CLIMATE CHANGE AND NEW YORK CITY'S ENERGY SECTOR: VULNERABILITIES, IMPACTS AND ADAPTATION STRATEGIES

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ABSTRACT

The energy sector in New York is vulnerable to changing average temperature and precipitation and more extreme weather events. These changes may affect the availability of renewable energy resources, including the state's large supply of hydropower, as well as the reliability and efficiency of the city and region's electricity generation, transmission and distribution infrastructure. Seasonal demand for space conditioning is also likely to change, with impacts on electricity distribution and costs in the summer, and natural gas and fuel oil markets in the winter and shoulder-season months. We first review existing literature on the impacts of climate change on energy supply and demand and identify potential vulnerabilities in New York City. Next we discuss possible anticipatory and reactive adaptation strategies. Supply-related strategies tend to focus on enhancing the power sector's capacity to operate under changed climatic conditions. Demand-side strategies tend to focus on reducing growth in peak demand through energy efficiency or price-response programs. We conclude by identifying research questions that fall into two broad categories: (1) the relationship between specific changes in climate and different aspects of the energy system and (2) the implications for local energy policy and governance. As part of ongoing research, we are working with local stakeholders to identify research priorities for New York City.

1. INTRODUCTION

As part of its long-term planning and sustainability initiative known as PlaNYC, the City of New York seeks to both adapt to and reduce its contribution to global climate change (City of New York 2007). Mitigation planning and implementation efforts have been underway for over two years, while adaptation planning efforts are still in their early stages (City of New York 2008). Central to the adaptation planning effort is a focus on the city's energy system. New York City's status as a leading global hub of commerce and culture, its 24 hours per day, seven days per week lifestyle (Mills and Huber 2004), and the energy sector's capital intensive nature with long planning horizons (Linder et al. 1987) all reinforce the need to understand how the local energy system will be affected by climate change. Previous power system failures linked to extreme weather events – such as those likely to occur in the future due to climate change (Wilbanks 2007) – have imposed significant economic and public health burdens on the city (McFadden 2006; Santora 2006; NYS Department of Public Service 2007). It is therefore important to understand how long-term climate change may affect local energy demand, system assets, and the economy.

This literature review is intended to support ongoing adaptation research and planning efforts by summarizing key issues identified in past local analyses or in studies focused on other urban, regional or national energy systems. Previous studies on how climate change may affect energy systems in the New York City metropolitan region include Linder et al. (1987), Morris et al. (1996), and Hill and Goldberg (2001). These studies laid a strong foundation for further work, but were limited by the coarse spatial resolution of global climate models making it difficult to craft place-specific adaptation responses (Amato et al. 2005). Our work is part of an ongoing climate change vulnerability and adaptation assessment of New York State.[1] This assessment will benefit from substantial progress in downscaling global climate change models to a city or regional scale, though many modeling challenges remain. The project, which includes a significant focus on New York City, is being carried out in close collaboration with several of the key stakeholders involved in the City of New York's adaptation planning efforts. Communication with stakeholders is expected to result in important insights into local vulnerabilities to climate change that may not be reflected in the literature review.

2. ENERGY SECTOR OVERVIEW

Our analysis of the energy sector focuses on energy supply and demand issues in the power sector, as well as direct consumption of natural gas, fuel oil, and steam in buildings. Changing climatic conditions – both locally and in areas geographically remote from New York City – can influence the supply of energy available for local use. Local changes in climate may also affect energy demand for heating and cooling.[2]

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[1] The project was initiated by the New York State Energy Research and Development Authority (NYSERDA) in late 2008 and covers a range of sectors including energy, water, infrastructure, and agriculture.

[2] We recognize that energy supply and demand will also vary significantly based on local economic conditions, technology choice, the policy and regulatory environment, and local behavioral practices. Such circumstances tend to be outside of the scope of this research paper, which is focused on assessing how changing climatic conditions attributable to global climate change may influence local energy demand levels and local energy production and relevant regional and hemispheric energy supply chains.

Table 1. New York City energy consumption

Category and Fuel type	Notes
Power generation	
-- Coal	Large, thermoelectric power plants outside NYC; coal was banned in local power plant use in the late 1970s.
-- Oil	Less than 1% of New York City's power supply comes from dedicated oil plants, although several central station power plants can (and do) switch from natural gas to fuel oil when market prices dictate.
-- Natural gas	Central station plants and on-site power production systems, such as microturbines; dominant fuel source in New York City power supply.
-- Nuclear	Large, controversial plants outside NYC.
-- Renewables	Predominantly from upstate hydropower, with contributions from solar, wind, biomass, and tidal power constituting <2% of power supply (NYC OLTPS 2008).
Direct fuel consumption in buildings	
-- High-temperature steam	Produced at in-city plants from natural gas and residual fuel oil; ~44% of NYC steam is produced at cogeneration plants (NYC OLTPS 2008); used for on-site heating and cooling; majority of demand is in commercial buildings.
-- Natural gas	Dominant fuel source for heating and hot water in NYC buildings; demand grew by 43% between 1995 and 2005 (NYC OLTPS 2008).
-- Fuel oil (distillate & residual)	Used for heating and hot water; demand remained flat between 1995 and 2005.
-- Renewables	Passive on-site heating and cooling applications.
Transportation fuels	Transport fuels fall outside the purview of this analysis.

New York City's electricity distribution capacity is already constrained by aging infrastructure, particularly during summertime peaks, an issue that may be exacerbated by climate change.

As Table 1 indicates, electricity is produced using a wide variety of technologies at locations both inside and outside the city, with the majority produced by in-city power plants (See Table 2).

Table 2. Electricity generation to supply New York City in 2005 - Source: NYC OLTPS 2008

Source	GWh	Percent
In-City	29,900	57%
Contract*	16,804	32%
Imported**	5,572	11%
Total	52,276	100%

**Bilateral contracts between Con Edison/New York Power Authority and upstate generators*
***Other imports from upstate New York and Pennsylvania-New Jersey-Maryland*

Natural gas accounts for 98% of in-city generation and 72% of NYC's total power supply (See Table 3). Although New York produces more hydropower than any other state east of the Rocky Mountains, hydro generation accounted for less than 10% of total power production in 2005 (Figure 1). Nuclear power is also an important, though controversial, component of New York City's energy supply, with ongoing debate around the relicensing of the state's largest facility, which is located approximately 25 miles north of New York City.

