2015

NCEI Climate Products and Services Market Analysis:

Power Sector Engagement

Global Science & Technology, Inc.

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This report was initially released in April of 2015 as a confidential and internal NCEI report. In the winter of 2015 Acclimatise went through the process of creating a public version of this report for distribution. This was done by ensuring that the written content was reviewed and approved by those interviewed. This report is the public version.

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Executive Summary

Acclimatise was commissioned by GST to understand how climate data from the National Centers for Environmental Information is used and adds value to the United States power sector. This report synthesizes the results from the analysis with the objective of increasing NCEI's insight and laying a knowledge base to improve ongoing engagement with the sector. These results are informed by interviews with 69 experts from companies, government bodies, trade groups, and non-profit institutions involved in or supporting power generation, transmission, and distribution. These interviews and research show that climate data is used to plan for the future, interpret past events, scrutinize investments, increase resilience, reduce carbon emissions, and to better serve the sector's customers.

The analysis shows that NCEI offers material and invaluable support to the US power sector through the provision of climate data products and services. Climate data has many in-depth applications in the power sector, but assigning value to these is challenging, particularly as NCEI data is often combined with data from other sources and tailored to meet specific needs within the sector. This report untangles various direct and indirect data applications, identifying what is useful, what is not applicable and further sector needs. It also presents estimates of the societal and economic value of climate data to the sector.

The importance of NCEI data to the power sector was clearly established throughout this engagement. Weather is the largest and costliest variable to the sector, and businesses rely on NCEI's quality controlled data for decision-making, and look to NCEI as a source of raw information and scientific authority. Interviewees describe the climate services community as fragmented and evolving, and in need of leadership and opportunities to address common areas of concern in the face of extreme weather and climate uncertainty. The power sector relies on government agencies to take this leadership role.

NCEI is respected by utilities and solution providers for the quality and breadth of data. In their view NCEI stands out among its international counterparts because its data is free and publicly available. Open access data levels the playing field allowing companies large and small, and those in the public sector, to make informed and evidence-based decisions. Free data also encourages experimentation with different datasets or analyses, giving organizations flexibility and room to innovate. NCEI, through its scientific excellence, quality standards, and open access, is helping to push forward the boundaries of knowledge, creating jobs, adding value to the economy, and underpinning the viability of the US power sector.

This report contains the following sections:

- Sector profile of power generation, transmission, and distribution in the US.
- Discussion of climate vulnerability to the power sector.
- Analysis and examples of the how this sector uses NCEI products and services.
- Value of climate data to the power sector.

This report also contains the results from a general survey of solution providers on the unit cost and revenue of their products and services sold which are based on NCEI data (Annex C).

Introduction

The National Centers for Environmental Information (NCEI, formerly the National Climatic Data Center) and Global Science & Technology, Inc. (GST) commissioned Acclimatise to engage with organizations in the United States' power sector to assess how they use climate data. This is part of NCEI's larger strategic plan to improve and increase engagement with end users.

The primary goal of this report is to increase NCEI's understanding of how the power sector uses climate data and to lay a knowledge base which will support ongoing efforts to improve engagement with the sector. To meet these goals, this report provides:

- A profile of the sector's essential economic and physical characteristics, trends and projections, and its vulnerability to climate change.
- Analysis and examples of how the power sector uses NCEI products and services.
- Discussion of the value of climate and weather data.

There are also two annexes with additional information:

- Annex A: a complete list of the 69 experts interviewed for this study.
- Annex B: a generic engagement model for reaching out to other sectors using the structure and methodology modelled in this report for the power sector.

1.1. Defining and mapping the sector

In consultation with GST and NCEI, it was agreed to focus this study on the electric power sector. This limited the analysis to US companies and supporting establishments involved in the generation, transmission, and distribution (GTD) of electricity, as defined by North American Industry Classification System (NAICS) code 2211 (US Census Bureau, 2012). This excludes the broader energy sector, which encompasses companies involved in the extraction, processing, and transportation of fossil fuels. As shown below, the power GTD sector represents a substantial part of the domestic economy, contains a wide range of actors, and is home to many distinct uses of climate data.

NAICS divisions represent defined sets of economic actors directly engaged in a specific activity. However, for the purposes of this sector engagement, we began with the sector NAICS code and then considered the wider range of companies and organizations that support the sector in their value chains. This includes suppliers of goods and services and those related to climate and weather data.

Table 1 maps the different kinds of companies and establishments that make up this broader power GTD sector. Special attention is given to organizations likely to require or provide climate and weather data. Mapping the sector is a critical first step towards defining the categories of the sector profile below, as well as identifying people to reach out to for interviews.

Table 1 - Map of actors in the power sector

US POWER SECTOR	Subsector	Categories
	Generation	Thermal (coal, gas, petroleum)
		Nuclear
		Hydro
		Solar
		Wind
		Other renewables (biomass, geothermal)
		Independent power producers (IPP)
		Consultants
		Software/data companies
		Technology hardware companies
		Regulatory bodies
		Trade associations
	Transmission	Regional Transmissions Organizations (RTO)
		Independent System Operators (ISO)
		Specific transmission companies
		Consultants
		Technology hardware companies
		Software/data companies
		Regulatory bodies
		Trade associations
	Distribution	Utilities (local power companies, may be investor-, publicly- or cooperatively-owned, municipal or rural)
		Nonutility power producers
		Retail and wholesale power marketers
		Consultants
		Technology hardware companies
		Software/data companies
		Regulatory bodies
		Trade associations

2. United States power sector profile

This profile surveys the core characteristics of the power sector in the US, summarizing its structure and significance for the economy and society. A range of economic, climatic and regulatory trends and challenges facing the sector are also discussed below.

2.1. Industry overview

The electric power sector operates and serves customers in all regions across the country; although the mix of energy sources, the age and structure of infrastructure, and regulatory forms vary widely.

The electric power industry is essential to all industrial, commercial, and residential activities. In 2013 (Figure 1 from the US Energy Information Administration), the US power sector sold $3.7 million Kilowatt-hours at an average price of 10.11 cents per kWh, earning $376 billion in revenue (EIA, 2014).

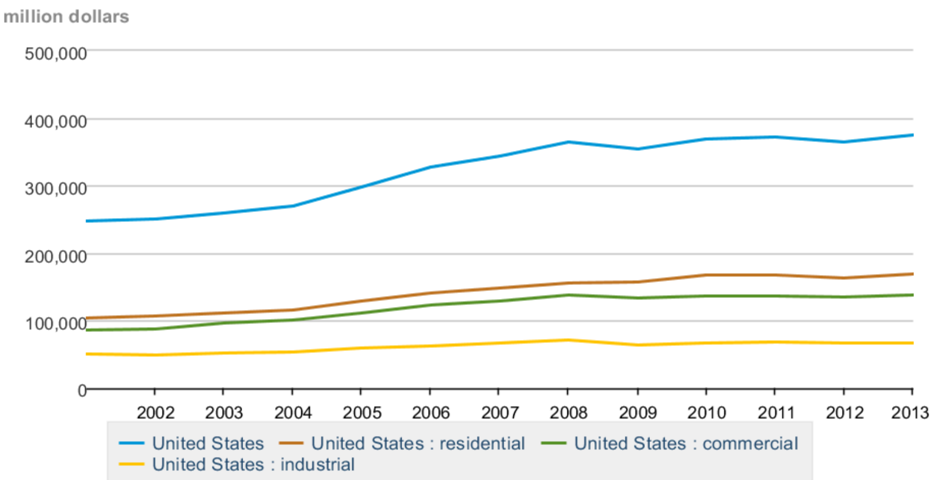


Figure 1 - Revenue from retail sales of electricity by sector, annual (figure sourced from EIA, 2014)

Sometimes referred to as the "largest machine on earth," the US bulk power system consists of over 360,000 miles of transmission lines that connect over 6,000 power plants (DOE, 2008). Altogether, the US Department of Energy estimates the asset value of the North American electricity infrastructure to be over $1 trillion (DOE, 2012).

According to the US Bureau of Labor Statistics, the sector employed over 480,000 people in 2013, 81% of which were employed by privately owned companies (BLS, 2014).

These official statistics for the power sector do not reflect the various supporting actors, such as technological hardware, software, and consulting firms, mentioned above.

2.1.1. Energy sources

Generation can be subdivided according to fuel sources, as seen in Figure 2. Coal remains the dominant source of electricity-generation, followed by natural gas and nuclear (EIA, 2014).

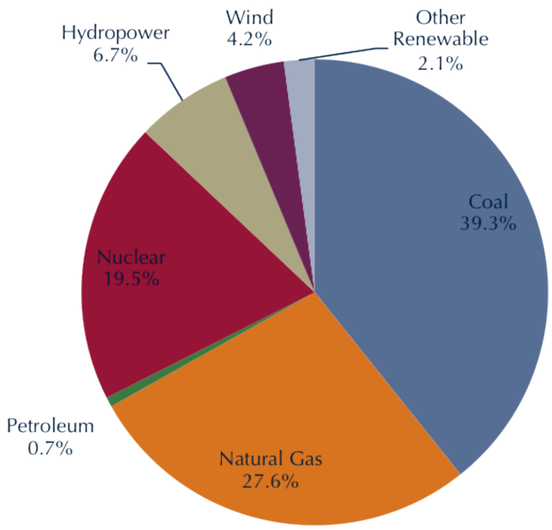


Figure 2 - Percentage of US net electricity generation by energy source, 2013 (figure sourced from EIA, 2014)

Despite its continued dominance of the national energy mix, coal-fired generation has steadily fallen 1.6% annually since 2000, while natural gas and non-hydropower renewables have increased annually by 4.9% and 9.2%, respectively (see Figure 3) (EIA, 2014). Government policies have played a role in these developments, including the American Recovery and Reinvestment Act in 2009, new and proposed US Environmental Protection Agency (EPA) emissions standards, and state-level Renewable Portfolio Standards and tax incentives, all of which have increased the competiveness of natural gas and renewables as compared to coal.

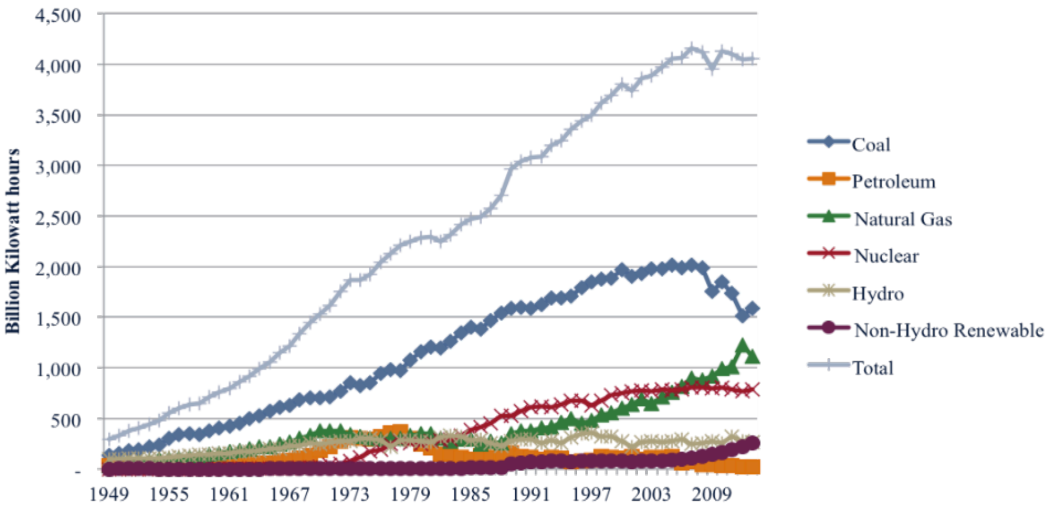


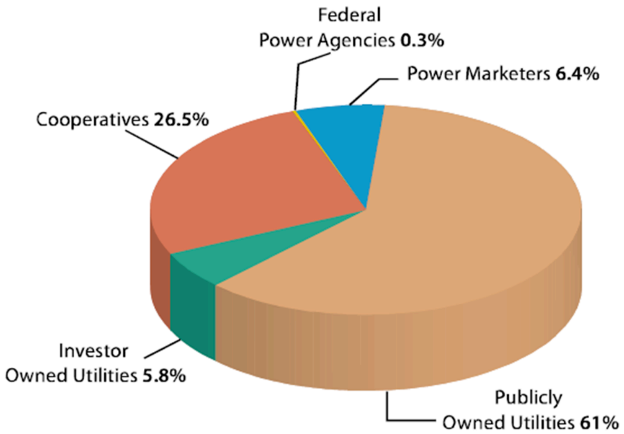
Figure 3 - Trends in electricity generation by source from 1949 to 2013 (figure sourced from EIA, 2014)

2.1.2. Sector constituents

A number of actors under diverse regulatory structures are involved in the US power sector. The primary groups include utilities, system operators, and regulators, along with a range of supporting actors.

2.1.2.1. Utilities

Electric utilities engage in the generation, transmission, and/or distribution of electricity for sale. They may be investor owned, publicly owned, cooperatives, or federal utilities. Utilities are regulated by local, state, and federal authorities and, in the case of electric cooperatives, by their board of directors. Descriptions of each category are listed below.



Number of Electricity Providers

		% of Total
Publicly Owned Utilities	2,009	61.0%
Investor-Owned Utilities	192	5.8%
Cooperatives	871	26.5%
Federal Power Agencies	9	0.3%
Power Marketers	211	6.4%
TOTAL	**3,292**	**100.0%**

Figure 4 - US electric utility industry statistics – number and percentage of electricity providers (figure sourced from APPA, 2015)

- **Investor-owned Utilities** (IOUs) are private companies with publicly traded stock. They are regulated and authorized to achieve an allowed rate of return determined, in most cases, by a state public service commission. Most IOUs are large (in financial terms) with multi-fuel operations across multiple states. While IOUs represent just 5.8% of the total number of utilities they serve nearly 70% of the power sector's customers nationally (APPA, 2015). Con Edison and Duke Energy are examples of IOUs.
- **Publicly-owned Utilities** are non-profit government entities financed through the sale of general obligation bonds and from revenue bonds secured from the sale of electricity. There are different types of publicly owned electric utilities in the country operating under different city, state, and federal authorities. They were established to provide service to their communities at cost and are able to issue low-cost, tax-exempt debt to finance construction projects (PPA, 2013). Publicly owned utilities account for over 60% of the total number of utilities in the US yet serve less than 15% of all customers (APPA, 2015). The Long Island Power Authority and the Los Angeles Department of Power and Water are examples of publicly-owned utilities.
- **Electric Cooperatives** are independent, non-profit electric utilities owned by the customers they serve. They typically serve rural areas often underserved by investor-owned utilities. Over a quarter of all utilities are cooperatives and serve about 10% of total customers (APPA, 2015). Pedernales Electric Cooperative in Texas is an example of a cooperative.
- **Other groups** include power marketers, such as ACES Power Management, who serve 4.3% of customers by buying and selling electricity as a commodity across the country. There are also two federal power agencies that serve a negligible amount of users.

