Adapting to Climate Change: Planning for Resilient Energy Systems and Maintaining Global Competitiveness

Susan Asam, ICF International

ABSTRACT

Climate change is expected to result in more extreme temperatures and more intense weather events. Savvy energy providers should be knowledgeable about the threats posed by climate change and consider strategies now to adapt and prepare for predicted changes. Climate change may, for example, result in hotter summer days for longer stretches of time. Peak system load will likely increase as demand for air conditioning and other cooling systems increases. More frequent and extreme weather events could make systems more vulnerable to disruption and/or failure.

The energy sector's role in policy measures to reduce greenhouse gas emissions as well as approaches for energy companies to manage the costs and opportunities associated with those policy measures are frequently discussed. There has been little discussion or thought thus far about how the physical impacts of climate change will impact the energy sector and frameworks to address the risks that those impacts pose to energy systems. This paper highlights some of the physical impacts of climate change of most concern to the energy sector, introduces the concept of adapting to those impacts, outlines a framework for screening risk, suggests an approach for beginning to address those risks, and provides a few examples of existing policy options that may help energy providers adapt to climate change and maintain global competitiveness.

Introduction

Global climate change, its predicted consequences, and actions or hesitancy to address the issue have become a daily news story in the United States in recent months. The weight of scientific evidence indicating that climate change is a real and serious problem continues to mount, and the rapidly increasing public consciousness of the issue is demanding political, business, and consumer responses. Climate change is a growing concern in all sectors of the economy, but the impacts of climate change on the energy sector are of particular concern. The time is ripe for energy providers to be aware of the impacts of climate change and proactive in considering how to address those impacts.

Global climate change continues to threaten human health, human settlements, and the environment as emission levels rise. Atmospheric concentrations of greenhouse gas (GHG) emissions have risen dramatically since the industrial revolution and have correspondingly increased the heat-trapping capability of the Earth's atmosphere (IPCC 2001a). Scientists predict that these atmospheric changes will lead to more extreme weather events, melting ice caps and sea level rise, increased incidence of diseases, and changes in agriculture, among other impacts (IPCC 2001a). Climate change is not just an "environmental problem," but one that is expected to impact the production of goods and services and, thus, economic competitiveness due in part to reduced availability of affordable and reliable energy.

Climate changes such as higher temperatures, more extreme storm events, and flashier precipitation are expected to impact the energy sector by increasing demand for summer cooling (especially for electricity-based cooling) and making systems more vulnerable to disruption and/or failure. The energy sector's role in policy measures to reduce greenhouse gas emissions as well as approaches for energy companies to manage the costs and opportunities associated with those policy measures are frequently discussed. There has been little discussion or thought thus far about how the physical impacts of climate change will impact the energy sector and frameworks to address the risks that those impacts pose to energy systems.

This paper highlights some of the physical impacts of climate change of most concern to the energy sector, introduces the concept of adapting to those impacts, outlines a framework for screening risk, suggests an approach for beginning to address those risks, and provides a few examples of existing policy options that may help energy providers adapt to climate change and maintain global competitiveness.

Impacts of Climate Change on the Energy Sector

Temperature Changes

Population and economic activity are expected to remain the primary drivers of energy demand, but climate change will likely play a role at the margins. Increases in summer temperatures due to climate change will lead to increased demand for air conditioning, which will strain generation, transmission, and distribution systems. Increased reliance on cooling systems in response to temperature changes is likely to place a disproportionate strain on peak demand (which translates into generating capacity requirements) rather than total energy consumption (which could be addressed through increases in total generation). The impacts of climate change are likely to be more profound for electricity providers, because air cooling is principally provided by electricity. (Rosenzweig and Solecki 2001, Smith and Tirpak 1989)

Projecting with certainty the magnitude of the increase in summer temperatures and the full suite of impacts that these changes will have on energy systems will be challenging. Climate modeling is often conducted at a scale that is too broad to produce meaningful projections for a specific location. Further, researchers have found that the relationship between temperature increases and energy use for cooling is non-linear due to the physics of latent and sensible heat and the strong influence of humidity (Scott et al. 1994). Generating capacity will, thus, need to be increased to meet an uncertain future demand.