Table 3. Percent of power generation by fuel source in 2007 - Source: NYC OLTPS 2008

Power generation	In-city	Imports & Contract*
Coal	-	15%
Natural Gas**	98%	36%
IGCC	*-*	*-*
Cogen - CC	*35%*	*-*
Combined Cycle	*37%*	*-*
Combustion Turbine	*14%*	*-*
Oil/Gas	*13%*	*36%*
Oil**	-	1%
Nuclear	-	27%
Hydropower	-	19%
Wind	-	-
Other	2%	2%
Total	100%	100%

**Contract generation is grouped with imports since most contract generation takes place outside of the city.*
***Plants that switch between natural gas and fuel oil are included in the natural gas total.*

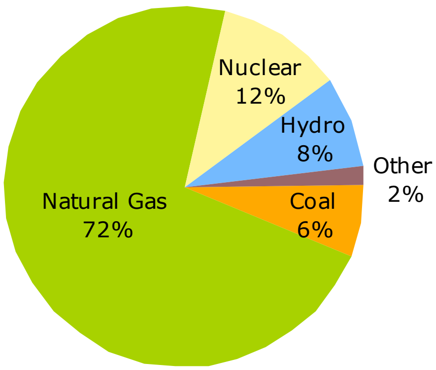

Figure 1. Power generation to supply NYC in 2005
Source: Author estimates based on NYC OLTPS 2008
Note: Power generation in 2005 was estimated using data on the electricity fuel mix from 2007 (see Table 2) and the breakdown between in-city and imported generation in 2005 (see Table 1). Data source: NYC OLTPS 2008.

Natural gas is also the dominant fuel used to meet residential and commercial heating and hot water demand, accounting for nearly 70% of direct fuel consumption in buildings in 2005 (NYC OLTPS 2008). Therefore, a key issue for the city is maintaining the reliability of natural gas distribution networks. Overall, residential and commercial buildings each account for approximately 45% of building-sector energy demand, with industrial firms responsible for the remainder (Figure 2).

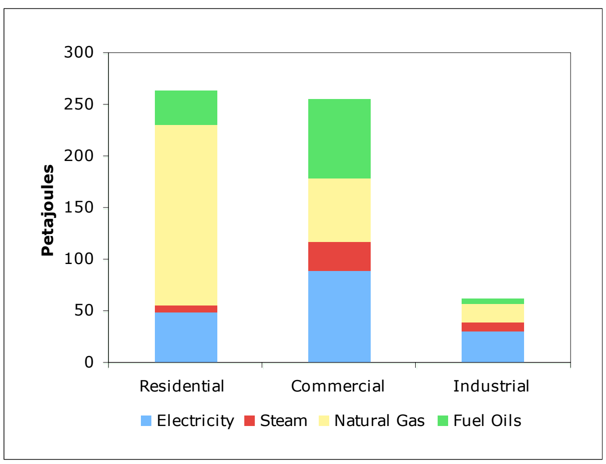

Figure 2. Energy demand in New York City buildings (2005) - Source: Author estimates based on NYC OLTPS 2008

Based on our analysis of energy data from the New York City Office of Long Term Planning and Sustainability and housing unit data from the Department of City Planning, the average residential housing unit in New York City consumes approximately 4,100 kWh per year, about 30% less than the average for residential housing units in New York State (NYC Department of City Planning 2006; NYSERDA 2007; NYC OLTPS 2008).

2.1 Market and regulatory issues

Market and regulatory conditions vary significantly by fuel type.

Con Edison is the private company holding the exclusive franchise for the transmission and distribution of electricity to over 99% of homes and businesses in the city. Local customers are free to purchase their electricity from a competitive marketplace of over 36 firms (New York State Public Service Commission 2009), with suppliers paying fees to transmit their electricity over Con Edison's wires.

The local natural gas market is structured similarly to local electricity markets, with Con Edison and another private firm (National Grid) responsible for distributing natural gas around the city. Customers are free to select their supplier from among 40 companies authorized to sell natural gas in New York City (New York State Public Service Commission 2009). Gas arrives in the city via a series of pipelines linked to the national natural gas distribution system, as there are no liquefied natural gas unloading terminals in the New York metropolitan region, although several have been proposed (Federal Energy Regulatory Commission 2008).

New York City's district steam system (owned and managed by Con Edison) is one of the largest in the world, with seven plants producing steam that is distributed to 100,000 business, residential, and institutional customers through 105 miles of pipes traversing Manhattan (Bevelhymer 2003; Ascher 2005).

These three energy markets are all regulated by the New York State Public Service Commission (2009), which is responsible for ensuring "safe, reliable [energy] service and reasonable, just rates." The City of New York wields little direct power over local energy markets, although the city can influence the state's oversight decisions through involvement in rate cases and other official regulatory proceedings (City of New York 2007; Hammer 2008).

Energy prices in New York City are high compared to other parts of the state and country, a function of high local real estate values and labor costs, dense development patterns, and the fact that much of the city's electricity distribution system is buried underground (City of New York 2007).

3. CLIMATE CHANGE PROJECTIONS FOR NEW YORK CITY

Global climate change is expected to alter both mean climate and the frequency and intensity of extreme weather events in the New York City area (Rosenzweig and Solecki 2001; NYC DEP 2008). The level of risk to the energy sector depends on changes in climate, as well as the magnitude of the consequences for energy supply, demand, and infrastructure given particular system vulnerabilities.

Table 4. Climate change projections for the New York City watershed region
Source, including notes: NYC DEP 2008

	Air temperature*		Precipitation*		Sea-level rise**	
Decadal average	Range (ºF)	Model-based probability (%)***	Range (%)	Model-based probability (%)***	Range (inches)	Model-based probability (%)***
2020s	+1.0 to +3.0	100	0 to +2.5	60	+2 to +6	100
2050s	+3.0 to +5.0	80	+2.5 to +7.5	64	+6 to +12	100
2080s	+5.0 to +8.5	67	+7.5 to +15.0	74	+12 to +22	89

**Relative to the 1970-1999 base period from five GCMs.*
***Relative to the 1970-1999 base period from three GCMs. Percentages rounded to the nearest integer.*
****Model-based probability that the projected increase will be within the range shown across selected GCMs and three emissions scenarios.*

The NASA Goddard Institute for Space Studies/Columbia University Center for Climate Systems Research (GISS) has developed regional-scale climate projections for the New York City area. GISS first created regional climate change scenarios for the Metro East Coast Assessment (Rosenzweig and Solecki 2001); the scenarios are periodically updated as models are improved, with the most recent version appearing in a New York City Department of Environmental Protection climate change assessment (NYC DEP 2008). GISS uses a suite of global climate models (known as General Circulation Models, or GCMs) and emissions scenarios to develop climate projections.[3] Climate projections for key variables, including air temperature, precipitation, and sea-level rise are summarized in Table 4.

