Chapter 8

Energy

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Introduction

This ClimAID chapter considers how global climate change may improve or exacerbate existing weather-related stresses on the energy sector and reviews possible short- and long-term adaptation strategies.[1] The chapter broadly groups specific vulnerabilities and opportunities into supply-side issues and demand-side issues, with a particular emphasis on the power sector. Transport-related energy considerations are covered in Chapter 9, "Transportation," of this report.

Research for this chapter was conducted both as a literature review and through direct stakeholder engagement with a range of energy companies operating in different parts of the state (see Appendix A).

8.1 Sector Description

Reliable energy systems are critical to commerce and quality of life. New York State's electricity and gas supply and distribution systems are highly reliable, but weather-related stressors can damage equipment, disrupt fuel supply chains, reduce power plant output levels, or increase demand beyond the energy system's operational capacity.

8.1.1 Brief Profile of the New York State Energy System

Energy is derived from a wide variety of fuel sources and technologies in New York State. Roughly 49 percent of the state's electricity is generated in-state using fossil fuels; nuclear power (30 percent) and renewables[2] (21 percent) account for the balance (NYISO, 2009) (**Figure 8.1**). The generation mix varies widely in different parts of the state. For example, approximately 50 percent of the fossil-fired power plant capacity is located in New York City and Long Island, while most hydropower capacity is located in the northern and western part of the state (USEPA, 2009). **Table 8.2** presents generation capacity by fuel type in each ClimAID region.

New York State is divided into 11 electricity load zones, which are managed by the New York Independent System Operator (NYISO) (**Figure 8.2**). These zones are drawn by primarily administrative boundaries and do not reflect unique geographic or operating characteristics. They do differ significantly from the seven ClimAID regions highlighted in this report (see Appendix B, and Chapter 1, "Climate Risks").

New York City is by far the largest load zone in the state, responsible for approximately one-third of total annual electricity demand statewide (**Table 8.3**). Between 2002 and 2008, the period for which data are readily available, load growth (in total gigawatt-hours) has occurred in nine of the 11 zones around New York State. Growth has not been consistent, as load has declined in one or more years in most zones, but on average the total annual electricity load has increased by 4.3 percent each year statewide (NYISO, 2009a).

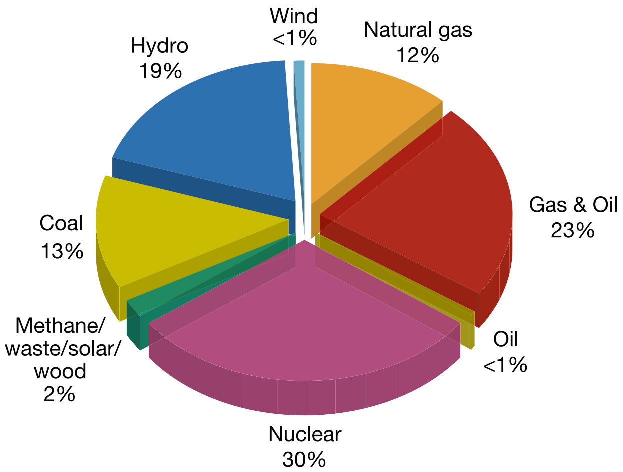
Thermal energy needs are satisfied in a variety of ways. New York State is home to more than a dozen district energy systems, which centrally generate steam, hot

Energy Unit	Description
Kilowatt (kW)	A measure of electrical power equal to 1,000 watts
Megawatt (MW)	A measure of electrical power equal to 1,000 kW (or 1 million watts)
Gigawatt (GW)	A measure of electrical power equal to 1,000 MW (1 billion watts)
Kilowatt or Megawatt peak (kWp or MWp)	Peak power plant generation capacity
Kilowatt hours (kWh), Megawatt hours (MWh), or Gigawatt hours (GWh)	A time-related measure of electrical energy. Running a 3,000 MWp power plant at 100% capacity for 1 hour would produce 3,000 MWh of energy.

Table 8.1 Definitions of key energy terms used in this chapter

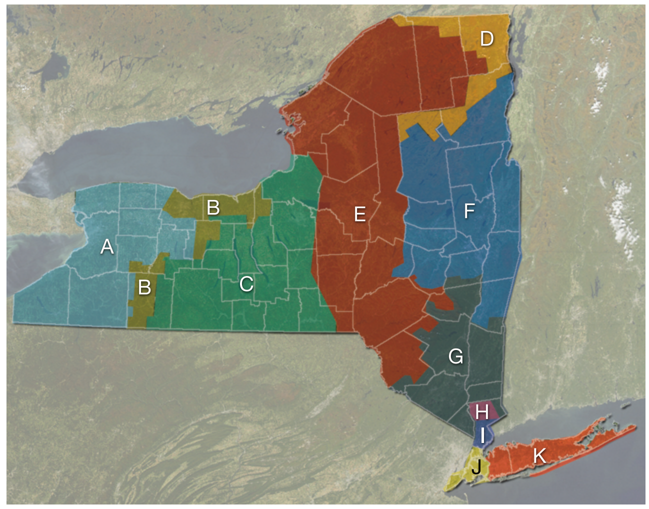
	Number of Power Plants (by fuel type) and Peak Generation Capacity (MWp)			
ClimAID Region	Fossil fuel	Nuclear power	Renewables	Total
Region 1	19	1	14	34
	2,761 MWp	517 MWp	2,628 MWp	5,905 MWp
Region 2	11		13	24
	3,548 MWp		1,106 MWp	4,654 MWp
Region 3	10		4	14
	775 MWp		11 MWp	786 MWp
Region 4	49		7	56
	12,996 MWp		137 MWp	MWp
Region 5	14	2	50	66
	1,350 MWp	2,339 MWp	594 MWp	4,283 MWp
Region 6	13	2	42	57
	3,968 MWp	2,784 MWp	304 MWp	7,056 MWp
Region 7	6		52	58
	566 MWp		1,263 MWp	1,829 MWp
New York State	122	5	182	309
	25,964 MWp	5,640 MWp	6,043 MWp	37,647 MWp

Table 8.2 New York State power plant data by ClimAID Region



Source: NYISO, 2009, p 61

Figure 8.1 New York State electricity generation by fuel type



Source: NYISO (2009a), basemap NASA

Figure 8.2 New York Independent State Operator (NYISO) load zones

water, or cold water and distribute it to customers via a series of underground pipes. New York City hosts one of the largest district energy systems in the world, with seven in-city plants producing steam that is distributed to 100,000 business, residential, and institutional customers through 105 miles of pipes traversing Manhattan (Ascher, 2005; Bevelhymer, 2003). Other large district energy systems can be found in Jamestown, Rochester, and Nassau County.

Natural gas is the most commonly used source of heating fuel in buildings around the state (**Figure 8.3**). There is a small amount of natural gas production in New York, primarily in the Finger Lakes region, which is sufficient to meet the needs of approximately 728,000 households (NYSDEC, 2010b). This could change significantly with the development of the Marcellus Shale, a vast natural gas deposit extending along the state's southern tier from western New York to the Catskills region. Access to this gas is currently being reviewed by State officials. There are currently no liquefied natural gas unloading terminals in the state, although several have been proposed (State Energy Planning Board, 2009b). The vast majority of the state's natural gas supply is obtained from the large national natural gas distribution system, which has several large feeders crossing the state.

The state's electricity, natural gas, and steam markets are regulated by the New York State Public Service Commission (2009), which is responsible for ensuring "safe, reliable [energy] service and reasonable, just

NYISO Load Zone	Average Annual Load (2002–2008) (GWh)	Annual Load (2008) (GWh)	Percent of State Annual Load (2008)	Average Peak Load (2002–2008) (MWp)	Peak Load (2008) (MWp)	Percent Load Growth Change (2002–2008)	Percent Average Annual Change
Zone A (Buffalo)	16,129	15,833	10%	3,113	2,611	-3.8%	-0.59%
Zone B (Rochester)	10,002	10,088	6%	2,143	2,001	1.72%	0.31%
Zone C (Syracuse)	16,863	16,719	10%	3,153	2,939	2.4%	0.45%
Zone D (Plattsburgh)	6,336	6,733	4%	1,493	949	4.22%	1%
Zone E (Utica, Watertown)	7,393	7,855	5%	1,569	1,388	9.45%	1.75%
Zone F (Albany)	11,452	11,594	7%	2,381	2,302	2.59%	0.51%
Zone G (Hudson Valley)	10,594	10,607	6%	2,496	2,344	3.77%	0.7%
Zone H (Upper Westchester)	2,467	2,935	2%	2,204	665	26.36%	5.55%
Zone I (Lower Westchester)	6,186	5,944	4%	1,641	1,440	-0.24%	0.02%
Zone J (New York City)	30,344	54,830	33%	11,347	11,262	3.1%	1.6%
Zone K (Long Island)	12,642	22,459	14%	5,748	5,281	1.33%	0.69%
Total	130,407	165,595	100%	37,288	33,181		

Note that prior to February 2005, Zone J and Zone K were a single, combined load zone.
Source: NYISO 2009a

Table 8.3 Load zones in New York State

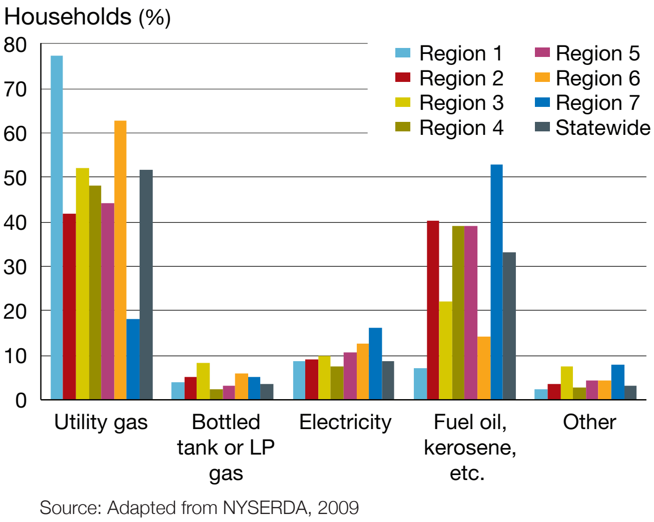


Figure 8.3 Fuels used for residential space heating in New York State by ClimAID Region

rates." In the late 1990s, the Public Service Commission oversaw the restructuring of New York State's electricity and gas markets, shifting from a system of vertically integrated, regulated monopolies to one involving separate power generators, distribution utilities, and energy service companies that sell power or gas to customers and pay fees to distribution utilities for the use of their pipes or wires.

Energy prices vary widely, with prices higher in eastern New York than in western parts of the state. Long Island and New York City (ClimAID Region 4) have the highest energy prices (Potomac Economics Ltd., 2009), due to transmission constraints; high real estate value, labor, and other utility operating costs; and past decisions to bury transmission and distribution system assets, making them more costly to service (City of New York, 2007). High voltage electricity transmission constraints create a situation where New York City and Long Island are considered to be a load pocket, meaning the region's electricity needs cannot be satisfied solely by electricity imports; some level of generation must occur within the city or region itself (NYISO, 2002).

The New York State Energy Research and Development Authority (NYSERDA), a public benefit corporation whose aim is to help New York meet its energy goals, has greatly influenced New York's energy system over the past 35 years. Its primary focus is on reducing energy consumption, promoting the use of renewable energy sources, and protecting the environment (NYSERDA, 2010). Through its investments in technology and market research and development projects, demand-side energy programs, and policy research, NYSERDA has changed the way New Yorkers obtain and use energy and has helped build the foundation for a cleaner energy future. Climate change issues have been on NYSERDA's radar screen since the late 1980s, when the agency financed one of the first-ever studies looking at how climate change will affect the New York State energy system (Linder et al., 1987). The ClimAID project, of which this chapter is one key part, offers a more updated analysis of many of these same issues.

8.1.2 Economic Value

New York households, businesses, and industries spent more than $72.2 billion on different forms of energy in 2008 (NYSERDA, 2010b). This was the seventh

	1994	1999	2004	2008
Residential				
Coal	3.3	2.5	1.6	1.7
Petroleum	2221.1	1950.4	3540.3	5072.0
Natural Gas	4891.3	4365.5	5592.9	6566.2
Electricity	7886.2	7354.3	7849.7	8973.2
Subtotal	15001.9	13672.7	16894.5	20613.1
Commercial				
Coal	9.5	6.9	7.7	8.8
Petroleum	1219.7	726.0	1854.1	2373.9
Natural Gas	2110.3	2394.7	4136.0	3765.7
Electricity	9617.6	9066.8	10999.7	13036.8
Subtotal	12957.1	12194.4	16997.5	19185.1
Industrial				
Coal	185.1	135.9	87.1	115.7
Petroleum	293.4	238.4	401.0	688.9
Natural Gas	1225.1	515.1	723.2	1070.5
Electricity	2896.9	1588.8	1658.2	1489.1
Subtotal	4600.5	2478.2	2869.5	3364.2
Transportation				
Coal				
Petroleum	11942.0	11535.8	17884.4	28688.7
Natural Gas				
Electricity	353.0	278.8	239.1	368.8
Subtotal	12295.0	11814.7	18123.5	29057.5
Total				
Coal	197.9	145.3	96.4	126.2
Petroleum	15676.2	14450.6	23679.8	36823.5
Natural Gas	8226.7	7275.3	10452.1	11402.4
Electricity	20753.8	18288.7	20746.7	23867.9
Total	44854.6	40160.0	54885.0	72220.1

Source: NYSERDA, Patterns and Trends: New York State Energy Profiles 1994–2008 (January 2010)

Table 8.4 New York State energy expenditures by sector and fuel type

NAICS Industry Code	Description	Paid Employees (March 2008)	Annual Payroll	Total # Establishments
21111	Oil and Gas Extraction	289	$21,432,000	52
22111	Electric Power Generation	6539	$699,298,000	124
22112	Electric Power Transmission, Control, and Distribution	28695	$2,702,645,000	272
22121	Natural Gas Distribution	3475	$308,945,000	97
23712	Oil and Gas Pipeline and Related Structures Construction	1530	$178,872	34
23713	Power and Communication Line and Related Construction*	4731	$315,972	179
23821	Electrical Contractors	53318	$3,177,234,000	5019
23822	Plumbing, Heating, and Air Conditioning Contractors*	57729	$3,291,321,000	6503

*Overstates energy sector figures due to inclusion of non-energy related employees.
Source: U.S. Census Bureau, CenStats Database: 2008 County Business Patterns (NAICS) – New York

Table 8.5 New York State energy sector employment and payroll (2008)

consecutive year energy expenditures have increased. (In contrast, total energy spending in New York State in 2002 was $38.45 billion, slightly more than half of current levels (NYSERDA, 2005).) **Table 8.4** details energy expenditures in the state for selected years by sector and fuel type.

Spending in 2008 on power and heating fuels was fairly evenly distributed between the residential and commercial sectors, with industrial energy use lagging far behind (NYSERDA, 2010b). Transportation fuel use is not broken out by sector in NYSERDA's most recent profile of state energy use, so it is difficult to ascertain if it is primarily household or business-related.

Residential Sector	Coal ($/ton)	Heating Fuel (¢/gal)	Propane (¢/gal)	Natural Gas ($/Mcf)	Electricity (¢/kWh)
1994	110.30	145.81	182.95	12.70	19.67
1999	98.99	130.04	156.21	11.77	17.12
2004	91.51	193.18	202.92	14.34	16.56
2008	122.35	385.23	314.67	16.75	18.30
Commercial Sector					
1994	56.15	103.70	136.60	9.46	16.36
1999	41.37	84.27	114.34	6.65	13.33
2004	47.54	153.53	162.43	11.59	14.78
2008	70.86	314.95	255.90	12.91	16.84
Industrial Sector					
1994	70.51	70.51	74.76	5.22	6.78
1999	64.79	64.79	82.04	3.90	4.76
2004	127.39	127.39	144.82	8.11	7.04
2008	82.27	317.99	268.16	12.97	10.14
Transport Sector	Gasoline (¢/gal)	Diesel (¢/gal)	Electricity (¢/kWh)		
1994	165.60	186.14	12.60		
1999	153.25	157.55	10.50		
2004	212.92	212.70	9.02		
2008	327.81	399.35	12.64		

Note: All figures in constant 2008 dollars. Source: NYSERDA, 2010b

Table 8.6 Average energy prices by fuel type and sector in New York State

The energy sector is directly responsible for tens of thousands of jobs around the state, with a payroll totaling in the billions. There are nearly 400 firms and more than 35,000 employees involved in electric power generation and transmission in New York, and another 3,800 jobs involved in oil and gas extraction and natural gas distribution (U.S. Census Bureau, 2008). Adding in oil and gas and power construction-related employment, along with electrical and heating, ventilation, and air conditioning contractors, nearly triples the size of this sector, although the data are distorted by the inclusion of trades that are not energy related (See **Table 8.5**). Payrolls for these jobs are sizable, totaling billions of dollars per year.

Average energy prices for different fuel sources are noted in **Table 8.6**. The prices of all fuel types have increased significantly over the years in New York State, with the exception of electricity, which has stayed relatively constant.

8.1.3 Non-climate Stressors

Non-climate stressors on the energy sector in New York State include rising demand due to growing population, more energy use for cooling and electronic devices, aging infrastructure, and rapidly changing technologies and policies.

8.2 Climate Hazards

Global climate change is expected to alter both average climate and the frequency and intensity of extreme weather events in New York State, affecting energy demand, system efficiency, and power supply potential.

Chapter 1 of the ClimAID report, "Climate Risks," discusses the key projected changes for different regions of New York State in the 2020s, 2050s, and 2080s.

Energy supply and demand projections are typically developed for a 20-year timeframe. Projections further into the future are affected by population and economic growth, the pace of technology change, and the policy environment, all of which are difficult to predict over longer time periods. Therefore, this chapter's assessment of climate risks emphasizes the near term (2020s), though we discuss expected changes in the

	Vulnerability	Principal Climate Variable(s)	Specific Climate-related Risks	Location	Crosscutting Links
Energy Supply and Distribution					
Power Supply	Thermoelectric power plants	Temperature	The thermal efficiency of power generation is affected by air temperature.	Statewide	
Power Supply	Coastal power plants (including cogeneration at wastewater treatment facilities)	Extreme weather events & sea level rise	Flood risk at individual facilities depends on the likelihood and intensity of storm surges associated with extreme weather events and their interaction with sea level rise. Operational impacts may be different than impacts on fuel storage or fuel unloading operations.	Statewide	Coastal Zones
Power Supply	Water-cooled power plants	Temperature	Water-cooled nuclear plants are affected by changes in the temperature of intake and discharge water, which is affected by changes in temperature.	Statewide	Water Resources
Power Supply	Hydropower systems	Precipitation & temperature	Hydropower availability at individual plants is affected by the timing and quantity of precipitation, as well as snowmelt; snowmelt is also affected by seasonal temperature.	Western, Central, and Northern NYS	Water Resources, Ecosystems, Agriculture
Power Supply	Wind power systems	Wind speed and direction	Availability and predictably of wind power	Western, Central, and Northern NYS	
Power Supply	Solar power systems		Availability and predictably of solar power	Statewide	
Power Supply	Biomass-fueled energy systems	Temperature & precipitation	Biomass availability depends on weather conditions during the growing season.	Western, Central, and Northern NYS	Ecosystems
Energy Transmission and Distribution Assets	Transmission lines (winter)	Extreme weather events	Frequency, duration, and spatial extent of outages are affected by winter storms, particularly ice storms and high winds.	Western, Central, and Northern NYS	Communications
Energy Transmission and Distribution Assets	Transmission lines (summer)	Temperature	Sagging lines can result from increased load associated with higher temperatures.	Statewide	Communications, Public Health
Energy Transmission and Distribution Assets	Transformers	Temperature	Transformers rated for particular temperatures may fail during prolonged periods of increased temperature.	Statewide	Communications, Public Health
Energy Transmission and Distribution Assets	Natural gas distribution lines	Temperature, extreme weather events, & flooding	Changing temperatures may affect vulnerability to frost heave risks, which can threaten structural stability of the pipeline. Flooding risks can also jeopardize pipeline stability/operations. Extreme weather events may threaten underwater pipelines in the Gulf Coast region, a large source of natural gas supply for New York.	Statewide	
Energy Demand and Consumption					
Electricity Demand	Total demand	Temperature (heating degree days & cooling degree days) & extreme weather events	Temperature affects demand for electricity in winter, summer, and shoulder-season periods. Extreme weather events may temporarily or permanently change demand patterns.	Statewide	
Electricity Demand	Peak demand in summer	Temperature and humidity (cooling degree days, heat index, & heat waves)	Temperature and humidity affect demand for electricity for cooling and can increase the summertime peak; increasing frequency, intensity, and duration of heat waves could be particularly problematic, leading to more brownouts and blackouts.	Southern NYS	Public Health
Electricity Demand	Power sharing	Temperature (heating degree days)	Warming temperatures can increase summer demand in traditional winter-peaking areas, leading to reduced availability of power for downstate regions.	Statewide	
Building-sited Energy Systems*	Cooling systems	Temperature	Cooling capacity may not be sufficient if the period of days with high temperatures is lengthy.	Statewide	Public Health
Building-sited Energy Systems*	Heating systems	Precipitation	Flood risk for boilers located in basements	Statewide	
Building-sited Energy Systems*	Building envelopes	Extreme weather events	Increased severity of storm regime may reveal weaknesses in building envelopes.	Statewide	
Building-sited Energy Systems*	Mechanical and electric systems	Extreme weather events	Failure of mechanical-electrical elements is related to extreme weather conditions.	Southern NYS	Public Health

* Building-sited energy systems are not discussed in detail in this report.