The effects of extreme high temperatures on energy systems are more certain; a series of unusual heat events experienced around the world within the past decade have demonstrated the consequences of heat waves and temperatures extremes (Box 1). Higher temperatures reduce the efficiency of equipment. "Climate conditions can alter the effective capacity and operating efficiency of gas turbines (used primarily for generating power during periods of peak requirements) and fossil fuel fired and nuclear steam generators (used to serve base load and intermediate load requirements)" (Rosenzweig and Solecki 2001). Air conditioning units can become less efficient as temperatures rise; at higher temperatures and as greater electric currents pass through copper wires, resistance increases (Rosenzweig and Solecki 2001). Steam generators are sensitive to air and water temperatures. When the temperature of cooling water rises, the efficiency of the condensing stage of the steam cycle is reduced—a problem observed in France during the 2003 heat wave (Kirkinen et al. 2005, Rosenzweig and Solecki 2001).

Rising temperatures will clearly place an additional strain on energy infrastructure and may cause more frequent failures.

Box 1. Heat Waves Can Cause System Failure When Energy Needs are Critical

Heat waves can wreak havoc on energy systems by impeding the proper functioning of equipment, causing equipment and lines to overheat or catch fire, and resulting in total shutdown in some cases.

During the 1999 heat wave in New York, energy supply fell short of demand, and blackouts occurred in Manhattan and parts of Long Island. Ambient conditions made generators unavailable or incapable of meeting their rated capability. Increased energy flow and higher ground temperatures caused "feeder" cables supplying energy to overheat. A number of component failures in the network led to a fire in one of the substations and a decision to shut down the entire Washington Heights network. (Rosenzweig and Solecki 2001)

During the 2003 heat wave in Europe (covering the hottest three-month period ever recorded in France), river water in France became too hot to properly cool the power stations (both conventional and nuclear) and energy production fell. A similar problem occurred in Queensland (Australia) in 2002. (Stern 2006)

These disruptions not only inconvenience customers, but also can have a dangerous impact on public health. Numerous studies have linked duration of heat waves, high humidity, low wind speeds, and high minimum temperatures to increased mortality (Rosenzweig and Solecki 2001). The 2003 heat wave in France, for example, resulted in an estimated 15,000 additional deaths (Stern 2006). Air conditioning needs are, thus, critical at the times when energy reliability may be most threatened.

It should be noted that climate change may also result in a decline in heating-degree days, which could reduce the impact on the energy system during cooler months. These changes will not cancel out or mitigate the increases in summer temperatures and the resulting strain on energy systems, however. Energy service providers, thus, must still consider the impacts of higher high temperatures and how to adequately prepare for them.

Storm Events

Climate change is expected to result in more extreme storms with high winds and precipitation, which, in turn, may cause more intense or widespread energy service disruptions. Storm events can damage infrastructure, including transmission towers and lines, poles, transformers, and pylons that support power lines. An ice storm that hit Canada in January 1998 caused a power failure affecting 3.6 million people, 90 percent of whom were without power for more than a week (Kerry et al. 1999). In 2005, Hurricanes Katrina and Rita took a terrible toll on the southern part of the US, including significant damage to the energy sector (Box 2). Already aging infrastructure may be further stressed by more extreme storm events (Rosenzweig and Solecki 2001).