Adaptation planning must consider not only the direction and magnitude of mean changes in climate, but also changes in variability and extremes that may affect the likelihood and frequency of reaching energy system thresholds. For example, heat waves are likely to become longer and more frequent (NYC DEP 2008), taxing the state's energy supply system and increasing the likelihood of brownouts or blackouts. More extreme rain events may flood power generation facilities located along waterways and increase the turbidity of water used to cool power plants. These types of extreme events are difficult to model using GCMs, but climate change is expected to intensify the hydrologic cycle, with an associated increase in climate variability and extremes (IPCC 2007). Several other difficult to model variables that affect the energy sector include wind speed, cloud cover, and humidity. Presently, GISS uses qualitative analysis to evaluate possible changes in these variables consistent with climate change scenarios.

Despite modeling advances, both quantitative and qualitative projections contain several uncertainties including the level of greenhouse gases (GHGs) in the atmosphere and the sensitivity of the climate system to GHG concentrations. Regional changes in climate depend both on the impacts of global climate change as well as local micro-climates, which can vary even within a small geographic area. In New York City, climate change may exacerbate the urban heat island effect (Rosenzweig et al. 2005).

Climate change projections for the 2020s, 2050s, and 2080s are a starting point for analyzing energy sector climate risks. Statistical analysis of historical data can complement model projections by shedding light on the relationship between particular meteorological conditions and energy supply and demand in the region. Extrapolating from historical analyses and translating model projections into useful metrics is a challenge. We are working with GISS and energy sector stakeholders to prepare data and metrics that can be used in existing industry models to project impacts on power demand, system efficiency, and power supply potential. Climate metrics that have been used in previous studies include the estimated change in summertime temperature and the change in the number of heating and cooling degree days (Linder et al. 1987; Rosenzweig and Solecki 2001).

4. CLIMATE CHANGE IMPACTS ON NEW YORK CITY'S ENERGY SECTOR

The city's energy sector may experience 'elemental' impacts related to changing climate patterns. In certain cases, climate change may help the energy system function more smoothly – by eliminating weather-related supply chain problems, for example – but it is more commonly noted 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).

4.1 Impacts on energy demand

In recent years, a number of studies have analyzed how climate change will affect energy demand in a certain city, state, or region (Amato et al. 2005). The general consensus is that there will be increased energy requirements for

[3] GISS currently uses five of the 22 global climate models recognized by the IPCC to develop regional projections for the New York City area: GFDL CM2.1, GISS ModelE, MPI ECHAM5, NCAR CCSM3.0, and UKMO HadCM3 (NYC DEP 2008). Three of the IPCC emissions scenarios are used: SRES B1, SRES A1B and SRES A2 (IPCC 2001).

cooling and reduced heating-related energy demand (Wilbanks 2007).

The most basic division between these studies is whether they are narrowly focused on projecting the impacts of climate change on the electricity sector, or whether they also account for climate change-related impacts on non-electric systems (such as gas or oil-fired heating systems) in homes and businesses (Scott 2007). The studies incorporating the latter generally assess the net energy demand impact on the region of interest, employing the logic that climate warming has distinct seasonal impacts that vary widely from location to location. Some areas see energy demand peak in winter, meaning climate change may reduce overall energy consumption. Other regions have summer peaks, meaning climate change will tend to exacerbate demand, as air conditioning loads grow in response to warming temperatures.

Methodologically, two styles of analysis dominate. The first is a statistical model which extrapolates future demand based on historical climate, energy use, and pricing data. The second model is structural, modeling energy demand using a 'bottom-up' approach employing information about the type and quantity of energy-using equipment deployed in homes and businesses under certain climatic and pricing conditions (Linder et al. 1987). Both approaches can be time-consuming and are subject to considerable uncertainty, particularly when the analysis seeks to project demand over a decades-long timeframe (Franco and Sanstad 2008). The choice of which model is most appropriate is dependent upon the question; Linder et al. (1987) decided the structural approach offered greater opportunity to fully parse weather-sensitive end uses of energy, such as air conditioning. Nonetheless, energy demand projection models are in wide use around the world, most commonly by electricity planners at utilities and by power transmission system operators who must accurately estimate how much power to produce and where it will be used.[4]

4.1.1 Total net energy demand

In early 2008, the US Climate Change Science Program released a comprehensive review comparing the results of different studies projecting climate change impacts on energy consumption in the US. Their assessment of the overall net energy demand impact was that the picture was "clouded" (Scott 2007) by the wide range of scenarios and assumptions used in the different studies, such as whether we are focused on energy consumed on-site or on total primary energy use.[5] In general, however, "the overall effect is more likely to be a significant net savings in delivered energy consumption in northern parts of the country…and a significant net increase in energy consumption in the south for both residential and commercial buildings, with the national balance slightly favoring net savings of delivered energy" (Scott 2007, pp 9).

None of the previous analyses covering New York City analyzed total changes in net energy demand attributable to climate change. Hill and Goldberg (2001, pp 130) did note, however, that heating and cooling trends were "expected to continue or become more pronounced" in the future, with total heating degree days declining by 20-40% by the 2080's (compared to the 1979-1996 base period) while cooling degree days will likely increase by 45-135% (Figure 3). As a result, "it is the effect of the rising requirement for electricity-based air cooling that is the principal climate change impact of concern" in the New York region.