Table 8.7. Summary of climate risks to the New York State energy system

2050s and 2080s as appropriate. To project changes in temperature, heating-degree days, and cooling-degree days, historical trends are used with global climate model projections and are extrapolated linearly. Other climate variables, including wind speed and cloud cover, affect the availability of energy resources, but are difficult to model and are, therefore, considered qualitatively (see Chapter 1, "Climate Risks").

Table 8.7 provides a high-level summary of key climate-change-related vulnerabilities associated with the energy sector. This chapter does not explore each of these issues in equal depth, reflecting different levels of information availability and the fact that certain vulnerabilities are likely to be more consequential than others.

A recent study notes the importance of indirect impacts that climate change may have on the energy sector, some of which may actually be greater than the direct impacts noted above (Bhatt et al., 2008). These include the financial impacts on investors or insurance companies linked to vulnerable energy system assets, and the financial impact on customers forced to grapple with changing energy prices or overall expenditure levels resulting from changing climate conditions. These issues are taken up as appropriate over the course of this chapter. A more lengthy discussion of the economic impacts climate change may have on the energy sector can be found in Chapter 3, "Equity and Economics."

8.2.1 Temperature

More frequent heat waves will cause an increase in the use of air conditioning, stressing power supplies and increasing peak demand loads. Increased air temperature will affect the efficiency of power plants. Warmer temperatures in the winter will decrease demand for heating.

8.2.2 Precipitation

Changes in precipitation patterns will affect hydropower, especially changes in droughts. Inland flooding could affect transformers and distribution lines, although little information is available documenting flooding impacts or potential in non-coastal regions, that is, along rivers used for cooling water or fuel delivery purposes (see Chapter 4, "Water Resources").

8.2.3 Sea Level Rise

Power plants were historically located along waterways to facilitate fuel delivery or for cooling purposes, making them vulnerable to anticipated sea level rise or storm surges associated with extreme weather events. However, has been little study of how storms and tidal surges have affected New York State power production assets over the past several decades. One case where problems did arise was a 1992 nor'easter, which flooded generators that provided power for safety signals on the New York City subway system (Dao, 1992). Past climate change studies focused on New York State make almost no mention of sea level rise impacts on the energy sector, although they do extensively assess impacts on other important infrastructure around New York City and Long Island (Rozenzweig and Solecki, 2001).

8.2.4 Other Climate Factors

In addition to temperature, precipitation, and sea level rise, there are other climate factors that have the potential to influence the energy industry in years to come, including water temperature, ice and snow storms, hydrology and stream flow, and wind.

Water Temperature

In New York, thermal discharge rules are established by the Department of Environmental Conservation's (DEC) Part 704 standards (Criteria Governing Thermal Discharges). The rules include several general rules applicable to all types of receiving waters (e.g., the need to avoid large day-to-day temperature fluctuations) as well as more specific criteria that vary by type of water body. These include several different surface water temperature standards (NYSDEC, 2010a):

- Non-trout waters: Water temperature at the surface of a stream shall not be raised to more than 90°F at any point.
- Trout waters: No discharge at a temperature over 70°F shall be permitted at any time, and during the period June–September, no discharge can raise the temperature of the stream by more than 2°F over the baseline spring water temperature.
- Lakes: Water temperature at the surface of a lake shall not be raised by more than 3°F over the previous water temperature.

- Coastal waters: Water temperature at the surface shall not be raised more than 4°F from October through June and more than 1.5°F from July through September.
- Estuaries: Water temperature at the surface shall not be raised to more than 90°F at any point.

Part 704 rules also specify limits on temperature changes in the "mixing zone," which is the water in the immediate vicinity or downstream of the discharge pipe.

Ice and Snow Storms

At the other end of the temperature spectrum are problems associated with ice and snow storms, which can weigh down and destroy power transmission and distribution equipment. Ice storms occur when snow formed high in the atmosphere passes through a warm atmospheric layer, melting completely before it enters a shallow cold layer near the ground. The raindrops freeze once they hit branches, wires, or the ground (Risk Management Solutions, 2008). Between 1949 and 2000, New York endured 31 ice storms, more than any other state in the country (Changnon and Changnon, 2002).

It is unclear whether the frequency or severity of ice storms will change across the state over the next few decades. By later this century, southern parts of the state, more likely than not, will experience fewer ice storms than they currently experience. The impact on the frequency or severity of ice storms in northern New York later this century is uncertain (see Chapter 1, "Climate Risks," for more details).

Hydrology and Stream Flow

Given the importance of this power source to the New York State energy system, past hydrologic studies have focused on the hydropower network's vulnerability to climate change, projecting that stream flow around the state could decline by 5 to 7 percent by 2015, resulting in a 6–9 percent drop in hydropower generation levels (Linder et al., 1987)[3]. Estimates made at the time suggested that non-hydro generation assets in the state must increase 1–2 percent by 2015 to offset this predicted loss in hydropower availability (see Chapter 4, "Water Resources," for current understanding of stream flow projections).

Wind

There is limited research examining how climate change will affect wind patterns or speeds in New York in the coming decades (see Chapter 1, "Climate Risks"). Studies in the Pacific Northwest project that there will be strong seasonal differences there; wind power potential in spring and summer months is projected to decline by 40 percent or more, while winter and fall month levels change very little, by the end of the 21st century (Sailor et al., 2008). One study examining both national and regional scales projects that wind speeds could decline by between 1 and 15 percent over the next 100 years, depending on which climate projections are used (Breslow and Sailor, 2002). A second analysis projects wind power decreases during all seasons across the majority of the United States, with typical decreases in the 10–20 percent range (Segal et al., 2001). None of these studies specifically highlights anticipated changes in New York or the Northeast, although maps included in the 2001 study show seasonal wind speed decreases in New York averaging 0–10 percent (Segal et al., 2001). There is also little information available on how climate change may affect wind speeds in the Atlantic Ocean offshore of New York City and Long Island. Given the interest in developing offshore wind farms in this region, this topic is worthy of further study.

8.3 Vulnerabilities and Opportunities

In certain cases, climate change may help New York's energy system function more smoothly—by eliminating weather-related supply chain problems through milder winter weather in some areas, for example—but it is more commonly projected that climate change will adversely affect system operations, increase the difficulty of ensuring supply adequacy during peak demand periods, and exacerbate problematic conditions, such as the urban heat island effect (Rosenzweig and Solecki, 2001). In the sections that follow, the chapter explores how climate-change-related risks may affect different aspects of the state energy system.

8.3.1 Energy Supply

Climate-change-related impacts on energy supply must first be differentiated between the impacts on thermoelectric power plants and those affecting different renewable power sources. Thermoelectric power plants generate electricity by converting heat into power. Conversion processes vary based on fuel sources at the power plant (e.g., nuclear, gas, oil, coal). Renewable power technologies harness naturally occurring resource flows (e.g., solar power, flowing water, wind) to generate electricity. Some forms of biomass—often considered a renewable resource—may be combusted in thermoelectric power plants, converted to liquid fuels, or used to generate heat for buildings or industry.

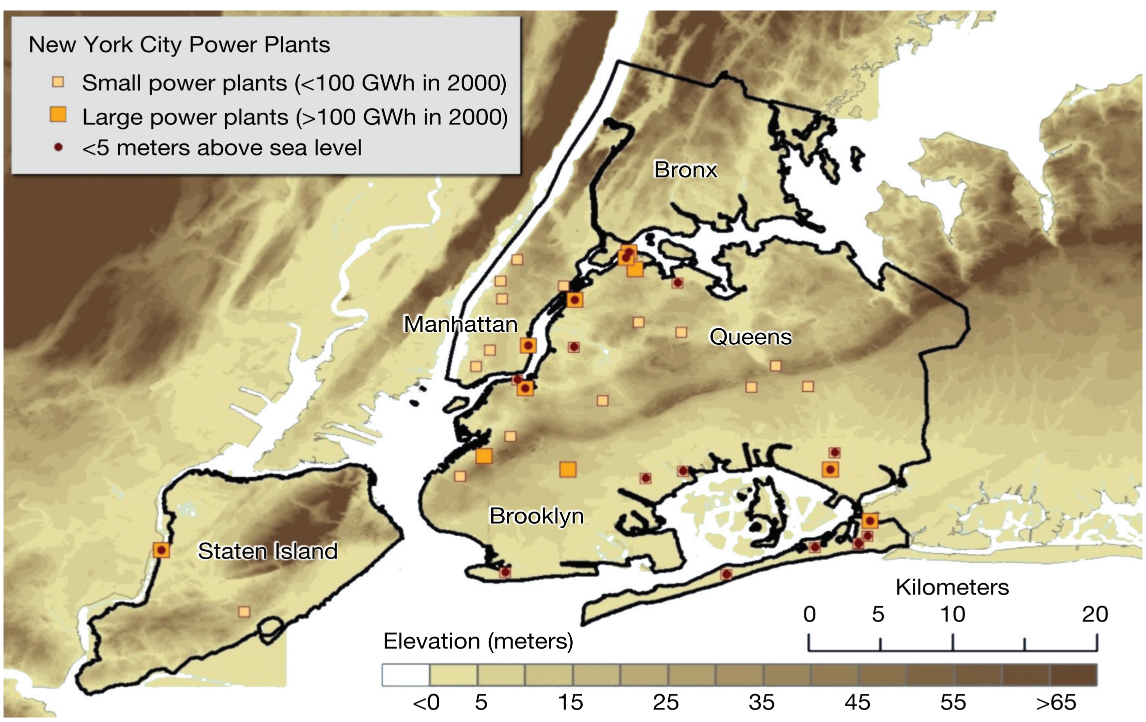
Impacts on Thermoelectric Power Generation and Power Distribution

Thermoelectric power plants are vulnerable to increases in flooding, droughts, water temperature, air temperature, and other extreme weather events. Plants located along coastal areas may be affected by rising sea levels and storm surges.

Flooding

Vulnerability is largely a function of the elevation of power plants and their proximity to the path that any storm-related tidal surge would follow during extreme weather events. To get a sense of the scale of vulnerability, this analysis overlaid New York City power plant locations obtained from the U.S. Environmental Protection Agency's (USEPA) eGrid database on a U.S. Geological Survey digital elevation model and identified power plants within 5 meters (about 16.4 feet) of current sea level. **Figure 8.4** shows that a majority of the city's largest power plants are at an elevation below 5 meters, which means they currently could potentially be affected by Category 3 or higher hurricane-induced storm surges.

A different flooding risk involves the elevation of the cooling water intake and outflow pipes at thermoelectric power plants. To the extent that these pipes become clogged by debris during flooding or storm surges, power plants may be forced to shut down (Aspen Environmental Group and M Cubed, 2005; Union of Concerned Scientists, 2007). One power plant operator with a facility fronting on a large lake in the northwestern part of the state noted that high winds can stir up debris that clogs their intakes located at the shoreline. The operator contrasted this situation with another of its plants, which has intakes extending much farther into an adjacent lake. The latter facility is far less vulnerable to this type of debris problem.



Sources: Data: Power plant data for 2000 were extracted from CARMA 2008; New York City digital elevation model is from the USGS 1999, which has a vertical error of +/- 4 feet. Map credit: Lily Parshall 2009.

Figure 8.4 Location and elevation of power plants in New York City

Table 8.8 presents the intake pipe depth at a number of power plants around New York State (NETL, 2009). Whether these intake depths may prove vulnerable to debris problems from flooding events is unclear, although deeper intakes are presumably less vulnerable than shallower intakes.

Drought

A recent U.S. Department of Energy study seeking to highlight potential drought-related water intake problems across the United States provided data on 12 large power plants around New York. The report did not pass judgment on whether current intake pipe depth levels were inadequate, because this is largely a location-specific issue (NETL, 2009).[4] New York State facilities tend to have shallower intake depths when compared to other plants around the U.S.; whether this will create problems at these facilities in the future is unclear. To date, there do not appear to be any instances where drought has created problems of this nature.

Water Temperature

The DEC thermal discharge rules may create challenges during extended heat waves, when the receiving waters may already be close to the upper temperature limit defined in the facility's operating permit. This situation may force the power station to reduce production to decrease the heat content of the water leaving the condenser (ICF, 1995). During Europe's deadly 2003 summer heat wave, several nuclear power plants in Spain and Germany closed or cut output to avoid raising the temperature of rivers cooling the reactors. The French government allowed nuclear power plants to discharge cooling waters at above-normal temperatures as an emergency measure to avoid blackouts (Jowit and Espinoza, 2006).

The five nuclear power plants in New York State are located either on the Great Lakes or the Hudson River. In both cases, these facilities draw cooling waters from deep-water sources less vulnerable to dramatic temperature rises. The situation at other thermoelectric power plants around state, several of which draw from shallower water sources, is less clear.

A different, and under-researched, topic relates to how climate change may affect biota levels in New York waterways currently used for power plant cooling. To the extent that biota levels increase, changes may be required in the screening processes currently employed at these facilities to ensure that the water flow into the facility is not inhibited in any way.

Air Temperature

Changes in ambient air temperature and air density levels resulting from climate change may affect power plant output levels. One potential temperature-related impact occurs at combined-cycle gas turbine facilities (Hewer, 2006). These units are designed to fire at a specific temperature, and when ambient air temperatures rise, air density declines, which reduces the amount of oxygen available to achieve peak output (ICF, 1995). Similar problems exist at steam turbine facilities.

Three studies discount the importance of these impacts, arguing that capacity and/or output reductions will be less than 1 percent under most climate scenarios (Stern,

Facility Name	Primary Fuel	Water Source	Intake Depth Below Surface	Intake Depth for this Type of Facility[1] (feet)		Intake Depth for this Type of Water Source[1] (feet)	
			(feet)	Mean	Median	Mean	Median
AES Cayuga	Coal	Cayuga Lake	44	16.1	12	21.6	17
AES Greenridge	Coal	Seneca Lake	11	16.1	12	21.6	17
AES Somerset	Coal	Lake Ontario	16	16.1	12	21.6	17
Dunkirk Generating Station	Coal	Lake Erie	21	16.1	12	21.6	17
Danskammer Generating Station	Coal	Hudson River	5	16.1	12	13.2	10
Roseton Generating Station	Gas	Hudson River	29	14.4	12	13.2	10
Fitzpatrick	Nuclear	Lake Ontario	12	16.8	13.5	21.6	17
CR Huntley Generating Station	Coal	Niagara River	10	16.1	12	13.2	10
Oswego Harbor Power	Oil	Lake Ontario	20	16.1	12	21.6	17
PSEG Albany Generating Station	Gas	Hudson River	24	14.4	12	13.2	10
Ginna	Nuclear	Lake Ontario	15	16.8	13.5	21.6	17
Rochester 7	Coal	Lake Ontario	36	16.1	12	21.6	17

[1] Based on nationwide data.
Source: NETL/DOE 2009, pp 20, A-10

Table 8.8 Cooling water intake depth at selected New York State power plants compared to national data

1998; Bull et al., 2007; and Linder et al., 1987). Several New York State utilities and power plant operators interviewed for this report also noted that the impacts of changing temperature levels are likely to be negligible, because the equipment is already designed to handle wide temperature swings between the winter and summer months. It may well be that changes in extreme temperatures are more relevant, since during such conditions the equipment's design parameters are more likely to be breached (David Neal, personal communication, October 30, 2009; Victoria Simon, personal communication, October 15, 2009). Moreover, depending on the rate at which climate change progresses, many vulnerable facilities will reach the end of their useful lives and be replaced with better-adapted ones before these long-term power generation impacts are felt (ICF, 1995; Victoria Simon, personal communication, October 15, 2009).

The New York State Reliability Council[5] reports that there is some decline in power output levels at higher temperatures, but the Council also characterizes the impact as rather small. As part of their technical assessment of the reliability of the state's power system, the New York State Reliability Council quotes the NYISO research finding that for each degree above 92°F, combustion power plants around the state collectively lose approximately 80 megawatts in production output (New York State Reliability Council, 2004). This decrease is built into their estimates of how much power will be available around the state under certain operating conditions. Given that the state has more than 37,000 megawatts of generation capacity overall and roughly 26,000 megawatts of fossil-fired combustion facilities (USEPA, 2009), this decrease is relatively minor (**Table 8.2**).

Rising ambient air temperatures may also affect the electricity transmission and distribution system. Because transmission and distribution lines and electrical transformers are rated to handle certain amounts of voltage for a given period of time, climatic conditions can lead to equipment failure by driving energy demand beyond the rated capacity. For instance, an extended heat wave in the summer of 2006 led to the failure of thousands of transformers in southern and northern California. Sustained high nighttime temperatures meant that the transformers could not cool down sufficiently before voltage levels increased again the next morning. Insulation materials within the transformers burned and circuit breakers tripped, knocking out the devices and causing more than a million customers around the state to lose power (Miller et al., 2008; Vine, 2008).

Power lines both above and below ground may also suffer mechanical failure as a result of higher ambient air temperatures. Power lines naturally heat up when conducting electricity; ordinarily, relief is provided by the cooler ambient air. Lines below ground rely on moisture in the soil to provide this cooling function. In both cases, as temperatures increase, the cooling capacity of the surrounding air or soil decreases, potentially causing above-ground lines to fail altogether or sag to levels where the public is placed at risk (Hewer, 2006; Mansanet-Bataller et al., 2008). The extent to which this is a problem in New York State is unclear. The New York Power Authority (NYPA) reports it regularly conducts sophisticated aerial surveys to assess hazards presented by sagging transmission lines (Victoria Simon, personal communication, October 15, 2009), but no data were available on how distribution line conductivity may change as a result of climate change.

The most newsworthy blackouts in New York City in recent years have tended to occur when heat waves extend over several days (Revkin, 1999; Waldman, 2001; Chan and Perez-Pena, 2006; Newman, 2006). In the past, two different State agency analyses have expressed concern about the age of local distribution network equipment and how this compounds system vulnerabilities on hot days when peak load levels increase dramatically (NYS Attorney General, 2000; NYS Department of Public Service, 2007). Little information has been published on this topic, however, so the extent of the problem is unknown.

One area where additional research may be beneficial is the link between the average temperature of extreme heat events and the duration of the heat event. For example, one distribution utility provided anecdotal information suggesting that the frequency of distribution system service interruptions appeared to be higher for multi-day heat events above 95°F than for multi-day heat events above 90°F. The company did not have evidence about the statistical significance of this finding, although an analysis of such tipping points (beyond which the likelihood of distribution system service interruptions significantly increases) might prove helpful in terms of system design, equipment ratings, or the development of operating procedures during extreme heat events (see Chapter 1, "Climate Risks").

