Saving Electricity Quickly

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ABSTRACT

Temporary shortfalls of electricity supply can occur as a result of a drought, a heat wave, a breakdown in a power plant or partial loss of transmission capacity. The traditional response has been to cut power to customers while trying to restore supplies but blackouts may be economically and politically unacceptable if the shortage is expected to continue more than a few hours. An alternative approach is to launch an aggressive program to quickly conserve electricity relying on a combination of measures to improve energy efficiency and change consumer behavior. Several regions, including Brazil, California, New Zealand, and Norway have recently implemented such programs. It is possible to quickly reduce electricity demand 3 – 20%, sometimes with programs started in only a few months. Moreover, the reductions in demand can be accomplished without major economic disruption or hardships.

These results (and the policies that achieved the savings) are important because temporary shortfalls in electricity supply are likely to occur more often. De-regulation and market liberalization have led to reduced reserves and safety margins through the whole electricity supply chain. This, in turn, makes the electricity supply system more vulnerable to unusual weather events or other disruptions. Global climate change, appearing in the form of increased weather variation, is likely to provide these disruptions.

Temporary Electricity Supply Shortfalls

Almost every part of the world has faced a temporary shortfall in electricity supply at one time or another. Such shortfalls—which occur with advance warning of hours to years—might occur as a result of reduced hydroelectric supplies caused by a drought, a breakdown in a power plant, a heat wave, or partial loss of transmission or distribution capabilities. During these crises the infrastructure to deliver electricity to the customer remains intact but the utility cannot supply as much power as the consumers wish. The end of the crisis is generally known, that is, the rains replenish the reservoirs, the power plant is repaired, the heat wave abates, or full transmission capability is restored.

Utility planners and government officials treat the demand for electricity as mostly fixed. When a small or brief shortfall occurs, the utility can drop some industries operating with interruptible contracts and perhaps wring additional reductions through Demand Response programs (IEA 2003), but what happens when these cuts are insufficient? To many planners familiar only with the supply side, blackouts are the only solution. Is it possible to rapidly cut electricity demand—at least temporarily—without causing lasting economic or environmental damage? Many regions have encountered shortfalls and successfully avoided blackouts through rapid-response conservation programs. Saving electricity "in a hurry", however, differs in many respects from traditional conservation programs geared towards "saving electricity slowly."

Reviewing the experience from recent shortfalls is doubly important because environmental and economic trends are likely to increase the frequency of electricity shortfalls.

Examples of Temporary Electricity Shortfalls

California's electricity shortfall in 2001 is perhaps the most famous recent electricity crisis but others have occurred in the last decade. Table 1 lists a few of the most recent shortages and their causes. For example, in 2002-03 Norway experienced a drought followed by a cold wave, severely depleting its hydro reserves. In the summer of 2003, Tokyo narrowly avoided blackouts after the utility took all its nuclear power plants off line for safety reasons.

The shortfalls listed in Table 1 demonstrate the diversity of causes. Unusual weather events, such as droughts, heat waves, cold waves, and floods, are a major cause. However, mechanical failures or safety threats were also responsible. Some shortfalls were either caused or exacerbated by de-regulation. The shortfalls nevertheless have two common physical features: first, the infrastructure to deliver electricity to the customers was still basically intact; and, second, the *duration* of the shortfall was reasonably certain (that is, the cold wave will end, the rains will start, the transmission line will be repaired, etc.). Most of the shortfalls were expected to last only a few months, though some were as brief as a few hours (when the heat wave abated) or as long as a year.

As indicated earlier, the goal of rapid-response conservation is to avoid blackouts. But it is often necessary to save electricity after a blackout, too. Systems with a heavy reliance on nuclear power are especially vulnerable because nuclear plants take longer to return to service than fossil-fired plants. In the case of the Ontario (and Northeast USA) blackout, five of Ontario's twelve nuclear plants were still off line one week after the blackout. In contrast, the majority of the fossil plants returned to service within 24 hours (Fraser 2003).