Flashier Precipitation

Climate change is expected to result in reduced or altered streamflow (e.g., lower low flows, altered timing of flows, or changes in geographical patterns of precipitation), which could impact hydropower operations (Darmstadter 1993, IPCC 2001b). The nature and magnitude of these impacts are still highly uncertain. Rosenzweig and Solecki (2001) contend that, "a rough estimate indicates that the reduction in stream flow could reduce hydro generation in New York 6.2-8.5% by 2015." The international group of scientists that studies climate change issues–the Intergovernmental Panel on Climate Change (IPCC)—projects that changes in streamflow timing (from spring to winter) in some regions could cause a net increase in hydropower production (i.e., hydropotential increases in the winter would be greater than reductions in the spring and summer) (IPCC 2001b). IPCC also notes, however, that it is unclear whether or not electric systems can take advantage of these winter increases and whether or not storage capacity would be adequate (IPCC 2001b).

Box 2. Impacts of Hurricanes Katrina and Rita on the Energy Sector

Researchers studying the storm damage caused by Hurricane Katrina estimated that the storm resulted in $231 million in electric utility damage in Louisiana, Alabama, and Mississippi (Burton and Hicks 2005). Entergy reported costs of approximately $700 million to repair extensive damage to infrastructure such as utility poles, wire, and transformers (see table below for details). Repairing this damage was no small feat; over 10,000 workers were contracted from companies across the US following Katrina and more than 13,000 were hired following Rita to restore power to affected areas.

Damage Sustained by Entergy

	Katrina	Rita
Utility poles destroyed	17,389	11,503
Spans of wire replaced	34,587	18,585
Transformers destroyed	3,478	2,301
Substations offline	263	443
Transmission structures damaged	1,000	700

Source: Entergy 2006

Other Climate Change Impacts

Other direct and indirect climate change impacts are likely to affect energy systems in addition to the major categories of direct impacts described above. For example, energy facilities located in coastal areas will face the additional threat of sea level rise. Sea level rise and the associated changes in coastlines could require relocation or retirement of some facilities. Increased cloudiness could impact the functioning of photovoltaic systems. Changes in wind resources could positively or negatively impact wind energy systems. Indirect impacts such as rising fuel prices and policy or regulatory changes (e.g., carbon taxes) could also significantly alter the economics of specific technologies and infrastructure choices. More research into the impacts of climate change on the energy sector will need to be conducted as it becomes an increasingly important factor in decision making.

Energy Sector Vulnerability

On the whole, climate change is expected to reduce the reliability of energy distribution and transmission (Kirkinen et al. 2005). Some areas will be more vulnerable to climate change impacts than others, but most will likely be impacted. The existing transmission and distribution system in the US is already fragile and results in significant line losses. The current infrastructure is aging, which makes it more prone to failure in the face of extreme conditions or events. Some damage to distribution systems may not show up until later, given the difficulty in identifying cracks and metal fatigue. Weaknesses in infrastructure that survive one extreme event may remain undetected, but lead to collapse in the future. Further, some regions of North America rely on a single transmission line; when that line is out of service, all power is lost to areas relying on it (Kerry et al. 1999). Energy consumers are frequently located a significant distance from power plants. For example, the Energy Association of New York State (2006) estimates that the typical transmission distance in New York is 300 miles. In Quebec, two-thirds of the electricity travels from about 300 to 750 miles to reach the end user (Kerry et al. 1999). Line losses are about five to eight percent on average, but can be as high as 13-16 percent of the generated electricity due largely to these long distances (Consumer Energy Council of America 2006). Maintaining the physical infrastructure of these systems will become more challenging as climate change makes them increasingly vulnerable to damage or failure. Regions that are constrained by the capacity of transmission lines into the region, such as New York City and its environs, will find it more difficult to increase capacity by importing power during peak demand periods. Geographically isolated regions, such as Hawaii, will similarly be constrained in their ability to import power to meet rising peak demand.

Adapting to Climate Change

Given the vulnerability of the energy sector and the expected impacts of future climate change, it is prudent to consider measures to reduce these vulnerabilities and adapt to prepare for and respond to these changes. Adapting to climate change is an issue that all sectors are beginning to think about. IPCC has identified the energy sector as one of the sectors that is likely to be the most sensitive to climate change, making it well-suited for and likely to benefit greatly from proactive adaptation measures.