Ice and Snow Storms
New York State's energy system has long been vulnerable to impacts of ice and snow storms. The great blizzard of 1888 led to the decision to bury most electric wires around New York City (*New York Times*, 1888). Ice storms typically affect a wide geographic area, making repair work a sizable task (John Allen, personal communication, September 29, 2009; James Marean, personal communication, September 29, 2009). With more than 15,000 miles of electric transmission lines and 200,000 miles of distribution lines across the state (New York State Public Service Commission, 2008), ice storms are particularly problematic.

In 1998, a massive multi-day ice storm resulted in more than $1 billion in damage across the northeastern United States and eastern Canada. In New York State alone, dozens of high-voltage transmission towers, 12,500 distribution poles, 3,000 pole-top transformers, and more than 500 miles of wire conductor required replacement, affecting 100,000 customers from Watertown to Plattsburgh. Most of the repairs were completed within two months, although some areas were not completely repaired for four months (EPRI, 1998). Subsequent research found that much of the equipment was not rated for a storm of that magnitude. Another major ice storm in December 2008 resulted in the loss of power to 240,000 customers in the state's capital region (Gavin and Carleo-Evangelist, 2008).

Impacts on Natural Gas Distribution Infrastructure

Ninety-five percent of the state's natural gas supply is imported via grid pipeline from other states and Canada. Underground storage facilities (primarily depleted gas wells) in western New York and Pennsylvania are important features of the state's natural gas system, ensuring that adequate supplies are available during the peak-demand winter months. They also provide some level of insurance against natural disasters that may disrupt the production or delivery of natural gas to the state at other times of the year (State Energy Planning Board, 2009b), although the extent of this benefit is unclear. For example, an extensive amount of underwater pipeline damage occurred in the Gulf Coast region during hurricanes Katrina and Rita in 2005. Buried onshore pipelines were also damaged (Cruz and Krausmann, 2008). As a result of these supply chain disruptions, natural gas prices spiked to unprecedented levels in New York in 2005 (State Energy Planning Board, 2009b).

The impacts of climate change on in-state gas distribution infrastructure are unclear. Gas distribution pipes are buried for safety reasons. Although this does not make them immune to flooding risks associated with extreme weather events (Associated Press, 1986; *New York Times*, 1994), there is little published evidence that this has been a significant problem in New York in recent decades. Gas pipelines are also vulnerable to frost heaves (Williams and Wallis, 1995), although the extent to which climate change may alter current frost heave risks is unclear. Both of these subjects may require additional research, although the research need not examine all regions of the state. Currently, large swaths of ClimAID regions 2, 5, and 7 (Catskill Mountains and West Hudson River Valley, East Hudson and Mohawk River Valleys, and Adirondack Mountains) lack gas distribution service because of the low population levels in these areas.

Impacts on Renewable Power Generation

Climate change may also affect renewable power output around the state by affecting the timing or level of the natural resource responsible for power generation.

Hydropower
New York's 338 conventional hydropower facilities collectively generate more hydropower than any other state east of the Rocky Mountains. With a peak generation capacity of 5,756 megawatts, they currently satisfy 15 percent of the state's total annual electricity requirements (State Energy Planning Board, 2009). Three facilities operated by the New York Power Authority are responsible for 80 percent of the state's total hydropower capacity. Two are fed by the Great Lakes watershed, while the third is a pumped storage facility located in the Catskills. The potential exists to deploy another 2,500 megawatts of hydropower around the state by 2022, but "environmental, siting, financial, and regulatory barriers suggest that relatively little new development is likely to occur" (State Energy Planning Board, 2009).

In a changing climate, power supply availability must be considered. In projecting power supply availability from different sources, the New York Independent System Operator assumes that non-New York Power

Authority hydropower generators around the state—which represent approximately 1,000 megawatts of installed capacity—experience power generation output declines of approximately 45 percent in July and August due to reduced water availability during the summer months (NERC, 2008; NYISO, 2004). This 45 percent de-rate factor (the output decline) assumes the state is not experiencing drought conditions; under such conditions, the de-rate figure might be even higher. (For comparison purposes, when the northeastern United States suffered from drought in 2001, actual output from these same non-New York Power Authority facilities declined by 65 percent during summer months compared to their peak-rated capacity (NYISO, 2004).)

Case Study A examines how climate change may affect hydropower output levels at two large New York Power Authority-owned facilities near Niagara Falls and on the St. Lawrence River in Massena, New York, noting the correlation between precipitation levels and the level of power produced by these facilities. To the extent precipitation levels are expected to increase across the state by 2080 (see Chapter 1, “Climate Risks”), hydropower production levels may actually increase over time, although there are likely to be seasonal differences.

As Chapter 1 notes, however, New York State is also expected to experience more frequent late-summer drought conditions over the coming decades, which could lead to sizable reductions in hydropower output levels. This would have significant cost repercussions around the state, as lost capacity would likely be replaced by more expensive forms of power generation (Morris et al., 1996). Moreover, because the impacts of climate change are likely to be felt at hydropower in surrounding states (and Canada) as well, New York may not be able to rely on the same level of electricity imports it has previously, exacerbating already tight local power supply markets and raising prices even higher.

Solar Power

Although there is relatively little solar photovoltaic technology currently deployed around New York (approximately 14.6 MW), estimates are that the state enjoys significant solar resources, exceeding that of any other renewable energy source in the state (State Energy Planning Board, 2009). Whether climate change will enhance or hinder local solar resources is unknown. One study modeled solar radiation in the United States through 2040, projecting that increased cloud cover attributable to rising carbon dioxide levels could reduce solar radiation levels by as much as 20 percent, particularly in the western United States (Pan et al., 2004). No clear trends were projected for the Northeast. Another study focused on Nordic (Scandinavian) cities estimates that a 2-percent decrease in solar radiation could reduce solar cell output by 6 percent (Fidje and Martinsen, 2006). A solar expert at SUNY Albany, Dr. Richard Perez, reviewed this literature but discounted these impacts, noting that because of differences in latitude between New York, Nordic areas, and other parts of the United States, New York State should “expect, in the worst case, a 1 to 2 percent decrease in [solar] PV yield, and the best case, no change at all” (Dr. Richard Perez, personal communication, September 9, 2009).

More research is necessary to examine the potential impacts of climate change on solar power, as decreases in solar photovoltaic system output in New York State would increase the per-kilowatt cost of solar power, reducing the cost competitiveness of photovoltaic systems compared to other forms of electricity. Research should also examine the extent to which such losses may be offset by advances in solar panel efficiency that will likely occur over time.

Wind Power

New York State’s proximity to the Atlantic Ocean and Great Lakes places it close to excellent conditions to support wind power development. According to the American Wind Energy Association (2009), New York ranks 15th nationally in terms of its overall wind power potential, although support from New York State’s Renewable Portfolio Standard and favorable federal tax rules have helped the state achieve a seventh-place ranking with regard to its current wind power deployment. Already, there are 791 large wind turbines installed around the state, with a peak generation capacity of 1,264 megawatts (American Wind Energy Association, 2009), and forecasts are that this could increase to more than 8,500 MW by 2015 (State Energy Planning Board, 2009). The majority of this capacity will come in the form of large wind turbine installations, as opposed to small rooftop turbines that are more scale-appropriate for urban areas.

Because wind turbine power output is a function of the cube of the wind speed, small changes in wind speed can translate into large changes in output. For example, a recent study notes how a 10-percent change in wind speed can lead to a 30-percent change in energy output (Pryor and Barthelmie, 2010). The consequences of changing wind patterns can thus be sizable in terms of the state's ability to rely on large quantities of wind power.

The same study also notes a dearth of research examining extreme wind speeds and gusts and their relationship to wind turbine design protocols (Pryor and Barthelmie, 2010). Given that current industry design criteria generally call for turbines to withstand 1-in-50-years wind speed events lasting no more than 10 minutes, more research may be necessary to assess whether these standards should be upgraded or whether they can be relaxed in the coming decades.

Biomass

Forestry and agricultural products currently make a very minor contribution to the state's overall electricity picture, combusted in biomass-only facilities near Utica and Chateaugay or co-combusted with coal at a power plant near Niagara Falls. These facilities have a peak generation capacity of 65 megawatts, and collectively generate approximately 440,000 megawatt hours of power per year (State Energy Planning Board, 2009a).

Biomass is also used as a primary fuel for heating purposes in some New York homes and businesses. In 2007, approximately 94 trillion British thermal units (TBtus) of heat were generated statewide from wood resources (State Energy Planning Board, 2009a), the vast majority of which was consumed in homes. Some of this wood is shredded and then reprocessed into uniform-sized pellets, which are designed for use in more efficient boilers and wood stoves.

Recently, interest has grown in the conversion of biomass into liquid fuels, some of which is blended with fuel oil for use in residential or commercial heating systems. As of 2008, there was one biodiesel manufacturing facility in the state, although there are more than a dozen fuel oil companies around the state that blend biodiesel with their fuel oil to sell to customers (State Energy Planning Board, 2009a). Most of their biodiesel is purchased from refiners located outside of the state.

The effects of climate change on New York's biomass-based energy systems is unclear. As the "Ecosystems" chapter (Chapter 6) notes, some species of trees may do better than others, a function of the level of temperature change, vulnerability to vectors, and level of drought conditions. Homes and businesses that rely on downed trees as the source of their wood may or may not find changes in the level of available supply; the impacts of climate change on wood resources is likely to be very local in nature. The effects on power plants or pellet manufacturers, which rely on managed forests or waste wood from manufacturing operations, are similarly unclear and may ultimately depend on the characterizations of different wood species, as the impacts are expected to vary (see Chapter 6, "Ecosystems"). These facilities tend to source their material many months or even years in advance from a range of suppliers, which may help offset any adverse impacts attributable to climate change, although this is an area where more research would be beneficial.

The impacts of climate change on biodiesel production or blending operations in New York State is similarly unclear, as production facilities tend to source material from an international feedstock market. The extent to which the supply chain will be affected is uncertain, and as the market for biodiesel fuel grows across the state, this may also be an area where further research would be beneficial.

8.3.2 Energy Demand

Climate change may affect energy demand for space heating and cooling. Electricity demand is most sensitive to changes in summer climate, whereas heating fuel demand is most sensitive to changes in the winter climate. Impacts may have multiple dimensions, including changes in total demand, seasonal variability, and peak demand (Amato et al., 2005; Wilbanks, 2007; Scott and Huang, 2007). Overall, in the northern United States, net energy demand is likely to decrease as a result of warmer winters. This effect is expected to outweigh air conditioning-related increases in summertime energy demand in the southern United States, leading to a net national reduction in total energy demand (Scott and Huang, 2007).[6]

To understand how climate change may affect energy demand in New York State, the ClimAID climate team first provided current trends and expected changes in heating degree days and cooling degree days, metrics that affect demand for space heating and cooling, respectively (see Chapter 1, "Climate Risks," for an analysis of current trends and expected changes in average temperature).[7] Next, the sensitivity of energy demand to changes in temperature was analyzed. This analysis was carried out only for electricity demand, as data are not available to analyze heating fuels. Finally, to project changes in electricity demand the analysis combined the information on projected changes in climate with information on the sensitivity of demand to those changes. The focus is on the 2020s because non-climate drivers dominate energy planning in the medium and long terms. The 2020s is defined as the 2011–2039 time period (consistent with Chapter 1, "Climate Risks"), so projections for the 2020s are an average of the projections for each of the 30 years in that time period.

Linear regression was used to estimate historical changes in temperature. Linear forecasts for future climate are then based on the assumption that the observed trend in climate over the historical period will continue into the future. This assumption may be reasonable over short time periods (up to 10 years). An advantage of linear forecasts is the ability to make projections for a specific geographic location using hourly, daily, and/or monthly data from a local weather station. The benefit of temporal specificity is offset by inclusion of only a limited number of variables. Therefore, these forecasts are compared with global climate model (GCM) projections that account for the dynamic relationships among many different climate variables.

New York State Heating and Cooling Seasons

In New York State, the heating season is longer than the cooling season, and 50 to 55 percent of heating degree days occurs during the winter peak months of December, January, and February, with the other 50 percent occurring during the fall and spring "shoulder" seasons. There is substantial variation among different regions of the state. For example, Binghamton, Utica, and Watertown have more than 7,000 heating degree days per year, whereas New York City has fewer than 5,000 (**Table 8.9**). On the other hand, New York City has more than 1,000 cooling degree days, whereas Binghamton, Albany, and Buffalo have 400 to 600 cooling degree days.[8] The direction and magnitude of changes in energy demand depend on changes in heating degree days, cooling degree days, and other climate-related changes as well as the sensitivity of demand to climate factors. In some cases, sensitivities may be nonlinear, for example if higher temperatures in the summertime lead to a significant increase in air-conditioning saturation rates (the number of households with some form of air conditioning).

Projected Changes in Heating Degree Days

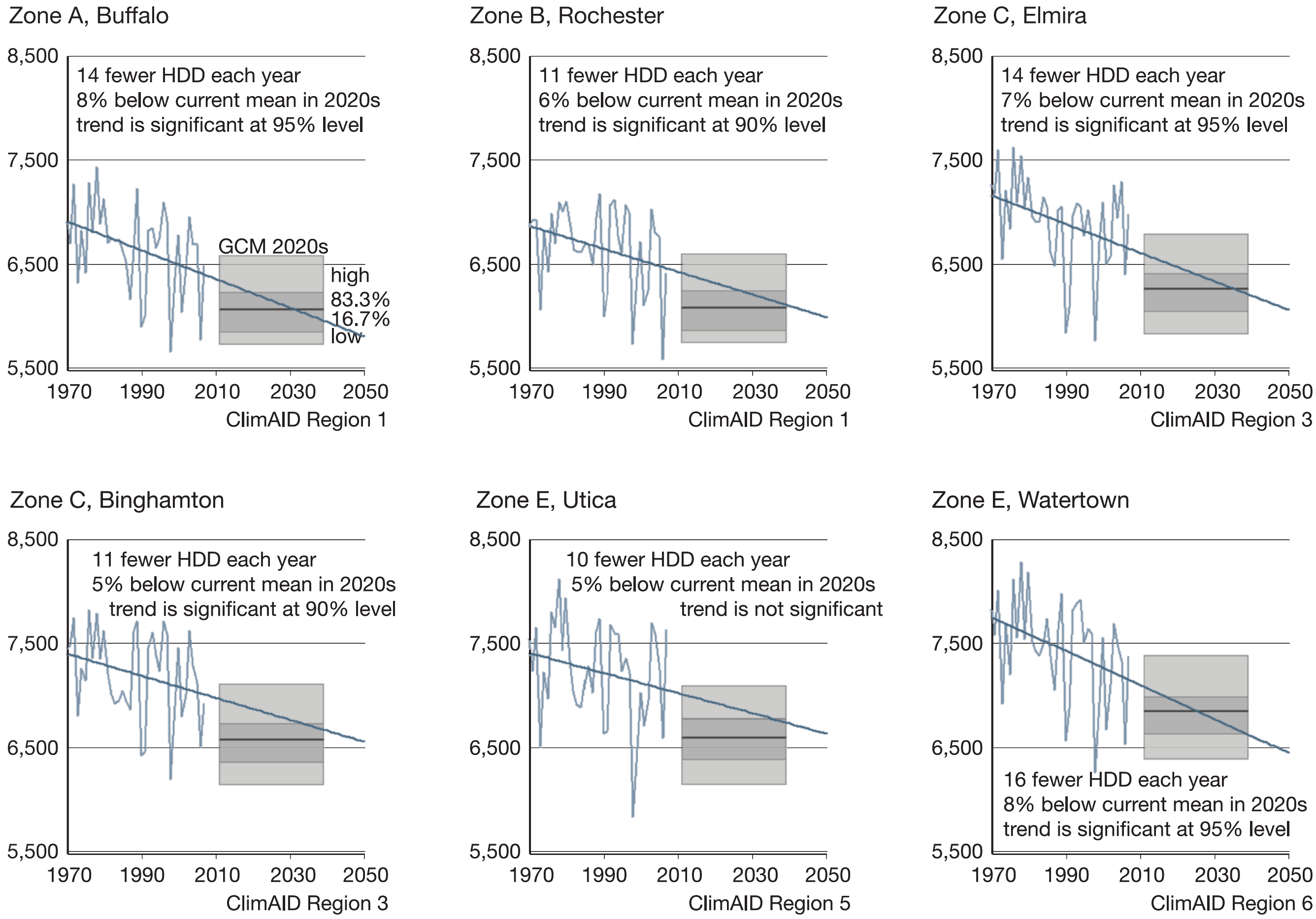
In all regions of the state, heating degree days have significantly declined over the past few decades (**Figure 8.5**). Annual heating degree days are expected to decline by between 5 and 8 percent in the 2020s compared to the current (1970–2007) average; expected changes are relatively consistent across all regions of the state. Global climate model projections for the number of heating degree days in the 2020s are broadly consistent with the linear forecasts. Agreement between these two methods should help to address the skepticism with which global climate models have historically been viewed by energy sector stakeholders. The two methods would not necessarily be expected to agree over the medium to long term.

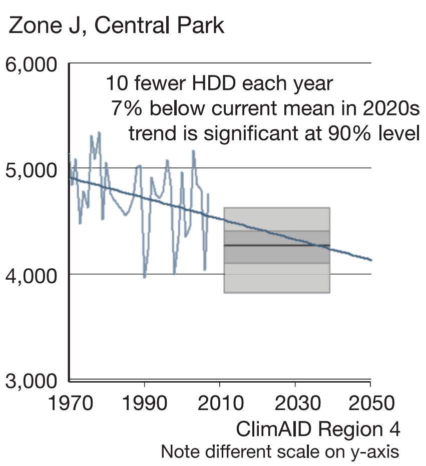
Warmer winters may reduce electricity demand for heating, although just 10% of New York State's heating demand is met with electricity. Declining heating degree days may also put downward pressure on demand for utility gas and fuel oil, the two primary sources of space heat in the state (**Figure 8.2**), although climate is just one of many drivers of demand for these resources. Additional research is needed to better understand how climate change may affect the breakdown of demand for natural gas for building heat versus power generation.