2.1.2.2. System operators

There are two categories of independent, non-profit power transmission system operators which ensure the effective functioning of transmission grids across the US: Independent System Operators (ISO) and Regional Transmission Organizations (RTO). These membership-based organizations serve nearly identical functions, but are based on different Federal Energy Regulatory Commission (FERC) orders (RAP, 2011). Both ISOs and RTOs coordinate, control and monitor the use of the electric transmission system by utilities, generators and marketers, but RTOs generally cover larger geographic areas. The Southwest Power Pool (SPP) is an example of an RTO. The New York Independent System Operator (NYISO) is an example of an ISO.

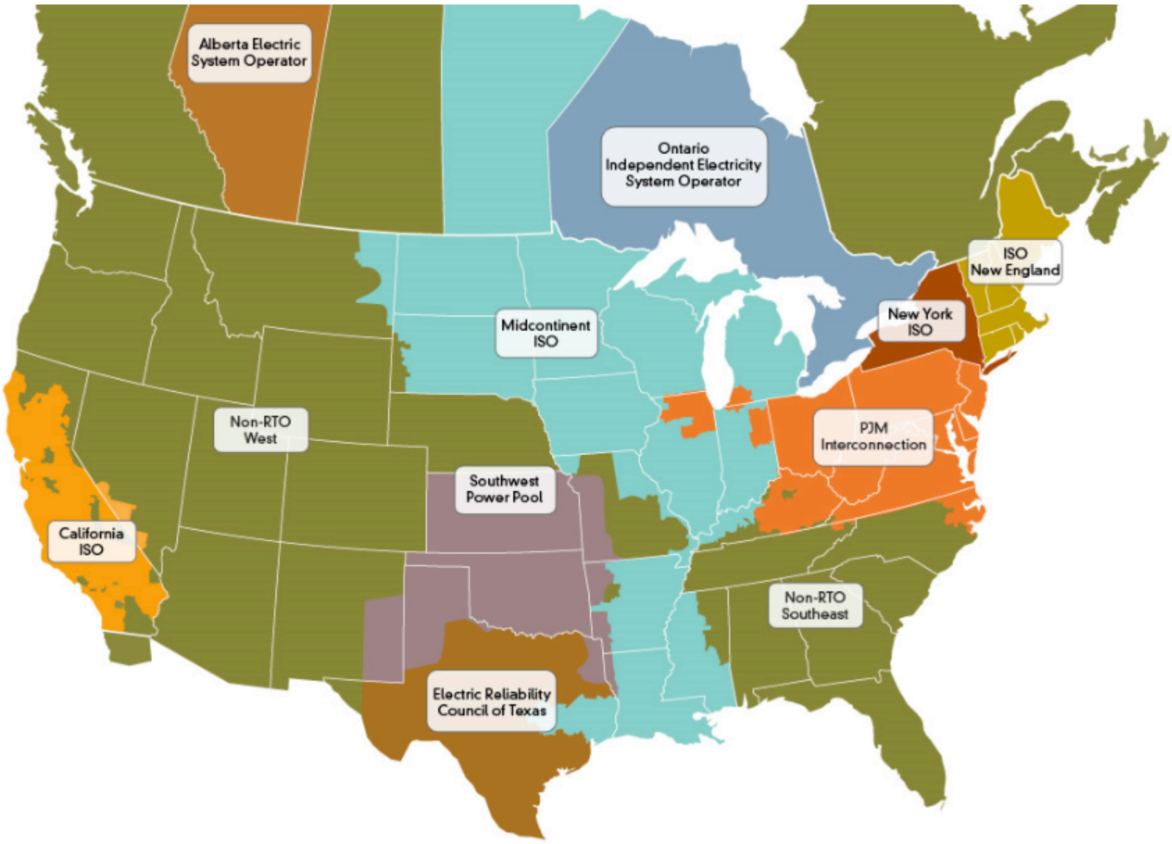


Figure 5 - Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) (figure sourced from Sustainable FERC, 2014)

2.1.2.3. Regulatory bodies

At the federal level, the Department of Energy (DOE) has the broadest responsibilities in regulating power generation, electric transmission, distribution and retailing. Additional regulatory bodies handle specific aspects of the US electric power sector, e.g. safety regulations and enforcement. These include the Federal Energy Regulatory Commission (FERC), an independent agency that oversees many activities in the sector, including prices, safety, mergers, and environmental matters.

Each state has its own public utility commission that works in partnership with FERC to regulate energy operations and safety. State public utility commissions are governing bodies that determine revenue requirements, set rate structures, and mandate quality standards for regulated utilities as well as serving as the arbiter of disputes between utilities and customers (RAP, 2011).

2.1.2.4. Supporting actors

In addition to the private and public sector actors described above, there is a wider 'ecosystem' of organizations providing support to the industry. These include firms specializing in technological hardware, engineering, industry consulting, and software development, together with academic research institutions, universities and trade and professional bodies. Many of these organizations assist companies by developing and promoting best practices.

2.1.3. Trends and forecasts

In recent years there have been several important emerging trends affecting the electric power sector. Private sector reports and government forecasts provide a snapshot into how the industry is changing. Data concerning efficiency improvements, innovation in generation, coal plant retirements, increased reserve of natural gas, and shifting investment and employment patterns all indicate significant changes in how Americans produce and consume electricity.

2.1.3.1. Demand and consumption

The rate of growth of electricity demand has steadily decreased since the 1950s and is forecast to level off at 1.5% annual through to 2040, accumulating in a 29% increase in power consumption as compared to 2012 (see Figure 6). However, demand increases are expected to be largely offset by advancements in energy efficient technologies that are changing the ways consumers use electricity (EIA, 2014).

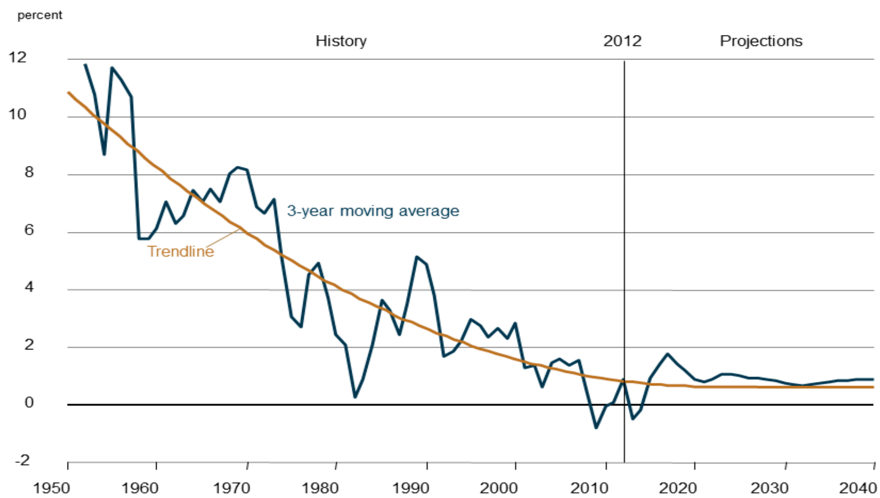


Figure 6 - US electricity demand growth, 1950-2040, EIA Reference case (figure sourced from EIA, 2014)

2.1.3.2. Fuel sources

While renewables continue to grow and nuclear remains steady, the largest shift in energy generation will be between coal and gas (see Figure 7). According to the US EIA, natural gas powered generation, which provided 27% of electricity in 2013, will grow to 35% by 2040. At the same time, coal use in generation is expected to drop from 39% in 2013 to about 32% in 2040. EIA attributes this trend to the relatively low cost of natural gas as well as the retirements of coal-fired power plants. Coal plant shutdowns will increase dramatically as new regulations for sulfur, nitrogen, and mercury emissions come into effect, in addition to President Obama's proposed Clean Power Plan limiting greenhouse gas emissions (BNEF, 2015). However, the number of coal plant retirements is not entirely proportional to a decline in coal-fired electricity generation capacity as a large percent of plants expected to retire operate at output levels lower than their capacity (EIA, 2014).

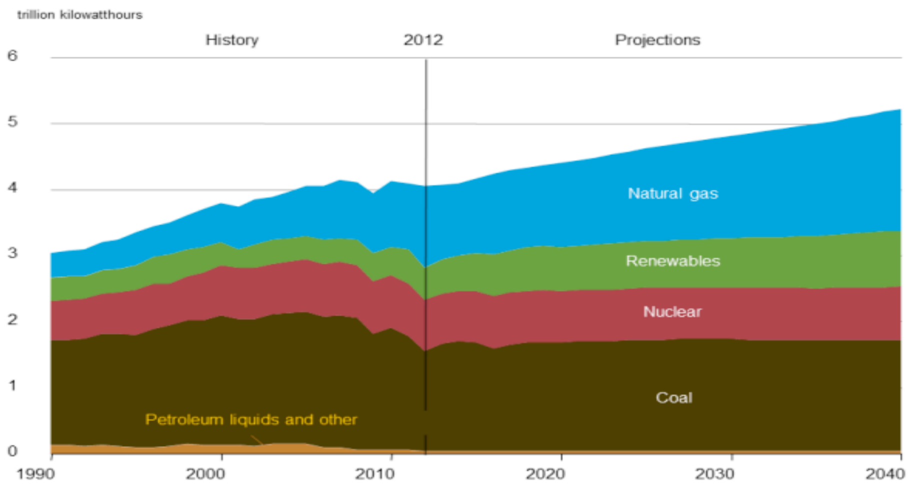


Figure 7 - Electricity generation by fuel, EIA Reference case, 1990-2040 (figure sourced from EIA, 2014)

2.1.3.3. Renewables

Renewable generation is the source of much innovation and movement in the power sector. The EIA foresees total renewable electricity generation growing by 1.9% annually in the coming decades, from 502 billion kWh in 2012 to 851 billion kWh in 2040 (see Figure 8). Non-hydropower renewables, namely wind, solar, geothermal, and biomass, will drive the growth at an average of 3.2% per year and will account for roughly two-thirds of all renewable electricity generation by 2040 (EIA, 2014).

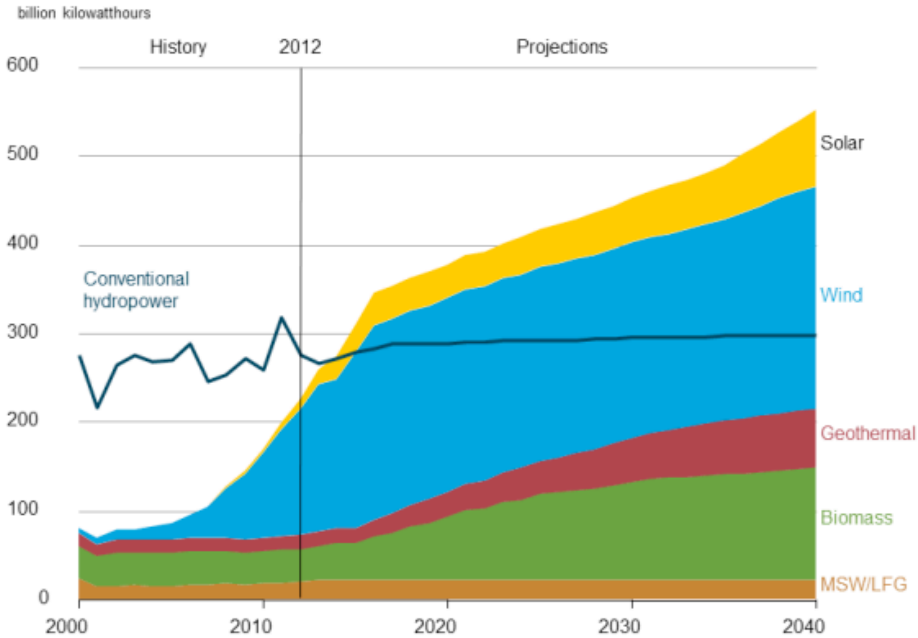


Figure 8 - Renewable electricity generation by type, all sectors, in the EIA Reference case, 2000-2040 (figure sourced from EIA, 2014)

Solar energy has seen significant growth in recent years with capacity increasing by 418% from 2010 to 2014 (EIA, 2014). EIA forecasts continued growth in solar but at the more modest rate of 7.0% annually from 2012 to 2040. Although photovoltaic (PV) capacity has increased in both the electric power (centrally sited) and end-use (customer sited) sectors, the scheduled expiration of the Solar Investment Tax Credit in 2016 will lead to a reduction in the upward trend (see Figure 9, EIA, 2014).

Wind power has also experienced impressive growth in the last 10 years. A recent DOE report found that installed capacity more than tripled between 2008 and 2014 (DOE, 2014). However, growth has not been constant (see Figure 9), with a temporary drop in 2013 between the expiration of a key federal incentive, the Production Tax Credit at the end of 2012, and its subsequent extension in 2013 (BNEF, 2015). The EIA predicts that wind generation will continue to grow at an average rate of 2.0% per year and provide the largest absolute increase in renewable generation as a result of starting from a higher baseline of installed capacity.