The IPCC defines adaptation to climate change as an “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2001b). In contrast to mitigation, which aims to reduce emissions or increase sinks of greenhouse gases to avert future climate changes, adaptation refers to the changes that must be made to respond to the impacts of climate change.

The incentive for adaptation is closely tied to the vulnerability of a given system. The energy sector’s vulnerability is a function of the sensitivity of the energy system to changes in climate, the ability for the energy system to adapt to climate change, and the degree of exposure of the energy system to climate hazards (IPCC 2001b). The more vulnerable a system is to climate, the more costly climate change impacts will be. As outlined in the previous section, climate change may pose direct physical threats to fragile and aging generation, transmission, and distribution infrastructure as well as indirect threats such as rising fuel prices. As an industry, the aim should be to strive for resilience by designing and operating systems that are not sensitive to climate variability and have the capacity to adapt.

Because scientists agree that climate changes are already occurring and will continue to take place even if current efforts to curb emissions of greenhouse gases are implemented immediately, adaptation is imperative. Adaptation exists in many forms, ranging from anticipatory to reactive, private to public, and autonomous to planned (Box 3). Regardless of the type of adaptation that is implemented, an adjustment in practices or processes to account for climate impacts reduces the risks of climate change. Not only is it critical for businesses to adapt, it is also critical that businesses guard against decisions that are maladaptive (i.e., likely to compound or exacerbate climate change impacts).

Box 3. IPCC (2001) Definitions of Types of Adaptation

Anticipatory Adaptation—Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.

Autonomous Adaptation—Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.

Planned Adaptation—Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

***Private Adaptation*—**Adaptation that is initiated and implemented by individuals, households or private companies. Private adaptation is usually in the actor's rational self-interest.

Public Adaptation—Adaptation that is initiated and implemented by governments at all levels. Public adaptation is usually directed at collective needs.

Reactive Adaptation—Adaptation that takes place after impacts of climate change have been observed.

The costs of climate change impacts and benefits of adapting to climate change are still highly uncertain. The recently released Stern Review on the Economic Impacts of Climate Change (Stern 2006) attempts to nail down more quantitative estimates of these costs and benefits due to increasing interest and concern about their magnitude. Further research will undoubtedly be undertaken in the coming years. Furthermore, the costs and benefits will likely vary widely depending on the opportunities and constraints faced by unique energy service providers and energy systems.

Despite these uncertainties, energy providers will benefit from thinking through these issues now. The energy industry meets two key criteria for identifying situations where adaptation strategies are most important:

1) System productivity is sensitive to climate change; and
2) Projects, assets, or capital investments have a very long lifetime and are difficult to reverse once decisions or commitments are made in the near term.

Energy system productivity is expected to be highly sensitive to climate change, as described in previous sections. It is well known that energy companies make decisions and infrastructure investments that involve large upfront capital investments with long-term consequences. The planning horizon can often be 40-50 years, a timeframe that warrants consideration of climate change. As decisions about energy investments are made moving forward, energy companies will need to factor climate change into the equation as a matter of prudent risk management. Researchers in Finland looking at the impacts of climate change on the electricity distribution network concluded in their 2005 report, “climate change is a threat to the profitability of electricity network business, but the effects can be compensated by taking the scenario results into account in design phase” (Kirkinen et al. 2005).

Climate Risk Assessment

Assessing the risk of the physical impacts of climate change and developing management strategies to address these impacts where they could be significant should be a key component to companies’ overall climate change strategy. Energy companies should incorporate the impacts of climate change into investment or operations planning under a limited set of circumstances, however. It is prudent to take climate change into account if it materially affects a company’s operations, its value chain, or its broader commercial environment. Companies should analyze their risk by assessing the sensitivity of each of these components to climate change.