Weather Station	ClimAID Region	NYISO Zone	Heating Degree Days (per year)	Cooling Degree Days (per year)
Buffalo	Region 1	Zone A	6,654	557
Rochester	Region 1	Zone B	6,663	585
Elmira	Region 3	Zone C	6,904	479
Binghamton	Region 3	Zone C	7,211	409
Utica	Region 5	Zone E	7,229	483
Watertown	Region 6	Zone E	7,457	521
Albany	Region 5	Zone F	6,813	567
NYC (Central Park)	Region 4	Zone J	4,740	1,158

Note: Maps showing the relationship between NYISO zones and ClimAID regions are shown in Appendix B. Note that these seven stations were selected for the analysis presented in this table as well as for Figures 5 and 6 because global climate model projections for heating degree days and cooling degree days were available for each of these stations. Source: Historical climate data obtained from NOAA

Table 8.9 Average annual heating degree days and cooling degree days, 1970 to 2007



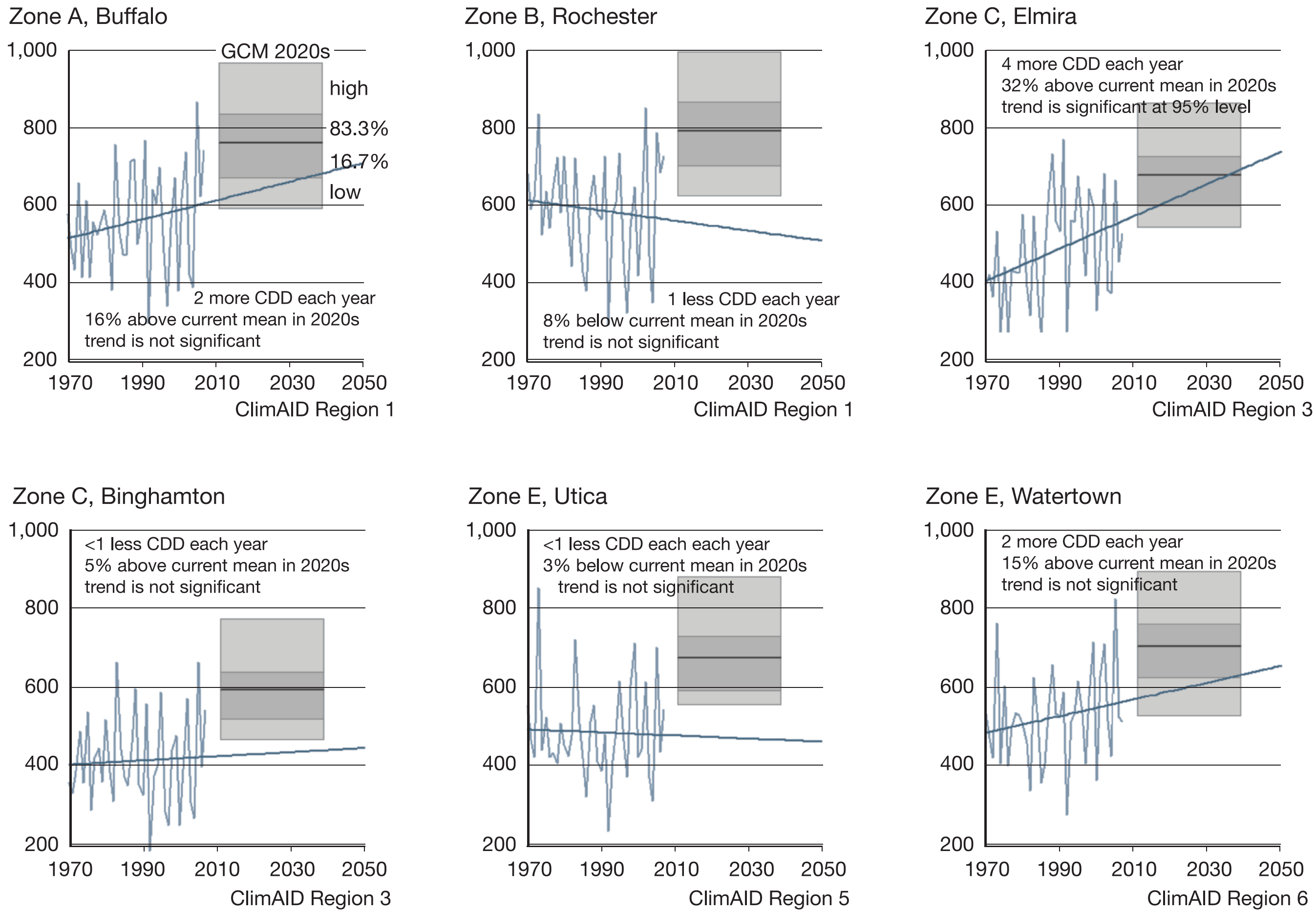


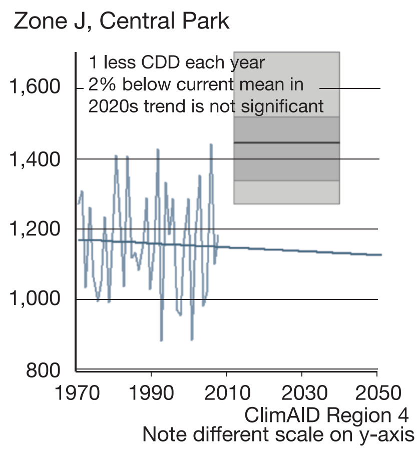
Note: The jagged line on each graph represents historical annual HDD, based on actual weather station data. The straight line indicates the trend in historical HDD, extrapolated into the future. The number of HDD in the 2020s was estimated by extrapolating the linear trend out to 2039 and then averaging the values for 2011–2039. The grey boxes show the range of GCM projections for the 2020s, with the black line in the center of each grey box indicating the mean GCM projection. Note that the trend is considered significant if the p-value is <0.1. Not all NYISO zones and ClimAID regions are represented; only those stations for which GCM projections for HDD were available are included. Data source: Historical climate data from NOAA; GCM projections from ClimAID.

Figure 8.5 Projected changes in heating degree days in selected regions of the state. The projections are for the 16 GCMs and 3 emissions scenarios used in ClimAID. Shown are the minimum, central range, and maximum values across the GCMs and emissions scenarios.

Projected Changes in Cooling Degree Days

New York State has a relatively short cooling season. In New York City, 79 percent of annual cooling degree days occur during the summer months; in many cities in northern and western New York, the figure is closer to 85 percent. Although the global climate models used in ClimAID project increases in cooling degree days on the order of 24–47 percent, depending on the region, these projections generally exceed forecasts based on linear extrapolation of current trends (**Figure 8.6**). Also, in most regions, historical trends in cooling degree days are not statistically significant, reducing confidence in the linear extrapolations.[9] Of the weather stations for which data were obtained, only Elmira has a statistically significant upward trend over





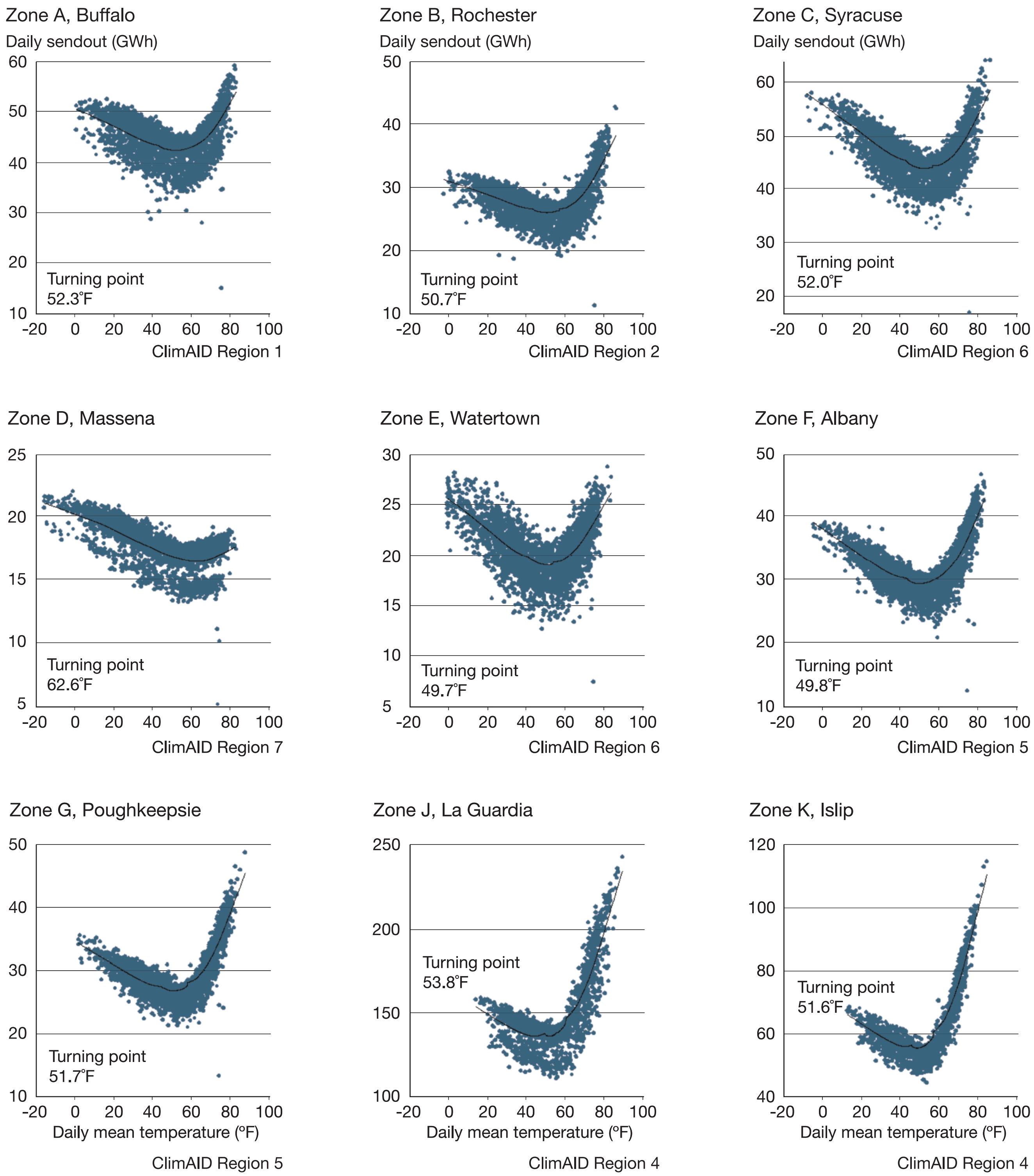
Note: The jagged line on each graph represents historical annual CDD, based on actual weather station data. The straight line indicates the trend in historical CDD, extrapolated into the future. The number of CDD in the 2020s was estimated by extrapolating the linear trend out to 2039 and then averaging the values for 2011–2039. The grey boxes show the range of GCM projections for the 2020s, with the black line in the center of each grey box indicating the mean GCM projection. Note that the trend is considered significant if the p-value is <0.1. Not all NYISO zones and ClimAID regions are represented; only those stations for which GCM projections for CDD were available are included. Data source: Historical climate data from NOAA; GCM projections from ClimAID.

Figure 8.6 Projected changes in cooling degree days in selected regions of the state. The projections are for the 16 GCMs and 3 emissions scenarios used in ClimAID. Shown are the minimum, central range, and maximum values across the GCMs and emissions scenarios.

the 1970–2007 period. Note that patterns of urban development can affect local temperature trends through heat island formation, an effect that was not accounted for in the data analysis.[10]

Electricity Demand

A key question for the power sector is whether climate change will require a significant shift in energy planning or will remain a small demand driver relative to population and economic growth, efficiency projects, and other factors. The need for new generation and/or transmission capacity depends on the geographic location and timing of the increases. All else being equal, warmer nighttime temperatures in the summer and/or a longer cooling season would not necessarily require new generation capacity.[11] However, if summertime peak demand increases at a faster rate than overall demand, the likelihood of brownouts or blackouts increases (Miller et al., 2008).[12] Also, although increases in average daily demand might not require new capacity, they can still affect energy prices, since more expensive generation sources may need to be online more frequently.



Time period is 2002-2008, except for Zones J and K, for which the time period is February 2005-2008.

Figure 8.7 Daily average temperature versus daily electricity demand (GWh) for each NYISO Zone

A few previous studies have analyzed how climate change may affect electricity demand and generation capacity in the United States. One of the first energy sector climate change assessments concluded that total electricity consumption in the United States would grow 4 to 6 percent between 1989 and 2055 as a result of increased temperature, with peak demand projected to grow 13 to 20 percent and capacity requirements (including reserve margin requirements) expected to increase 14 to 23 percent (Smith and Tirpak, 1989). Several studies analyzing different utility service areas have found that peak demand is likely to increase faster than annual electricity sales, but none of these studies analyzed New York State (Baxter and Calandri, 1992; Franco and Sanstad, 2008; ICF, 1995).[13]

Two previous studies have analyzed electricity demand in New York. A 1987 study of New York State used a range of climate and demand growth models, concluding that by 2015 peak demand would grow by 8 to 17 percent while overall demand attributable to climate change would equal 2 percent in the region of New York City, Long Island, the Hudson Valley, and other suburban and rural areas northwest of New York City (Linder et al., 1987).[14] The Metro East Coast study, which examined the New York metropolitan region, projected a 17 percent increase in summertime daily peak demand by the 2080s, based on results from several models and climate change scenarios (Hill and Goldberg, 2001).[15]

The ClimAID analysis of temperature and load data from 2002 to 2008 shows that all NYISO load zones have higher average daily electricity demand during the cooling season than during the heating season, with the exception of Zone D in the northernmost corner of the state (**Table 8.10**). This reflects the low penetration rate of electric heating relative to electric air conditioning.[16] This feature of the data should not be confused with the fact that most parts of New York State consume more energy for heating than cooling each year.

Each load zone has unique heating and cooling seasons that differ based on the timing and temperature range experienced during the winter, summer, and shoulder-season periods. **Figure 8.7** illustrates the relationship between daily average temperature and daily electricity demand. In each zone, there is a unique turning point below which load increases as temperature decreases in the winter. For most zones, the turning point occurs at an average daily temperature of between 49 and 54°F (maximum daily temperature between 53 and 63°F).[17] From this turning point until about 65°F, there is typically a flat zone over which electricity demand neither falls nor rises, representing the short shoulder seasons in late spring and early fall. Above 65°F, demand rises, typically by a larger amount per degree Fahrenheit than during the heating season. Note that some zones—most notably NYISO Zone E (Watertown)—span a large latitudinal range, so load may reflect a combination of different heating and cooling seasons in the southern versus the northern part of the zone. As **Figure 8.7** makes clear, the sensitivity of heating and cooling loads to temperature varies across the zones. **Tables 8.10** and **8.11** show the sensitivities for each zone, assuming a linear relationship between daily average temperature and demand below the turning point for the heating season (**Figure 8.7**) and above 65°F for the cooling season. Although the sensitivity calculations are confined to temperature, other climatic variables interact with temperature to affect demand. Principal among these is relative humidity, and further research is needed to incorporate humidity into the electricity demand analysis.

Electricity Demand Sensitivity to Temperature During the Heating Season

During the heating season, electricity demand typically decreases by 0.4 to 0.8 percent for every 1°F increase in temperature, corresponding to absolute demand changes of between 72 megawatt hours (Zone D—Massena) and 560 megawatt hours (Zone J—New York City). The zones with the largest percent changes do not necessarily have the largest absolute changes, which are related both to the zone's total load and the percentage of heating demand met with electricity. Load size is more important than electric heating penetration. For example, Zone D, which has both the smallest load size and the largest share of heating demand met with electricity, is less sensitive to temperature than Zone J, which has the largest load size and smallest share of heating demand met with electricity.

Electricity Demand Sensitivity to Temperature During the Cooling Season

Combining information on projected changes in climate with information on the sensitivity of demand to those changes can give a sense of how electricity demand may be affected by climate change, all else being equal. Electricity demand is more sensitive to temperature during the cooling season (i.e., summer). NYISO Zones

F, G, J, and K (Albany, Poughkeepsie, New York City, and Long Island) account for nearly two-thirds of total daily demand during the cooling season. In Zone K (Long Island), changing the temperature by 1ºF results in a demand change of 2.0 to 2.9 percent. Absolute changes in these NYISO zones are also much larger. For example, in New York City, daily demand rises by 3,427 megawatt hours with each additional 1ºF rise in temperature. This is more than six times larger than heating-season (i.e., winter) sensitivity. Peak demand is more sensitive to temperature than total daily demand. For example, in Rochester, peak demand increases by 2.3 percent with each additional 1ºF versus a 1.8-percent increase in total daily demand. The largest absolute increase in peak demand is in NYISO Zone J (New York City), which experiences a 166-megawatt increase for each additional 1ºF. This is lower than the sensitivities reported in two earlier studies, which found demand increases on the order of 404 to 740 megawatts (Linder et al., 1987) and 240 to 309 megawatts (Hill and Goldberg, 2001) for each additional 1ºF rise in temperature. This sensitivity value, however, corresponds well with the 2001 study estimate (Hill and Goldberg, 2001) after accounting for the fact that Zones J and K were previously a single zone. This adjustment gives a combined sensitivity of 295 megawatts, within the range reported by the 2001 study (Hill and Goldberg, 2001).

The number and type of air conditioners within each zone are the primary determinants of sensitivity during the cooling season, and the zones differ widely in terms of the percentage of residential households with air conditioning. For example, in 2003, 84 percent of housing units in New York City and Long Island (Zones J and K) had either window or central air conditioning systems installed. This saturation rate is much higher than that found in either Rochester or Buffalo (Zones B and A), although the data for those cities reflect slightly earlier time periods (U.S. Census Bureau, 2004).

		Heating Season			Cooling Season		
NYISO zone	Weather station	Average daily electric demand (MWh)	Standard deviation daily electric demand (% of average)	Peak electric load (MW)	Average daily electric demand (MWh)	Standard deviation daily electric demand (% of average)	Peak electric load (MW)
Zone A	Buffalo	44,255	8%	2,870	46,260	10%	3,113
Zone B	Rochester	27,107	8%	1,609	29,693	12%	2,143
Zone C	Syracuse	46,576	9%	3,061	48,078	10%	3,153
Zone D	Massena	17,636	10%	1,493	16,565	9%	1,219
Zone E	Watertown	20,509	13%	1,569	21,468	12%	1,436
Zone F	Albany	31,075	9%	2,370	34,417	12%	2,381
Zone G	Poughkeepsie	28,128	8%	1,794	32,892	13%	2,496
Zone J*	NYC (LGA)	137,109	7%	7,761	169,186	14%	11,347
Zone K*	Islip	56,850	7%	3,633	74,821	14%	5,748

*In zones J and K, calculations are based on data from February 2005 to 2008.
Sources: Load data were obtained from NYISO (2009a); weather station data were obtained from NOAA and NYISO (2009b)

Table 8.10 Average daily electricity demand and average annual peak load for each NYISO Zone for the 2002–2008 period

		Heating Season			
		Change in daily electricity demand and peak load with respect to a 1ºF increase in average daily temperature			
NYISO zone	Weather station	Change in daily electricity demand (MWh)	% change in daily electricity (%MWh)	Change in daily peak electricity load (MWp)	% change in daily peak electricity load (%MWp)
Zone A	Buffalo	-191	-0.4%	-9	-0.4%
Zone B	Rochester	-119	-0.4%	-6	-0.5%
Zone C	Syracuse	-262	-0.6%	-12	-0.6%
Zone D	Massena	-72	-0.4%	-3	-0.4%
Zone E	Watertown	-157	-0.8%	-7	-0.7%
Zone F	Albany	-201	-0.6%	-10	-0.6%
Zone G	Poughkeepsie	-171	-0.6%	-8	-0.6%
Zone J*	NYC (LGA)	-560	-0.4%	-27	-0.4%
Zone K*	Islip	-338	-0.6%	-18	-0.6%

*In zones J and K, calculations are based on data from February 2005 to 2008.
Sources: Load data were obtained from NYISO (2009a); weather station data were obtained from NOAA and NYISO (2009b)

Table 8.11 Heating season sensitivity of electricity demand to a 1ºF increase in temperature over the 2002–2008 period

During the cooling season, peak demand increases as more and more air conditioners come online, up to the point at which all air conditioners have been turned on and/or demand response or other load management programs are initiated to prevent demand from rising above system capacity. An increase in the air conditioning saturation rate is the largest potential impact of climate change on electricity demand, because it would increase demand by larger amounts than what is implied by the sensitivities in **Tables 8.10** and **8.11**.

In western New York, air conditioning saturation rates are relatively low, so there is greater potential for climate-related summertime demand growth (Sailor and Pavlova, 2003). This could lead to local increases in the sensitivity of demand to temperature as well as system-wide impacts on demand levels and pricing. Impacts on peak demand and overall system capacity depend on the breakdown between room air conditioners, which tend to be used more heavily when owners are home (including at night), and central air conditioning, which is used more evenly over the course of the day (Linder et al., 1987). Increases in residential central air conditioning would likely have a larger impact on peak demand because additional load would be added to the system at the time of the commercial peak in the mid-afternoon.

Projected Changes in Statewide Electricity Demand in the 2020s

Based on the ClimAID team's global climate model projections, an average annual temperature increase of 1.5 to 3.0ºF is expected in most parts of the state by the 2020s (see Chapter 1, "Climate Risks"). Assuming these changes are consistent across both the heating and the cooling season and that daily average changes are approximately equal to the annual average change in temperature, and using the sensitivities shown in **Table 8.12** (and assuming they remain unchanged), global climate change may increase summertime peak demand by up to 497 megawatts in New York City in the 2020s, a 4-percent increase over current peak demand. In other parts of the state, peak demand increases attributable to climate change will be much lower (**Table 8.14**). Note that the global climate models project a significant departure from historical trends in summertime cooling degree days (**Figure 8.6**).