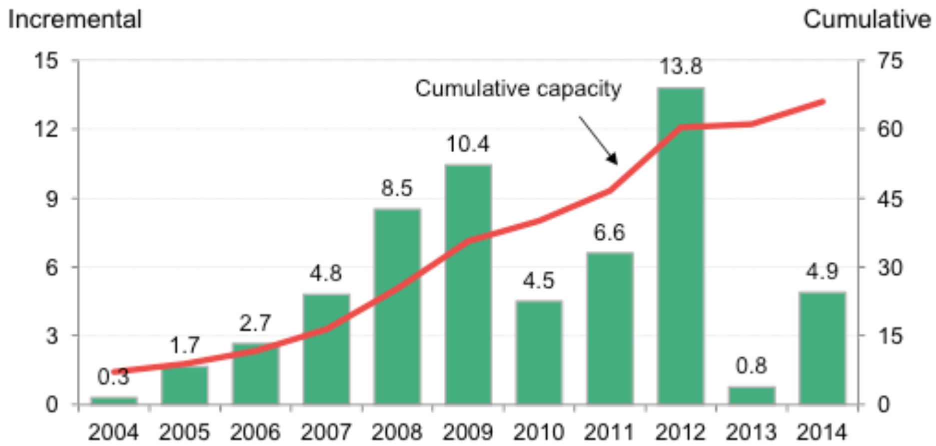


Figure 9 - US large-scale wind installations in gigawatts, 2004-2014 (figure sourced from BNEF, 2015)

The fundamental reason for the growth in wind and solar energy are falling costs along with government support in the form of tax benefits or other incentives. A study by the asset management firm Lazard shows that the levelized cost of energy, or the cost per unit of energy produced, has fallen 58% and 78% over the past 5 years for wind and solar power, respectively (see Figure 10) (Lazard, 2014). Many industry analysts and utility executives say that this trend is expected to accelerate (Cardwell, 2014).

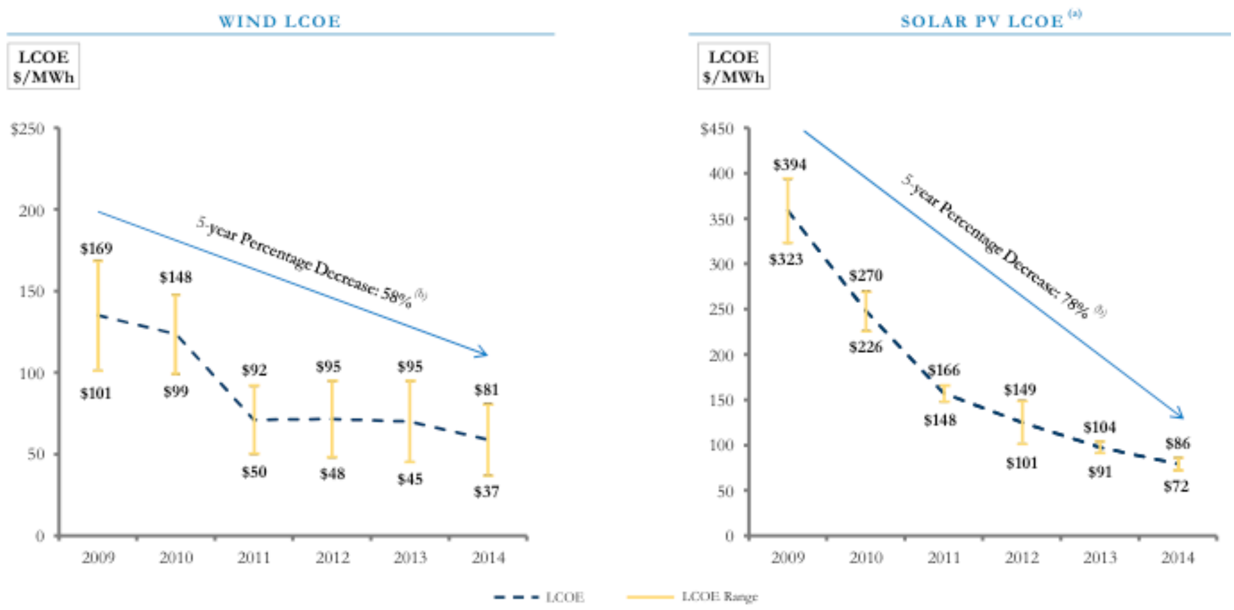


Figure 10 - Levelized cost of energy for wind and solar PV (figure sourced from Lazard, 2015)

Other renewables are predicted to see significant increases as well, though from much lower starting points than wind and solar. Geothermal power follows solar as the second-fastest growing source of renewable electricity generation in the EIA's analysis. It is forecast to increase from less than 16 billion kWh in 2012 to 67 billion kWh by 2040, at a 5.4% average annual growth rate. Biomass generation is also expected to see significant growth at an average of 4.4% per year from 2012 to 2040 (EIA, 2014).

2.1.3.4. Investment

Many of the trends described above have been driven by industry investment patterns. Maintaining and improving electric power infrastructure to meet demand has required steadily increasing expenses as much of the nation's energy infrastructure has begun to age. As a whole, investor owned utilities have more than doubled their annual capital investments over the past decade, boosting expenditures from a total of $43 billion in 2003 to a projected $103.3 billion in 2014 (EEI, 2014b). The bulk of this spending has been spread across generation, transmission, and distribution, with the key priorities of increasing reliability, decreasing congestion, connecting new sources of generation (including renewables), and upgrading old infrastructure (EEI, 2014b). Other investments were largely motivated by the need to harden transmission and distribution networks against extreme weather events.

Since 2007, total investment in renewables from both the public and private sector has amounted to $386 billion. Investments in 2014 were $51.8 billion, part of a steadily upward trend in total investment (as seen in Figure 11). This number places the US as the second biggest investor in clean energy behind China (BNEF, 2015).

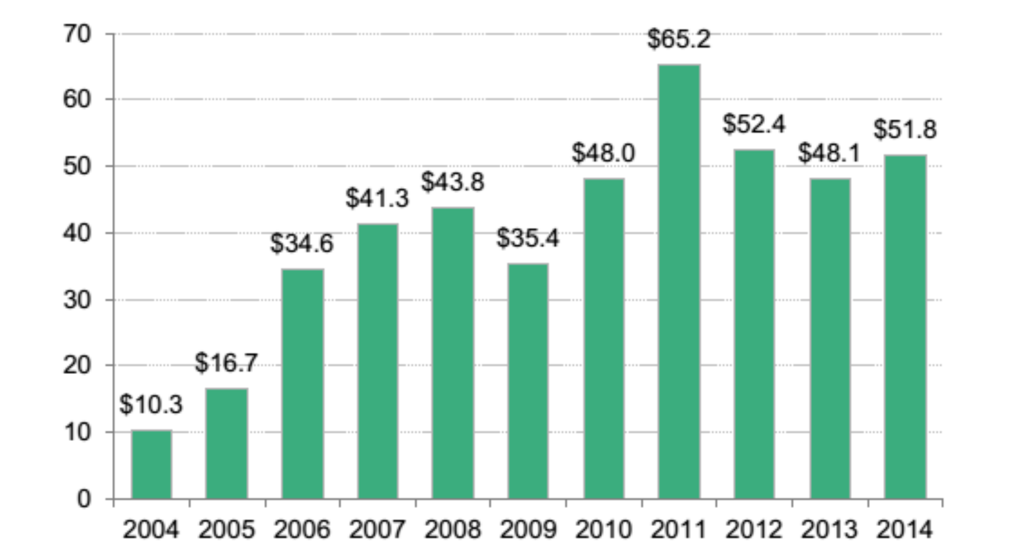


Figure 11 - US clean energy investments, 2004-2014 (figure sourced from BNEF, 2015)

2.1.3.5. Employment

Even as investments into infrastructure and facilities have increased, the US Bureau of Labor Statistics (BLS) predicts a substantial decline in the private sector electric power utility workforce over the next decade, down to 350,600 workers by 2022. The bureau attributes this trend to new technologies which allow power plants to be operated and maintained with fewer workers while increases in energy efficiency help compensate for rising demand for power (BLS, 2013).

2.1.4. Challenges and Opportunities

The trends described above are already remaking the landscape of electricity generation, transmission, and distribution. Going forward, the electric power sector will face a variety of issues that may threaten traditional business models and operating procedures.

2.1.4.1. Anemic demand growth

Over recent decades, improvements in energy efficiency, spurred by government mandates and technological innovations, along with shifting customer behavior, have slowed growth in electricity demand. These factors, combined with the emergence of distributed generation (discussed below), have caused sale volume to weaken as sales no longer track GDP growth, as had been the historical pattern (see Figure 12). This decreases the revenue streams of utilities. Analysts and industry experts believe this trend will force utilities to seek increased rates to stabilize earnings and may diminish their ability to invest in infrastructure upgrades, climate resilience measures, or renewable energy (Aspen Institute, 2013).

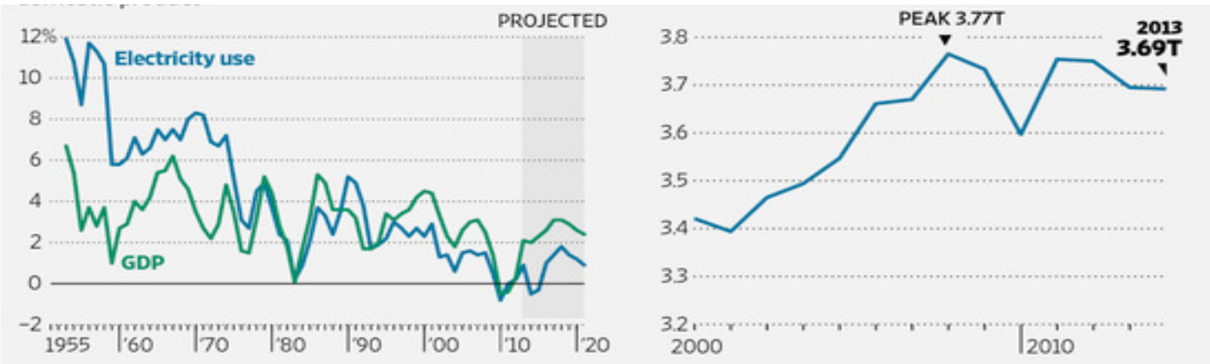


Figure 12 - Growth trends for US electricity use and US GDP (figure sourced from EIA, 2014)

2.1.4.2. Distributed generation

Distributed generation (DG) threatens to further upend the traditional utility business model. DG is energy produced at point of consumption from sources such as rooftop solar PV, small scale combined heat and power plants, onshore wind farms, or other sources, rather than at a central location. These small, flexible systems can power homes, businesses, and communities, but threaten utilities with lost revenues, and ultimately those who rely on DG still rely on utility grid infrastructure for backup or to sell excess power. In losing revenues while still paying for expensive grid maintenance, utilities are forced to raise costs for other customers, creating a positive feedback loop that encourages even more customers to switch to DG systems. This scenario could lead to a "utility death spiral" (EEI, 2013).

2.1.4.3. Smart grid development

Smart grids are the application of digital communications and information technologies, computer processing, and networking capabilities used to monitor, analyze, and control electricity consumption and generation (DOE, 2015). They provide utilities with actionable information that allows them to better control their generation and distribution, as well as to better manage usage patterns and reduce costs. The automation and integration computing technologies in smart grids can better anticipate and troubleshoot problems, such as power outages and equipment failures, than human system operators, saving time, money, and resources. From 2010-2013, the power sector spent $18 billion on smart grid projects, with half of the total stemming from investments made under the 2009 American Recovery and Reinvestment Act[1] (DOE, 2014). However, adoption of these systems varies greatly across the nation as different state and local policies and incentive structures evolve.

2.1.4.4. Terrorism and cyber security risks

In addition to natural disasters, the power sector has to consider human threats to its infrastructure and operations. Sophisticated attacks on physical grid infrastructure, as well as infiltration and sabotage of digital systems pose challenges for the industry by threatening grid reliability and functionality (GAO, 2012). The cyber threat has grown in magnitude as automated systems have proliferated with the development of smart grid technologies.

[1] This Act included a number of spending and tax benefit programs to stimulate the national economy, including investments directed at the power sector.

2.1.4.5. Regulation

Forthcoming EPA greenhouse gas regulations would impose new standards for utility emissions, and have been met with resistance by power sector groups who argue that they will increase costs, decrease system reliability, and cause utilities to lose billions of dollars in stranded assets (Power Mag, 2014). Should the regulations go into effect, this would likely result in a substantial number of coal plant retirements while boosting natural gas and renewable generation.

2.1.4.6. Vehicle electrification

The growth and development of the electric vehicle market is widely viewed as a potential boom to the power industry. The Edison Electric Institute (EEI) called electric vehicles a "quadruple win" in terms of boosting demand, engaging with customers, meeting environmental goals and reducing operational costs through the electrification of their own fleets (2014). In emphasizing the importance of electric vehicles the report concluded, "the electric utility industry needs the electrification of the transportation sector to remain viable and sustainable in the long term" (EEI, 2014a).

2.2. Climate vulnerability

In this section an introduction to the impacts on the power sector is provided. Other more detailed reports are available, including the 2014 National Climate Assessment chapter on Energy[2]. The power sector is vulnerable to the physical effects of climate change, including rising temperatures, decreased water availability, and the increased frequency and severity of extreme weather events, all of which can impact power generation, transmission, and distribution. Table 2 summarizes some of the vulnerabilities relative to key elements of the power sector.

Table 2 - Projected climate impacts and corresponding effects on electricity systems (Dell et al., 2014; World Bank, 2011)

Category	Climate impact	Effect on sector
Thermoelectric Power generation (coal, natural gas, and nuclear)	• Increasing air and water temperature • Decreasing water availability • Increasing intensity of storm events, sea level rise, and storm surge • Increasing intensity and frequency of flooding	• Reduced generation capacity and efficiency, and increased risk of exceeding thermal discharge limits • Reduction in available generation capacity • Increased risk of physical damage and disruption to inland and coastal facilities
Hydropower	• Increasing air temperatures and evaporative losses • Changes in precipitation and decreasing snowpack • Increasing intensity and frequency of flooding	• Reduction in available generation capacity and changes in operations • Increased risk of physical damage and changes in operations
Wind power	• Variation in wind patterns • Storm surges • Extreme weather events	• Uncertain impact on resource potential • Damage to offshore wind turbines • Damage to physical infrastructure

[2] The NCA 2014 energy report is available here: http://nca2014.globalchange.gov/report/sectors/energy

Solar energy	• Increasing air temperatures • Humidity and cloud cover changes • Decreasing water availability	• Reduction in generation efficiency • Uncertain change in power output • Reduction in potential concentrated solar energy generation capacity
Transmission and distribution	• Increasing air temperatures • More frequent and severe wildfires • Increasing intensity of storm events	• Reduction in transmission efficiency and available transmission capacity • Increased risk of physical damage and decreased transmission capacity • Increased risk of physical damage

2.2.1. Thermoelectric power

Thermal power systems produce the majority of the electricity in the US, and face several climate vulnerabilities.

Each kWh of electricity generated at a thermal plant requires roughly 94.6 liters of water, which is largely used for cooling (World Bank, 2011). These facilities are the largest single consumers of freshwater in the US, with estimated withdrawals at over 200 billion gallons per day, accounting for 40% of all freshwater usage nationwide (DOE, 2013). While changes in the timing or quantity of water supply can impact generation, specific impacts on production will differ across the country under climate change scenarios, with some regions seeing increases while others experience significant decreases in water availability.