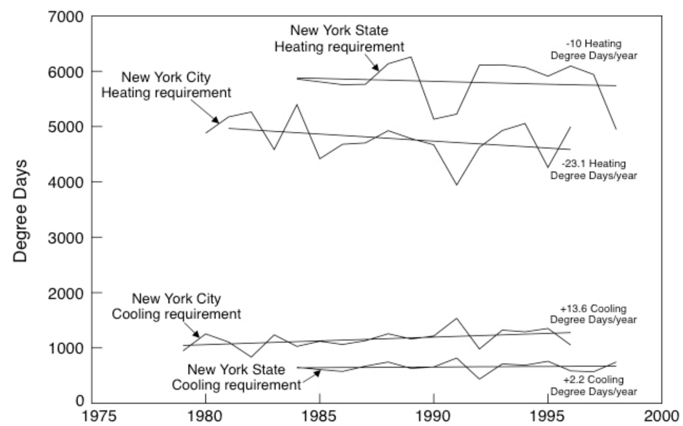

Figure 3. Cooling and heating-degree days in New York City and New York State - Source: National Weather Service and NYSERDA in Hill and Goldberg 2001

4.1.2 Peak vs. total demand

There are also differences depending on whether we focus on total cumulative power demand over the course of a year (measured in gigawatt-hours) or in the total amount of energy demanded at a point in time (measured in MWp). Both carry significant cost consequences for electricity users, but they vary in terms of whether they require the construction of new generation capacity.

Ceteris paribus, warmer nighttime temperatures and longer electric-powered cooling seasons can both generally be satisfied by the same level of power generation capacity required to satisfy the highest demand on a typical summer day. This is true because nighttime demand levels are generally lower than afternoon temperatures, and 'shoulder' season peak demand is less than summertime peak demand. However, when summertime peak demand increases at a faster rate than overall demand, additional generation capacity may be required, as there is an increased likelihood of brownouts or blackouts (Miller et al. 2008).[6]

[4] Although we will not discuss the varying methodological approaches in further detail in this report, we expect to take up methodological issues in another report in the near future.

[5] Primary energy use calculations include transmission system losses and other system inefficiencies.

[6] 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.,

Smith and Tirpak (1989, pp 87) crafted one of the first comprehensive energy sector climate change assessments, concluding that in the near term, total electricity demand in the US would likely increase 1-2% as a result of climate change, peak demand would increase 2-6%, and new system capacity requirements (including reserve margin requirements) would increase 9-20%. By 2055, however, consumption was expected to grow 4-6% as a result of climate change (all else being equal), while peak demand jumps by 13-20% and capacity requirements increase 14-23%. The national cost implications of these increases are sizable, amounting to $3-6 billion dollars per year in 2010 and $33-73 billion/year by 2055.[7]

Franco and Sanstad (2008) and Baxter and Calandri (1992) similarly found in their analyses of electricity demand in California under different climate and time scale scenarios that peak demand increases faster than annual electricity sales. ICF (1995) also found this to be the case in their analysis of demand in the service territories of six utilities in different parts of the US and Japan.

In New York State, two studies bear relevance. In 1987, the New York State Energy Research and Development authority partnered with the US Environmental Protection Agency, the Electric Power Research Institute, and the Edison Electric Institute to examine climate change impacts on New York's 'upstate' and 'downstate' electric systems. The downstate analysis covered New York City, Long Island, the Hudson Valley, and other suburban and rural areas to the northwest of New York City. Given the large geographic region covered, it is difficult to isolate the proportion of the analysis strictly relevant to New York City.

The analysis employed a range of climate and demand growth models, ultimately concluding that by 2015, peak demand would grow by 8-17% while overall demand would grow by no more than 2% compared to the 1985 base year. The annual electricity production cost impacts of climate change will be in the range of $65-$161 million per year, although no base cost estimates were given to help us judge the scale of these increases.

Hill and Goldberg (2001) offered a more recent perspective on this question. As with the Linder study, Hill and Goldberg looked at a broader geographic region than just the five boroughs of New York City, making it difficult to cull out impacts on 'Zone J', which roughly covers Con Edison's service territory in New York City as well as Westchester County, a suburban area north of the city. The model also did not attempt to ascertain impacts on year-round demand, instead focusing on projecting impacts on peak summer demand decades into the future. Despite these limitations, the impacts are sizable, with daily peak load expected to grow by up to 17% by the 2080s depending on which climate model and climate change scenario was employed (Hill and Goldberg 2001, pp 134-135) (See Figure 4).

The study also found that a 1°F increase in temperature leads to a downstate peak load increase of 240-309 MW, lower than the 404-740 megawatt per degree Fahrenheit finding in the Linder et al study (Hill and Goldberg 2001, pp 135). Again, it is important to note that both studies represent demand impacts for a larger geographic area than just New York City. A study on urban heat island mitigation in New York City found that a 1ºF increase in temperature is associated with a 134 MW increase in electric load during summertime heat-wave conditions, lower than the two studies focused on climate change impacts (Rosenzweig et al. 2006).

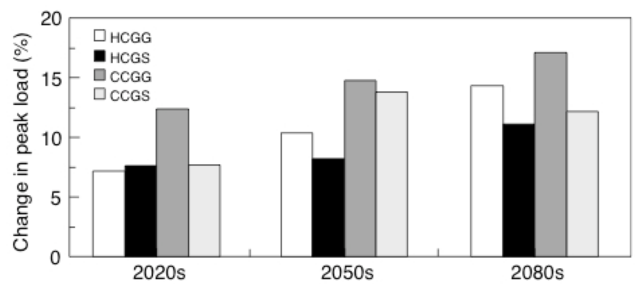

Figure 4. Increase in peak electricity demand in the New York Metropolitan Region under July 1999 conditions with temperatures and relative humidity projected for future decades - Source: Hill and Goldberg 2001, pp. 135. [Note: Bars represent low and high range of two global climate models, the Hadley Center (HC) and the Canadian Centre (CC) models.]

4.1.3 Sectoral Demand

Industrial, commercial, and residential buildings all have very distinct demand sensitivities to climate (Amato et al. 2005). Some of these differences stem from substantial variation in how much of each sector's energy consumption is space-conditioning related, for either heating or cooling. In the US, just 6.8% 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% and 27.3% of their total demand, respectively (EIA 2007; EIA 2009a; EIA 2009b). If supply becomes more constrained, or if costs increase because of rising demand, impacts may disproportionately fall on these two 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

1996 noted that Con Edison's summertime peak demand was 40% higher than its winter peak demand, freeing up winter-time generating capacity.) 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.

[7] Costs include capital, fuel, and O&M associated with climate-change related modifications in utility investments and operations.

residential sector (Amato et al. 2005). Rising temperatures due to climate change compound the problem, increasing the level of cooling necessary to address this heat gain.

