated solar power (CSP) units at the global level. For California and Nevada they reported reductions in power output for both PV and CSP units on the order of a few percent at the end of this century, in comparison with historical conditions. But an uncertainty analysis suggests a low level of confidence in their results for this region. In addition, as suggested by Rasmussen, Holloway, and Neme (2011), reliance on just a few models is not advisable because modeling results at the regional level can change, depending on the model used for the study.

High ambient temperatures affect the performance of some PV systems (Kawajiri, Oozeki, and Genchi 2011) such as crystalline silicon PV modules, which are one of the most popular technologies on the market but do not perform well under the dry and hot conditions common to the Southwest. There are, however, other PV technologies that are less sensitive to ambient temperatures (Crook et al. 2011).

In summary, solid scientific information is lacking on how climate change would affect the amount of solar irradiation reaching ground level in the Southwest and, therefore, how it would affect PV and CSP systems. But higher ambient temperatures will have some detrimental effects on some PV system technologies.

Evolution of the energy sector

Climate-related policies have the potential to significantly alter the energy sector. A shift from the traditional fossil fuel economy to one rich in renewable energy sources has significant implications for related water use, land use, air quality, national security, and the economy. This section explores potential evolutionary paths for both electricity generation and transportation fuels.

EVOLUTION OF THE ELECTRICITY GENERATION FUEL MIX. Climate change and the policies adopted to address climate change are likely to cause a shift in the fuel mix used to generate electricity. There are multiple sources of information on potential global and U.S. energy scenarios (e.g., Wilbanks et al. 2007), but they lack regional detail and do not allow for an estimation of how the energy system in the Southwest could be transformed. Nevertheless, two potential illustrative scenarios are explored that, broadly speaking, are consistent with a business-as-usual path and with a future in which strong mandates to reduce greenhouse gas emissions materialize. These two scenarios could be seen as compatible with the spirit of the IPCC's high- and low-emissions scenarios, respectively, as discussed before in this report (see Chapter 2), though they do not specifically represent these two global emission scenarios.

The business-as-usual scenario comes from the "reference case" presented in the U.S. Energy Information Administration's *Annual Energy Outlook 2011* report (EIA 2010). Results for the EIA's Southwest region are used; however, it should be noted that the regional boundaries used by EIA do not fit perfectly the boundaries for the Southwest used in this report (the EIA boundary captures roughly 80% of the electricity generation within the Southwest region delimited for this report). The reference case assumes that current laws and regulations remain in place, such as the mandates in California, Arizona, Colorado, and Nevada to increase the amount of electricity generated from renewable sources of energy. This is reflected in the contribution of renewable sources of energy going from 16% in 2009 to about 27% in 2035, the end year of the EIA simulations. This new electricity generation would come from a mix of wind, solar, and geothermal with limited additions of hydroelectric. The electricity generation from nuclear units and coal-burning power plants would remain at about the same levels as in the recent past but minor increases in generation from natural-gas-burning power plants is observed in the EIA scenario. We speculate that under this business-as-usual scenario the same general trend would continue past 2035.

There are multiple options with regard to the evolution of the electricity system in the Southwest if strong measures are taken to reduce greenhouse gas emissions. A new

study, for example, uses a long-term capacity expansion model for the electricity system for the Western United States (Wei et al. 2012), taking into account hourly electricity demand and the hourly availability of generating resources, especially intermittent sources such as solar and wind power plants. This modeling system uses geographical information about electricity generation and demand to estimate the regional evolution of the electricity system. As shown in Figure 12.8, by 2050, solar, wind, and geothermal resources would become major sources of electricity in the Southwest. Electricity generation from coal-burning power plants without carbon capture and sequestration disappears in this potential scenario.

The evolution of the electricity system will impact water resources. Thermal electricity generation withdraws copious amounts of water for cooling. While only a very small fraction of the water withdrawn is actually consumed (i.e., evaporated to the atmosphere) the water that is returned to its source, such as rivers and the ocean, is not pristine, containing at least some levels of thermal pollution (Averyt et al. 2011; Cooley, Fulton and Gleick 2011). Different power plants and energy systems can have substantially different levels of impacts on water resources: energy crops for biofuels can require from very little to a substantial amount of water; wind resources do not withdraw water; and solar power generation requires from very little to large amounts of water, depending on the conversion technology (Cooley, Fulton and Gleick 2011; Kenney and Wilkinson 2012).