The estimated changes in peak demand shown in **Table 8.14** assume that the sensitivity of demand to temperature is linear (i.e., an increase in temperature from 80 to 85ºF has the same impact on demand as an increase from 90 to 95ºF) and that the sensitivities observed today will remain unchanged in the future.

		Cooling Season			
		Change in daily electricity demand and peak load with respect to a 1ºF increase in average daily temperature			
NYISO zone	Weather station	Change in daily electricity demand (MWh)	% change in daily electricity (%MWh)	Change in daily peak electricity load (MWp)	% change in daily peak electricity load (%MWp)
Zone A	Buffalo	632	1.3%	37	1.6%
Zone B	Rochester	569	1.8%	35	2.3%
Zone C	Syracuse	686	1.4%	41	1.7%
Zone D	Massena	91	0.5%	5	0.7%
Zone E	Watertown	338	1.5%	19	1.7%
Zone F	Albany	723	2.0%	42	2.4%
Zone G	Poughkeepsie	786	2.3%	48	2.8%
Zone J*	NYC (LGA)	3,427	2.0%	166	2.0%
Zone K*	Islip	2,256	2.9%	129	3.2%

*In zones J and K, calculations are based on data from February 2005 to 2008.
Sources: Load data were obtained from NYISO (2009a); weather station data were obtained from NOAA and NYISO (2009b)

Table 8.12 Cooling season sensitivity of demand to a 1ºF increase in temperature over the period 2002–2008

	Percentage of Housing Units with Window AC Units						Percentage of Housing Units with Central AC Units					
Metropolitan Region	1994	1995	1998	1999	2002	2003	1994	1995	1998	1999	2002	2003
Buffalo	20%				26%		15%				24%	
New York City/Nassau/Suffolk/Orange		57%		63%		67%		11%		13%		17%
Rochester			27%						26%			

Source: U.S. Census Bureau (1996, 1997, 2000, 2001, 2003, 2004); weather station data are from NOAA and NYISO (2009b)

Table 8.13 Air conditioning saturation rates for select metropolitan regions in New York State (1994–2003)

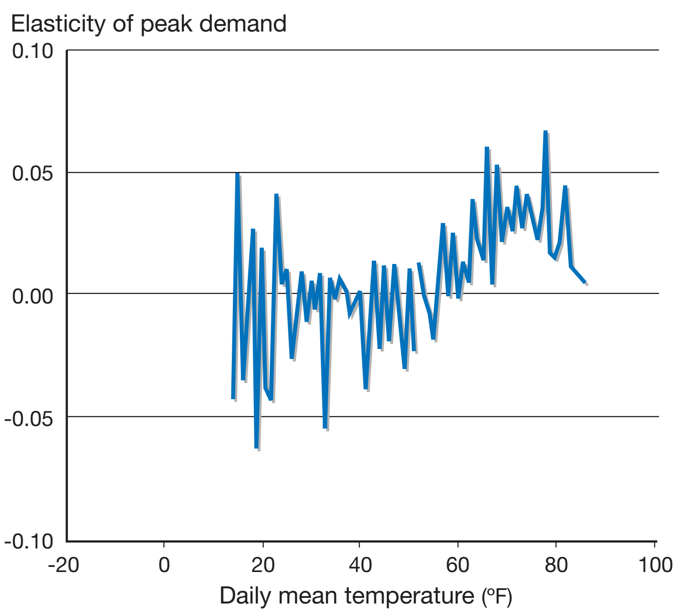
NYISO Zone	Weather Station	Heating Season: Decrease in MWp electricity demand in 2020s	Cooling Season: Increase in MWp electricity demand in 2020s
Zone A	Buffalo	14–27	55–111
Zone B	Rochester	9–18	53–105
Zone C	Syracuse	19–37	61–122
Zone D	Massena	5–10	7–15
Zone E	Watertown	11–21	29–57
Zone F	Albany	15–29	63–126
Zone G	Poughkeepsie	12–25	72–145
Zone J	NYC (LGA)	40–80	249–497
Zone K	Islip	27–58	194–387

Note: Based on global climate model projections for changes in average temperature and the demand sensitivities in Tables 8.10 and 8.11. Global climate models project that average annual temperature will increase by 1.5 to 3.0°F in the 2020s compared to 1970–2000 baseline period. Climate projections from ClimAID.

Table 8.14 Projected changes in peak electricity demand in the 2020s compared to current peak demand

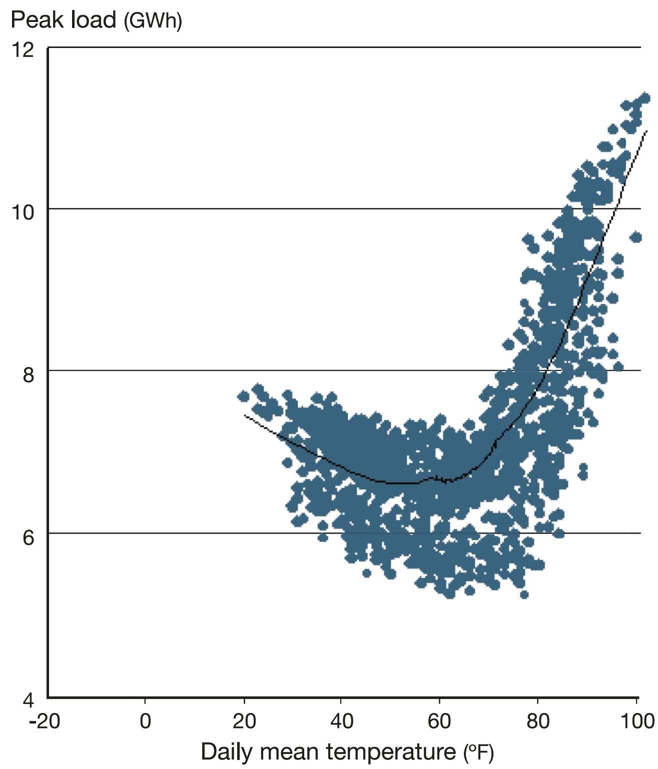
An example of a case where current sensitivities may not reflect future sensitivities is an increase in air conditioning saturation rates, which would increase the sensitivity of demand to increases in temperature. Two examples of cases where the relationship between temperature and demand is nonlinear can be seen in **Figures 8.8** and **8.9**. In NYISO Zone K (Long Island), demand is increasingly sensitive to temperature as temperature rises during the cooling season (**Figure 8.8**). In this case, the source of the nonlinearity is likely related to the prevalence of summer homes on Long Island, with the largest number of homes occupied during the hottest months of the year. **Figure 8.9** shows the relationship between maximum daily temperature and peak demand in Zone J (New York City). Demand starts to flatten after all air conditioners in the zone are already running and/or demand response programs have been activated. Appendix B shows the relationship between maximum daily temperature and peak demand in all zones. With the exception of Zone J (New York City), patterns are similar to what is shown in **Figure 8.7**.

In general, projected changes of the estimated linear sensitivities should be viewed as a starting point for assessing how climate change may affect demand, but with the understanding that climate change may have nonlinear impacts on demand drivers that are not captured by the sensitivities, such as the increased saturation of air conditioners.



Note: Elasticities are expressed as percentages, with 0.05 indicating a 5% increase in peak demand with respect to a 1°F increase in temperature. Time period is February 2005-2008.

Figure 8.8 Elasticity of peak electricity demand in Zone K (Long Island) with respect to mean daily temperature recorded at Islip



Time period is February 2005-2008.

Figure 8.9 Daily maximum temperature recorded at LGA versus daily peak load (MW) for Zone J (New York City)

Sectoral Impacts

Within each NYISO zone, the mix of building types—industrial, commercial, and residential—affects the sensitivity of electricity demand to temperature, because different types of buildings vary in their demand for space conditioning (Amato et al., 2005). In the United States, just 6.8 percent of industrial energy use is related to space-conditioning functions, reflecting the greater energy intensity of the sector's various production processes. The residential and commercial sectors use far more energy on heating and cooling, at 49.3 percent (residential) and 27.3 percent (commercial) of their total demand (EIA, 2007; EIA, 2009a; EIA, 2009b). If supply becomes more constrained or if costs increase because of rising demand, impacts may disproportionately fall on the residential and commercial sectors.

In most energy models, commercial buildings are assigned a lower balance point temperature (Rosenthal and Gruenspecht, 1995), the threshold at which a building must be heated or cooled to maintain occupant comfort. Some argue the lower balance point is justified because commercial buildings tend to experience a higher internal heat gain from office equipment and lighting than the residential sector (Amato et al., 2005). Rising temperatures due to climate change are likely to compound the problem, increasing the level of cooling necessary to address this heat gain.

Studies examining differences among the energy sectors are somewhat contradictory, perhaps reflecting location-specific circumstances. One study found the residential sector will experience a greater percentage increase in per-capita demand than the commercial sector, although the residential sector has a lower base demand (Amato et al., 2005). In contrast, a different analysis of electricity consumption in eight states (including New York) that used three different global climate models found the impact of climate change on the sectors varies widely. For New York State, the study found that the residential sector would increase energy consumption by 2.9 to 6.3 percent per person compared to a commercial sector increase of 4.8 to 7.6 percent per person, by the middle of the 21st century (Sailor, 2001).

Additional Data and Research Needed to Support NYISO Demand Forecasting

The analysis presented above, as well as the large database of New York State climate data assembled by the ClimAID team, lays a foundation for additional research. A more detailed follow-up analysis could address how to systematically incorporate long-term climate change—and particularly changes in extreme conditions that affect peak demand—into zone forecasts. A combination of global and regional models and statistical analysis of historical data with extrapolation of the results into the future would provide a suite of methods for understanding how extreme changes may alter short-term (10-year) demand forecast.

8.4 Adaptation Strategies

There is an extensive literature discussion on steps the energy sector might take to adapt to climate change. Strategies are both descriptive (e.g., "a guiding principle should be resilience" (Franco and Sanstad, 2006)) and prescriptive (e.g., plant trees to shade homes and reduce heat uptake; use reflective surfaces on rooftops (Vine, 2008)). Adaptation strategies emphasize different temporal scales, cost levels, target audiences, technologies, and policy decisions and decision rules. Many adaptation strategies proffered serve a dual role as climate change mitigation strategies. As an example, steps to reduce cooling demands in buildings, a common climate change mitigation strategy, can eliminate or reduce energy system failures or generation capacity growth requirements.

An area of some commentary is the role uncertainty plays in adaptation planning. One study notes the challenge of making climate change adaptation investment decisions in the face of uncertainty over what future energy demand will look like, even in the absence of climate change (Linder et al., 1987). Recall that the modeling exercises discussed earlier all sought to isolate climate-change-related demand impacts from normal demand growth trends, which are affected by household income levels, population patterns, technology innovation, efficiency mandates, etc. (Scott and Huang, 2007). The confidence interval surrounding future demand projections can, thus, be quite wide, exceeding the anticipated impacts of climate-change-related demand growth (ICF, 1995).

A recent analysis offers advice on how to proceed in the near term in light of this situation, highlighting the benefits of a "no-regret[s]" approach (Hallegate, 2008). Under this approach, adaptation strategies are pursued that prove beneficial regardless of whether the anticipated climate risk ultimately materializes. Energy efficiency initiatives are "no-regret measures par excellence" (Mansanet-Bataller et al., 2008), because there are energy savings and other cost-saving benefits accrued, regardless of whether climate-change-related impact projections prove accurate. However, monitoring climate changes over time is essential to implementing effective adaptation measures in the longer term, as projected impacts could exceed the ability of no-regrets strategies to cope.

Because this system requires constant refurbishment and eventual replacement over long timescales, it makes sense to align implementation of adaptation measures into the natural replacement cycle of vulnerable system assets.

8.4.1 Key Adaptation Strategies

Past analyses of climate change impacts on New York City have described a range of potential adaptation strategies. One analysis presents a list of energy-efficiency measures for buildings, in rank order based on payback period (Audin, 1996). Others note the need for additional investment in generation capacity (Morris and Garrell, 1996). Conservation is characterized as being of paramount importance, including passive building design strategies that reduce or avoid the need for air conditioning. A more recent study concurs, offering a range of policy and technology responses appropriate at both the community and building scales (Hill and Goldberg, 2001).

In general, adaptation strategies target either energy supply or energy demand. Supply-related measures are fairly straightforward, focused on enhancing the capacity of the power generation, transmission, and distribution system to operate under a range of future climatic conditions (Franco and Sanstad, 2006). Known as "hardening" strategies, these tend to emphasize physical improvements, such as the use of higher temperature-rated transformers and wiring and the construction of flood-prevention berms around power plants (Mansanet-Bataller et al., 2008).

Local hardening strategies are already being implemented. In 2002, the New York Power Authority constructed a new 500-megawatt power plant in Queens near the East River. FEMA 100-year flood maps identified the location as being vulnerable to flooding and, therefore, the facility would need to meet flood-proofing standards. To address this issue, the New York Power Authority decided to raise the facility to 20 feet above sea level as a precaution against future sea level rise and storm surges (Victoria Simon, personal communication, October 15, 2009). Since 2007, Con Edison has also been proactive on this front, voluntarily launching a 10-year plan to replace 186 underground transformers located in Category 1 floodplains around the city, at a cost of $7 million. The new transformers are saltwater submersible and can thus better handle intrusion from storm surges than the equipment currently in use (New York State Department of Public Service, 2007).

Tree-trimming management programs by utilities are considered an important deterrent to ice- and snow-related problems, reducing the likelihood that falling trees or limbs will damage distribution wires. Warmer average temperatures may ironically exacerbate this winter threat, extending the growing season for trees and shrubs, forcing utilities to shorten the visitation cycle (i.e., how frequently an area is trimmed) along their transmission and distribution network (Karl Schoeberl, personal communication, October 28, 2009).

Resilience can also be delivered via soft approaches. Such strategies focus on managing risk and specific climate change impacts without making extensive (or expensive) capital improvements. Soft strategies include adjusting reservoir release policies to ensure sufficient summer hydropower capacity (Aspen Environmental Group and M Cubed, 2005) and shading buildings and windows or using green roofs (Gaffin, 2009) or high-albedo roof paints and surfaces to reduce solar gain within a building (Amato et al., 2005; Hill and Goldberg, 2001; Vine, 2008).

Demand-related measures found in the literature are more varied, reflecting traditional demand-side strategies targeting all types of energy consumption, such as a carbon tax (Overbye et al., 2007) or improved public education programs (Vine, 2008), as well as those more narrowly focused on reducing air conditioning demand growth.

Table 8.15[18] presents a wide range of adaptation strategies included in the literature, broken out by whether they focus on energy supply or demand and by which stakeholders are in a position to implement these strategies. Most articles and reports detailing these ideas offer little insight into such matters. Several studies do note barriers to the implementation of adaptation strategies, such as cost, the number of actors involved in specific decisions (Vine, 2008), and market structure (Audin, 1996), but these studies largely ignore governance concerns.

Source	Adaptation Strategy	Agency/Organization with Primary Responsibility for Implementation						
		Other NYS Agencies	NYISO	NYS PSC	NYSERDA	Consumers	Power Plant Owners	Distribution Utilities
Energy Supply								
(Mansanet-Bataller et al., 2008)	Protect power plants from flooding with dykes/berms.			X			X	
	Bury or re-rate cable to reduce failures.			X				X
(Stern, 1998)	Establish new coastal power plant siting rules to minimize flood risk.	X		X				
	Change water management rules to protect hydropower supply availability.	X						
(Sanstad, 2006)	Install solar PV technology to reduce effects of peak demand.				X	X		X
(Aspen Environmental Group and M Cubed, 2005)	Use increased winter stream flow to refill hydropower dam reservoirs.	X						
	Develop non-hydropower generation resources to reduce need for hydropower generation during winter.	X		X	X		X	
(Hill and Goldberg, 2001)	Construct additional transmission line capacity to bring more power to New York City to address peak demand periods.		X					X
	Upgrade existing local transmission and distribution network to handle increased load.		X					X
(Overbye et al., 2007)	Retrofit/reinforce existing energy infrastructure with more robust control systems that can better respond to extreme weather and load patterns.		X				X	X
	Automate restoration procedures to bring energy systems back on line faster after weather-related service interruptions.		X				X	X
Energy Demand								
(Miller et al., 2008)	Design new buildings and retrofits with improved flow-through ventilation to reduce air conditioning use.	X			X	X		
	Use fans for cooling to decrease air conditioning use.					X		X
(Commonwealth of Australia, 2007)	Increase use of insulation in new buildings and retrofit existing buildings with more insulation and efficient cooling systems.					X		X
	Reduce lighting and equipment loads.					X		
(Vine, 2008)	Improve information availability on climate change impacts to decision makers and the public.	X	X	X	X			X
	Use multi-stage evaporative coolers to reduce energy consumption in new buildings.					X		X
	Establish stricter window-glazing requirements in new buildings.	X						
	Plant trees for shading and use reflective roof surfaces on new and existing buildings.				X	X		X
(Stern, 1998)	Establish price-response programs to achieve behavioral response on energy use.		X					X
	Reduce or eliminate energy subsidies so prices reflect true cost.	X	X					
	Establish new air-conditioning efficiency standards.	X						
(Morris and Garrell, 1996)	Improve and rigidly enforce energy-efficient building codes.	X						
(Audin, 1996)	Install power management devices on office equipment.				X	X		X
	Upgrade building interior lighting efficiency.				X	X		X
	Improve domestic hot water generation and use.				X	X		X
	Improve HVAC controls.				X	X		X
	Upgrade elevator motors and controls.				X	X		X
	Design HVAC improvements (e.g. variable flow, thermostats on individual radiators).				X	X		X
	Install more efficient HVAC equipment.				X	X		X
	Improve steam distribution.			X	X		X	X
(Hill and Goldberg, 2001)	Weatherize low-income households.	X			X	X		X

Table 8.15 Selected climate-change adaptation strategies for the energy sector

8.4.2 Larger-scale Adaptations

The ClimAID team's interactions with stakeholders including a range of energy utilities and power generation firms made clear that there is wide divergence in the level of attention paid to climate change issues by New York's energy sector. Climate change mitigation has been on most of these firms' radar screens for some time, because of the requirements of the Regional Greenhouse Gas Initiative, audit filings such as the Carbon Disclosure Project, or their need to interconnect with new renewable-energy installations proposed in their service territories (see www.rggi.org and www.cdproject.net). In contrast, many of the energy companies characterized climate change adaptation as a relatively new area of focus. Climate change does not appear to be identified as the source of any current operating challenges or changes in operating conditions. Few have engaged in comprehensive assessments of their potential climate-change-related operating vulnerabilities. There were some exceptions, principally among companies with operations in New York City, as many of the firms were involved in the climate change adaptation initiative spearheaded by the city's Office of Long Term Planning and Sustainability (NPCC, 2010). Those companies were more likely to have convened internal working groups, hired or appointed a climate change coordinator, developed new policies and procedures, or actually begun to make operational changes or procurement decisions with adaptation considerations in mind. New York State might similarly benefit from multiple regional climate working groups or a comprehensive statewide initiative aimed at ensuring key utilities and large-scale power generation facilities are taking steps to reduce their climate-change-related vulnerabilities. A regional approach might allow for better targeting of localized issues or challenges. However, because many energy companies operate in multiple regions of the state, a statewide approach might be logistically easier for the climate teams at each company by avoiding unnecessary repetition.

Additionally, stakeholders expressed interest in an authoritative climate-risk database that could be used by a regional working group. Regardless of the organizational structure chosen for statewide climate change adaptation planning for the energy sector, such a database is central to this planning work. Stakeholders agreed that such data would be most helpful if it were updated on a regular schedule, and if it were officially sanctioned by State officials as the basis on which operating plans and investment strategies are to be made. This would eliminate the potential for disagreements by officials at different regulatory agencies over the quality of data, methodology, etc.