A risk screening approach can help narrow down the set of issues to those that are business-relevant and potentially important to address in the near term. Business risks can be grouped into three broad categories: (1) resources probably will be affected by the impacts of climate change and adaptive measures should be incorporated in the short term, (2) resources will probably be affected by the impacts of climate change but adaptive actions can (and often should) be addressed later, and (3) resources are unlikely to be affected by the impacts of climate change. Once companies have screened risks by classifying them into one of these three categories, they can focus in more depth on assessing the vulnerability of risks falling into category 1. Risks falling into category 2 can be addressed on an ongoing basis or later, while risks falling into category 3 need no further consideration of the impacts of climate change.

Assessments of vulnerability on category 1 risks should include analysis of the potential physical impacts of climate change (e.g., temperature, hydrology, sea level rise); the sensitivity of structures, processes, and operations to climate averages and extremes (considering geographic variability in structural designs, operations, and productivity as well as seasonal variability in operations); and design standards that are keyed to weather and hydrologic extremes (e.g., 100-year floods, 2-year 24-hour rainfall events, 100 km/hr wind, category 3 hurricanes). Once key climate change risks have been identified and specific vulnerabilities have been assessed in more detail, companies can work to develop adaptive strategies to manage those risks and vulnerabilities. The following section introduces a sampling of existing energy sector programs and policies that can provide an adaptive benefit.

Climate Change Adaptation Options

Programs to manage energy demand as well as strategic system design decisions and infrastructure investments are all likely to be good candidates for enhancing system resilience in the face of climate change.

Energy Efficiency

Reducing energy demand is one of the most obvious and direct ways to prevent strains on limited energy supply now and in the face of future climate change. Energy efficiency measures reduce overall energy demand, during both peak and off-peak load periods. They provide an adaptive benefit while also helping to mitigate climate change (through an overall reduction in the greenhouse gas emissions that exacerbate it). A recent paper looking into the peak demand impacts of energy efficiency has shown that energy efficiency programs can and has resulted in significant peak demand savings in certain states and regions (York et al. 2007). While climate change adaptation may not drive decisions to implement energy efficiency programs, energy systems will benefit from the resulting decrease in energy demand that will free up system capacity.

Demand-Side Management

Demand-side management programs aim to influence the amount and timing of consumer's energy demands towards the most efficient use of limited energy supply resources. They, thus, offer a promising policy approach to addressing a more constrained future energy supply.

Demand response programs, including load response and price response programs, target peak load reductions and are designed to increase energy system reliability. They are typically utilized during emergency conditions or when price levels exceed allowable caps. These programs are, thus, well-suited to address the kinds of reliability issues that may become more pressing in the face of climate change.

Load response programs include curtailable load programs, interruptible load programs, scheduled load programs, or direct load control programs. The programs differ in the party controlling the reduction, the size of the targeted load reduction, the incentives, and the enabling technologies, but are similar in intent and results. Load response programs are typically designed to shut off non-critical end uses, regardless of whether the provider/utility controls the reduction (e.g., direct load control) or the customer controls the reduction (e.g., scheduled load). Non-essential energy needs can be shifted to non-peak hours of the day under load response programs. For example, certain industrial processes can be scheduled to run overnight when energy demand is lower. Commercial customers such as hotels can turn off fountains, lights, or escalators in areas that are not occupied. Residential customers can run dishwashers and irrigation systems at night. Price responsive programs such as demand bidding and critical peak pricing are typically triggered by reliability concerns or energy market prices. Both load response programs and price response programs could help address tighter energy supply or shortages caused by more extreme temperatures.

Backup Generators

Backup or emergency generators can be called upon as part of a demand response program or as a stand alone program. In both cases, load can be transferred to backup generators when peak loads are expected to exceed generation capacity. Calling upon backup generators is a load shifting strategy rather than a curtailment of load, but can help meet energy demand in emergency situations.

Distributed Generation

Climate change should be factored into network design decisions such as geographic placement of systems and the size and connectivity of units. Distributed generation relies on smaller redundant units that can back each other up, increasing the geographic diversity of energy systems, and decreasing reliance on a synchronous system of large interconnected units. All of these aspects will help manage the risk of any one unit going offline and causing a widespread system-wide failure as a result of an extreme weather event.