Studies examining sectoral differences are somewhat conflicted, however, perhaps reflecting location-specific circumstances. Amato et al (2005) find the residential sector will experience a greater percentage increase in per capita demand than the commercial sector, although as Figure 5 makes clear, the residential sector is working off of a lower base demand.

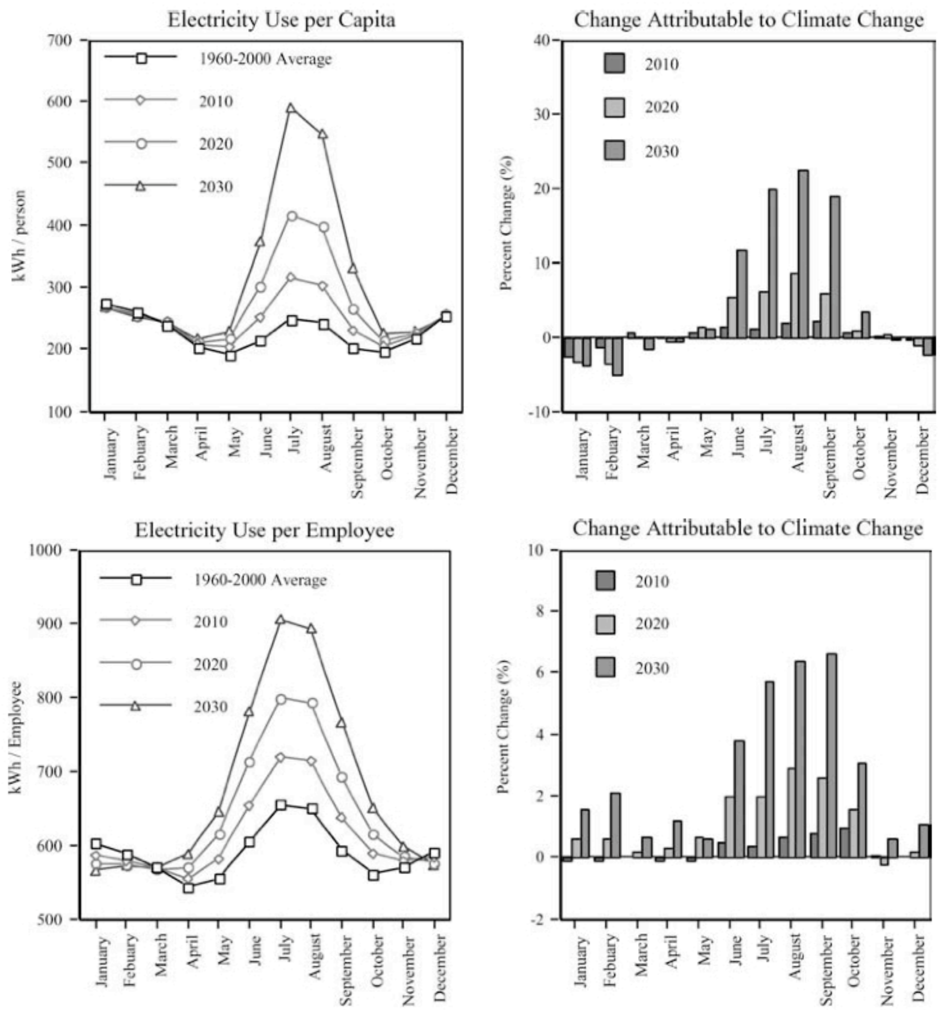

Figure 5. Residential and commercial electricity use per capita under different climate scenarios
Source: Amato et al. 2005, pp 193, 196

Table 5. Annual per capita consumption impacts of various GCM climate change scenarios
Source: Sailor 2001

State	Residential sector impact (%)			Commercial sector impact (%)		
	CCC	GFHI	UKHI	CCC	GFHI	UKHI
California	11.2	11.7	12.6	11.6	11.4	12.4
Florida	12.7	13.8	18.8	7.3	8.1	10.6
Illinois	12.4	12.2	13.5	6.1	5.8	6.9
Louisiana	2.6	3.1	3.3	4.5	5.8	6.2
New York	3.5	6.3	2.9	4.8	7.6	5.2
Ohio	6.4	7.6	6.2	7.9	8.1	9.0
Texas	9.3	9.7	13.8	5.1	5.5	7.2
Washington	−11.3	−10.5	−14.5	−0.2	2.6	2.4

By contrast, Sailor's analysis of electricity consumption in eight states finds the sectoral impact of climate change varies widely, but does not provide an explanation or analysis of these differences.[8]

Air conditioning saturation levels refer to the level of air conditioning system ownership in a city. Saturation levels in residential buildings may be partly responsible for outcomes indicating greater residential sector impacts since low saturation rates represent the potential for dramatic demand growth as temperatures increase[9] (Sailor and Pavlova 2003). Table 6 highlights air conditioning unit deployment levels in a variety of cities around the US; the lower the total score, the greater the potential for demand growth. Of particular interest is the breakdown of air conditioning system type. Room air conditioners tend to be used more heavily when owners are home (including at night), whereas central air conditioning units appear to be used more evenly over the course of the day (Linder et al. 1987). Linking this fact back to the previous discussion, saturation growth could thus link to the need for *either* peak or overall system capacity.

New York City reportedly has air conditioning installed in nearly two thirds of all buildings, a higher rate than other cities located upstate but lower than cities located in the upper midwest or the south. Data was drawn from national surveys carried out in 1992 (commercial) and 1996 (residential), so it likely understates current conditions.

Table 6. Air conditioning saturation levels in selected US cities - Source: Sailor and Pavlova 2003

City, State	% of buildings with window AC units	% of buildings with central AC systems	Total
Los Angeles, CA	27.3%	23.9%	51.2%
San Francisco, CA	6.0%	15.0%	21.0%
Sacramento, CA	22.1%	62.7%	84.8%
New York, NY	53.1%	10.1%	63.2%
Rochester, NY	25.6%	17.5%	43.1%
Buffalo, NY	16.3%	8.8%	25.1%
Columbus, OH	21.4%	56.1%	77.5%
Cincinnati, OH	32.3%	50.9%	83.2%
Cleveland, OH	25.7%	34.2%	59.9%
Houston, TX	14.7%	78.9%	93.6%
San Antonio, TX	27.8%	60.6%	88.4%
Dallas, TX	17.3%	78.5%	95.8%

4.2 Impacts on energy supply

New York City's energy supply may experience a range of climate change-related impacts, the majority of which can be expected to reduce the amount of power that can be generated locally. We differentiate between impacts on thermoelectric power plants and impacts relevant to different forms of renewable power technologies.