Heating and cooling processes are affected by ambient conditions such as temperature, pressure, and humidity (World Bank, 2011). Increased air and water temperatures reduce the efficiency of thermoelectric generation, which can reduce power output and require additional fuel consumption, increasing costs.

Higher air temperatures increase the air volume and energy consumption in the compressor, reducing energy production capacity. The magnitude of this impact can reduce power output from between 0.3% and 1.8% for each 1°C increase in air temperature (DOE, 2013). While relatively small in percentage terms, these reductions can have substantial accumulated consequences for power generation.

Limits on thermal discharge also pose challenges for thermoelectric generation. If the water being discharged is considerably warmer than the ambient water temperature, this form of thermal pollution can damage aquatic ecosystems and contravene regulations on discharge (PNNL, 2012). Climate change is expected to make it more difficult for plants to comply with these rules and this may disrupt or reduce generation. Several facilities have faced temporary shut downs when higher water temperatures disabled their ability to meet compliance (DOE, 2013). For example, in 2007, 2010, and 2011, heat waves in the Southeast caused the temperature of the Tennessee River to exceed 32.2°C. This forced the power plant to operate below its normal capacity to avoid exceeding thermal discharge limits. This increased costs to operators who were either forced to bring more expensive generation plants online, or buy energy on the spot at a higher market price (PNNL, 2012).

The projected increase in the frequency and severity of extreme weather events is another threat. Storm surge, sea level rise, hurricanes, and flooding all represent considerable risk, particularly for coastal and riverside facilities (DOE, 2013).

2.2.2. Hydropower

Hydropower generation likely faces the largest degree of climate risk among renewable sources. Rising temperatures, changing precipitation patterns, and decreased snowpack are already having material impacts on hydropower facilities (DOE, 2013). Changing precipitation patterns, seasonal and annual runoff, and streamflow could either increase or reduce hydropower generation capacity, depending on the region (ORNL, 2012). Water loss from increased evaporation and upstream consumption could directly reduce generation capacity (CCSP, 2007).

Indirectly, increasing ambient air and water temperatures could affect water quality, which may have significant effects on aquatic habitats and wildlife. The potential for these adverse impacts may lead to regulatory limits on hydropower flow releases to mitigate ecological damage (FERC, 1996). These requirements would reduce peak generation capacity and diminish operational flexibility of hydropower facilities (DOE, 2013).

Extreme weather can also impact hydropower production. Increasing intensity and frequency of flooding can increase river flows and generation capacity if the excess water remains within a dam's reservoir capacity (DOE, 2013). However, in severe cases, floods can be destructive to hydropower infrastructure. Sediment and debris carried by floodwaters can cause blockages and damage facilities' critical structural components, increasing repair costs and reducing the lifetime of infrastructure.

2.2.3. Wind

While the availability and reliability of wind power is a function of climate conditions, it is uncertain how climate change will affect wind patterns. No consensus exists as estimates of future wind resources vary greatly based on region, emissions scenario, and climate model (DOE, 2013). Severe weather events however can affect the performance and durability of turbines (World Bank, 2011). Extreme wind speeds can exceed maximum operational capacity and shut down power production. Even as both onshore and offshore turbines can be affected by extreme weather, their relatively short lifespans make them more adaptable in the long term to changing conditions than hydropower or thermoelectric facilities which have high capital and environmental costs and a longer physical and economic lifespan (World Bank, 2011).

However, unlike thermoelectric and hydropower plants, wind power generation does not use water in its generation process making it an attractive alternative in scenarios with decreased water supplies (GAO, 2014).

2.2.4. Solar

Climate change will have different impacts on solar power production based on whether PV cells or concentrating solar power (CSP) are used.

PV cells see decreases in generation efficiency when air temperatures increases, and can also be negatively impacted by changes in cloud cover, humidity, haze, and dust (DOE, 2013). The degree to which PV efficiency is impacted by temperature depends on the type of semiconducting material used in the cell. Crystalline silicon PV cells can see conversion efficiency decrease by roughly 0.08% per 1.8°F (1°C) increase in air temperature above 77°F (25°C (DOE, 2013). Newer technologies are affected as well, but to a lesser extent (DOE, 2013).

Cloud cover has drastic impacts on PV output, with production decreasing between 40%-80% within seconds during cloud cover instances and increasing back when the sky becomes clear (DOE, 2013). Higher wind speeds can have diverging impacts on panels as it can cool modules, boosting efficiency and output, but can also cause increased panel abrasion in arid regions and can spread dust particle deposits decreasing production capability (ADB, 2012).

While decreasing water availability would not have a significant impact on solar PV power generation, the same is not true for CSP. Similar to thermoelectric generation, CSP plants require large amounts of water for cooling which makes them vulnerable to increasingly scarce water supplies (World Bank, 2011).

2.2.5. Transmission and distribution

The US electricity grid is highly vulnerable to climate and weather impacts, in particular increasing temperatures. The system is further extremely vulnerable to extreme events such as hurricanes, blizzards, and thunderstorms. A recent report from the White House and DOE found that 58% of power outages in the US since 2002 were caused by severe weather (see Figure 13) (DOE, 2013). The study estimated that these incidents cost the US economy between $18 and $33 billion annually, with some analyses putting the figure as high as $70 billion (White House, 2013). These estimates have led to an increased emphasis on improving grid resiliency to adjust to extreme weather. Extreme weather, climate change and climate variability are discussed in detail in Section 2.2 on climate vulnerability below.

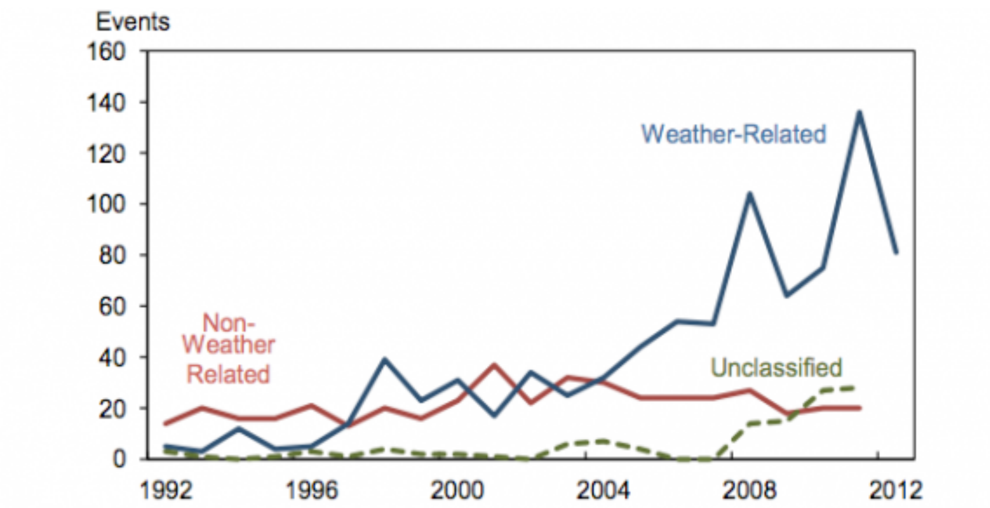


Figure 13 - Observed outages to the bulk power system, 1992-2012 (figure sourced from EIA, 2013)

Currently, approximately 7% of all electricity generated at power plants annually is lost in transmission and distribution (EIA, 2012). These losses increase as temperatures rise and transmission lines lose their capacity to carry a current (ORNL, 2012b). At the same time, hotter temperatures increase power demand for cooling, stressing the distribution system and decreasing substation efficiency and lifespan (CEC, 2012). Higher temperatures also have negative impacts on physical assets as heat can cause overhead transmission lines to sag which poses numerous fire and safety hazards and increases the likelihood of power outages (DOE, 2013).

Increasing temperatures combined with increased drought have led to more frequent and severe wildfires, which are a potent risk for transmission and distribution systems (DOE, 2013). Not only can power poles be incinerated, heat, smoke and particulate matter associated with wildfires can also negatively affect the capacity of transmission lines (CEC, 2012). Furthermore, soot accumulation can cause leakage currents which can lead to outages. Fire retardants essential to firefighting efforts can also damage transmission lines.

Transmission and distribution infrastructure are also threatened by natural hazards such as flooding, landslides, falling rocks, and hurricanes (World Bank, 2011). For example, falling trees during storms and high winds can bring down distribution lines or damage other network components.

Rising temperatures will amplify these vulnerabilities just as increased demand puts further stress on the system. The cumulative impact of climate change on transmission and distribution systems may be even more disruptive than on power generation. Whereas the failure of any individual power plant can be offset by other generation sources, transmission and distribution routes have limited redundancy and transmission lines are often located in remote locations (ADB, 2012).

3. Climate data in the power sector

Climate data has multiple applications across the power sector and is used by a wide variety of actors. This section shares examples from 69 interviews of how NCEI products and services are applied, directly or indirectly, in support of power generation, transmission, and distribution.

Results of outreach

Before contacting users and representatives in the power sector, our team engaged with 18 staff who produce or distribute climate data products and services to the power sector. These included staff from Regional Climate Centers, Regional Climate Service Directors (RCSD), state climatologists, NCEI in Asheville, the Cooperative Institute for Climate and Satellites (CICS), and GST.

The next step was to reach out to potential data users in the sector. Contacts were identified through introductions from the 18 climate data providers and distributors, further research, existing contacts, and by asking each interviewee for recommendations of who else to speak to. In total, 110 interview requests were sent by email to individuals representing utilities, solution providers, regulators, regional energy bodies, academic institutions, trade associations, sector groups, and government agencies that use climate data. A total of 51 of the 110 people contacted agreed to an interview (mostly by telephone, though several interviews were conducted via email).

All users were screened for whether they do or do not use NCEI data (though only the Center's previous name and acronym were used in emails and phone calls). Most said that their organization uses NCEI data on a regular basis, though this use could be direct or indirect. In the latter case, some users did not know they used NCEI data; when the interview determined, though questioning or further research, that an organization did in fact use data from NCEI, these scores were updated.

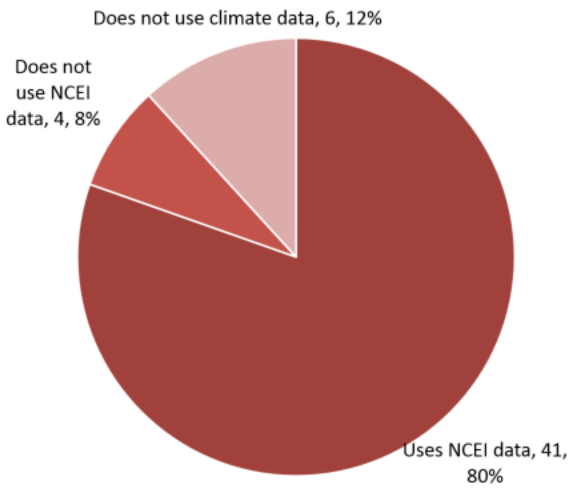


Figure 14 – Source of climate data: number and percentage of respondents from the user community

In total, 69 individuals were interviewed for this study. They represent a wide range of sector actors and perspectives, as shown in Figure 15 below.

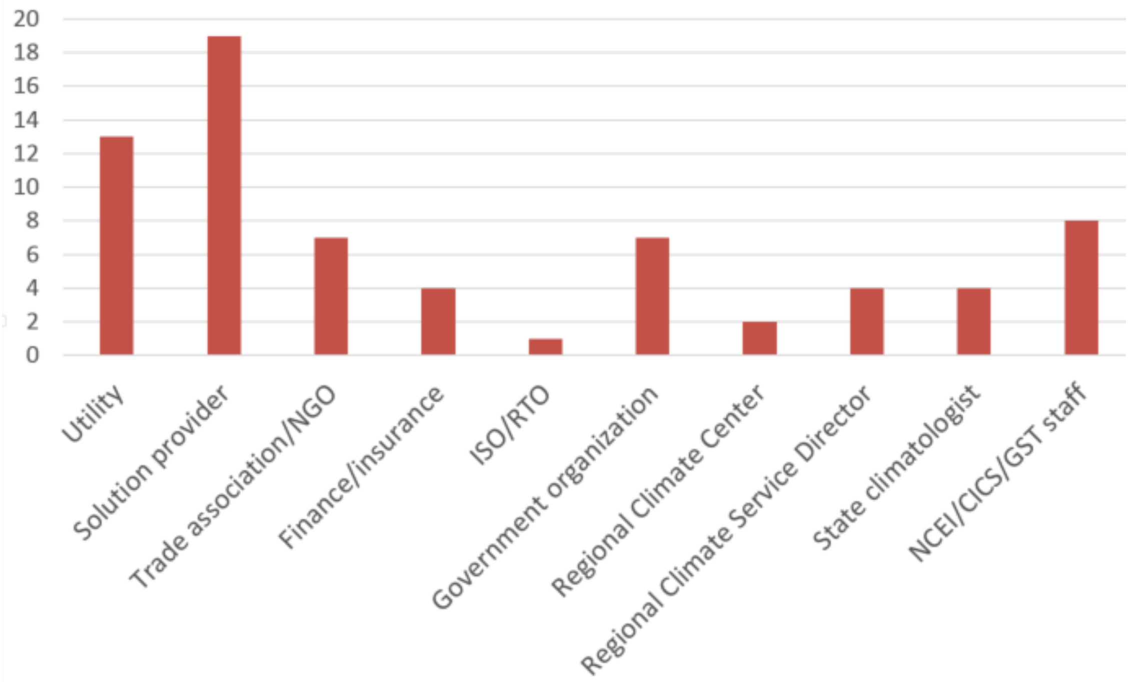


Figure 15 - Power sector interviewees by category

3.1. Examples of data use

Nearly all interviewees use climate data on a regular basis for operations, maintenance, and/or planning in the power sector. Climate data is used for various purposes across the sector, e.g. for daily transmission and distribution planning as well as for long-term planning of infrastructure and system design. The importance of the accuracy and accessibility of climate information was stressed repeatedly throughout the course of the interviews.