Finally, New York might also benefit from a formal review process that examines whether the state's currently regulatory and market policies for electric, gas, and steam utilities will continue to be appropriate in the wake of future climate change. Several issues arose in the course of this chapter's research that suggest the need for thoughtful consideration of this question.

First, because of expected long-term reductions in heating degree days around the state, there may be a disproportionate economic impact on natural gas customers in some regions, as the full cost of maintaining the system may ultimately be shouldered by a smaller rate base. Understanding the extent of this problem and how it might be addressed would likely prove important both to local ratepayers and the utilities involved.

Second, State regulators and distribution utilities may increasingly find themselves in situations where, because of uncertainty over the exact severity or timeliness of climate risks in different parts of the state, it is unclear whether capital investments proposed by utilities to enhance the climate resilience of their distribution system will be eligible for rate reimbursement. State regulators must balance the need for a safe and reliable system with the imperative of keeping prices at reasonable levels. Guidelines clarifying this matter might prove helpful for utility capital investment and maintenance planning purposes.

Similarly, the current NYISO wholesale market dispatch system satisfies statewide electricity demand based on a formula that essentially prioritizes the lowest cost sources of power. In the future, the reliability of a provider may prove equally important, particularly during extreme weather events. Power generators may be more willing to make capital investments that enhance their climate resilience if they knew there was a way to account for these expenditures in the dispatch system.[19]

In all of these cases, the issues link directly to the fundamental nature of the market and regulatory system in New York. A comprehensive review may find that no significant structural changes are necessary, but it may also uncover specific issues that can be addressed more satisfactorily under an amended market or regulatory regime.

The final area where the state may benefit from some type of policy review or activity is demand-side management. This chapter highlights the impacts changing temperatures may have on the state electricity system by the 2020s, some of which may be disproportionately felt in certain ClimAID regions. It was beyond the scope of this analysis to assess the efficacy of NYSERDA's current demand-reduction initiatives or funding programs, but it may prove informative to assess whether climate change should be more explicitly factored into the agency's program model. For example, given that climate-change-related temperature increases are likely to have the greatest impact on electricity demand in ClimAID Region 4 (New York City and Long Island), NYSERDA might consider prioritizing demand-side funding in that region because of the sizable system-wide benefits that would be achieved. Conversely, because air conditioning saturation rates are likely to grow at a faster rate in certain sections of northern, central, and western New York State, NYSERDA may decide to dedicate funds aimed at addressing this growth rate.

8.4.3 Co-benefits, Unintended Consequences, and Opportunities

Prioritization of efficiency and demand-side management to reduce the impacts of climate change on the energy sector will reduce greenhouse gas emissions, yielding mitigation co-benefits. Shading buildings and windows, use of highly reflective roof paints and surfaces, and green roofs will also create adaptation and mitigation synergies. These actions will keep building occupants and residents cooler while reducing the use of air conditioners, thereby lowering fossil fuel emissions from power plants. However, adoption of such programs needs to be distributed across the state and its citizens in order to avoid unintended consequences to vulnerable groups. The existing equipment replacement cycle provides opportunities to increase system resiliency, while climate change may provide New York State with opportunities in regard to biomass, hydropower, and other renewable energy sources.

8.5 Equity and Environmental Justice Considerations

Although large-scale blackouts are relatively rare, these events typically occur during the summer months, when electricity demand is highest. The effects of climate change on the frequency of large-scale blackout events is uncertain, yet examination of such events nonetheless highlights important equity concerns. For example, although not solely heat related, an analysis of the 2003 blackout that affected much of the Northeast revealed that even in a case where a very large region is affected, the impacts are felt unevenly across sectors and households (Anderson et al., 2007). Using a modified input-output analysis to model the effects of the 2003 blackout, Anderson et al. found that apart from the utilities themselves, retail trade suffered the greatest aggregate financial loss.

Larger businesses with backup energy sources are more likely to withstand the shock associated with a large-scale outage or a major blackout. Of those businesses that suffered losses in 2003, perhaps 10 to 15 percent had supplementary insurance to cover the damage; the smallest businesses were less likely to hold such insurance, meaning they had to absorb the losses and hope for government loans (Treaster, 2003). Another important consideration is workforce impact. In the Anderson et al. analysis, loss of labor was estimated to account for two-thirds of the total financial losses in the blackout. The people most likely to bear these losses are those living farther from their jobs or more dependent on inoperable forms of transportation, which tends to be people of color and low-income individuals (Bullard, 2007). Those who can afford to take a few days or weeks off and absorb lost wages are most likely to be resilient (Chen, 2007).

In addition to business closures, an important cross-cutting element with the health sector involves increased health risks and the vulnerability of health services (see Chapter 11, "Public Health"). The Northeast blackout significantly increased EMS calls and ambulance responses, as well as high rates of failure on respiratory devices (Prezant et al., 2005). Anderson et al. estimated that the health services sector had the second highest workforce losses in the blackout due to business closures. Decreased availability of health workers at times of increased service needs raises further questions about the capacity of the health sector to care for the infirm, elderly, and disabled in the event of a blackout. Especially critical is care of heat-related health stress, since power outages are most likely to occur during extreme heat events. Heat-related health vulnerabilities are detailed in Chapter 11, "Public Health".

8.6 Conclusions

ClimAID's main findings on vulnerabilities and opportunities, adaptation strategies, and knowledge gaps are described below.

8.6.1 Main Findings on Vulnerabilities and Opportunities

- Impacts of climate change on energy demand are likely to be more significant than impacts on supply. Climate change will adversely affect system operations, increase the difficulty of ensuring adequate supply during peak demand periods, and exacerbate problematic conditions, such as the urban heat island effect.
- More frequent heat waves will cause an increase in the use of air conditioning, increasing peak demand loads and stressing power supplies.
- Increased air and water temperatures may affect the efficiency of power plants, with impacts varying across the state.
- Energy infrastructure in coastal areas of southern New York State is vulnerable to flooding as a result of sea level rise and severe storms.
- Hydropower, located primarily in northern and western New York State, is vulnerable to drought and changes in precipitation patterns.
- The availability and reliability of solar power systems are vulnerable to changes in cloud cover, although this may be offset by advances in technology; wind power systems are similarly vulnerable to changes in wind speed and direction. However, changes in cloud cover and wind speed and direction are uncertain.
- Transformers and distribution lines for both electric and gas supply are vulnerable to extreme weather events, temperature, and flooding.
- Decreases in heating demand will primarily affect natural gas markets, while increases in cooling demand will affect electricity markets; such changes will vary regionally.
- The indirect financial impacts of climate change may be greater than the direct impacts of climate change. These indirect impacts include those to investors and insurance companies as infrastructure becomes more vulnerable and those borne by consumers due to changing energy prices and the need to use more energy.

8.6.2 Adaptation Options

- Equipment replacement cycles present opportunities to improve system resiliency.
- Transformers and wiring may require derating to ensure they continue to function as expected at higher temperatures.
- Berms and levees can protect infrastructure from flooding. It may also help to raise the elevation of sensitive energy technology in flood-prone locations.
- Saltwater-resistant transformers may help protect against electric system damage from sea level rise and saltwater intrusion.
- Tree-trimming programs are of critical importance to protect power lines from wind, ice, and snow damage.
- Reservoir release policies may need to be adjusted to ensure sufficient late-summer hydropower capacity.
- Demand-side management and energy efficiency initiatives may provide "no regrets" benefits to the state energy system in the near term, regardless of how climate change ultimately manifests itself across the state. Monitoring of impacts on the energy system is needed in the long term.
- Solar gain in buildings can be reduced by shading buildings and windows, using highly reflective roof paints and surfaces, and installing green roofs.
- Regional or statewide working groups may help increase the level of attention paid to climate change issues by power generators and utilities around the state.
- Power generators and utilities may benefit from the creation of an authoritative climate risk database to ensure that State regulators and other agencies rely on the same information in their rulemaking.
- New York may benefit from a formal review of how well climate change considerations are factored into the State's regulatory and market programs for electric, gas, and steam utilities.

8.6.3 Knowledge Gaps

Throughout the chapter, areas where additional research is needed have been noted. These include:

Energy Supply

- Potential vulnerabilities associated with cooling waters at thermoelectric power stations around the state. These include vulnerabilities associated with water temperature increases during heat waves; blockages to cooling water intakes during other extreme weather events; and impacts on biodiversity in waterways used for cooling water purposes that might necessitate changes in the cooling system design. Such a review would help policymakers considering whether intake or discharge rule changes are in order.
- The existence of temperature tipping points, beyond which the likelihood of distribution system service interruptions significantly increases. Given anticipated changes in the number and duration of heat waves around the state, this information could prove helpful in identifying deficiencies in current equipment rating or system design practices.
- Potential impacts of climate change on wind patterns and speeds in selected areas of the state currently used or proposed for wind farm development. Given anticipated growth in wind system deployment around the state, this information would be helpful for energy planning purposes.
- Potential impacts of climate change on biomass-based heat production around the state (either at a large central station or co-firing facilities) and on a more localized basis in regions of the state that depend heavily on biomass combustion for heat production in residential and commercial facilities.
- Potential impacts of climate change on ice storm frequency in different parts of the state over the coming decades. This information would be useful in assessing whether design rule changes are required for electricity transmission and distribution towers and poles.
- Potential impacts of climate change on hydropower availability in different parts of the state. This information could also be helpful in informing policymakers about the potential need for rule changes regarding water releases from hydropower facilities at different times of the year or day. This information might also prove important in assessing the need to pursue rule changes governing releases on the Niagara River, given the priority currently placed on the allocation for Niagara Falls during tourist season.

Energy Demand

- Potential impacts on the demand for natural gas and other heating fuels around the state, given anticipated decreases in heating degree-days over the coming decades. Such information would prove helpful in determining the economic impact on individual customers and local gas distribution utilities in different regions of the state.
- Ways to better incorporate climate change into demand forecasts for each load zone, and to enhance models' incorporation of the impacts of extreme events on electricity demand. Such information would be helpful to State energy planners, because this will clarify how much additional generation capacity must be developed over the coming decades or whether it can be addressed by other means, such as demand-reduction initiatives.

Case Study A. Impact of Climate Change on New York State Hydropower

There are nearly 370 large and small hydropower developments in New York, and their collective output gives the state more hydropower than any other state east of the Rockies (EIA, 2009).

Two projects are responsible for the lion's share of the state's hydropower production; both are operated by the New York Power Authority (NYPA), the largest state-owned power operation in the United States. The Niagara Power Project, located on the Niagara River between Lake Erie and Lake Ontario, is the hydropower leader in the state, generating more than 13,000 gigawatt-hours (GWh) of electricity in 2007. The second project, the St. Lawrence-FDR Project[20], generated another 6,600 GWh that same year (NYPA, 2007).

Both projects are fed by water from the massive Great Lakes Basin, a 300,000-square-mile watershed that extends 2,000 miles from end to end (Croley, 2003). Because four of the five Great Lakes are bisected by the U.S.-Canada border, the governance of the lakes (and thus operations at these two large hydropower systems) is bound up in a web of international treaties and bi-lateral and multi-lateral agreements designed to satisfy the competing interests of two countries, eight states, and one Canadian province.

The Boundary Waters Treaty of 1909 established the International Joint Commission (IJC), an important adjudicator in Great Lakes hydropower issues. Under the Boundary Waters Treaty, the IJC acts on applications for hydropower dams and other projects in waters along the U.S.-Canadian border, seeking to balance the impacts of the projects on different stakeholders. The IJC has jurisdiction over Great Lake water management issues, with day-to-day responsibilities for water flow levels and other important operating decisions delegated to different IJC-created Boards.

Some of the most important jurisdictional decisions arise from a 1950 treaty between Canada and the United States that establishes baseline guarantees on how much water must flow over Niagara Falls during daytime hours in the tourist season. The IJC's International Niagara Board of Control oversees implementation of the 1950 treaty. Key decisions about the Robert Moses Power Dam are handled by the International St. Lawrence River Board of Control.

Both Boards have "Orders of Approval" that guide water-release planning at their respective facilities. The goals are relatively straightforward: to balance river or lake height at different locations to generate hydropower, satisfy municipal water system needs, accommodate commercial navigation, and protect private property and wildlife from flooding and erosion (International Lake Ontario/St. Lawrence River Study Board, 2006). In practice, however, this means regular fine-tuning of water release levels at different hydro system assets. On a weekly basis, orders are sent out to NYPA and other hydro dam owners/operators to open or close water intake and release gates to meet water height and release targets. Factors influencing these decisions include local climate circumstances, including wind, rain, snow, ice, drought, etc.

At Niagara, guidance comes from a 1993 Board of Control Directive focused on maintaining a mean surface elevation of 171.16 meters (562.75 feet) in the Chippawa/Grass Island Pool upstream of Niagara Falls, balancing this target against treaty obligations for water release over the falls a few miles downstream that vary between day and night and tourist/non-tourist seasons (FERC, 2006). On the St. Lawrence River, Plan 1958-D calls for reduced flow rates during ice formation in early winter to allow more stable ice covers to form on Lake St. Lawrence, reducing the potential for ice jams that would lead to upstream flooding problems on the St. Lawrence River and Lake Ontario[21] (FERC, 2003).

Effects of Potential Changes in Great Lakes on Hydropower

Understanding how climate change may affect the Great Lakes is a topic of increasing interest to stakeholders around the region. Because of the interconnected nature of the lakes—water from Lake Superior eventually finds its way to the Atlantic Ocean via the other lakes and the Niagara and St. Lawrence Rivers—climate studies must necessarily examine the entire Great Lakes Basin.

The earliest studies dating back to the 1980s and 1990s all note the likelihood that temperatures in the Great Lakes Basin will gradually warm and that precipitation and water levels will change. (For example, see Croley, 1983; Cohen, 1986; Quinn, 1988; USEPA, 1989; Mortsch and Quinn, 1996; Chao, 1999). For example, the EPA analysis applied three different general circulation models (GCMs) to assess future impacts on the basin. Under all three climate models, the EPA projected that precipitation levels would stay relatively constant, but that snowmelt and runoff would decline and lake evaporation levels would increase, resulting in a net decrease in overall lake levels.

Lofgren et al. (2002) found more variable results. Under one model (CGCM1)[22], lake levels were expected to drop by an average of 0.72 meters by 2030 and 1.38 meters by 2090 compared to a 1989 baseline. Another model (HADCM2)[23], in contrast, forecast sizeable precipitation increases, which ultimately lead to lake level increases of 0.01 meters by 2030 and 0.35 meters by 2090. Croley's (2003) simulation using four different climate models found high levels of absolute variability, although the trends clearly fall in the same downward direction under the majority of the scenarios (see **Table 8.16**).

More recent work carried out for the International Joint Commission has begun to look at both annual impacts (in terms of lake level changes and outflow rates) and more discrete seasonal impacts. For instance, in the case of Lakes Erie, Ontario, and Superior, Fay and Fan (2003) note that mean annual lake outflow may decline by 5 to 24 percent on Lake Ontario and 5 to 26 percent on Lake Erie, depending on which climate model is applied. Mean lake level changes also decline, by 0.10 to 0.85 meters on Lake Erie and by 0.04 to 0.54 meters on Lake Ontario (see **Table 8.17**).

Given the depth of the Great Lakes, such changes appear quite modest in terms of absolute elevation, but there are implications for the New York State energy sector.

A 2006 IJC report examining alternatives to the 1958-D Order of Approval estimated that the economic impact of climate change on hydropower production at NYPA's St. Lawrence/FDR project could vary from -$28.5 million to $5.86 million, depending on which GCM is employed (personal communication. Victoria Simon, New York Power Authority, February 19, 2010). The "not-as-warm-and-wet" scenario was the only one of the four models to produce a positive economic impact. Data are not presented in that study to explain what this translates into in terms of increases or decreases in overall power production. However, NYPA has developed two alternative estimates, calculating that a 1-meter decrease in the elevation of Lake Ontario would result in a loss of roughly 280,000 megawatt-hours (MWh) of power production at the St. Lawrence/FDR project. NYPA also estimates that a 5–24 percent reduction in water flow from Lake Ontario would result in production losses of approximately 340,000 to 1,650,000 MWh/year (Victoria Simon, personal communication, June 9, 2010).

There is evidence that during times of drought, power output at the Niagara Project has been curtailed because of the pre-eminence of the obligation to ensure adequate flow over Niagara Falls. According to the New York Power Authority, in the 1960s, when the Great Lakes basin endured one of the most severe droughts of the century, generation levels at the Niagara Power Project dropped "dramatically while [Niagara] Falls retained its full flow" (Victoria Simon, personal communication, December 10, 2009). **Figure 8.10** compares the annual power output levels at the Niagara Power Project[24] with the Niagara River's mean monthly discharge level near Buffalo. Although the annual power output data make exact month-to-month comparisons difficult, there are discernable changes in power production levels that correlate closely (r=0.89) to periods when the river's discharge rates increase or decrease. To the extent climate change increases the incidence of drought in the Great Lakes Basin, hydropower production levels across the state will likely decline.

NYPA's hydropower is sold through contracts to business customers participating in NYPA economic development programs, municipal and rural electric

	Base Case	Warm & Dry	Not-as Warm & Dry	Warm &Wet	Not-as Warm & Wet
		HadCM3A1FI	CGCM2A21	HadCM3B22	CGCM2B23
Superior	841	-180	54	-161	-80
Michigan	818	-273	-232	-232	-59
Huron	572	-173	-135	-168	-21
Erie	843	-350	-330	-266	45
Ontario	1926	-272	-223	-254	21

Note: CGCM2 is a global climate model from the Canadian Center for Climate Modeling and Analysis. Results from ensemble simulations related to the SRES A2 greenhouse gas scenario (A21—warm and dry) and the SRES B2 greenhouse gas scenario (B23—not as warm but dry) are shown. HADCM3 is a global climate model from the United Kingdom Meteorological Office's Hadley Centre. Results from the SRES A1FI greenhouse gas scenario (A1FI—warm and wet) and from the SRES B2 greenhouse gas scenario (B22—not as warm but wet) are shown. Source: Crowley, 2003, p. 62

Table 8.16 Projected changes in Great Lakes net basin supply (mm) for four climate change scenarios, through the 2050s

	Base Case	Warm & Dry	Not-as Warm & Dry	Warm &Wet	Not-as Warm & Wet
		HadCM3A1FI	CGCM2A21	HadCM3B22	CGCM2B23
Lake outflow (annual mean, in cubic meters/second)					
Lake Erie	6576	4867 (-26%)	5410 (-18%)	5153 (-22%)	6263 (-5%)
Lake Ontario	7770	5890 (-24%)	6460 (-17%)	6170 (-21%)	7420 (-5%)
Change of lake level from base case (m)					
Lake Erie					
Winter		-0.79	-0.55	-0.69	-0.15
Spring		-0.79	-0.53	-0.62	-0.10
Summer		-0.83	-0.54	-0.64	-0.13
Autumn		-0.85	-0.57	-0.73	-0.21
Annual		-0.81	-0.55	-0.67	-0.15
Lake Ontario					
Winter		-0.45	-0.27	-0.32	-0.07
Spring		-0.54	-0.30	-0.29	-0.04
Summer		-0.49	-0.23	-0.30	-0.08
Autumn		-0.40	-0.19	-0.36	-0.12
Annual		-0.47	-0.25	-0.32	-0.08

See note on models for Table 8.16. Source: Fay and Fan 2003 in Mortsch, Croley and Fay, 2006

Table 8.17 Lake outflows and change of lake levels from base case (m) for various climate scenarios

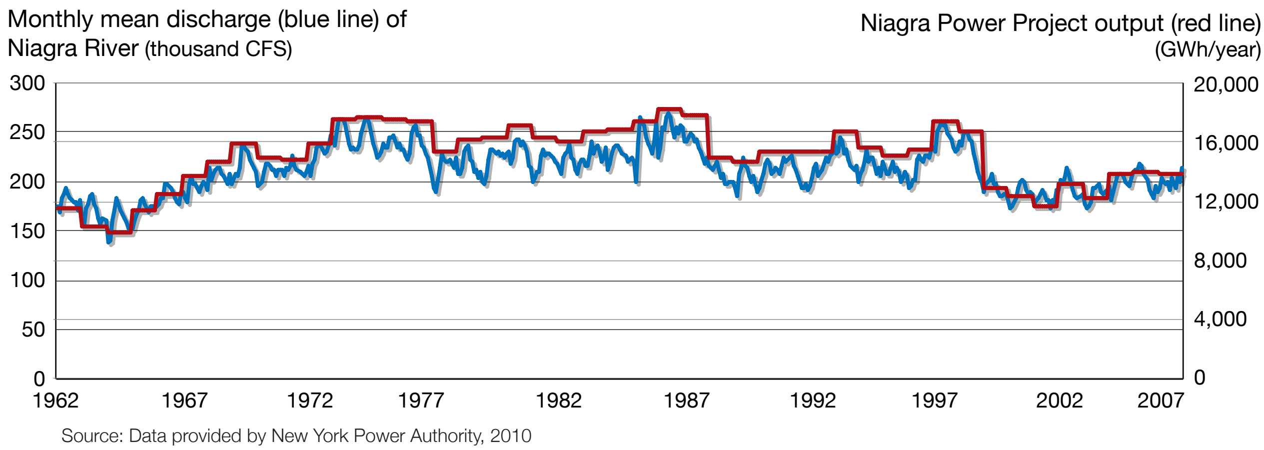


Figure 8.10 Comparison of power output levels of Niagara Power Project and monthly mean discharge rate of Niagara River (1962–2006)

cooperatives, investor-owned utilities, and other contractual arrangements. Any substantial reduction in water levels in the Great Lakes could potentially have an impact on these customers and others throughout the state. For "firm"[25] hydropower service customers, low water levels mean NYPA satisfies production shortfalls with higher-priced electricity purchased on the NYISO wholesale markets. For "interruptible"[25] service customers, low water levels mean that 100 percent of their interruptible power needs will be met through wholesale market purchases. The economic impact of a significant drought may also extend to non-NYPA customers, as greater demand for non-hydropower sources will tend to drive up prices across New York and in adjacent wholesale markets.