4.2.1 Impacts on thermoelectric power generation

Thermoelectric power plants are vulnerable to rising sea levels, increases in air and water temperatures, and extreme weather events.

Flooding: Power plants were historically located along waterways to facilitate fuel delivery and for cooling purposes, making them vulnerable to anticipated sea-level rise or storm surges associated with extreme weather events (Aspen Environmental Group and M Cubed 2005). Vulnerability is largely a function of the elevation of these facilities, and their proximity to the path that any storm-related tidal surge would follow during extreme weather events.

There is little in the literature examining this issue in a systematic manner. Aspen et al (2005) did explore potential impacts at power plants on the California coast, noting debris from storm surges may be problematic at facilities with low-lying water intake and outflow pipes. Nuclear power plants are particularly vulnerable, because of the higher level of risk associated with the loss of cooling water capacity (Union of Concerned Scientists 2007). The Diablo Canyon nuclear power plant on the central California coast has a policy of curtailing power production by 80% to avoid problems if intake flow is impeded by debris generated during heavy coastal storms. On average, this occurs approximately twice per storm season (Aspen Environmental Group and M Cubed 2005).

Climate change studies focused on New York City and 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 the city. In general, these studies argue that the impacts of storm surge will be the more significant problem, although the impacts are highly location specific (Jacob et al. 2001). Interestingly, there is little mention in the popular press detailing any effects on in-city power production assets from significant storms and tidal surges hitting New York City over the past several decades (McFadden 1985; McFadden 1992).

The majority of New York City's larger power plants are located along the water, at elevation levels less than 5 meters above sea level, or well-within reach of moderate storm surge estimates previously identified by Rosenzweig and Solecki (2001) (See Figure 6). The extent to which these facilities have adopted flood prevention or abatement plans is unclear.

[8] The case of Washington State is different, however, where electric heating use (a common residential strategy) is expected to decline as winters become warmer.

[9] Recent air conditioning demand increases in Europe offer a cautionary tale, as growth rates there far exceed rates elsewhere. (See Tagliabue 2003).

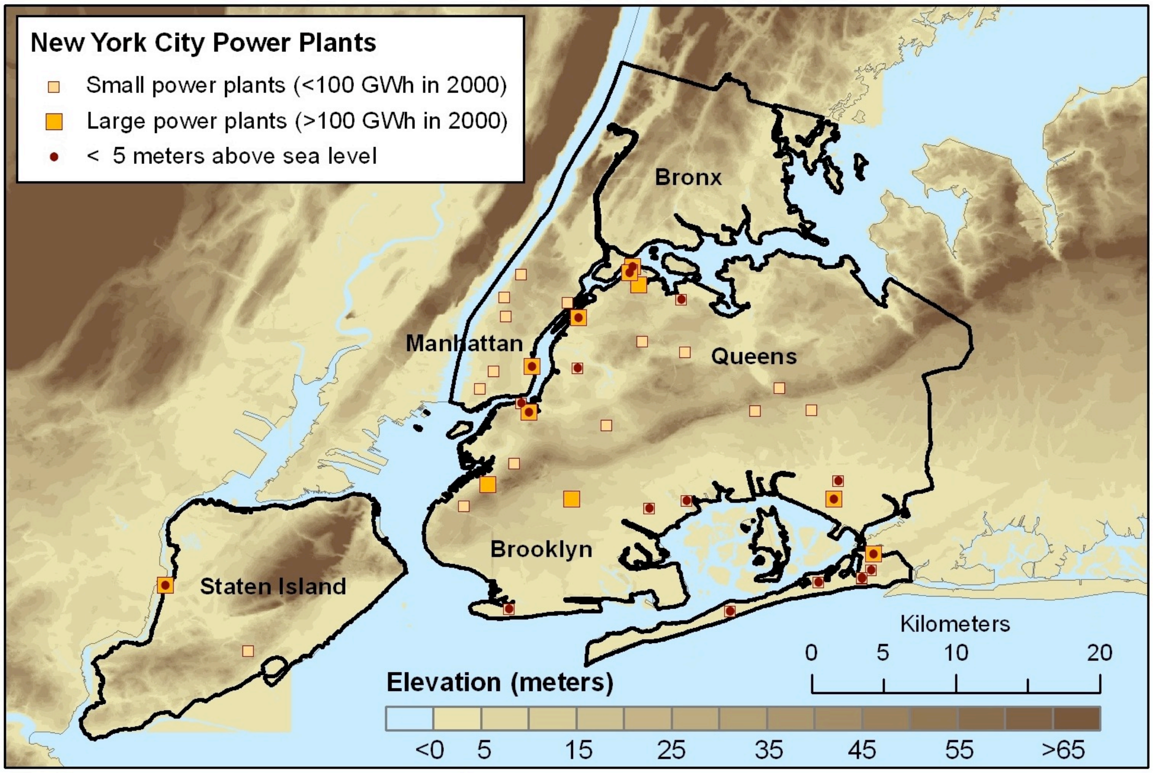

Figure 6. Location and elevation of power plants in New York City - Data sources: Power plant data for 2000 was extracted from CARMA 2008. New York City digital elevation model is from the USGS 1999. Map credit: Lily Parshall, 2009.

Water temperature: A different type of water-related impact has to do with the temperature of water entering and exiting thermoelectric power plants. To protect aquatic life, many states regulate water effluent from power plants, restricting (ICF 1995, pp 737):

- the absolute temperature of water discharged from a power plant;
- the absolute temperature of water downstream from power plants; and/or
- the temperature rise of waters receiving cooling water effluent from power plants

Most problems arise at facilities with limits on the maximum temperature of discharge waters, as the receiving waters may already be close to the maximum limit on hot summer days. This situation forces the power station to reduce production to decrease the heat content of water leaving the condenser (ICF 1995, pp 7-37). During Europe's deadly 2006 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 there to discharge cooling waters at above-normal temperatures as an emergency measure to avoid blackouts (Jowit and Espinoza 2006).

High incoming water temperatures can impact power output in other ways, increasing 'back pressure' on the turbine units (which can damage the turbine blades) and reducing overall operating efficiency. Studies by the Tennessee Valley Authority found that when intake water temperatures increase from 75°F to 85°F, the rated output capacity of a facility can decline by up to 26% (Miller et al. 1991).