The energy and climate sector non-profit organization C2ES reports that utilities often use weather and climate data acquired from private consultants, since consultants understand the decision making and types of data that are most relevant for power utilities (Joe Casola, pers. comm.). With some exceptions this was found to be largely true in this study. The choice of NCEI data, and the choice of variables used by utilities vary widely. Climate Normals, data on heating degree days (HDD) and cooling degree days (CDD) are used commonly. Global Historical Climatology Network (GHCN) and data on weather extremes are also used. Some utilities employ in-house climatologists or meteorologists, and deploy their own operational networks and mesonets (e.g. San Diego Gas and Electric), or develop in-house products.

Specific applications of NCEI data are described below.

3.1.1.1. Load forecasting

When trying to understand fluctuations in energy markets or problems in matching supply and demand, the biggest explanatory value is usually weather. The Northeast Energy Network Performance Analysis (NOAA) 2003 states that 90% of load forecasting errors are due to weather, making accurate forecasts extremely valuable (Wesley Hyduke, pers. comm.). Once the role of weather is identified and understood, it allows a utility to address other issues (Robert Zacher, ComEd, pers. comm.). The importance of accurate weather and climate data is crucial, since if misjudged due to bad data, this can lead to brownouts with financial, industrial, and health ramifications. Understanding load also informs the buying and selling of electricity on regional markets in anticipation of price fluctuations.

Many solution providers are involved in load forecasting. Schneider Electric, for example, has 50 meteorologists on staff who provide temperature data to utilities in an hourly resolution forecast system that stretches 15 days into future. Though other variables are included, understanding temperature is the main driver of load forecasting. The Automated Surface Observing System (ASOS) is their main data source from NCEI, which they also archive internally and use for testing and refining their models. Schneider Electric staff also use Climate Normals from NCEI (Wesley Hyduke, pers. comm.).

All utilities spoken to, whether public or private, said that a primary goal of their operational planning is to make load forecasts as accurate as possible and that this requires reliable weather and climate data. These forecasts combine many kinds of data, and from many sources, with weather and climate playing a central role for three reasons: 1) their influence on demand; 2) their physical impact on installations; and 3) in the case of renewables, their influence on the supply of water, wind, and solar for generation.

Electric utilities frequently use climate information to estimate demand and supply both in the long and short term, and use that information to optimize generation from the hourly to annual scales (Robert Zacher, pers. comm.). This is done by inputting the weather forecast (particularly temperature figures) into load forecasting models to estimate what load they can expect to meet.

Case study: HOW ONE NON PROFIT COUNCIL USES NCEI DATA TO SUPPORT ITS REGION

Regional non-profit bodies also provide forecasts. The Northwest Power and Conservation Council (NPCC) serves power utilities in its region by providing 5 and 20-year forecast loads, based on hourly and annual levels of demand, respectively. More than half of their system is hydro, and they use an 80 year hydrograph for their main water systems to estimate flows. These and other services are based on climate and weather data that they acquire from NCEI and NWS. The NPCC:

- compares NCEI's Climate Normals to historic energy demand to determine the cause and affect relationship;
- uses NCEI's Typical Meteorological Year (TMY) datasets to find correlations between temperature, wind, and hydro conditions to see how these affect electricity demand;
- uses climatic forecast models from regional universities, combined with demand forecasts, to understand future conditions. Historical data from Climate Normals are tied into these models;
- provides its members with historical weather data to assist in efficiency studies, when for example they are trying to determine the effectiveness of energy efficiency programs, which can leads to billions of dollars in savings for customers and the utilities.

Though often indirect, NPCC attributes material benefit from using NCEI data across their region. They have also had positive interactions with NCEI. For example, when the Council had to create regional zones to represent different climates and their varied HDDs, NCEI helped them get population weighted HDD and CDD days and subzone averages. This allowed NPCC to manipulate the data quickly and efficiently, saving weeks of work (Tom Eckman, pers. comm.).

Bonneville Power Administration (BPA) is a self-funding federal non-profit agency based in the Pacific Northwest. Operating on what is essentially a private-sector business model, BPA sells energy primarily produced by 31 hydroelectric plants. BPA uses a variety of observed weather data, including from NOAA, to monitor weather, snowpack and stream flow. Using ASOS stations, BPA looks to historic temperature to prepare hourly load forecasts (Erik Pytlak, pers. comm.).

Lower Colorado River Authority (LRCA), a non-profit public utility in Texas, maintains a diverse generation portfolio to supply its wholesale electric customers with power. Bob Rose at LCRA described how load forecasts help them save money:

“The biggest benefit of climate and meteorological information is a better load forecast and having a better idea of what will be happening in the next few days. Accurate information saves us money in the long run, because we may not need to have certain plants running. That reduces costs such as purchases of gas or coal” (Bob Rose, pers. comm.).

Case study: FOR SHORT OR LONG-TERM PLANNING, ACCURATE CLIMATE DATA IS NECESSARY

Seattle City Light, like many utilities, uses Climate Normals from NCEI to forecast future loads. In the short term they also use other weather data to adjust load based on actual weather. They use seasonal forecasts of stream flow based on the Climate Prediction Center’s El Nino/La Nina predictions to plan for the operations of dams in the one month to one year timeframe.

They develop a 20-year plan (updated every 2 years) to evaluate if the utility has sufficient resources to meet energy demand over the next 20 years. This resource plan relies on Climate Normals for demand and historical variability in observed stream flow for supply.

SCL uses NCEI’s website to access the information they need and funds research projects with universities to get additional information for planning purposes. Crystal Raymond at SCL says “the better the data the more we can narrow the uncertainties and what these climate impacts are – and the better we can plan” (Crystal Raymond, pers. comm.).

Despite the common use of Climate Normals for forecasting, many companies in the power sector raise issues with them. While 30 years is still seen as an industry standard, some consultants are not sure they are good enough anymore and have asked for an update to the 30 year Normals or perhaps, even 10 to 20 year datasets (Wesley Hyduke, pers. comm.).

Many consultants were pleased that they had access to 10-year NCEI Normals. Others however believed that more information was required. Commonwealth Edison, which serves the Chicago metropolitan region, prefers to use Normals from NCEI but wishes that they were updated more frequently. To compensate, ComEd develops their own dataset in the middle of the 10 year Normals cycle, so that they have an updated set every 5 years (Robert Zacher, pers. comm.).

ComEd staff are also wrestling with what trend sample to use for Climate Normals (whether 10, 20, or 30 years). If their goal is to assign a value to weather impacts, but climate change is shifting weather patterns, they believe that it might be best to work with only the recent past. However, despite that problem, they see the last 10 year trend as presenting too much variability, and still rely on 30 year Normals updated every 5 years. They are looking for leadership on these issues and hope that NCEI can help the sector think through these challenges (Robert Zacher, pers. comm.).

3.1.1.2. Forecasting hydrological conditions

Weather and climate data are used to estimate the generation of hydroelectric facilities. Water resources and the subsequent hydroelectric generation potential can vary widely year to year and from season to season. Data on snowpack, spring and summer stream flows, temperature, and precipitation are closely monitored.

Accurate hydrological data information is needed for hydropower and thermal electric plants. The National Water and Climate Center (NWCC) for example provides a Snow Survey and Water Supply Forecasting Program which provides data used by many utilities. These include providing data for conservation, tools for assessing water supplies and climate, and resources for addressing questions on local and regional conditions, drought and climate trends. For its forecasts the NWCC uses both data collected from snow sensing sites and data from NCEI (including climate outlooks for El Niño and Pacific Decadal Oscillation), the Western Regional Climate Center, the River Forecasts Centers, Oregon State University, and the United States Drought Monitor (Michael Strobel, pers. comm.).

Another example is PacifiCorp, which owns 47 hydropower facilities, located in Washington, Oregon, California, Idaho, Utah and Montana to power households and businesses across the West. Their team uses climate and weather data to facilitate flexible generation and load dispatch to meet demand as it changes during a day or across seasons, helping them to:

- Anticipate trends in precipitation for hydropower plants
- Forecast future reservoir conditions for flood control and to schedule irrigation releases
- Forecast the volume of storage water available for irrigation, which is done months ahead, as well as planning short term flood control releases during high intensity precipitation events
- Determine evaporation from reservoirs

PacifiCorp uses public wind, precipitation, temperature, snow, solar radiation data, and products for their operations, though little of this is sourced directly from NCEI. However, PacifiCorp collects some of their own data at installations, and submit some of those data records to NCEI through the NWS Cooperative Observer Program (Connely Baldwin, pers. comm.).

3.1.1.3. HDD and CDD

Closely tied to load forecasting is the practice of calculating HDD and CDD. Detectent uses climate data to build a disaggregation tool for calculating CDD and HDD at a high resolution. This tool maps weather stations to zip codes, and then maps temperature and humidity to those areas. Historical climate data from NCEI is used to tune and prove these models, testing results against known outcomes. One novel use of this information is correlating HDD and CDD to transformer loading, from which they estimate equipment maintenance and replacement schedules (Todd Thayer, pers. comm.).

3.1.1.1. Forecasting for other renewables

Meteorological and climate data are expected to have an increasingly important role as the relative proportion of generation from renewable energy sources such as wind and solar increases. However, most of the data pertaining to irradiance, wind and renewables, are produced by the private sector and maintained in propriety data sets.

Accurate solar irradiance and cloud data are needed to determine the output of solar facilities. However, most of the contacts interviewed said that they were not aware of NCEI data being used for forecasting solar generation or operations. Wind data from NCEI datasets may not be useful, as it is collected at sea level rather than at the common height for installed turbines, 80 meters above sea level. Instead, a number of private companies have developed their own proprietary datasets. However, several contacts expressed the desire for this data to come from a free and reputable source like NCEI.

The National Renewable Energy Laboratory (NREL) provides the renewable generation market in the US and multiple countries around the world with research, guidance, and access to data. Though they have no climatologists on staff, they have begun using climate data, sourcing historical and projected data on temperature and precipitation from NCEI and NCAR. NREL staff want to use more climate data and evaluate its importance relative to energy and climate resilient pathways, but face some basic misalignments in the level of detail of climate data. A main issue is that climate data is not at a sufficiently detailed geospatial or temporal resolution for wind, solar, and biomass. NREL works with NOAA and private vendors to access the data they need, but would like to see climate science evolve regarding the standards for downscaling. Quality and resolution of data sets over long temporal scales is critical to effective energy planning applications (Doug Arent, pers. comm.).

Case study: WHY IS A LEADING ENERGY SERVICES COMPANY LOOKING FOR DATA OUTSIDE OF NCEI?*

Meteorologists from one major energy services company (which requested to be kept anonymous) discussed the strengths and weaknesses of using Climate Normals and NCEI products. This company relies on temperature data in Normals to compare and contextualize forecasts, which allows them to anticipate energy demand. However, the power sector typically uses a 10-year climatological outlook. NCEI's 30 year Normals are not recent enough (1981-2010) to meet their needs. They say that a 10 year climatology would be a huge benefit to the power sector, as the most recent 10 years better captures the latest warming or cooling trends. This kind of data increases the value of derivative products like weather hedging, and allows this energy services company to better gauge the market. They would like to see NCEI meet this sector need (anonymous meteorologists, energy services company, pers. comm.).

3.1.1.2. Real-time weather services

Organizations like Earth Networks/WeatherBug serve utilities with real-time weather and lightening data, forecasting solutions and visualization tools to help customers interpret the weather and what it means to them as electricity companies. Though not willing to reveal the precise details of which datasets are used and how, they said that climate data from NCEI provides key inputs and is used for ground-truthing real time forecasts (meteorologist at Earth Networks, pers. comm.).

3.1.1.3. Managing transmission infrastructure

The transmission infrastructure built and operated by ISO/RTO system operators also requires climate data. Though many consultants and sector experts spoke about transmissions, only one ISO agreed to an interview. The California ISO operates the majority of the state's grid and facilitates the wholesale energy market with the goal of lowering prices and diversifying resources across the state. This ISO uses climate data in a number of ways:

- To prepare monthly market disruption reports, which are used to understand the impact of things like weather on energy prices;
- To prepare load forecasts for the next day, identifying trends and determining how much energy needs to be bought; and
- To forecast energy production, including for wind and solar, up to 9 days out.

To do this, the California ISO uses NWS and NCEI data on precipitation, temperature, humidity cloud cover and other variables. Climate data is particularly used for training forecast models and informing renewable operations. Most of this data is provided through intermediary consultants who access NOAA data directly (Jim Blatchford, pers. comm.).

3.1.1.4. Siting of facilities and asset management

It takes years to build a power plant and understanding climate trends is crucial for deciding where to site and how large a power plant should be. Several interviewees (e.g. Brian D'Agostino at San Diego Gas and Electric) said that archival climate data and predictions for 10 to 20 years in the future, combined with population data, are primary inputs in the decision making process for siting new facilities (Brian D'Agostino, pers. comm.). NCEI Climate Normals, are a go-to source for many utilities, including BPA, for a variety of long term planning purposes (Erik Pytlak, pers. comm.). However, Robert Reed at Alabama Public Service Commission emphasized that 30-year Normals are not predictive of next year and certainly not predictive of 20 years from now. In his opinion there is a strong need when siting assets for more flexible Normals, that bear the imprimatur of NCEI, as these would assist in the design and planning of future installations (Robert Reed, pers. comm.).

Consultants are providing a number of new tools to utilities. One being developed by Earth Networks/WeatherBug focuses on asset management, which helps them determine how equipment fares under variable weather conditions. By looking at historical weather data to see how weather affected assets over the last decade or more, they can work to build resiliency using past weather information (meteorologist at Earth Networks, pers. comm.).

Case study: HOW CAN NCEI BALANCE THE NEEDS OF LARGE VS. SMALL SOLUTION PROVIDERS?

A leading international meteorological services company based in Europe, but with a small American office, highly values the raw data it gets from NCEI. A senior meteorologist on staff said that without NCEI's contributions, their sector and their company would not exist. However, because this company has a large R&D team on staff, they see any value-added products coming from NCEI as posing direct competition to their business.

One of their chief products is an advanced forecasting software that relies heavily on NCEI data for training forecast models. They sell this to companies who use it at almost every stage of developing and operating power GTD installations:

- assessing infrastructure siting based on 40 years of historical climate data;
- aiding the construction of energy installations on and off shore with weather forecasts;
- data to inform operations and maintenance;
- wind and solar power forecasts;
- inform power and commodity trading based on weather data;
- manage transmission and distribution networks in the face of weather hazards and provide early warning of extreme weather; and
- estimate power production capacity and demand.