Cast Study B. Climate-change-induced Heat Wave in New York City

Coping with summer heat waves is a key challenge for the energy sector in New York State. Under climate change, heat waves affecting New York are likely to become more frequent and to increase in duration (see Chapter 1, "Climate Risks"). Within New York City, where urban heat island effects are already prominent during warm periods of the summer, worsening heat waves under climate change pose a challenge for the city's energy sector (Rosenzweig et al., 2006). With these worsening heat waves, it is likely that blackouts may occur somewhat more frequently (although to an extent reduced by the regular, ongoing investment of the electricity industry). This cross-cutting example considers the social equity and economic implications of energy outages associated with summer heat waves in New York City, although the effects will likely be similar in urban regions around the state. This ClimAID case study is specifically designed to illustrate equity and economic issues that have arisen in the past during heat-wave-related outage events, in order to highlight those that may potentially arise under climate change. (The public health effects of heat waves in New York State are addressed in Chapter 11, "Public Health.")

Sustained high temperatures contribute to increased energy usage during heat wave events, primarily for cooling of indoor space and industrial equipment. When high temperatures persist overnight during these extended heat waves, the likelihood of outages increases. The design of the local grid system will affect whether the outages will be geographically isolated or more widespread. However, heat waves can also be associated with multiple outages across the city under conditions of prolonged heat stress.

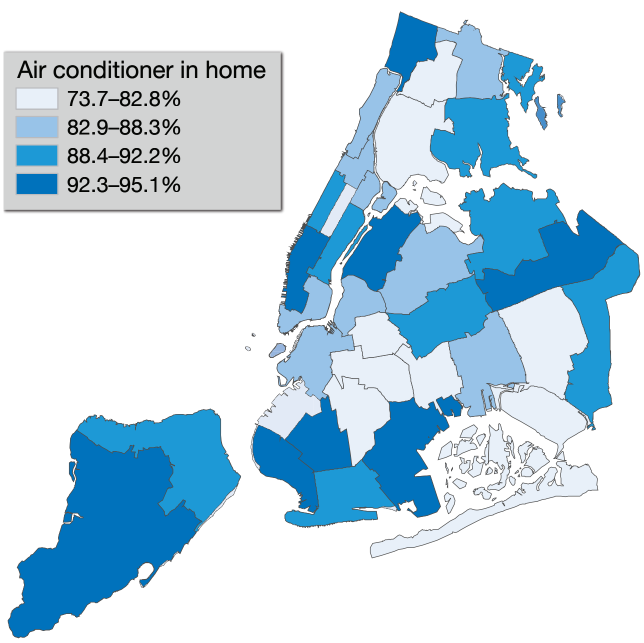
Equity and Environmental Justice Issues

In considering potential equity and environmental justice issues associated with heat-wave and outage events in New York City, we consider three types of impacts: 1) effects of sustained high temperatures, 2) effects of outages, and 3) effects of adaptation measures.

Heat waves place a physical and financial burden on nearly all segments of the population in New York City. Concerning the spatial distribution of heat wave impacts, heat waves under climate change are likely to intensify existing urban heat island patterns, meaning that areas that are already warmer due to heat island effects will become relatively hotter during a heat wave (Rosenzweig et al., 2005). While heat island effects occur in many parts of the city, a NYSERDA study of heat effects in New York City noted that heat island effects are prominent in many lower-income neighborhoods, such as Fordham in the Bronx and Crown Heights in Brooklyn (Rosenzweig et al., 2006). Such areas tend to have fewer street trees than other neighborhoods, leading to hotter conditions at the sidewalk level. Researchers in other cities have also noted similar correlations between locations of poor neighborhoods and more severe urban heat island effects due to higher settlement density, lack of open space, and sparse vegetation (e.g., Harlan et al., 2006).

Differential prevalence of indoor air conditioning may also exacerbate the effects of extreme heat. As noted earlier, 84 percent of housing units in New York City had some form of air conditioning in 2003. However, these rates are not uniform across the city. Results of the New York City Community Health Survey indicate that higher poverty areas, particularly in northern Manhattan, the South Bronx, and areas of Brooklyn, have lower rates of home air conditioning than many other parts of the city (see **Figure 8.11**).

Heat waves mean higher energy costs for all consumers, but these costs are not borne equally by all residents.



Note: Percentages are age adjusted.
Source: NYC Community Health Survey 2007, Bureau of Epidemiology Services, NYC DOHMH

Figure 8.11 Home air conditioner use in New York City, 2007

These costs represent a larger share of household income for lower-income customers. As a result, lower-income households with air conditioners may be more reluctant to use them in times of extreme heat. During the Chicago heat wave of 1995, reluctance by low-income households to use air conditioning due to concerns about energy costs was a significant factor contributing to mortality (Klineberg, 2003). Furthermore, while heat wave events lead to increased energy usage throughout New York City, locations in the city with greater heat island effects (i.e., the hottest locations) have been found to experience greater increases in energy demand (Gaffin et al., 2008). These spatial differences may exacerbate energy cost burdens on those lower-income areas that are subject to heat island effects.

Higher energy usage due to sustained high temperatures may also contribute to increased air pollution during heat wave events. Under heat wave events, less efficient and more highly polluting sources of power may be used to meet peak demand. High levels of ozone due to the combination of high temperatures and air pollution are particularly harmful for the elderly and ill, as discussed in Chapter 11, "Public Health".

Historically, heat waves in New York City have been associated with sustained power outages in some neighborhoods. For example, the Washington Heights/Inwood blackout of July 1999 was a summertime, heat-related outage that affected more than 200,000 residents living north of 155th Street in Manhattan (Office of the Attorney General, New York State, 2000). Within the affected region, which is dominated by high-poverty areas, among those hardest hit by the outage were elderly residents of high-rise apartments, where elevator service failed and fans and air conditioners for cooling were inoperable (Office of the Attorney General, New York State, 2000).

Concerning adaptation of the energy sector to heat waves, some current options are expansion of smart grid initiatives, demand management, load reduction efforts, and on-site generation. All of these measures have the potential to raise social equity issues. For example, different households will have different capacity to invest in the equipment needed for on-site generation. Such differences in capacity to adapt represent an important type of equity issue that needs to be taken into account as adaptation strategies are put into place.

Economic Analysis of Heat Wave Impacts

Electric power generation, transmission, and distribution systems play an important role in supporting the economy of the United States. Hence, power outages and other disruptions are likely to negatively affect economic activity, mainly by restricting infrastructure and other services on which the economy relies. Power failures, which may take place when electricity demand exceeds supply such as during a heat wave, have both direct and indirect impacts on the economy, national security, and the environment.

Economic losses from electric service interruptions are not trivial, as illustrated by different studies. A 2001 report that extrapolated from surveyed businesses the losses due to poor power quality, outages, and other disruptions (referred to collectively as "reliability events") estimated costs to U.S. consumers to range from $119 billion to $188 billion per year (EPRI, 2004). The Pacific Gas & Electric Company (PG&E) used direct costs of reliability events (based on a combination of direct cost measures and willingness-to-pay indicators) to assess that such power disruptions cost its customers approximately $79 billion per year (USEPA, 2010). A 2004 Berkeley National Laboratory comprehensive study of end-users focusing on power outages alone[26] estimated annual losses to the national economy of approximately $80 billion (LaCommare and Eto, 2004). The figures provided by these studies coincide with estimates by the U.S. Department of Energy, ranging from $25 billion to $180 billion per year (USDOE, 2009).

Given the number of major power outages, including those in the Northeast in 1965, 1977, and 2003, different methodologies have been developed to estimate their associated economic costs. While much of the earlier research has focused on calculating physical damage and cost of replacement of major infrastructure systems, fewer studies have been conducted to assess the overall economic impacts.

Estimates of the economic impact of the 25-hour blackout that affected most of New York City on July 13 and 14 of 1977 are sketchy, with damage costs assessed at $60 million. More information is available on the costs of the cascading blackout that started on August 14, 2003, and affected 55 million people. Initial reports projected that economic losses would range from $4 billion to $6 billion. Others estimated that this major power outage translated into a $10 billion loss for the national economy, and an ICF Consulting report put the price tag between $7 billion and $10 billion (Knowledge@Wharton, 2003; USEPA, 2010; The Public Record, 2008; ICF, 2003; Anderson and Geckil, 2003; ELCON, 2004). Moreover, this blackout contributed to at least eleven fatalities, including six in New York City (Knowledge@Wharton, 2003).

Certain sectors of the economy were particularly affected during the 2003 blackout, with the airline industry losing an estimated $10–$20 million, mostly because of grounded flights. In New York City, where over 14 million people were affected, it has been estimated that approximately 22,000 restaurants collectively lost $75–$100 million in foregone business and wasted food. In addition, the City of New York reported losses of $40 million in lost tax revenue and $10 million in overtime payments to city workers (Knowledge@Wharton, 2003). Adding to the losses was the cost of using "defensive measures" such as backup generators as well as servicing them, given that half of New York City's 58 hospitals experienced some kind of failure during the blackout (USEPA, 2009).[27]

While cascading blackouts have significant impacts, the majority of power outages are localized blackouts and brownouts, and the cumulative impact to the national economy may be quite large.[28]

Localized service outages in New York City include the July 3–9, 1999, blackout that affected 170,000 Con Edison customers, including 70,000 in Washington Heights, as well as the nine-day blackout that started on July 16, 2006, in Long Island City (in Queens) and affected 174,000 residents (New York State Public Service Commission, 2000; Chan, 2007). Most reports of economic losses focus on customer claims, which for the 1999 blackout amounted to $100 each to compensate residents for spoilage of food and medicine and $2,000 each to business customers. These fees were raised to $350 and $7,000, respectively, in 2006. Total claims paid by Con Edison in 2006 amounted to $17 million; an additional $100 million was estimated to be spent by the utility on recovery costs to repair and replace damaged equipment (Cuomo, 2007).

However, economic compensation paid by utilities to affected customers represents only a portion of total economic losses to society, and does not even take into account the value of unsold (or unserved) electricity to communities and businesses. Several approaches have been developed to attempt to estimate the overall economic cost of blackouts. In general, most methods focus on calculating the value added that customers place on power reliability, which can be quantified by the consumers' willingness to pay, taking into account their income, or in the case of businesses, their revenues net of economic losses due to power failures. Nevertheless, the value-added approaches do not account for all the societal benefits that result from reliability improvements, as they fail to estimate the associated improvements in public safety and health or environmental benefits. These societal benefits must be incorporated separately.

The value added of electricity reliability is often presented as customer damage functions that may take into account a number of variables. Such values may be estimated by 1) calculating the direct costs of power outages based on customers' experience, 2) conducting surveys to estimate the consumer's willingness-to-pay (WTP) or willingness-to-accept compensation (WTA) to avoid such outages, and 3) estimating by indirect analytic methods.

The first approach attempts to estimate the value that electricity services represent to each customer, based on losses experienced to particular facilities operations. What is referred to as the customer's value of service (VOS) can be measured in terms of the direct costs of an outage, which may include damaged plant equipment and/or replacement costs, spoiled products, additional maintenance costs, production losses/lost revenue, costs of idle labor, and potential liabilities.

The WTP/WTA approach provides another measure of the "cost of reliability" of electrical services considered in terms of how consumers value such services, or more precisely the value assigned to the lack of survey interruptions. Various studies provide survey-based estimates of the WTP for different groups of electric power customers. While economic losses to commercial and industrial facilities from power interruptions may be monetized in a straightforward manner (e.g., on the basis of lost profits), assessing the direct costs to residential customers may be more complicated, in part because surveyed customers do not always describe economic losses in monetary terms but rather as disruptions or hassles. Rather than assigning values to such inconveniences (which go

Sector	Annual kWh
Medium and large C&I	7,140,501
Small C&I	19,214
Residential	13,351

Table 8.18 Average kWh usage per year by customer class

Interruption Cost	Interruption Duration				
	Momentary	30 min.	1 hour	4 hours	8 hours
Medium and Large C&I					
Morning	$8,133	$11,035	$14,488	$43,954	$70,190
Afternoon	$11,756	$15,709	$20,360	$59,188	$93,890
Evening	$9,276	$12,844	$17,162	$55,278	$89,145
Small C&I					
Morning	$346	$492	$673	$2,389	$4,348
Afternoon	$439	$610	$818	$2,696	$4,768
Evening	$199	$299	$431	$1,881	$3,734
Residential					
Morning	$3.7	$4.4	$5.2	$9.9	$13.6
Afternoon	$2.7	$3.3	$3.9	$7.8	$10.7
Evening	$2.4	$3.0	$3.7	$8.4	$11.9

Note: C&I = Commercial and Industrial. Source: Lawrence Berkeley National Laboratory (2009), Estimated Value of Service Reliability for Electric Utility Customers in the United States; prepared by Michael J. Sullivan, Ph.D., Matthew Mercurio, Ph.D., Josh Schellenberg, M.A, Freeman, Sullivan & Co.; June, 2009. Accessed online on 1/12/10 from: http://certs.lbl.gov/pdf/lbnl-2132e.pdf

Table 8.19 Estimated average electric customer interruption costs per event in US 2008$ by customer type, duration, and time of day

Interruption Cost	Interruption Duration				
	Momentary	30 min.	1 hour	4 hours	8 hours
Medium and Large C&I					
Agriculture	$4,382	$6,044	$8,049	$25,628	$41,250
Mining	$9,874	$12,883	$16,368	$44,708	$70,281
Construction	$27,048	$36,097	$46,733	$135,383	$214,644
Manufacturing	$22,106	$29,098	$37,238	$104,019	$164,033
Telecommunications & Utilities	$11,243	$15,249	$20,015	$60,663	$96,857
Trade & Retail	$7,625	$10,113	$13,025	$37,112	$58,694
Fin., Ins., & Real Estate	$17,451	$23,573	$30,834	$92,375	$147,219
Services	$8,283	$11,254	$14,793	$45,057	$71,997
Public Administration	$9,360	$12,670	$16,601	$50,022	$79,793
Small C&I					
Agriculture	$293	$434	$615	$2,521	$4,868
Mining	$935	$1,285	$1,707	$5,424	$9,465
Construction	$1,052	$1,436	$1,895	$5,881	$10,177
Manufacturing	$609	$836	$1,110	$3,515	$6,127
Telecommunications & Utilities	$583	$810	$1,085	$3,560	$6,286
Trade & Retail	$420	$575	$760	$2,383	$4,138
Fin., Ins., & Real Estate	$597	$831	$1,115	$3,685	$6,525
Services	$333	$465	$625	$2,080	$3,691
Public Administration	$230	$332	$461	$1,724	$3,205

Note: C&I = Commercial and Industrial. Source: Lawrence Berkeley National Laboratory (2009), Estimated Value of Service Reliability for Electric Utility Customers in the United States; op. cit.

Table 8.20 Estimated average electric customer interruption costs per event in US 2008$ by duration and business type (summer weekday afternoon) beyond the cost of food and medicine spoilage), economists often rely on WTP or WTA surveys in order to assess loses to residential customers (Lawton et al., 2003). Such surveys describe different scenarios and ask residential customers how much they would be willing to pay for power reliability or the amount of money they would require to accept service interruptions.

A 2009 report (Sullivan et al., 2009) that conducted a metadata analysis using 28 different customer-value-of-service reliability surveys that had been carried out by 10 major U.S. electric utilities between 1989 and 2005 provides average estimates of the value of service reliability for electricity customers in the United States (except in the Northeast). The information collected is classified by customer types surveyed, including both

Interruption Cost	Interruption Duration				
	Momentary	30 min.	1 hour	4 hours	8 hours
Medium and Large C&I					
Summer Weekday	$11,756	$15,709	$20,360	$59,188	$93,890
Summer Weekend	$8,363	$11,318	$14,828	$44,656	$71,228
Winter Weekday	$9,306	$12,963	$17,411	$57,097	$92,361
Winter Weekend	$6,347	$8,977	$12,220	$42,025	$68,543
Small C&I					
Summer Weekday	$439	$610	$818	$2,696	$4,768
Summer Weekend	$265	$378	$519	$1,866	$3,414
Winter Weekday	$592	$846	$1,164	$4,223	$7,753
Winter Weekend	$343	$504	$711	$2,846	$5,443
Residential					
Summer Weekday	$2.7	$3.3	$3.9	$7.8	$10.7
Summer Weekend	$3.2	$3.9	$4.6	$9.1	$12.6
Winter Weekday	$1.7	$2.1	$2.6	$6.0	$8.5
Winter Weekend	$2.0	$2.5	$3.1	$7.1	$10.0

Note: C&I = Commercial and Industrial. Source: Lawrence Berkeley National Laboratory (2009), Estimated Value of Service Reliability for Electric Utility Customers in the United States; op. cit.

Table 8.21 Estimated average electric customer interruption costs per event in US 2008$ by customer type, duration, season, and day type

medium and large commercial and industrial (C&I) non-residential consumers with sales greater than 50,000 kilowatt-hours (kWh) per year, with an average of 373 employees; small commercial and industrial non-residential customers with sales ≤50,000 kWh per year; and residential customers. The metadata analysis provides an average kWh usage per customer type, as summarized in **Table 8.18**.

Summary results for the cost of power interruptions are given in **Tables 8.19–8.21**, including estimates of the costs of power interruptions per event by customer class, business type, size of the facility and time of the event, and geographical location. Information is also available on the expected cost of unserved energy, which is a metric widely used for expressing interruption costs, as shown on **Table 8.22**, which provides another example of the value of service (VOS) direct cost estimation approach.

The information summarized in the tables shows that large commercial and industrial customers experience losses averaging $20,000 and $8,166 for a 1-hour power interruption during a winter afternoon and summer afternoon, respectively. As the power outage increases in duration, so do costs, sharply during the winter and significantly in the summer.