EVOLUTION OF THE TRANSPORTATION FUELS MIX. The transportation system in the Southwest will likely mirror the transportation system in the rest of the country (see Chapter 14). The EIA estimates an increase of more than 15% in the amount of total liquid fuels consumed for the U.S. transportation sector in 2035 as compared with 2009 consumption for the reference case (EIA 2010). As indicated before, the reference case assumes that only current laws and regulations remain in place. EIA also reports an “extended policies” case for which EIA assumes a 3% annual increase of corporate average fuel economy (CAFE) standards until 2025, then no change until 2035. In this case, total liquid fuel consumption for the U.S. transportation sector would increase only by about 4% from 2009 to 2035. Hybrid electric cars and/or cars fueled by alternative fuels play an important role in achieving the more stringent CAFE standards.

If drastic reductions in greenhouse gas emissions are required, several studies have found that for the United States it is more practical and less costly to reduce emissions in the electricity-generating sector and to electrify the rest of the sectors as much as possible (Clarke et al. 2007; Fawcett et al. 2009; National Research Council 2010); the situation is not different for the Southwest (Wei et al. 2012). Biofuels could play an important role in the availability of liquid fuels for the transportation sector (Parker et al. 2010) but could only replace a small percent of current levels of primary energy consumption (Field et al. 2008). At the same time, liquid biofuels could play a key role in replacing transportation services that cannot be easily electrified, such as air transport. Several studies suggest that biofuels must be produced in a way that does not increase net greenhouse-gas emissions, does not hinder food security, and does not result in negative ecological impacts (e.g., Tilman et al. 2009). In addition, new studies suggest that it is also important to consider the biogeophysical consequences of bioenergy crops, such as local cooling or warming, or changes in water demand (e.g., Georgescu, Lobell, and Field 2009, 2011).

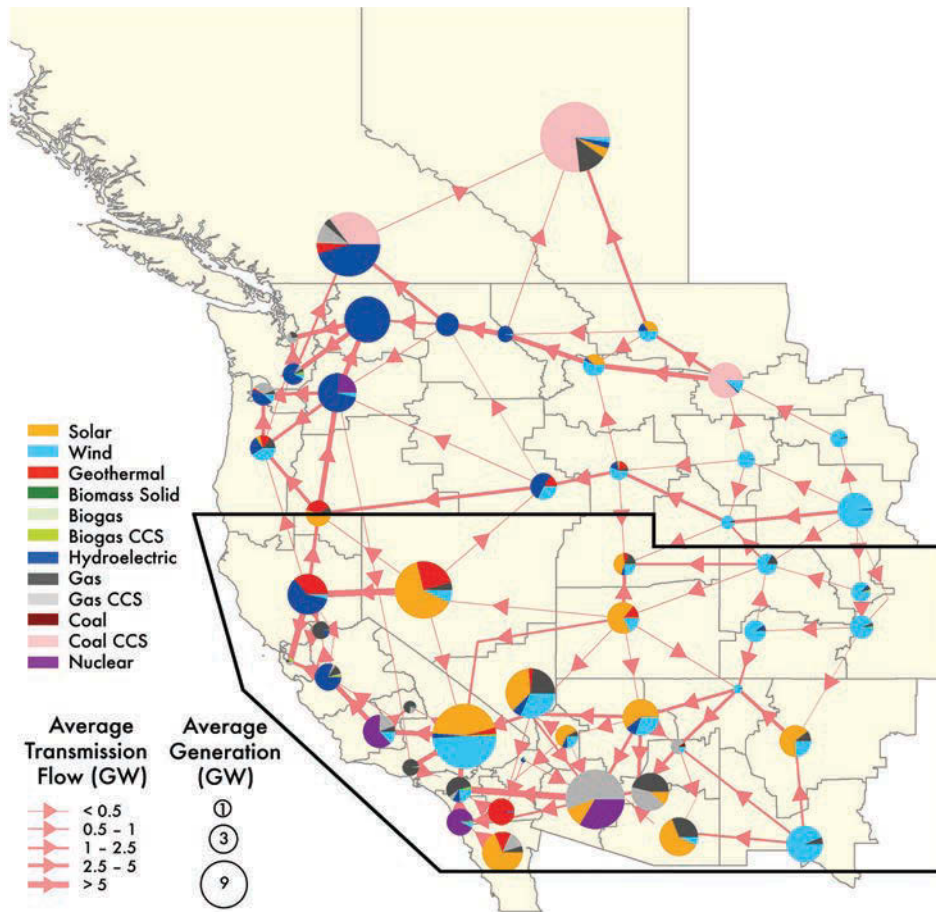


Figure 12.8 Projected generation and transmission flow in 2050. The map shows projected average generation and average transmission flow between load areas (electricity demand zones) under high regulation of green-house gas emissions. The size of each pie represents the amount of generation in the load area in which the pie resides. The flows of electricity are depicted as straight lines for clarity. Reproduced from Wei et al. (2012).