Though focused on Europe, this international company relies on NCEI's global data sets as its primary raw input from which it creates these tools to serve its customers. As they have a large team of data analysts they are very wary of NCEI 'overstepping its boundaries' and increasing the user-friendliness of products and services. They worry that this would allow other consultancies to steal part of their market share as well as increase the number of companies who could work directly with NCEI data, without a solution provider intermediary. This company considers the challenge of accessing and using NCEI data a source of competitive advantage (anonymous manager at meteorological services company, pers. comm.).

3.1.1.5. Retrospective analysis and ground-truthing

In addition to utilizing data for forecasting to avoid outages or damage, it is also used for retrospective outage analysis. Utilities use climate and weather data as a part of their risk and emergency management strategy, in particular to understand what types of weather, and at what magnitude, correlate with certain types of power outages. This data helps in answering questions about how severe certain extreme events are anticipated to be in the future, how bad they were in the past, and to compare it to outages or damages that utilities have experienced before (Joe Casola, pers. comm.).

Many utilities rely on experts like Earth Networks/WeatherBug to provide historical climate data utilized to analyze the correlation of severe weather impacts to outages. Beyond enabling this forensic analysis, Earth Networks/WeatherBug also provides utilities with service territory-level weather data used to create short term forecast feeds that are then ingested by utility-based storm predication and outages models for improved accuracy by as much as 50%. More and more utilities, including companies like Detroit Edison and National Grid are interested in analyzing these correlations (meteorologist at Earth Networks, pers. comm.).

Case study: HOW ONE SOLUTION PROVIDER CALCULATES LIABILITY USING PAST CLIMATE DATA

Power System Engineering, Inc. (PSE) is a full service consulting firm for electric utilities. PSE's clients include distribution cooperatives, generation and transmission cooperatives, investor-owned utilities, municipal utilities, public utility districts and industry associations. One service that PSE provides is using historical data to determine how extreme weather events impact the performance and reliability of the electric power infrastructure. The aim is to use these results to establish modernized design standards for the construction of new facilities and hardening of existing facilities, with the intent of mitigating against future weather caused outages. This is also relevant for benchmarking the reliability of utilities. PSE develops econometric models to quantify the impacts of external variables utilities are facing, and advises what the expected reliability performance should be or could be under given circumstances. Therefore data, especially on hourly wind speeds, lightning strikes and ice storms (ice accumulation and concurrent wind speeds), are essential and some of this information is sourced from NCEI (Erik Sonju and Steve Fenrick, pers. comm.).

3.1.1.6. Technology development

Siemens, among other equipment developers, designs and sells technology for power systems. Site performance is estimated using local weather and meteorological data, or estimates provided by clients. Site-specific local climate-meteorological data is used to estimate the performance of turbines at their clients' proposed thermal and renewable sites. Clients will typically provide expected local climate and meteorological data based on historical information, which Siemens uses as a proxy for conditions expected during commencement of commercial operation. This gives engineers a window into the likely weather extremes that could affect the installation's generation and performance characteristics. Local weather predictions will not typically alter basic hardware design features, but it may affect the turbine (or facility) performance. Gas turbine performance is highly dependent upon the ambient temperature, pressure and relative humidity. Performance guarantees are typically evaluated based on actual site environmental conditions, with correction factors that adjust the site conditions to original contract conditions. Data on temperature, precipitation, and humidity are obtained from many sources and datasets, often from NCEI (Bruce Rising, pers. comm.).

3.1.1.7. Service maintenance and restoration

Many utilities use climate and weather data to forecast storms and/or use historical weather archives to understand weather impacts on their systems. Some use products like NEXRAD to assist in preparation before a major storm hits their system (Brandon Hertell, pers. comm.).

Southern California Edison (SCE) uses climate data to understand outage management, storm predictions, and help them interpret impacts to transmission and distribution systems. They use a large statistical ensemble that includes data from NCEI, and conduct these studies both before and after extreme weather events. Whenever SCE sees extreme weather events developing, they send alerts to transmission and distribution monitoring and repair teams. Wind, intense rain (which could cause erosion), and drought conditions (wind plus dry conditions) are all potentially problematic (Paul Roller, pers. comm.)

Case study: SECTOR ORGANIZATIONS SUPPORT UTILITIES, AND SOLUTION PROVIDERS

Climate and Energy Solutions (C2ES) is an independent, nonpartisan, non-profit organization that provides information and analysis on the scientific, economic, technological and policy dimensions of climate and energy challenges.

There are other trade and sector organizations that work with private companies. Another is Edison Electric Institute, an association of shareholder-owned utilities that provides policy and technical resources to its members. These resources occasionally touch on issues related to extreme weather and climate.

Non-profits and trade and sector organizations can be effective translators of climate information and can help utilities understand how climate data can be valuable. However, because of differences in missions and technical capacities, these organizations are typically not in competition with service providers. When working in this capacity, non-profits and trade sector organizations can perform an important role in building the market for the climate products and services (Joe Casola, pers. comm.).

3.1.1.8. Strategic investments and market analysis

Climate data is often used to inform or conduct due diligence on investments. Some further examples are provided below.

Siemens conducts strategic market assessments for new power projects and will review a range of economic, engineering and environmental factors in such an evaluation. This can include project economics (including financing and capital costs), access to energy resources (pipelines and transmission lines), water resources and local meteorological data (sometimes obtained from NCEI). The review may highlight the appropriate technology selection for a specific project based on the final location. This can be useful to decide a level of commitment for a potential investment or product line (Bruce Rising, pers. comm.).

GE Energy Financial Services has a team that invests in innovative power generation, with significant financing of wind and solar, for which they rely on climate and weather data. This data is, however, usually acquired and handled for them by consultants, which they believe to be common among their peers. They use this data to consider the design case for a given asset, assessing siting and operational thresholds. The other use of data is predictive, as they work to understand how environmental conditions are likely to affect generation. They use these results to buy or build generation facilities that can serve peak markets during periods of extreme weather (Senior Risk Manager, GE Energy Financial Services, pers. comm.).

3.1.1.9. Insurance services

Weather and climate data are of high importance to the finance, insurance and reinsurance sectors. One strong example comes from Nephila, an insurance provider that protects businesses and municipalities from the adverse financial impacts of day-to-day weather and natural catastrophe events. They use historical climate data from NCEI and other sources to assess the likelihood of historical weather events, correlate weather variability with the buyer's variability of financial performance, and to estimate the potential benefit of weather insurance in mitigating negative financial performance for the buyer. They rely on private weather data providers who work all over the world collecting data from different sources, both private and public. GHCN Daily and Integrated Surface Database (ISD) are the main data products they use from NCEI, and some of the products that they trust most (Matt Coleman, pers. comm.).

Energy companies like natural gas suppliers and electricity providers are regular buyers of weather insurance. Based upon an estimate of the amount of weather insurance currently sold to energy companies, an analyst at Nephila estimates that the amount of financial risk due to weather that the energy sector insures is worth at least $2 billion annually (Matt Coleman, pers. comm.). More broadly, the global weather insurance market is growing, with individual deals reaching hundreds of millions of US dollars.

For insurance and reinsurance firms, the role of government as the main source of credible and authoritative data is crucial. When pricing and settling a weather risk transfer contract, all negotiating parties must consider the data authoritative. In the US and in many other parts of the world, Nephila considers NCEI as setting the standard for climate data. Though Nephila identified ways in which NCEI can improve its data formatting and organization, they say that such concerns are minor when compared to the value they obtain from the data.

3.1.1.10. Setting regulation

Many regulators use climate and weather data to assist in overseeing utilities in their jurisdiction. For example, in some states Climate Normals are used by commissioners for setting electricity and natural gas rates (Robert Reed, pers. comm.). Also, commissions will require that utilities use climate data, for example, to calculate weather-normalized numbers to demonstrate past and expected usage (Robert Zacher, ComEd, pers. comm.). Commissions can also require utilities to undertake rigorous vulnerability assessments informed in part by climate and weather data, as in the case of Con Ed and the New York Public Service Commission after the severe impacts of Hurricanes Irene and Sandy.

4. Value of climate data to the power sector

The interviews and research conducted for this project indicate that companies and organizations across the power sector find material benefit in using climate and weather data. Only a limited number of users were able or willing to provide figures showing the financial benefit that this data offers to their organization. This section contains examples of monetary value, primarily found in the interviews conducted for this report and supplemented with desk-based research. In addition, please see Annex B for results of a survey sent to climate and weather service solution providers (not power sector specific) on the value of climate data.

The examples below show the application of climate data and the value of that application, through the prices of products, estimates of losses avoided, demonstrated cost savings, increased income, etc. The variety of examples makes it difficult to estimate the value of the whole sector, but does indicate the breadth and depth of the value of climate information.

Associating value with NCEI products and services is more an exercise in attribution than causation. Climate and weather data are rarely used in isolation and few if any of these examples of value can be attributed to NCEI alone.

These examples are all related to power GTD. However, to collect as many points of reference as possible, examples from both weather and climate data are used, the results are not limited to the US, and values included can be both real and estimated. Also, not all sources were able to confirm if the data they used was sourced from NCEI.

DESCRIPTION OF VALUE	VALUE (real or estimated)	USES NCEI DATA?
Tennessee Valley Authority manages a 42,000 sq. mile river system that includes an integrated series of 49 dams to provide multiple benefits including flood control, navigation, power, water quality and supply, and recreation. They achieve this through the use of many data resources, including an in-house rain and stream gauge network, co-operated USGS gauge networks, short and near term weather predictions from NOAA; the Weather Prediction Center, the Hydro-meteorological Predication Center, the Lower Mississippi River Forecast Center, and climate and weather data from NCEI, including Climate Normals and data on extremes (Jeff House, pers. comm.).	$240 million annually (averaged) in avoided damage $1 billion annually in shipper saving Approximately $500 million annually in hydropower value Quality of life, abundant water supply, recreation value, ect	Yes
Three out of five wildfires in the San Diego Gas and Electric (SDG&E) service area were allegedly caused by electrical distribution systems. In 2007, a combination of dry conditions and strong Santa Ana Winds damaged power distribution and transmission systems and fueled massive fires that burned over 300,000 acres, or 13 % of SDG&E's service territory. These fires were attributed to damage to the electricity system, and the utility had to pay $2 billion in hundreds of	$ Billions of liability avoided after major wildfire	Yes

settlement cases. The company carries an enormous financial risk by operating the electric grid in such a high fire risk area so the company took proactive measures to mitigate this multi-billion dollar risk. Working with the Western Regional Climate Center and data from its own mesonet, SDG&E used hourly weather analysis going back 30 years to rate the fire potential of weather conditions and create an index that can support day to day operations. In May 2014, drought conditions and a strong Santa Ana wind replicated the conditions of 2007, but SDG&E was prepared and preemptively shut off select circuits of their distribution grid. None of the wildfires that happened during that event were found to be caused by their power systems, and the company avoided/decreased potentially very large internal and community impacts (Brian D'Agostino, pers. comm.).		
Nephila structured a basket of deals for a US utility that operates across multiple geographies, to protect against low revenue that results during a warm winter (Matt Coleman, pers. comm.).	$15 million of coverage (basket of insurance products)	Yes
Nephila structured a deal for a single US utility to protect against low revenue that results during a warm winter (Matt Coleman, pers. comm.).	$10 million of coverage (single insurance product)	Yes
Nephila used Brazilian (INMET) and Uruguayan (InUMet) weather data as primary inputs to co-structure an insurance product (via the World Bank) worth $450 million to protect against drought for a hydroelectric installation in South America. This international deal represents a realistic deal size that could be reached in the US. If such a deal were executed within the US, NCEI data would likely serve as the data used to price and settle the transaction (Matt Coleman, pers. comm.).	$450 million of coverage (single insurance product	No
The global market for weather risk transfer for energy utilities is valued to be at least $2 billion. Insurance coverage of this value is purchased on an annual basis. As the market continues to grow and increasingly serve the renewable energy sector (in addition to the traditional energy sector), that value could grow to exceed $5-10 billion (Matt Coleman, pers. comm.).	$2 and $10 billion annually	Yes & No
US electricity generators save $166 million annually using 24-hr temperature forecasts to understand electricity demand and optimize their mix of generating units (Teisberg et al., 2005).	$166 million annually in US	Uncertain
Using an ENSO forecast helped a plant manager save in natural gas purchases over the course of the 1997–1998 winter season when, seeing predictions of a warm winter, the plant manager chose to not lock in a price but instead buy natural gas on the spot market	$500,000 in annual savings for one generation plant (in 1998 USD)	Uncertain

(Changnon et al., 1999).		
The Snow Survey and Water Supply Forecasting (SSWSF) Program supports decision-making in the operations of Idaho Power, which owns and runs 17 hydroelectric plants. The amount of snowpack and its rate of melt have a significant impact on the generation of its plants. Idaho Power uses SSWSF on a daily basis to inform its "fill and spill" operations and cloud-seeding operations. SSWSF extensive historical information, based in part on Climate Normals, allows the utility to make probabilistic forecasts up to a year in advance that allow it to adjust its operations and forecasts, saving millions of dollars every year (Mike Strobel, pers. comm., Nelson, 2008 & Pierce, 2010).	$18 million approximate potential annual revenue loss	Mostly from other sources, but also incorporates Climate Normals from NCEI
Utility operators could save $15 million annually and improve grid reliability using day-ahead trading with a program to improve solar irradiance forecasts (Lazo, 2015).	$15 million annually	Uncertain
Streamflow forecasts were used to increase energy production from major Columbia River hydropower dams by 5.5 million MWh/year, resulting in significant increases in annual revenue (Hamlet et al., 2002).	$153 million increase in annual revenue (average)	Uncertain
It was shown that estimating the impact of short-term wind speed forecasts on the price of electricity in Scotland allowed providers to raise the prices of wind energy by 14% (Barthelmie et al., 2008).	$7.50 per MWh increase in price (2003 USD)	No
The Electric Power Research Institute sells a report from October 2014 titled "Integration of Internal and External Data Sources to Support Transmission Operations, Planning, and Maintenance: Weather Event and Public Data Assessment"[3].	$25,000 for one report	Yes
EPRI sells a 2008 report called "Weather Normalization of Reliability Indices"[4] using historical weather and utility reliability data to explore the relationship between weather and power system operating parameters.	$4,750 for one report	Yes
The sale of weather derivatives in the electric power industry indicates one way of valuing better weather predictions. HDDs and CDDs, which are key in load forecasting and facility management, are the main focus of weather derivatives used in the sector (Hertzfeld et al., 2003).	$4 billion in weather derivatives	Uncertain
Xcel Energy, a mid-western power company, has calculated the value of variable generation forecasts. Their Senior Trading Analyst Drake Bartlett showed that by improving their ability to predict and account for short-term variability, Xcel was able to save $38 million over 5 years. Data for their variable generation forecast is provided by Global	$38 million saved over 5 years	Uncertain

[3] The report is available here:
http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002589
[4] The report is available here:
http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001015857

Weather Corporation, who mostly use datasets of uncertain origin (Xcel Energy, 2008).		