Heat Wave and Power Outage Adaptation Measures

According to a 2009 report by the American Society of Civil Engineers, electricity demand since 1990 has grown approximately 25 percent but construction of transmission facilities has declined by roughly 30 percent (American Society of Civil Engineers, 2009). In 2003, other reports estimated that investment in high-voltage transmission lines had decreased by 45

Facility Outage Impacts			Annual Outages		Annual Cost	
Power Quality Disruptions	Outage Duration per Occurrence	Facility Disruption per Occurrence	Occurrences per Year	Total Annual Facility Disruption	Outage Cost per Hour*	Total Annual Costs
Momentary Interruptions	5.3 Seconds	0.5 Hours	2.5	1.3 Hours	$45,000.00	$56,250.00
Long-Duration Interruptions	60 Minutes	5.0 Hours	0.5	2.5 Hours	$45,000.00	$112,500.00
Total			3	3.8 Hours		$168,750.00
Unserved kWh per hour (based on 1,500 kW average demand)			1,500 kWh			
Customer's Estimated Value of Service, $/unserved kWh			$30 /unserved KWh			
Normalized Annual Outage Costs, $/kW-year			$113 $/kW-year			

Note: Outage costs per hour estimated based on facility data and include production losses, increased labor, product spoilage, and other costs.
Source: USEPA – Combined Heat and Power Partnership; Calculating Reliability Benefits, http://www.epa.gov/CHP/basic/benefits.html

Table 8.22 Value of service direct cost estimation percent over the previous 25-year period (ELCON, 2004). Moreover, the Energy Department expects that electricity use and production will increase by 20 percent over the next decade but the nation's high-voltage electric network will only increase by 6 percent in the same time period. After the major blackout of 2003, there have been calls for investments ranging from $50 billion to $100 billion to reduce severe transmission bottlenecks and increase capacity (Knowledge@Wharton, 2003).

While long-term planning and investments are necessary, significant improvements are needed over the next few years to ensure that operators can have access to the necessary information to properly manage power flows and transmission systems. Investments to upgrade the grid can provide network operators with clearer metrics of the potential risks in order to avoid major power outages (Apt et al., 2004). The costs of installing sensors nationwide are much smaller than those for a single blackout event. A recent report made the case for installing sensors every 10 miles over the existing 157,000 miles of transmission lines in the United States and found that, at a cost of $25,000 per sensor, total costs would amount to $100 million if all sensors were replaced every five years. Such investment would increase the average residential electricity bill by 0.004 cents per kilowatt hour. The total would be roughly one-tenth the estimated annual cost of blackouts (Apt et al., 2004).

Other adaptation measures to prevent power outages include reducing demand and distributed generation. Load-shedding strategies may be used during heat waves in advance of peak-demand episodes and include broad calls for consumers to reduce demand as well as voluntary and mandatory load reduction programs, for which customers receive a number of incentives. Customers participating in voluntary options such as the "Distribution Load Relief" program must reduce at least 50kW or 100kW (for individuals or aggregators respectively) to receive compensation of at least $0.50 per kWh after each event. Other mandatory programs are similarly structured with additional incentives such as reservation (capacity) fees and bonus payments (Con Edison). Other, long-term strategies to increase overall network capacity include demand-side management, which decreases the need for investments in additional power generation.[29]

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Appendix A. Stakeholder Interactions

The ClimAID Energy team interacted with relevant stakeholders around the state through meetings and one-on-one interviews. Drafts were shared with selected stakeholders to obtain their feedback on different topics and to ensure the accuracy of specific information contained in the report.

The first stakeholder meeting was held at NYSERDA's office in Albany in March 2009. Stakeholders invited to the meeting included a range of power plant operators, officials from New York-based energy and environmental organizations, distribution utilities, and New York State officials, including the New York Independent System Operator. Of the 38 invitations sent out, 18 individuals from 15 organizations were represented. A list of participating stakeholders is included at the end of this appendix.

The first meeting introduced the ClimAID project and solicited feedback on the first draft of the energy sector analysis that was completed in early 2009. A draft stakeholder survey was also shared to obtain feedback on its length and content. Based on feedback provided by the stakeholders, the survey was shortened considerably and tailored to reflect the unique perspective of each sector participant (e.g., utility, power plant operator, etc.).[30]

Energy demand forecasting was also discussed at the meeting, with the stakeholders providing important information regarding their concerns about the ClimAID team's efforts to forecast climate-change-related demand impacts beyond a 20–30 year timeframe, arguing that longer-term forecasts were subject to other factors (e.g., technology changes, population changes, climate change mitigation policies) that made it difficult to forecast demand with a high level of certainty. As a result, a decision was made by the ClimAID Energy team to concentrate on demand impacts, taking into account only those climate change impacts projected for the 2020s, and to convene a separate demand modeling working group.

Following the initial meeting, individual meetings and phone calls were conducted with six different stakeholders representing distribution utility and/or power generation operations in different parts of the state. These conversations were in-depth, lasting between 45 minutes and two hours. In some cases, a single company representative was interviewed, while in other cases there were six company participants, each with a different area of specialization.

In most cases, follow-up questions were submitted to these companies to clarify information raised in the original meeting or to solicit additional information. These interviews were helpful both in validating many of the conclusions drawn by the literature review, and in identifying nuanced differences or more recent information specifically relevant to New York State.

The demand modeling working group met in June 2009 to solicit input from stakeholders on priorities with respect to understanding how climate change may affect energy demand in New York State. After this meeting, a follow-up call was held to discuss methodological issues and further refine the objectives. During this call and subsequent communications, the group determined that additional statistical analysis of historical climate data should be prioritized over producing demand forecasts for the state. There are some efforts to incorporate climate change into demand forecasts, so the group saw an opportunity for the ClimAID team to provide data and analysis to support these efforts. The results of the demand modeling research are included in the Energy Demand section of the chapter (section 8.3.2).

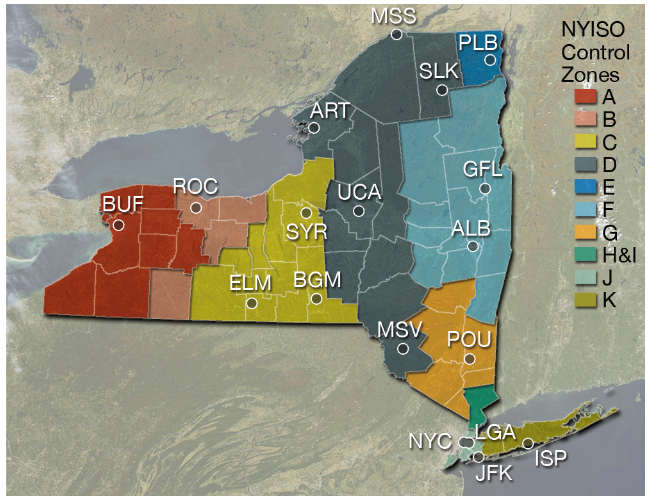
Stakeholder Meeting Participants, March 2009

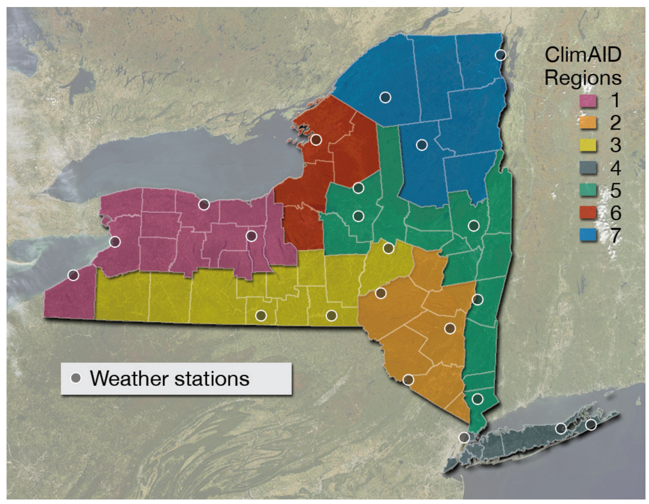
- AES
- Alliance for Clean Energy New York
- Environmental Energy Alliance of New York
- Cogentrix
- Con Edison
- Dynegy
- FirstLight Power/Suez GDF
- Long Island Power Authority
- National Grid
- NRG Energy
- New York Independent System Operator
- New York Power Authority
- TransCanada/Ravenswood
- US PowerGen

Demand Modeling Meeting Participants, June 2009

- Con Edison
- New York State Department of Public Service
- National Grid
- New York City Office of Long-Term Planning and Sustainability
- New York Independent System Operator
- New York Power Authority
- New York State Department of Environmental Conservation
- New York State Energy Research and Development Authority

Appendix B. Relationship between NYISO Load Zones and ClimAID Regions





ClimAID Regions: 1. Western New York Great Lakes Plain; 2. Catskill Mountains and West Hudson River Valley; 3. Southern Tier; 4. New York City and Long Island; 5.East Hudson and Mohawk River Valleys; 6. Tug Hill Plateau; 7. Adirondack Mountains. Source: NYISO (2009a), basemap NASA

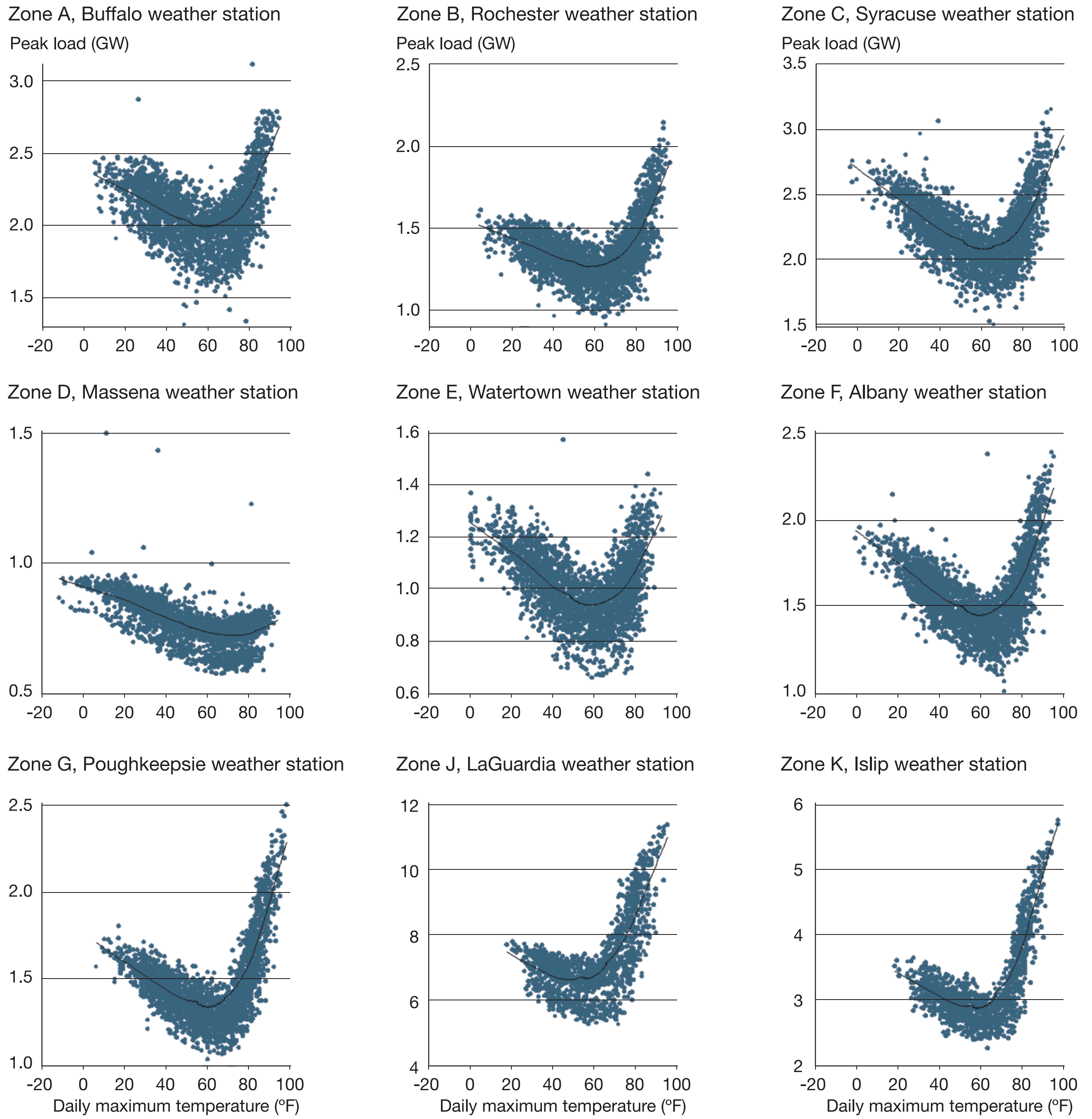
Figure 8.12 Locations of weather stations used in ClimAID climate analysis related to NYISO load zones

[1] Interactions with out-of-state infrastructure may be discussed, but are not a direct focus of the ClimAID report.

[2] The New York Independent System Operator (NYISO) Gold Book characterizes conventional hydropower plants as a renewable resources, although it acknowledges this does not match the definition used in other New York State policies, including the Renewable Portfolio Standard.

[3] There has not been any follow-up analysis examining the accuracy of these projections.

[4] In general, the DOE report suggested there is a heightened vulnerability at power plants with shallow intake depths, because of the risk that water levels may be inadequate, exposing the intake pipe or resulting in limits in how much water the power plant may siphon off. Drought conditions may also result in higher water temperature levels at depths close to the intake, creating problems at facilities requiring specific intake water temperatures.



Time period is 2002-2008, except for Zones J and K, for which the time period is February 2005-2008.

Figure 8.13 Maximum daily temperature (°F) versus daily peak electricity demand (mw) for each NYISO Control Zone

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5 The Reliability Council is the official entity authorized by the Federal Energy Regulatory Commission to analyze supply and demand levels in New York State on a periodic basis, identifying conditions that may affect future system reliability and issuing rules that the New York Independent System Operator and other entities must abide by when making supply and power distribution decisions.

6 Assessment of the overall net energy demand impact is clouded by the wide range of scenarios and assumptions used in different studies, as well as different approaches to energy accounting. For example, some studies assess impacts on delivered (on-site) energy consumption whereas other studies assess impacts on primary energy demand, after accounting for generation, transmission, and distribution losses.

7 HDD=65- T_{mean} if $T_{mean}<65°F$. CDD= T_{mean}-65 if $T_{mean}>65°F$, where T_{mean} is the mean daily temperature. Total annual HDD/CDD is the sum of daily HDD/CDD.

8 Cooling degree days (CDD) are calculated as the mean daily temperature minus 65 deg F. For example, if the mean temperature is 75 deg F, then there are 10 CDD. Total annual CDD are the sum of daily CDD. Similarly, heating degree days (HDD) are calculated as 65 deg F minus mean daily temperature, and total annual HDD is the sum of daily HDD.

[9] Chapter 1, "Climate Risks," provides some additional analysis of historical climate data that is in general agreement with our findings. Historical temperature trends for different weather stations around the state are shown for several different periods: 1900–1999, 1970–2000,
and 1970–2008 (see Table 1.2 in the climate chapter). In general, significant upward trends in mean annual temperature are driven by significant increases in winter temperature, although significant increases in summer temperature are observed for some stations and time periods. The 1970–2008 period is comparable to the CDD trends covering 1970–2007 shown in Figure 6; over this period, with the exception of Elmira, trends in summertime temperature are not significant (see Table 2c in the climate chapter).

[10] Gaffin et al. (2008) estimate that one-third of the observed increase in mean annual temperature in New York City of 2.7°F is attributable to a strengthening urban heat island, with two-thirds of the increase attributable to global climate change. Urban development can lead to a higher concentration of heat-trapping built surfaces and a lower concentration of vegetation, which can increase local temperature. Heat island mitigation strategies include urban forestry, planting of street trees, and incorporating more reflective surfaces into the urban environment.

[11] This is true because nighttime demand levels will remain lower than afternoon demand levels and because "shoulder season" peak demand will still be lower than the summertime peak. Shoulder season refers to the months between peak demand and low demand (late spring and early fall in New York).

[12] This is partly a function of where a city or region derives its power. Because most cities can and do draw on power generated outside of the city limits, it is common for areas with surplus capacity to sell power to areas experiencing a shortfall. (For example, Morris et al., 1996 noted that Con Edison's summertime peak demand was 40 percent higher than its winter peak demand, freeing up winter-time generating capacity in New York City.) To the extent warming temperatures drive up peak summer demand in traditional winter-peaking areas (and vice-versa), there may be less power available to share, creating the need for additional generation capacity across the system.

[13] Baxter and Calandri (1992) and Franco and Sanstad (2008) analyzed impacts on electricity sales in California. ICF (1995) analyzed the service territories of six utilities in different parts of the U.S. and Japan.

[14] To carry out this study, NYSERDA partnered with the U.S. Environmental Protection Agency, the Electric Power Research Institute, and the Edison Electric Institute. Climate change impacts on both "upstate" and "downstate" electric systems were examined. There has not been any follow-up analysis examining the accuracy of these projections.

[15] The MEC report's study region was comprised of 31 counties in the New York Metropolitan area, which extends into Connecticut and New Jersey, so results are not directly comparable to estimates for New York City or New York State. Also, Hill and Goldberg (2001) focused on projecting impacts on peak demand, rather than annual demand.

[16] Note that a small portion of the rise in electricity demand in the winter, relative to shoulder seasons, may be related to additional lighting demand on shorter, winter days.

[17] Turning points were computed by running locally weighted (Lowess) regressions of demand on temperature and saving the Lowess smoothed estimate for each temperature observation. The temperature value corresponding to the minimum of the Lowess smoothed variable was defined as the turning point.

[18] NYSERDA has long been active in funding research and deployment of many of the strategies listed in Table 12. Since its inception, NYSERDA has provided support for renewable energy technology deployment and market development efforts, including solar PV techology. For example, by the end of 2006, NYSERDA had provided financial support for nearly three-fourths of all of the solar PV systems installed outside of the Long Island Power Authority (LIPA) service territory, although the number is likely even higher now. (A separate funding program sponsored by LIPA targets PV deployment on Long Island.) Demand-side management efforts are another long-time focus of NYSERDA, and most of the demand-side strategies listed in Table 12 have recently been or are currently eligible for funding from various NYSERDA programs.

[19] Under the current system, suppliers are penalized if they fail to deliver supply they had formally committed to the NYISO system, meaning the system suggested here might prove redundant. Such penalties do little to protect against climate-related system failures, however, and may encourage firms to underbid their capacity to deliver power during extreme events, artificially increasing prices beyond levels otherwise justified.

[20] The St. Lawrence–FDR Project includes the Moses-Saunders power dam (a single structure featuring 32 turbines divided equally between the New York Power Authority and Ontario Power Generation), the Long Sault Dam, and the Iroquois Dam.

[21] Since 2000, the IJC has been examining alternatives to Plan 1958-D, and one plan known as Plan 2007 is currently awaiting final approval; its prospects are unclear.

[22] Canadian Center for Climate Modeling and Analysis (model version CGCM1)

[23] United Kingdom Meteorological Office's Hadley Centre (model HadCM2)

[24] The Niagara Power Project includes generation output from both the Robert Moses Niagara Power Plant and the adjacent Lewiston Pump Generation Plant.

[25] "Firm" power customers can expect power to be available at all times, except possibly in emergencies. "Interruptible" power customers may pay a lower rate, but the utilities have the right to curtail their power for periods of time if necessary (e.g., due to high demand and/or reduced power availability).

[26] Excluded from this calculation are estimated losses due to power-quality events.

[27] As reported in the *New York Times*, August 16, 2003.

[28] As described above, nationwide costs may reach up to $180 billion annually, much more than the cost of the 2003 major blackout.

[29] This may include investments in distributed generation, which has been defined as the electricity production that is on-site or close to the load center and is interconnected to the utility distribution system (http://www.energy.ca.gov/papers/2004-08-30_rawson.pdf).

[30] Because the survey was primarily aimed at soliciting New York State-specific information to supplement the original literature review that formed the basis for much of this chapter, the Energy Team decided to narrow the stakeholder survey to power plant operators and distribution utilities in different regions of the state.