Electricity shortfalls such as those listed in the table will increase in frequency and possibly in severity. De-regulation and market liberalization have caused many utilities to reduce generating reserves and transmission capacity. Operators of fuel supply networks, such as pipelines, oil storage facilities, coal transport, etc., have also sought to operate with smaller reserve margins. The result of these actions is an increased vulnerability to disruptions throughout the electricity supply system. Global climate change could have an impact, too. Climate change is likely to manifest itself first by greater and more frequent variations in weather patterns (even if mean values change only slightly) (Easterling *et al*. 2000; IPPC 2001). These fluctuations translate into more droughts, heat waves, cold waves, floods, and other triggers to short-term electricity crises. The urban heat island phenomenon will amplify the electricity impacts of heat waves in regions with major air conditioning needs.

Table 1. Examples of Temporary Shortfalls

Country & Date	Immediate Cause of Shortfall	Other Related Aspects
Chicago, USA, 1995	Heat wave caused high electrical demand on over-taxed transformers	Failure to renew infrastructure
Southern Australia, 1998	Explosion at gas production facility limited gas supplies to power plants	Possible market manipulation
Brazil, 2001	Drought and economic upturn causing increased demand	Partial de-regulation failed to increase electricity supplies
Sweden, 2001	Anticipated cold wave combined with expected high demand on Monday	De-regulation led to mothballing of peak plants
California, 2001	High number of plants out of service, reduced imports	Incomplete de-regulation, shortage of natural gas, drought in nearby areas, market manipulation by independent generators
New Zealand, 2001	Drought	
Auckland, New Zealand 2001	Transmission line cut	
Tokyo, 2003	Nuclear plants shut down	Utility admits to preparing inaccurate safety reports. Severely limited connections to neighboring utilities.
Presque Isle, USA, 2003	Flood damages cooling system of power plant	Remote location prohibits substitution via transmission
New Zealand, 2003	Drought	Uncertainty surrounding de-regulation discouraged construction of new generation capacity
Norway, 2003-2004	Drought, early and unusually cold winter	Reduced oversight of supplies after de-regulation
Ontario, 2003	Slow re-start of nuclear power plants following US/Canada blackout	Occurred during situation of long-term supply shortfall
Italy, 2003	Heat wave combined with unexpected reduction in imports	Failure to build new generating capacity for many years. Coincided with reduced availability of power from Germany wind farms
France, 2003	Heat wave and drought led to increased demand and reduced output	Occurred during period when many nuclear plants were shut down for maintenance. Other plants could not operate because thermal limits in rivers had been exceeded.
Southern California, 2003	Forest fire interrupted transmission	

Policies to Encourage Saving Electricity Quickly and Slowly

Policies to save electricity quickly differ from traditional energy efficiency policies to save electricity slowly. First, only a temporary reduction in electricity demand is needed; after the crisis is over, demand can return to earlier levels and the efforts will still be considered successful. Failure to achieve that reduction may lead to immediate economic dislocation or hardship.

Second, behavioral measures to reduce electricity demand will be relatively more important during temporary shortfalls. There will typically be insufficient time or delivery infrastructure to install technical efficiency improvements to achieve large reductions.

Third, energy prices will play a more limited role during a temporary shortfall. There may be insufficient time to adjust prices because of regulatory delays or logistical problems to delivering new bills to customers. For example, many regions deliver utility bills every two months, so customers will not see increased prices until the shortfall is well underway (or even passed). European utilities read residential meters only once a year and provide estimated bills for the rest of the year. Thus, customers will not see any indication of their conservation efforts until many months have passed. France's "tempo" residential tariff schedule—which allows the utility to impose a rate roughly ten times higher than normal for at most 22 days per year—could not be activated because it targeted only winter heating peaks (EDF 2004). Demand Response programs, while still important, will probably be unable alone to help the market clear if the shortfall exceeds the zone of price elastic response.

Finally, the shortfalls may become highly politicized and will require different policies. Ministers of energy, governors of states, and presidents of utilities have lost their jobs for failing to fix the crises. In Norway, electricity rates rose fourfold in a matter of weeks. The sudden increase—whose impact was exacerbated because it occurred during an unusually cold winter—quickly shifted the problem to the political arena.