Annex A: Interview contacts from power sector outreach

Utilities and transmission companies and organizations

Bob Rose, Chief Meteorologist, Lower Colorado River Authority

Brandon Hertell, Meteorologist, Con Edison

Brian D'Agostino, Meteorologist, San Diego Gas and Electric *and* leader of American Meteorological Society's Energy Committee

Connely Baldwin, Water Resources Engineer/Hydrologist, PacifiCorp

Crystal Raymond, Climate Adaptation Strategic Advisor, Seattle City Light

Dennis Kelter, Manager of Load Forecast, Commonwealth Edison Co

Erik Pytlak, Manager, Weather and Streamflow Forecasting, Bonneville Power Administration

Jeff House, Short Term Load Planner, Tennessee Valley Authority

Jim Blatchford, Manager, Short Term Forecasting, California ISO

Kresta Davis-Butts, Operations Hydrology Leader, Idaho Power

Paul Roller, Meteorologist & Energy Forecasting Analyst, Southern California Edison

Robert Zacher Jr., Principal Load Forecasting Analyst, Commonwealth Edison

(anonymous) Senior Load Forecasters at major municipal utility

Wesley Hyduke, Director of Meteorology Operations, Schneider Electric

Solution providers

Adam Simkowski, Meteorologist, ACES

Alison Taylor, Vice President, Sustainability-Americas, Siemens

Bill Morris, Senior Meteorologist, ACES

Bruce Rising, Strategic Business Management, Siemens

Erik Sonju, Vice President - Power Delivery Planning & Design, Power System Engineering, Inc.

Kristin Ann Larson, Director of Weather Forecasts, Global Weather Corporation

Mary Glackin, Glackin and Associates, LLC

Richenda Connell, Chief Technical Officer, Acclimatise

Robert Blevins, CEO and Senior Meteorologist, Meteorological Connections LLC

Ryan Oates, Junior Meteorologist, Noble Americas

Stephen Bennett, Senior Vice President, Verisk Climate

Steve Fenrick, Leader of Economics and Market Research Group, Power System Engineering

Todd Thayer, Sr. Director Operations, Detectent

Wei-Tai Kwok, Chief Operating Officer, Andalay Solar

Wesley Hyduke, Director of Meteorological Operations, Schneider Electric

(anonymous) Manager and Analyst at leading international meteorological services company

(anonymous) Meteorologist at Earth Networks

(anonymous) Meteorologist at large American energy company

(anonymous) Vice-president at Texas-based energy services firm

(anonymous) Two representatives from a US energy services company

Trade associations/sector organizations

Benjamin Matek, Industry Analyst, Geothermal Energy Association

Jillian M. Vignoe, Senior Project Consultant, Edison Electric Institute

Joe Casola, Staff Scientist and Program Director for Science and Impacts, C2ES

Matt Marsh, Environmental Protection Specialist, Western Area Power Administration

Ryan Schuchard, Associate Director Climate Change, Business for Social Responsibility

Tom Eckman, Power Planning Director, Northwest Power and Conservation Council

William K. Drummond, Executive Director, Mid-West Electric Consumers Association

Finance/insurance companies

Brook Porter, Associate, Kleiner Perkins Caufield and Byers

John Kunasek, Head of Power & Utilities Americas, KPMG

Matt Coleman, Portfolio Analyst, Nephila Inc.

(anonymous) Senior Risk Officer, GE Energy Financial Services

Non-NCEI government agencies

Doug Arent, Executive Director of the Joint Institute for Strategic Energy Analysis, National Renewable Energy Lab

Jane Callen, Economic Information Officer, US Department of Commerce/Economics and Statistics Administration

Joe Intermill, Service Coordination Hydrologist, NOAA

Michael Strobel, Director, National Water and Climate Center

Robert Reed, Chairman of NARUC Gas Subcommittee, and Natural Gas Manager, Alabama Public Service Commission

Shawn Lange, Utility Engineering Specialist III, Missouri Public Service Commission

Thomas Wilbanks, Group Leader, Environmental Sciences Division, Oak Ridge National Laboratory

Regional Climate Service Directors, Regional Climate Centers, and State Climatologists

Beth Hall, Director, Midwest Regional Climate Center

Charles E. Konrad, Director, Southeast Regional Climate Center

David Brown, NOAA Regional Climate Services Director, Southern Region

Doug Kluck, NOAA Regional Climate Services Director, Central Region

Ellen Mecray, NOAA Regional Climate Services Director, Eastern Region

John Nielsen-Gammon, Texas State Climatologist

Kevin Werner, NOAA Regional Climate Services Director, Western Region

Mike Anderson, State Climatologist, California Department of Water Resources

Stuart Foster, State Climatologist, Kentucky Climate Center

Wendy Ryan, Assistant State Climatologist, Colorado Climate Center

NCEI, GST, and CICS

Anthony Arguez, Normals Program Manager, National Centers for Environmental Information

Candace Hutchins, Project Manager, Global Science & Technology, Inc.

Carl Schreck, Research Associate, Cooperative Institute for Climate and Satellites

Dan Wunder, Program Manager, Global Science & Technology, Inc.

DeWayne Cecil, Chief Climatologist, Global Science & Technology, Inc.

Greg Hammer, Meteorologist, User Engagement and Services Branch, National Centers for Environmental Information

Jenny Dissen, Outreach, Cooperative Institute for Climate and Satellites

Tamara Houston, Physical Scientist, User Engagement and Services Branch, National Centers for Environmental Information

Annex B: Survey on the value of climate and weather services[5]

NCEI is a major creator and supplier of climate and historical weather data, which it provides free of charge. Once the data is formatted, edited or undergoes value-added processes, this generates direct value to the US economy both as a decision-making resource as well as creating a marketplace for 'intermediaries', firms that add value to raw data. In this section we share results from a survey with the goal of providing a data baseline approximating the value of services, and in turn help indicate the value of the unpriced data offered by NCEI and other government data providers.

There have been some attempts to estimate the value of climate and weather data. Private companies in the US create and sell an estimated 15 million value-added products and services that are built on this data (Konkel, 2014). However, existing estimates of the value of these services or of the market as a whole appear to be simplistic or generalized. For example, in a recent analysis, the Department of Commerce's Economics and Statistics Administration (ESA) estimated that weather data is valued 6.2 times higher than the government cost of producing forecasts (ESA, 2014). In 2008, NOAA's chief economist said that "NOAA real-time data supplies a burgeoning private weather service industry with well over $700 million in value added annually" (Weiher, 2008). A further literature review and internet search showed additionally contradictory estimates (Wisenberg, 2011; Spiegler, 2007), and that few if any companies in this subsector post their prices publicly.

Though a full value analysis is out of the scope of this project, Acclimatise created a short and anonymous survey to ask solution providers if they could share the approximate revenue and cost per item of the products and services they sell which are based on government-provided climate and weather data. Solution providers made up a major part of the interviewee groups contacted for both studies, but the majority of the contacts were unwilling to share monetary figures over the phone or on their websites. The benefit of using a survey was that it provided users with anonymity. Because of the sensitive nature of these questions, a low response rate was anticipated. Many of the firms interviewed were asked to complete this survey, and in order to avoid duplication and reduce the onus placed on participants this survey included only 5 questions targeted at understanding value.

A total of 116 solution providers were contacted for this survey. They were identified through a number of means, including NCEI staff, past NCEI workshop attendance, National Weather Service (NWS) solution provider lists[6], research done for previous Acclimatise studies, and targeted online searches. Because NCEI data has both climatological and meteorological applications, and because these are often blended both in practice and in the opinion of practitioners, the survey did not differentiate between the two fields.

4.1. Results

This survey was sent to 116 weather and climate solution providers working in the US. A total of 17 companies completed the survey, a 12% response rate. Though this sample is not large or statistically significant to permit a full estimation of the market value, results do provide points of

[5] Please note that this survey was not specific to the power sector. Due to the general lack of data on the value of climate services and the anticipated low response rate, this survey was sent to as wide a range of solution providers as possible. So while some of the 116 consulting companies surveyed were also interviewed or contacted for an interview in the power sector engagement study, most were not.

[6] Available here http://www.nws.noaa.gov/im/metdir.htm and here http://www.nws.noaa.gov/im/more.htm.

reference which allow NCEI to better understand the market value of its products and services and the price points of some products and services.

4.1.1. Questions 1 and 2

In response to Question 1, all respondents said that they use weather and/or climate data.

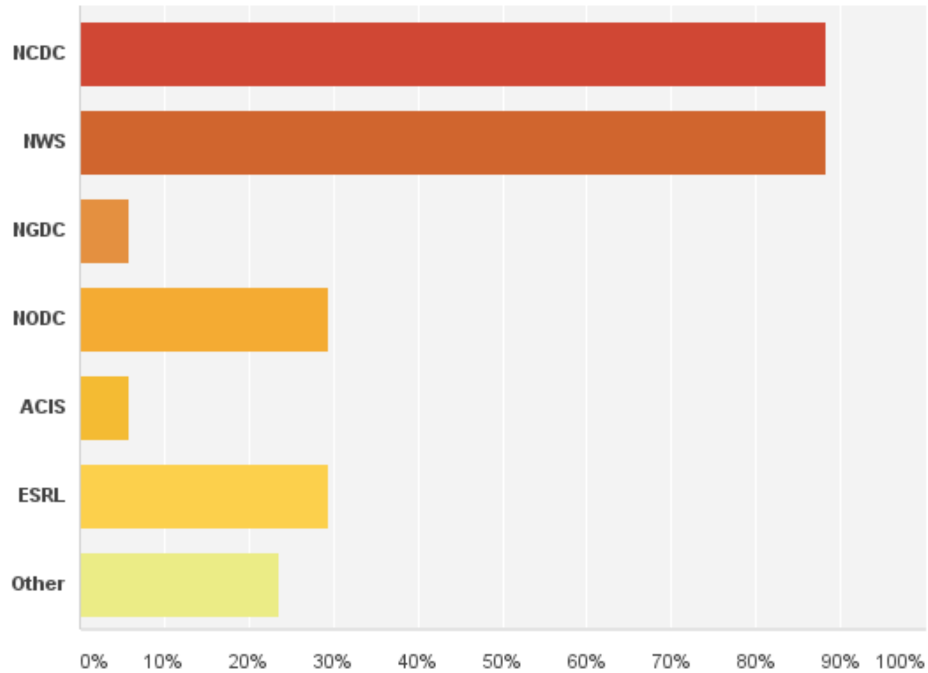


Figure 16 - Responses to question "Where do you access weather and climate data?"[7]

In response to Question 2, NCEI and NWS were cited as the primary, and for many the only, source of weather and climate data. The fact that NCEI data is hosted by a number of the sources listed below was not highlighted in the creation of the survey, as the origin of data is a point of common confusion among data users. Respondents also included a number of other data sources;

- European Centre for Medium-Range Weather Forecasts (ECMWF)
- State and Regional Climate Centers
- Other countries: Japan, European Union, etc.
- Federal Aviation Administration (FAA)
- National Hurricane Center (NHC)
- National Severe Storms Lab (NSSL)
- CoCoRaHS/Co-op observers
- Miscellaneous: "various sites that display forecast model data", other vendors (lightning), weather enthusiasts

There is potentially some reporting bias as in its initial outreach email Acclimatise emphasized its ties to NCEI, making users familiar with NCEI more likely to respond than users familiar with other data providers. However, these responses still underscore the predominant role NCEI and NWS play in the field of climate and weather data.

[7] Note that full names of answer options were used in the survey.

4.1.2. Question 3

Users were asked to describe the products and services they sell. Many categories of applied meteorological and climatological applications were noted, falling under the following categories:

- Creation of value added products for sale to specific industries such as infrastructure development, engineering, contractors, property managers, insurance, legal, weather enthusiasts, media, etc.
- Forensic meteorology.
- Certified weather statements.
- Real time and near real time weather data and products.
- Global weather forecasting services.
- US weather forecasting services.
- Global marine weather forecasts and hindcasts.
- Satellite derived irradiance data and forecasts.
- Tropical cyclone impact analysis and forecasts.
- Radar, hail, hurricane, snow, ice, and wind products, both as forecasts and as post-event analyses.
- Operational weather modification programs.
- Studies on extreme weather forecasts.
- Sale of weather options to organizations with weather-related financial risk.

This list is not an exhaustive representation of applications, as it reflects only the applications of the companies who responded to the survey. However, this list highlights the diversity of data applications among even a small sample.

4.1.3. Question 4

Most respondents shared approximate values of their climate and weather services, products, and/or subscription services they sell. The wide range of figures align with what is known of the sector, namely that the size, sophistication, and specialization of solution providers varies widely, with a similar diversity in the value of their products and services as well. Some companies are composed of only a single consultant with a very limited range of services, while other companies have large dedicated teams working on diverse projects.

	Sample size	Range	Total combined revenue	Mean
Combined annual revenue	11	$40,000 to $5,000,000	$14,335,000	$1,303,182
Products (annual revenue)	7	$400,000 to $5,000,000	$7,750,000	$1,392,857
Services (annual revenue)	7	$40,000 to $5,000,000	$6,585,000	$940,714
Subscriptions (average unit cost)[8]	5	$200 to $500,000		
Products (average unit cost)	3	$50 to $15,000		

[8] For the purposes of this survey, it was assumed that a subscription could provide products, services, or both, and that annual revenue for subscriptions is folded into the figures for products and services as relevant.

Services (average unit cost)	4	$310 to $32,000	

Eleven companies estimated their total annual revenue from products and/or services, at an average revenue of $1,303,182. If this average can be multiplied across the 116 solution providers contacted for this survey, their total annual revenue would be over $150 million dollars.

The data points on unit costs (products, services, and subscription services) were too few, and the units themselves too disparate, to allow for analysis.

A consistent challenge in assessing the value of climate and weather data is differentiating between causation and attribution. Climate and weather data are nearly always combined with data and technical knowledge from other fields to create new applied products and services. Thus, these prices below reflect the value of products and services that rely on climate and weather data as a critical input among many inputs.