There is a dearth of published data discussing the discharge limits or other water temperature-related operating rules for power plants in New York City. Past studies analyzing climate change impacts on the local power sector have also ignored this topic.

Changes in ambient air temperature and air density levels resulting from climate change may also affect power plant output levels. A recent study of the country's power sector by the UK Met Office found that of the 160 'process elements' that make up the sector's supply and demand chain – from oil and gas extraction to combustion to end use in homes and businesses – fully one-third of these process elements had a "fundamental sensitivity" to temperature (Hewer 2006, pp 10).

One of the most significant temperature-related impacts occurs at combined cycle gas turbine facilities (Hewer 2006). In general, these units are designed to fire at a specific temperature, and when ambient air temperatures rise, air density declines, reducing the amount of oxygen available to achieve peak output (ICF 1995). Similar problems exist at steam turbine facilities.

Stern (1998), Bull et al. (2007), and Linder et al. (1987) discount the importance of these impacts, arguing that capacity and/or output reductions will be less than 1% under most climate scenarios. ICF (1995) also reminds us that depending on the rate with which climate change progresses, it may well be that vulnerable facilities will reach the end of their useful life and be replaced before these long-term power generation impacts are felt.

Air temperature: Perhaps more time-relevant are temperature-related impacts on the electricity transmission and distribution system. Several reports note that because transmission and distribution lines, as well as transformers, are "rated" to handle certain amounts of voltage for a given period of time, climatic conditions can lead to equipment failure by increasing 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 over 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, causing above-ground lines to sag to dangerous levels or fail altogether (Hewer 2006; Mansanet-Bataller et al. 2008).

New York City's energy system has long been vulnerable to climate-related impacts. It was the great blizzard of 1888 that first led to the decision to bury most electric and telecommunication wires around New York City (New York Times 1888). To the extent warming winter temperatures result in fewer snow and ice storms, there may be reduced impacts in those portions of the city where there are many trees and power distribution lines are still situated above ground, including in the northwest Bronx.

At the other extreme, the most newsworthy blackouts in recent years have tended to occur when heat waves have settled in for a multi-day stay (Revkin 1999; Waldman 2001; Chan and Perez-Pena 2006; Newman 2006). Two different state agency analyses have expressed concern about the age of portions of Con Edison's local network, 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).

4.2.2 Impacts on renewable power generation

The literature also identifies climate-related supply impacts on certain renewable power technologies relevant to New York City.

Hydro: Vine (2008, pp 5) effectively summarizes the potential impacts of climate change on hydropower by noting that generation levels are linked to "the amount, timing and geographic patterns of precipitation" and the temperature of the region, which influences whether precipitation falls as rain or snow.[10] In the western United States, and in other parts of the world, most modeling exercises predict that climate change will affect hydropower generation levels, although there is considerable uncertainty about the magnitude of the impact because of the difficulty in discerning climate change impacts at different altitudes. Elevation is critical because retention dam operating rules can vary significantly between high- and low-altitude dams, depending on whether their primary function is to provide water supply, flood control, or power generation (Linder et al. 1987; Aspen Environmental Group and M Cubed 2005; Franco 2005; Vine 2008).

Hydrologic studies summarized in New York State's first comprehensive assessment of the impacts of climate change on the state energy system unanimously indicate "a potential reduction in overall water availability is likely in the Great Lakes Region of the United States and Canada, despite projected increases in precipitation" (Linder et al. 1987, pp 2-15). Overall, Linder et al (1987, pp 5-18) predicted that stream flow around the state could decline by 5.1-7% by 2015, resulting in a 6.2-8.5% drop in hydro generation levels. Projections were that non-hydro generation assets in the state must increase by 1.3-1.7% by 2015 to offset this predicted loss in hydropower availability.

More recent projections are not available, nor are any studies predicting hydropower impacts in New York State over a longer time scale. Research also has yet to be conducted examining potential hydropower generation impacts in New York State based on the elevation of different facilities.

Morris et al (1996) notes that little hydropower from upstate New York is ultimately delivered downstate, but the impacts of decreased (inexpensive) hydropower availability around the state (and in surrounding states and Canada) could nonetheless have significant cost impacts on New York City as the overall supply market tightens. This is true despite the fact that New York City hosts so much supply generation capacity, as these facilities tend to charge higher prices for power than upstate sources, reflecting higher local operating costs.

Solar: Although there is little solar photovoltaic technology currently deployed around New York City thus far,

[10] Snowpack effectively serves as a secondary water reservoir, gradually releasing water over the course of the spring (and into the summer in certain parts of the country.) Availability during late spring and summer means hydropower tends to be available when it is needed most, during peak power demand periods.

estimates are that the city enjoys significant solar resources (CEMTPP 2006; City of New York 2007). Whether climate change will enhance or hinder local solar resources is unknown. One study regularly cited in the literature modeled solar radiation in the US through 2040 (Pan et al. 2004). The study projects that increased cloud cover attributable to rising CO_2 levels could reduce solar radiation levels by as much as 20%, particularly in the western United States (Pan et al. 2004). Another study focused on Nordic cities translates this into power output levels, predicting a 2% decrease in solar radiation will reduce solar cell output by 6% (Fidje and Martinsen 2006). Assuming both studies are accurate, the future decrease in solar PV system output in New York City could be significant, undermining current efforts to raise local deployment levels (US Department of Energy 2008).

Tidal power: New York City is home to one of the world's first kinetic hydropower systems, affixed to the base of the East River where it generates power 18 hours per day from the two-way current flow. Verdant Power, the company operating this system, recently applied for permission to greatly expand its small pilot operation to generate up to 1 MW of power during peak flow periods (Federal Register 2008). So far, no information is available on whether climate change will affect the speed of the current in the East River, or whether there may be operational problems or enhanced power output during extreme weather events associated with climate change.