Policymakers must make decisions with less reliable information during a crisis. Few regions maintain accurate breakdowns of electricity by end use, so it is easy to promote measures that will not significantly alleviate the problem. For example, Tokyo Electric Power Company initially targeted electricity savings among residential groups until newspapers pointed out that these groups were not major electricity users during the critical hours of peak demand. Policymakers in New Zealand probably confused energy and power when they appealed to consumers to manually switch off their electric water heater storage tanks for parts of the day (because this measure did little to alleviate their energy crisis). Policies to save electricity quickly are necessarily more *ad hoc* because targets with the largest potential may not be the most susceptible to rapid change.

Measures to Save Electricity Quickly

There are two ways to save electricity quickly. First, efficiency improvements can be made to the energy-using equipment such that consumers receive the same services but with less electricity consumed. (These are sometimes called "technical fixes") In these situations the end user is barely (or not at all) aware that improvements have been made. In the second case, the energy consumer takes deliberate measures to reduce energy use through changes in operations or procedure which may also cause inconvenience and result in a loss of service or amenity. These are typically called "behavioral" changes.

Technical Efficiency Measures

The technical measures to save electricity quickly are similar to those used to save electricity slowly except that they may be implemented with greater intensity by combining them with special subsidies or delivery schemes. Three examples are described below.

Retrofits—especially retrofits of large, energy-using facilities—are attractive targets during an electricity crisis. About 8% of industrial electricity is used to make compressed air, much of which is lost through leaks (Rosenberg 2003). The compressed air systems therefore represent a source of major savings. California supported inspections and tune-ups of compressed air facilities in factories. Retrofits of eight factories yielded verified savings of 2 MW.

Lighting replacements have been the most frequently used retrofit strategy. Replacing incandescent light bulbs with compact fluorescents (CFLs) was used in Brazil, California, and New Zealand. California consumers installed nearly eight million CFLs during the crisis period, resulting in almost 500 MW of demand reduction (Pang 2003). California cities replaced millions of traffic lights with LED lamps, each saving about 80 watts. California aggressively encouraged consumers to replace older appliances with new units qualifying for the Energy Star endorsement of high efficiency.

Fuel switching offers large electricity savings. Electricity is often used to heat air or water, especially in the residential sector and in sparsely populated areas. There are numerous opportunities to burn wood, oil, or natural gas directly to obtain the desired heat. Homeowners in Norway and New Zealand, for example, reverted to existing wood stoves and boilers for space and water heating. Fuel switching is an important electricity-savings measure because it removes the homes' largest electricity-consuming end uses. The greatest benefits from fuel switching will generally occur during shortages caused by cold weather but some measures can also save summer peak power. For example, Brazilians replaced in-line electric shower heaters with gas-fired units, thus saving about 3 kW electrical demand per unit.

Effectiveness of Technical Measures

Technological modifications require an existing infrastructure in order to deploy the products in a short time, stretching from the manufacturer capable of quickly expanding production to skilled personnel to install them. In most cases, there will not be enough time, or the infrastructure is inadequate, to establish new efficiency improvement and retrofit programs large enough to reduce demand significantly. Norway, for example, addressed its electricity shortage by establishing programs to install heat pumps, energy management systems, and wood pellet stoves. Skilled personnel were overwhelmed and it is unlikely that these measures cut Norway's electricity demand during the crisis. On the other hand, California already had an established network to deliver its "saving electricity slowly" programs. This network, while still inadequate, was able to rapidly increase activities during the crisis and deliver significant electricity savings. Regions that are vulnerable to temporary electricity shortfalls should consider their programs to "save electricity slowly" as a kind of insurance policy that will also serve as the backbone of a team to save electricity during a crisis.

Policies to Induce Changes in Behavior

The difficulty in deploying technological measures creates an even greater reliance on measures to temporarily change consumer behavior. The tool to accomplish these changes has usually been a centrally-coordinated media campaign, combined with other activities and policies to reinforce the message. The key steps to successful programs are described below.