The responses below from individual companies are broken down by unit cost and revenues, which allows some insight into specific business models.

Company description	Annual subscription costs	Product costs (by unit)	Service costs (by unit)	Total annual revenue
“Global weather forecasting services.”	$6,000		$6,000	$2,700,000
“Certified Weather Statements to contractors, property managers, insurance and legal clients”	$1,200	$50		$100,000
“Tropical cyclone impact analysis and forecasts”	$40,000	$15,000	$30,000	$670,000
“Value added products for various industries, weather enthusiasts and forensic meteorology services”	$200 to $500			$1,300,000
“Applied meteorological and forensic consulting services”			$750	$75,000
“Forensic meteorology”	$310			$350,000

4.1.4. Comments

Several respondents left comments for NCEI in an optional text box at the end of the survey. These unedited comments are below.

- “It is very important that NOAA and related government agencies do not offer products that compete with private sector products. Good coordination with the private sector is essential. Government agencies should provide the data products that the private sector would not otherwise provide, e.g. raw satellite feeds and numerical weather forecasts, not irradiance data and forecasts."

- "Very glad to see you are exploring how to help the private sector (especially small business) gain access to NOAA's datasets so we can add value for specific business applications."
- "Eliminate the redundancy of Regional Climate Centers and NCDC."
- "NCDC is our most essential source of weather and climate data."

4.2. Conclusion

These results and comments, collected in a short timeline and from a small sample, indicate that climate and weather data have significant value to the private sector and in turn to the US economy. These results also provide some figures to begin to approximate that value. Moreover, as a dozen companies were willing to share highly confidential financial information, this signals the great value that they derive from the NCEI data. The respondents recognize that their businesses model relies on the availability of NCEI quality controlled data. There is room to build on this rapport and identify further opportunities to expand on the results of this survey and build a more complete picture of the market value of climate and weather data products and services.

Bibliography

American Public Power Association, 2015. *US Electric Utility Industry Statistics.* Available at: http://www.publicpower.org/files/PDFs/USElectricUtilityIndustryStatistics.pdf

Asian Development Bank (ADB), 2012. *Climate Risk and Adaptation in the Electric Power Sector.* Available at: http://adb.org/sites/default/files/pub/2012/climate-risks-adaptation-power-sector.pdf

Aspen Institute, 2013. *2013 Energy Policy Forum: The Future of the US Electricity Sector*. Available at: http://www.aspeninstitute.org/sites/default/files/content/docs/pubs/2013_energy_policy_forum.pdf

Barthelmie, R.J., F. Murray, and S.C. Pryor, 2008. "The economic benefit of short-term forecasting for wind energy in the UK electricity market." *Energy Policy* 36:1687–1696.

Block, P., 2011. Tailoring seasonal climate forecasts for hydropower operations. Hydrology and Earth System Sciences 15:1355–1368.

Bloomberg New Energy Finance (BNEF), 2015. *2015 Factbook: Sustainable Energy in America.* Available at: http://about.bnef.com/content/uploads/sites/4/2015/02/Sustainable-Energy-in-America-2015-Factbook.pdf

Bureau of Labor Statistics (BLS), 2013. *Quarterly Census of Employment and Wages -- Private, NAICS 2211 Power generation and supply, All States and US 2013 Annual Averages, All establishment sizes*. Available at: http://www.bls.gov/cew/apps/table_maker/v3/table_maker.htm#type=0&year=2013&qtr=A&own=5&ind=2211&supp=0

US Climate Change Science Program (CCSP), 2007. *Effects of climate change on energy production and distribution in the US.* Available at: http://downloads.globalchange.gov/sap/sap4-5/sap4-5-final-all.pdf

California Energy Commission (CEC), 2012. *Estimating Risk to California Energy Infrastructure from Projected Climate Change.* Available at: http://www.energy.ca.gov/2012publications/CEC-500-2012-057/CEC-500-2012-057.pdf.

Changnon, S.A., R.A. Pielke Jr., D. Changnon, R.T. Sylves, and R. Pulwarty., 1999. "Human factors explain the increased losses from weather and climate extremes." *Bulletin of the American Meteorological Society* 81(3):438–442.

Changnon, D., & Changnon, S. A., 2010. Major growth in some business-related uses of climate information. Journal of applied meteorology and climatology, 49, 325-331.

Cardwell, D. 2014. *Solar and Wind Energy Start to Win on Price vs. Conventional Fuels,* New York Times. Available at: http://www.nytimes.com/2014/11/24/business/energy-environment/solar-and-wind-energy-start-to-win-on-price-vs-conventional-fuels.html

Dell, J., S. Tierney, G. Franco, R. G. Newell, R. Richels, J. Weyant, and T. J. Wilbanks, 2014. Ch. 4: Energy Supply and Use. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 113-129. doi:10.7930/J0BG2KWD.

Economics and Statistics Administration (ESA), US Department of Commerce, 2014. Fostering Innovation, Creating Jobs, Driving Better Decisions: The Value of Government Data. July 2014. Available at: http://www.esa.doc.gov/sites/default/files/revisedfosteringinnovationcreatingjobsdrivingbetterdecisions-thevalueofgovernmentdata.pdf

Edison Electric Institute (EEI), 2011. *Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business.* Available at: http://www.eei.org/ourissues/finance/Documents/disruptivechallenges.pdf

Edison Electric Institute (EEI), 2013. *Key Facts about the Electric Power Industry*. Available at: http://www.eei.org/resourcesandmedia/key-facts/Documents/KeyFacts.pdf

Edison Electric Institute (EEI), 2014a. *Transportation Electrification: Utility Fleets Leading the Charge.* Available at: http://www.eei.org/issuesandpolicy/electrictransportation/FleetVehicles/Documents/EEI_UtilityFleetsLeadingTheCharge.pdf

Edison Electric Institute (EEI), 2014b. *EEI Capital Expenditures with Functional Type.* Available at: http://www.eei.org/resourcesandmedia/industrydataanalysis/industryfinancialanalysis/QtrlyFinancialUpdates/Documents/EEI_Industry_Capex_Functional_2014.07.00.pptx

Federal Energy Regulatory Commission (FERC), 2014. *About FERC: What FERC does.* Available at: http://www.ferc.gov/about/ferc-does.asp

Government Accountability Office (GAO), 2012. "Cyber Security: Challenges in Securing the Electricity Grid." Available at: http://www.gao.gov/assets/600/592508.pdf

Government Accountability Office (GAO), 2014. *Energy infrastructure risks and adaptation efforts,* Washington, DC. Available at: http://www.gao.gov/assets/670/660558.pdf

Gunasekera, D. (2004). Economic issues relating to meteorological services provision. BMRC Research Report no 102. August 2014. "Economic value of meteorological services: a survey of recent studies".

Hamlet, A.F., D. Huppert, and D.P. Lettenmaier, 2002. "Economic value of long-lead streamflow forecasts for Columbia River hydropower". *Journal of Water Resources Planning and Management* 128:91–101

Hertzfeld, H., Williamson, R., Sen, A., 2003. "Weather satellites and the economic value of forecasts: evidence from the electric power industry". Paper delivered at International Astronautical Conference, Bremen, Germany, September.

Konkel, Frank, 2013. "NOAA to Seek Partnership to Boost Data Sharing." Federal Computer Weekly. (December 19). Available at: http://fcw.com/Articles/2013/12/19/NOAA-data-RFI.aspx

Lazard, 2014. *Lazard's Levelized Cost of Energy Analysis— Version 8.0.* Available at: http://www.lazard.com/PDF/Levelized%20Cost%20of%20Energy%20-%20Version%208.0.pdf

Lazo, J.K., Waldman, D.M., Morrow, B.H., and J.A. Thacher, 2010. Assessment of Household Evacuation Decision Making and the Benefits of Improved Hurricane Forecasting. Weather and Forecasting, 25(1). February 2010. Available at: http://journals.ametsoc.org/doi/pdf/10.1175/2009WAF2222310.1

Lazo, J.K. 2013. "The Economic Value of the Weather (and Climate and Water) Enterprise". Presentation to 2013 AMS Washington Forum. Available at: http://www.ametsoc.org/boardpges/cwce/docs/profiles/LazoJeffreyK/2013-04-AWF.pdf

Lazo, J. K., & Chestnut, G. L., 2002. Economic value of current and improved weather forecasts in the US household sector. Stratus Consulting.

National Rural Electric Cooperative Association, 2014. *Co-op Facts & Figures – Electric Utility Comparison*. Available at: http://www.nreca.coop/wp-content/uploads/2014/12/AnnualMeetingFactSheet.pdf

North American Electric Reliability Council (NERC), 2013. *Regional Entities: Maps – NERC Interconnections*. Available at: http://www.nerc.com/aboutnerc/keyplayers/pages/regional-entities.aspx

Oak Ridge National Laboratory (ORNL), 2012a. *Climate Change and Energy Supply and Use*. Technical Report for the US Department of Energy in Support of the National Climate Assessment Report. Available at: http://www.esd.ornl.gov/eess/EnergySupplyUse.pdf.

Oak Ridge National Laboratory (ORNL), 2012b. *Climate Change and Infrastructure, Urban Systems, and Vulnerabilities*. Available at: http://www.esd.ornl.gov/eess/Infrastructure.pdf.

Pacific Northwest National Laboratory (PNNL), 2012. *Climate and Energy-Water-Land System Interactions*. Technical Input Report to the US Department of Energy in support of the National Climate Assessment
http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21185.pdf

Perrels. A., Frei T., Espejo F., Jamin L., and A. Thomalla, 2013. Socio-economic benefits of weather and climate services in Europe. Advances in Science & Research 10: 65–70. 2013. Published 28 May 2013.

Pierce, J.A.S., 2010. "A Measure of Snow: Case Studies of the Snow Survey and Water Supply Forecasting Program." NRCS Utah. September. Available at: http://www.wcc.nrcs.usda.gov/ftpref/downloads/factpub/MeasureofSnowFullReport.pdf

Public Power Association (PPA), 2013. *Issue Brief: Municipal Bonds and Public Power.* Available at: http://www.publicpower.org/files/PDFs/MunicipalBondsAndPublicPowerFeb2013IB.pdf

Power Mag, 2014. *Viewpoints on the EPA's Clean Power Plan Abridged*. Available at: http://www.powermag.com/viewpoints-on-the-epas-clean-power-plan-abridged/

Spiegler, D. B., 2007. "The private sector in meteorology - An update." American Meteorological Society. Accessed at: https://www.ametsoc.org/boardpges/cwce/docs/DocLib/2007-07-02_PrivateSectorInMeteorologyUpdate.pdf

Sustainable FERC, 2014. ISO/RTO Operating Regions. Available at: http://sustainableferc.org/wp-content/uploads/2013/10/ISO-RTO-Operating-Regions.jpg

Teisberg, T., Weiher, R., and Khotanzad, A., 2005. "The economic value of temperature forecasts in electricity generation." American Meteorological Society. December.

The Regulatory Assistance Project, 2011. *Electricity Regulation in the US: A Guide*. http://www.raponline.org/document/download/id/645

USAID, 2013. The Value of Climate Services across Economic and Public Sectors. A Review of Relevant Literature. Technical Report. October 2013. Prepared by Engility-International Resources Group (IRG).

US Census Bureau, 2012. *2012 NAICS Definition: Sector 22 -- Utilities2211 - Electric Power Generation, Transmission and Distribution*, http://www.census.gov/cgi-bin/sssd/naics/naicsrch?code=2211&search=2012%20NAICS%20Search

US Department of Agriculture,2008 . *A Measure of Snow. A Report Based on Case Studies of The Snow Survey and Water Supply Forecasting Program*. Available at: http://www.wcc.nrcs.usda.gov/ftpref/downloads/factpub/MeasureofSnowSummary.pdf

US Department of Energy (DOE), 2015. *Cybersecurity,* Office of Electricity Delivery and Energy Reliability http://energy.gov/oe/services/cybersecurity

US Department of Energy (DOE), 2012. *Large Power Transformers and the US Electricity Grid,* Infrastructure Security and Energy Restoration Office of Electricity Delivery and Energy Reliability. Available at: http://energy.gov/sites/prod/files/Large%20Power%20Transformer%20Study%20-%20June%202012_0.pdf

US Department of Energy (D0E), 2008. *The Smart Grid: An Introduction.* Available at: http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_SG_Book_Single_Pages%281%29.pdf

US Department of Energy (DOE), 2013. *US energy sector vulnerabilities to climate change and extreme weather.* Available at: http://energy.gov/sites/prod/files/2013/07/f2/20130710-Energy-Sector-Vulnerabilities-Report.pdf

US Department of Energy (DOE), 2015. *What is the Smart Grid?*, Available at: https://www.smartgrid.gov/the_smart_grid/smart_grid

US Energy Information Administration (EIA), 2012. "How much electricity is lost in transmission and distribution in the US?" Available at: http://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3

US Energy Information Administration (EIA), 2014. *Annual Energy Outlook 2014: Market Trends: Electricity demand.* Available at: http://www.eia.gov/forecasts/aeo/MT_electric.cfm

US Energy Information Administration (EIA), 2015. *Electricity Data Browser*. http://www.eia.gov/electricity/data.cfm

US Energy Information Administration (EIA), 2007. *Electric Power Industry Overview 2007*, 2007 http://www.eia.gov/electricity/archive/primer/

US Environmental Protection Agency, 2012. *Reducing Air Pollution from Power Plants*. Available at: http://www.epa.gov/airquality/powerplants/

Weiher, R., 2008. "Assessing the Economic & Social Benefits of NOAA Data". A presentation to the NAS/OECD Conference in Paris. Available at: http://www.oecd.org/sti/ieconomy/40066192.pdf

Wisenberg Brin, D., 2011. Weather services become a big business. Retrieved October 3, 2014, from http://www.cnbc.com/id/43672839

White House, 2013. *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*. Available at: http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf

World Bank, 2011. *Climate Impacts on Energy Systems. Key Issues for Energy Sector Adaptation.* Energy Sector Management Assistance Program (ESMAP). Available at: http://www.esmap.org/sites/esmap.org/files/DocumentLibrary/E-Book_Climate%20Impacts%20on%20Energy%20Systems_BOOK_resized.pdf

Xcel Energy, 2008. *Responsible by Nature. A report on the Economic, Environmental and Social impacts of Xcel Energy*. Available at: https://www.xcelenergy.com/staticfiles/xe/Corporate/Corporate%20PDFs/2008_Xcel_Energy_Corporate_Responsibility_Report.pdf