Climate impacts on primary energy production

As noted above, the Southwest accounts for 12.7% of our nation's primary energy production. Climate change has the potential to influence this production in at least three ways. First, energy policies aimed at mitigating the impacts of climate change could significantly alter the mix of primary fuels used to generate electricity and fuel transportation (see above), thus influencing the demand for the primary fuels. Specifically, emission standards could cause a move to renewables and away from coal and petroleum. However, demand for natural gas and uranium would likely increase, potentially offsetting losses in coal production. Potential losses of petroleum production will be more difficult to offset as water availability will challenge biofuel production in the Southwest (DOE 2011). Because these primary energy sources are traded internationally, emission

policies would need to be matched in much of the rest of the world before significant impacts would be felt locally.

Second, climate change could increase the demand for electricity: higher temperatures are likely to be met with higher demands for cooling (Section 12.3.1). Alternatively, higher cooling needs could spawn improvement in cooling/energy efficiencies or higher energy prices, which would reduce electricity demand.

Third, climate change could impact the availability of water needed for primary energy extraction and processing (DOE 2006). Reduced water supplies (see Chapters 6 and 10) could affect current production and especially the development of new resources. A particularly good example is the ongoing struggles over water and oil shale development in the Piceance Basin (Western Resource Advocates 2009).

Cost of climate change

In 2009, total expenditures for end-use energy (such as retail electricity and motor gasoline) in the Southwest was about \$160 billion. California contributed about 66% to these expenditures (EIA 2010). Any changes in energy prices due to climate change or climate change policies will have a direct economic impact on consumers. For example, since retail electricity expenditure in the Southwest was about \$52 billion in 2009 (EIA 2010), the postulated increases in electricity demand due to higher temperatures discussed previously would have represented a few billion dollars per year for the current electricity generation and demand system. The estimation of changes of energy expenditures in the rest of this century due to physical changes in our climate is extremely difficult because it will depend on multiple uncertain factors such as the price of energy, population growth, technology evolution, and human behavior.

Climate policies directly limiting greenhouse gas emissions or indirectly affecting emissions via requirements such as renewable portfolio standards will also affect the cost of energy. At the same time, the potential benefits of policies such as increasing energy security, limiting climate change, reducing air pollution, and perhaps creating local jobs must be considered. The authors are not aware of a comprehensive study along these lines for the Southwest.

Climate policies at the national and international levels designed to reduce greenhouse gas emissions will directly impact the energy sector, given that currently fossil-fuel combustion is by far the dominant source of these emissions. Conventional modeling studies at the national level suggest that drastic reductions of greenhouse gases would reduce gross domestic product (GDP) by at most a few percent, delaying a given GDP level only for a few years (National Research Council 2010). However, as indicated before, this represents at best only a partial economic analysis because it does not take into account the benefits of limiting the impacts of climate change. In addition, the economic models used in these studies assume perfectly functioning markets and any restrictions on emissions, by design, result in economic penalties (DeCanio 2003). Ironically, these models do not take into account the effect that climate change would have on economic activity and energy demand, for example, diverting economic resources to mitigate climate damages (Hallegatte and Hourcade 2007). More realistic economic models are sorely needed.

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Endnotes

- i Includes biofuel-based transportation fuels and electricity generated with renewable energy (e.g., solar, wind, geothermal, biomass, hydroelectric).
- ii Several reports have considered potential climate impacts on the energy industry at the national and international levels (e.g., Karl, Melillo, and Peterson 2009; Beard et al. 2010; Ebinger and Vergara 2011). Here we direct attention to the Southwest region of the United States.
- iii These projections are similar to estimates presented in another recent study of California peak loads and climate change (Miller et al. 2007), which projects 90th percentile peak demand increases of 6.2% to 19.2 % under the IPCC's (2007) high-emissions scenario.
- iv Non-potable sources are now required in California for new permitting of thermoelectric water use (California Water Code, Section 13552).
- v An 86°F (30°C) ambient temperature approximately corresponds to a 248°F (120°C) hot spot conductor temperature at a typical transformer (Swift et al. 2001).
- vi Caution needs to be taken, however, as the analysis by Sathaye and colleagues (2011) was conducted at a scoping level and site-specific analyses are necessary to determine actual risks.

- vii The authors caution about the reliability of these reported trends, however, given the potential problems with the wind measurements due to such factors as changes in the location of the monitoring stations, degradation in the performance of the instruments used to measure wind speed, and changes in land use close to the monitoring stations.