The ultimate goal is to convince consumers to adopt—and maintain for the duration of the crisis—behaviors that will reduce electricity use but intermediate goals are often needed. First, the consumers need to be convinced that a crisis truly exists. Consumers often attributed the problem to de-regulation. In Norway, New Zealand, and Brazil, it was easier to convey the message by depicting empty reservoirs. But especially in California and Tokyo, information campaigns first needed to overcome widespread skepticism because many customers felt that the crisis was artificial.

Next, the solution to the crisis needs to be linked to individual behaviors. Both California and New Zealand adopted goals for individual consumers and schemes to reward those who surpassed the goals. The California plan called for a 20% savings so as to achieve a 20% bill rebate, while New Zealand's "10 for 10" plan simply called for consumers to reduce electricity demand 10% for 10 weeks (until the rainy season was expected to begin). Brazil's plan was more draconian: it *required* 20% reductions (compared to the previous year) by all customers or face shut-off of electrical service.

Third, the consumers needed to be educated as to which conservation measures were effective. Media campaigns tried to distill the long list of possible measures into a short list that consumers could remember and implement. Technology options—such as CFL replacements—can reinforce the conservation messages presented in the campaign.

Fourth, campaigns sought to sustain consumer commitment by bombarding them from different directions. Humor played an important role in television and print advertisements exhorting conservation in Norway, New Zealand, Brazil, and California (but was mostly absent in Tokyo). Brazil started competitions between communities to see who could save the most. Brazilian television stations also displayed the reservoir levels every evening. California and Tokyo created websites to allow consumers to follow electricity supplies and demand in real time (TEPCO 2004; CAISO 2004; LBNL 2004). At the same time, symbolic conservation actions by high-profile customers—such as grocery stores and fast-food outlets—ensured that consumers could not escape reminders of the crisis. (These symbolic measures saved electricity, too.)

Programs to save electricity through changes in behavior have the advantage that they can be implemented almost immediately. The Swedish utility realized on a very cold Friday that it would not have sufficient capacity to meet the extra demand anticipated by an even colder Monday and higher industrial demand at the start of the workweek (Forsman 2002). It issued an appeal to consumers to withhold demand on Monday (which they did). California's 20-20 plan and Brazil's rationing scheme were conceived and introduced in only a few weeks and media firms have experience developing whole advertising campaigns in a matter of days. But the size and persistence of the energy savings is less certain than for technical measures. The best mix of measures for a specific supply shortfall will depend on the type of shortfall (capacity versus energy), extent of advance warning, and expected duration.

Exceptional Measures to Conserve Electricity

Some conservation measures only become apparent in the face of a crisis. For years Brazil had high inflation rates, sometimes exceeding 40%/month. Brazilians adopted a strategy of buying all their groceries as soon as they received their paycheck and before the money became worthless. Millions bought freezers to store the food until their next paycheck. By the time of the electricity crisis inflation had fallen to levels not requiring such extreme measures and normal shopping patterns returned. Most consumers kept their freezers even though they did not need them anymore. The authorities urged consumers to switch off freezers when the electricity crisis began. Millions of Brazilians ceased using freezers. Consumers often saved 20%—the electricity reduction demanded by the government—by this measure alone.

Industries with fixed, long-term electricity contracts can be critical sources of conserved electricity during a crisis if they are allowed to re-sell their electricity at market rates. Aluminum smelters and other minerals operations in Norway, New Zealand, and the Pacific Northwest freed-up huge amounts of electricity and possibly contributed the difference between disaster and squeaking through. In the Pacific Northwest, for example, nearly 5 GW were made available, equal to California's total conservation effort (McAuliffe 2003).

Results

Regions with aggressive conservation programs achieved savings of 3-20% after as little as only a few days of operation (see Table 2). In most cases, the programs avoided blackouts almost entirely.