Decentralized electric power generation can increase system reliability, result in shorter and less widespread outages, improve power quality, reduce line losses, mitigate transmission and distribution congestion, and increase system capacity with lower transmission and distribution investment. Commercial and industrial entities can generate their own power on site. Technologies such as microturbines and fuel cells are well-suited for distributed generation, because they are small, modular, flexible in terms of location, and can be obtained with short lead time (Rosenzweig and Solecki 2001, Lovins et al. 2002). Box 4 highlights some examples of how distributed generation can both enhance resilience to climate change while also increasing competitiveness.

Box 4. Distributed Generation Can Enhance Resilience and Increase Competitiveness

- ✓ A large number of small units will have greater collective reliability than a small number of large units, assuming reliability is roughly the same for both.
- ✓ Shorter construction periods reduce the probability that reality differs from projections and, thus, reduces financial risk from overbuilding.
- ✓ Smaller units reduce the risk of investing in a technology that becomes obsolete by the time it is installed and fully operable.
- ✓ Shorter lead times reduces the risk of changes in regulatory rules during construction or shortly thereafter.
- ✓ Smaller, more modular units can better adapt to and more cheaply guard against future uncertainty, thus offering less costly and more flexible options to planners.
- ✓ Many distributed resources do not use fuels and avoid the costly risk associated with volatile fuel prices.

(Lovins et al. 2002)

Hardening transmission and distribution lines to respond to greater risk can be expensive (IPCC 2001b). Distributed generation may provide a less costly alternative to enhance the resilience of energy systems and maintain a competitive edge.

Conclusion

This paper introduces some of the impacts of climate change on the energy sector, a basic framework for assessing climate risk, and a sampling of options to consider in order to enhance system resilience and maintain global competitiveness. Other adaptation options could and should be considered. For example, network design planning efforts could also consider the use of underground cabling and development of new materials that resist short circuits. The examples introduced in this paper illustrate, however, that existing decisions and choices could aid in adapting to future climate change. It is not too early to start thinking about the impact climate change may have on existing systems and how to better equip them to withstand those impacts. The first step towards addressing climate change is to conduct a vulnerability assessment to determine how exposed the system is to climate change, how sensitive the energy system is to climate change, and the degree to which the infrastructure, practices, and processes underlying the system can be adjusted to offset the risks posed by climate change. Once key vulnerabilities are identified, options for modifying the infrastructure, practices, and processes can be considered to adapt to anticipated and unanticipated changes. It is time for energy companies to begin to address the physical impacts of climate change as a matter of prudent risk management. Taking steps to adapt to climate change will also help to ensure that their customers will not face the inconveniences or possibly even life-threatening consequences of system and service disruptions.

References

Burton, Mark L. and Michael J. Hicks. 2005. “Hurricane Katrina: Preliminary Estimates of Commercial and Public Sector Damages,” Huntington, WV: Marshall University Center for Business and Economic Research.

Darmstadter. Joel. 1993. “Paper 5. Climate Change Impacts on the Energy Sector and Possible Adjustments in the MINK Region,” *Climatic Change* 24: 117-129.

Edison Electric Institute. 2006. “Highlights of EEI Member and Non-Member Residential/Commercial/Industrial Efficiency and Demand Response Programs for 2006,” Available at: [http://www.eei.org/industry_issues/retail_services_and_delivery/wise_energy_use/programs_and_incentives/progs.pdf], Accessed November 21, 2006.

Entergy. 2006. “Teamwork Louisiana Newsletter,” Available at: [http://www.entergy-louisiana.com/content/Economic_Development/docs/Spring_2006.pdf], Accessed November 21, 2006.

Consumer Energy Council of America. 2006. “Distributed Energy Forum,” Available at: [http://www.deforum.org/economic.htm], Accessed November 21, 2006.