Wind power: Wind maps published by the State of New York show that there are regions around New York City that enjoy strong wind characteristics, such as areas in the Atlantic Ocean just off the Queens shoreline (NYSERDA 2006). Thus far, there have been very few wind turbines installed around the city, for safety, economic, and logistical reasons (Belson and Dunlap 2008). No information is currently available projecting whether climate change will affect local wind patterns or speeds. Research examining this question at national and regional scales project wind speeds could decline by between 1 and 15% over the next 100 years, varying depending on which climate assumptions are used. Because wind turbine power output is a function of the cube of the wind speed, wind power generation levels could potentially decline by upwards of 30-40% (Breslow and Sailor 2002). These estimates must be treated with caution, however, because there are acknowledged differences between wind map estimates and site-specific conditions in cities, due to the high levels of wind turbulence caused by the built environment (Dutton et al. 2005). Already, the natural variability in wind speeds can lead to unexpected decreases in output and questions about the reliability of wind power, as is currently happening in the UK (Gray 2009). Whether climate change will significantly affect local wind speeds in urban areas is currently unclear.

5. CLIMATE CHANGE ADAPTATION STRATEGIES RELEVANT TO NEW YORK CITY'S ENERGY SECTOR

There is a rich literature discussing 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, pp 18)] 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 level, target audience, technology and policy decisions, and decision rules. Many adaptation strategies proffered serve a dual role as climate change mitigation strategies. That is, by taking steps to reduce cooling demands in buildings, energy system failures or generation capacity growth requirements can be avoided or reduced.

At the most basic level, it is important to distinguish between adaptation strategies that target energy supply and those that target demand. Supply-related measures are fairly straightforward, focused on enhancing the capacity of the power generation and transmission and distribution system to operate under a range of future climatic conditions (Franco and Sanstad 2006). Demand-related measures found in the literature are more of a mixed bag, 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.

Within these broad categories, we can also differentiate between anticipatory and reactive adaptation strategies (OECD 2008). Anticipatory strategies emphasize the 'hardening' of system assets such as power generation facilities or transmission and distribution grids. Overbye (2007, pp 2) notes that modern power systems were designed to operate under certain climate parameters, "and these assumptions may be strained by new weather patterns." Hardening strategies include the use of higher temperature-rated transformers and wiring, and the construction of flood-prevention berms around power plants (Mansanet-Bataller et al. 2008).

Hardening strategies can also involve "soft" approaches, focused 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), shading buildings and windows, or using high-albedo roof paints and surfaces (Hill and Goldberg 2001; Amato et al. 2005; Vine 2008).

Table 7 presents a wide range of adaptation strategies included in the literature, broken out by category.

It is worth noting that most articles and reports detailing these ideas offered little insight into scalar governance issues such as which stakeholder or level of government should, or is capable of, taking the lead on promoting or implementing a particular strategy. 'Capacity to act' is critical in energy and climate planning efforts, particularly when working at the local level (Hammer 2008). 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 ignored governance concerns.

Table 7. Selected climate-change adaptation strategies for the energy sector.

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

An area of some commentary is the role uncertainty plays in adaptation planning. The existing power system infrastructure in the US was recently valued at $800 billion (Overbye et al. 2007). Because this system requires constant refurbishment and eventual replacement over long timescales, it may make sense to align implementation of adaptation measures into the natural replacement cycle of vulnerable system assets.

Linder et al. (1987) note the challenge of making climate change adaptation investment decisions in the face of even greater uncertainty over what future energy demand will look like in the absence of climate change. 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 2007). The confidence interval surrounding future demand projects can thus be quite wide, exceeding the anticipated impacts of climate change-related demand growth (ICF 1995).

Linder et al. (1987) argue the cost of 'underbuilding' must be weighed against the cost of 'overbuilding' generation capacity. In either case, ratepayers will bear a cost burden, albeit at different times. Linder et al.'s perception, however, is that "recent historical and current utility supply and financial conditions…make it difficult to justify construction of long lead-time, capital intensive generating plants in anticipation of climate change which is very uncertain."

Hallegate (2008) offers advice on how to proceed in light of this situation, highlighting the benefits of a "no-regret[s]" approach. Under this model, 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, pp 16) as there are non-greenhouse gas emission reduction and other cost-saving benefits accrued regardless of whether climate change-related impact projections prove accurate.

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

6. CONCLUSIONS AND OPEN RESEARCH QUESTIONS

This literature review has identified a broad range of potential impacts of climate change on New York City's energy sector. We suggest several avenues of research that are needed to develop effective adaptation strategies for the city. Research questions fall into two broad categories: (1) the relationship between specific changes in climate and different aspects of the energy system and (2) the implications for local energy policy and governance. As part of ongoing research, we are working with local stakeholders to identify research priorities for New York City.

6.1 Climate impacts

- What is the net energy impact of warmer summers, winters and shoulder-season months and how will this affect base peak energy load?
- How will the increased frequency and duration of summertime heat waves affect peak energy load?
- How will climate change affect air conditioning saturation levels in New York City?
- What is the current price elasticity of energy demand in New York City, and will this change in the wake of climate change?
- How will projected changes in precipitation and snowmelt affect the availability of hydropower in New York and surrounding states?
- How will climate change affect in-city renewable resource availability?
- How much additional generating capacity is required to maintain system reliability for a given climate change scenario for a given utility?
- How will climate change affect individual energy system assets, including power generation facilities, transmission and distribution wires, and gas distribution networks?
- How will climate change affect water temperature at power plant intake and discharge points, and how will this affect power plant operations in New York City?
- How will climate change affect natural gas supply availability in New York City?
- What is the marginal impact of climate change on planned energy supply capacity increases associated with population and economic growth?
- What is the impact of rising sea levels and anticipated storm surge on local power plant operations and power distribution system assets in New York City?

6.2 Policy and governance

- What type of weather-related management strategies are currently employed at local power plants and by local electricity distribution utilities, and is there a need or plan to change these strategies to adapt to changing climatic conditions?
- What types of climate change metrics do energy sector stakeholders need to support climate change adaptation planning efforts?
- Does climate change adaptation require a rethinking in the way local and state energy markets are structured or regulated?
- What role will demand and supply market 'game-changers' such as plug-in hybrids and decentralized generation play in New York City's future energy system, and how might these game-changers affect adaptation efforts?

- Is climate change adaptation planning reflected in the Indian Point nuclear power station re-licensing efforts currently underway?
- To what extent can anticipated increases in summertime peak electricity demand in New York City be met solely through demand-side management efforts?
- What are the costs and benefits of particular energy efficiency measures for particular sectors under different climate scenarios?
- What are the costs and benefits of particular anticipatory and/or reactive strategies for ensuring adequate generation, transmission and distribution capacity?
- How can energy planning efforts account for multiple levels of uncertainty associated with climate change projections and system responses?

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