ADAPTING TO CLIMATE CHANGE:
Planning for Resilient Energy Systems

Susan Asam, Anne Choate
ICF International

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 evidence indicating that climate change is a real and serious problem continues to mount, and a growing 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 service 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 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 melting ice caps and sea level rise, increased incidence of diseases, more extreme weather events, and changes in agriculture, among other impacts (IPCC 2001a).

Climate changes such as higher temperatures, more frequent and 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 contribution to climate change and options for reducing GHG emissions are frequently discussed. There has been little discussion or thought, however, about how energy service providers will be impacted by climate change and policy options for ensuring that systems are resilient to those changes.

Savvy energy service providers should be knowledgeable about the threats posed by climate change and consider strategies to adapt to predicted changes. Proactive energy managers could enhance system resilience to climate change by factoring climate impacts into decisions regarding demand-side management programs, system design, and infrastructure investments.

This paper discusses the impacts of climate change that are likely to be of concern to energy service providers. It then provides recommendations regarding existing policy options that could help enhance energy system resilience in the face of a changing climate.

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 the magnitude of the increase in summer temperatures and the full suite of impacts that these changes will have on the energy system will be challenging. Climate modeling is still fraught with uncertainty and 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

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 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.

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.

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 frequent and extreme storms with high winds and precipitation, which, in turn, may cause more frequent 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 frequent and extreme storm events (Rosenzweig and Solecki 2001).

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

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).

Other climate change impacts

Other climate change impacts are likely to affect energy systems in addition to the major categories of 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. More research into the impacts of climate change on the energy sector will need to be conducted as it is increasingly factored into 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 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 the 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 effects 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 increased variability in water supply. 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.

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.

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, adaptation is imperative. Adaptation exists in many forms, ranging from anticipatory to reactive, private to public, and autonomous to planned adaptation (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).

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.

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, they will need to factor climate change into the equation not just for environmental reasons. It is also a matter of prudent risk management for decision makers to consider the risks that climate change poses and possible means for adapting to those risks. 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).

Adaptation options

Actions to adapt to climate change can and should be undertaken by numerous actors beyond energy service providers. For example, the building industry could design buildings to maximize natural ventilation and cooling or incorporate better insulation into existing buildings. Urban planners can reduce urban heat island effects by limiting the use of pavement and promoting the use of green roofs. Governments could adopt new building codes to increase building efficiency. This paper presents a sampling of some of the actions that energy service providers could consider, as well as actions that may already be underway for reasons unrelated to climate change.

Some decisions will be more sensitive to climate change than others, and some will have more flexibility to be adjusted in response to or in anticipation of climate change. Decisions regarding programs to manage energy demand, system design, and infrastructure investments, which are all likely to be good candidates for incorporating consideration of climate change, are discussed below.

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 growing number of states are taking energy efficiency actions by establishing energy efficiency portfolio standards, public benefit funds for energy efficiency, building codes for energy efficiency, and state appliance efficiency standards (Table 1). These policy measures can help encourage businesses and consumers to change their behaviors and provide energy service providers with implementation support in the form of information, technical assistance, and funds. While climate change adaptation is unlikely to drive decisions to implement energy efficiency programs, energy systems will benefit from the resulting decrease in energy demand that will free up system capacity.

Table 1. Summary of Selected State Energy Programs

State	Energy Efficiency Portfolio Standards	Public Benefit Funds	Demand Response Programs	Interconnection Standards for Distributed Generation
AL				
AK				
AZ		✓		✓ (c)
AR				
CA	✓	✓	✓	✓
CO			✓	
CT	✓	✓	✓	✓
DE				✓
FL			✓	
GA			✓	
HI	✓ (a)			✓
ID			✓	
IL	✓	✓	✓	✓ (c)
IN			✓	✓
IA			✓	✓ (c)
KS			✓	
KY			✓	
LA				
ME		✓		
MD			✓	
MA		✓		✓
MI		✓	✓	✓
MN			✓	✓
MS				
MO			✓	
MT		✓		

State	Energy Efficiency Portfolio Standards	Public Benefit Funds	Demand Response Programs	Interconnection Standards for Distributed Generation
NE			✓	
NV	✓ [a]		✓	
NH		✓	✓	
NJ	✓ [b]	✓	✓	✓
NM				✓
NY		✓	✓	✓
NC				✓ [c]
ND			✓	
OH		✓	✓	✓
OK				
OR		✓	✓	
PA	✓ [a]		✓	✓ [c]
RI		✓	✓	
SC				
SD			✓	
TN				
TX	✓	✓		✓
UT				
VT		✓		✓ [c]
VA			✓	
WA			✓	✓ [c]
WV				
WI		✓	✓	✓
WY				
DC		✓		

[a] Indirect Standards
[b] Program under development
[c] Proposed Rules
Sources: U.S. EPA (2006), Edison Electric Institute (2006)

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. They 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).

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.

Conclusions

This paper provides only a sampling of some of the impacts of climate change on the energy sector and possible options to consider in order to enhance system resilience. 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 the 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.

A few energy service providers are already implementing some of the recommended options listed above. Pacific Gas and Electric (PG&E) issued a climate change policy framework in May 2006, which states that they will lead by example with regard to climate change. Among other steps that they plan to take, they list "developing and investing in robust customer energy efficiency programs" and "identifying and pursuing alternative ways to generate, procure and deliver vital energy resources, including renewable energy and clean, distributed technologies" (PG&E 2006a)—two actions that will also help them to adapt to a changing climate.

The first step for energy service providers interested in addressing the issue of 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 the key vulnerabilities are identified, options for modifying the infrastructure, practices, and processes can be considered to adapt to anticipated and unanticipated changes.

Proactive energy service providers who begin to address this issue now can help to ensure that their customers will not face the inconveniences of power outages, that they will not be held accountable for public health crises, and that their infrastructure investments will not be damaged or destroyed.

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