Energy Association of New York State. 2006. “Transmission Lines in NYS: Brief Description and Facts,” Available at: [http://www.energyny.org/index.cfm?CFID=905459&CFTOKEN=43499073&c=10038&a=10104], Accessed November 22, 2006.

IPCC (Intergovernmental Panel on Climate Change). 2001a. “Climate Change 2001: The Scientific Basis,” Geneva: IPCC.

IPCC. 2001b. “Climate Change 2001: Impacts, Adaptation, and Vulnerability,” Geneva: IPCC.

Kirkinen, Johanna, Antti Martikainen, Hannele Holttinen, Ilkka Savolainen, Osmo Auvinen and Sanna Syri. 2005. “Impacts on the energy sector and adaptation of the electricity network business under a changing climate in Finland,” FINADAPT Working Paper 10, Finnish Environment Institute Mimeographs 340, Helsinki , 36 pp.

Leahy, Kevin, Robert McElfresh, and John Stowell. 2004. “Air Issues: Report to Stakeholders, Cinergy Corp.,” Available at: [http://www.pewclimate.org/companies_leading_the_way_belc/company_profiles/cinergy/], Accessed November 10, 2006.

Lovins, Amory B., E. Kyle Datta, Thomas Feiler, Karl. R. Rábago, Joel Swisher, André Lehmann, and Ken Wicker. 2002. “Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size,” Snowmass, CO: Rocky Mountain Institute.

Mendelsohn, Robert, Wendy Morrison, Michael E. Schlesinger, and Natalia G. Andronova. 2000. “Country-Specific Market Impacts of Climate Change,” *Climatic Change*, 45: 553-569.

Mendelsohn, Robert. 2000. “Efficient Adaptation to Climate Change,” *Climatic Change*, 45: 583-600.

PG&E Corporation. 2006a. “Climate Change Policy Framework,” Available at: [http://www.pge.com/about_us/environment/features/climatechange.html], Accessed November 10, 2006.

PG&E Corporation. 2006b. “Global Climate Change: Risks, Challenges, Opportunities and a Call to Action,” Available at: [http://www.pge.com/about_us/environment/features/climatechange.html], Accessed November 10, 2006.

Rosenthal, Donald H and Howard K Gruenspect. 1995. “Effects of Global Warming on Energy Use for Space Heating and Cooling in the United States,” *Energy Journal*, 16: 2, 77-97.

Rosenzweig, Cynthia and William D. Solecki, Ed. 2001. "Climate Change and a Global City: The Potential Consequences of Climate Variability and Change, Metro East Coast Regional Assessment," A Report of the Columbia Earth Institute, Center for Climate Systems Research, Columbia University, Prepared for the U.S. Global Change Research Program, Available at: [http://ccsr.columbia.edu/cig/mec/index.html], Accessed November 10, 2006.

Scott, M.J., L.E. Wrench, and D.L. Hadley. 1994. "Effects of Climate Change on Commercial Building Energy Demand," *Energy Sources* 16:317–332 as referenced in Rosenzweig and Solecki (2001).

Smith, Joel B. and Dennis Tirpak, Ed. 1989. "The Potential Effects of Global Climate Change on the United States," Report to Congress. U.S. EPA Office of Policy, Planning, and Evaluation, EPA-230-05-89-050.

Tol, Richard S.J. 2001. "Estimates of the Damages Costs of Climate Change," *Environmental and Resource Economics*, 21: 47–73, 2002.

Stern, Nicholas. 2006. "Stern Review on the Economics of Climate Change," Pre-publication edition Available at: [http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm], Accessed November 10, 2006.

U.S. EPA. 2006. "Clean Energy-Environment Guide to Action," Available at: [http://www.epa.gov/cleanrgy/stateandlocal/guidetoaction.htm], Accessed November 21, 2006.

York, Dan, Martin Kushler, and Patti White. 2007. "Examining the Peak Demand Impacts of Energy Efficiency: A Review of Program Experience and Industry Practices," ACEEE Report Number U072.