Table 2. Summary of Estimated Electricity Savings

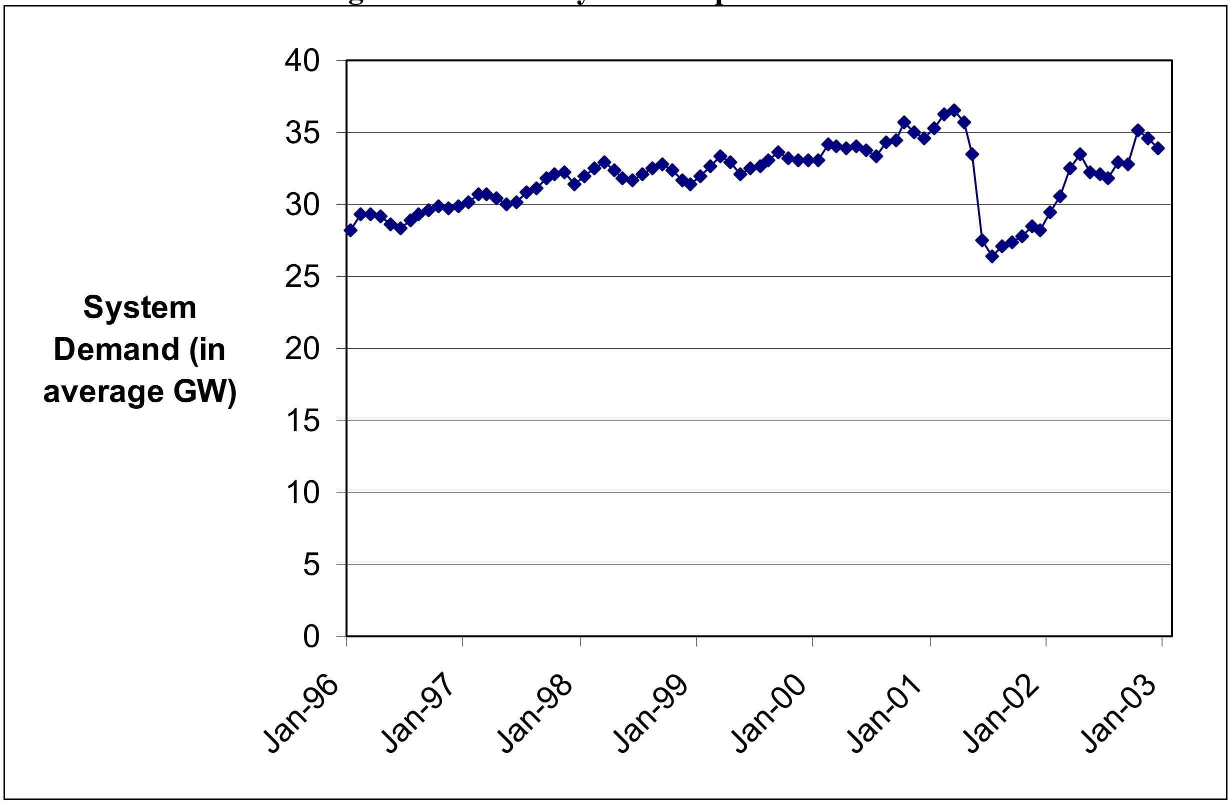
Location	Savings
Brazil	**20%***
California	**15%**
New Zealand	**10%***
Norway	**8%***
Sweden	**4%***
Tokyo	**3%***
Italy (June 2003)	**Unknown but probably very small**

* With no major blackouts

It is difficult to measure energy savings because it is the difference between the crisis period and a base period. Nearly all the estimates include a weather adjustment which introduces an element of uncertainty. Tokyo, for example, had one of its coolest summers in history during the crisis, so the weather adjustment is likely to introduce considerable uncertainty. California's savings are for peak demand because cutting the peak was the principal program target; the overall electricity savings were nevertheless above 10%.

The largest savings appeared to have occurred in Brazil. The rapidity and persistence of the conservation program are demonstrated in Figure 1.

Figure 1. Electricity Consumption in Brazil

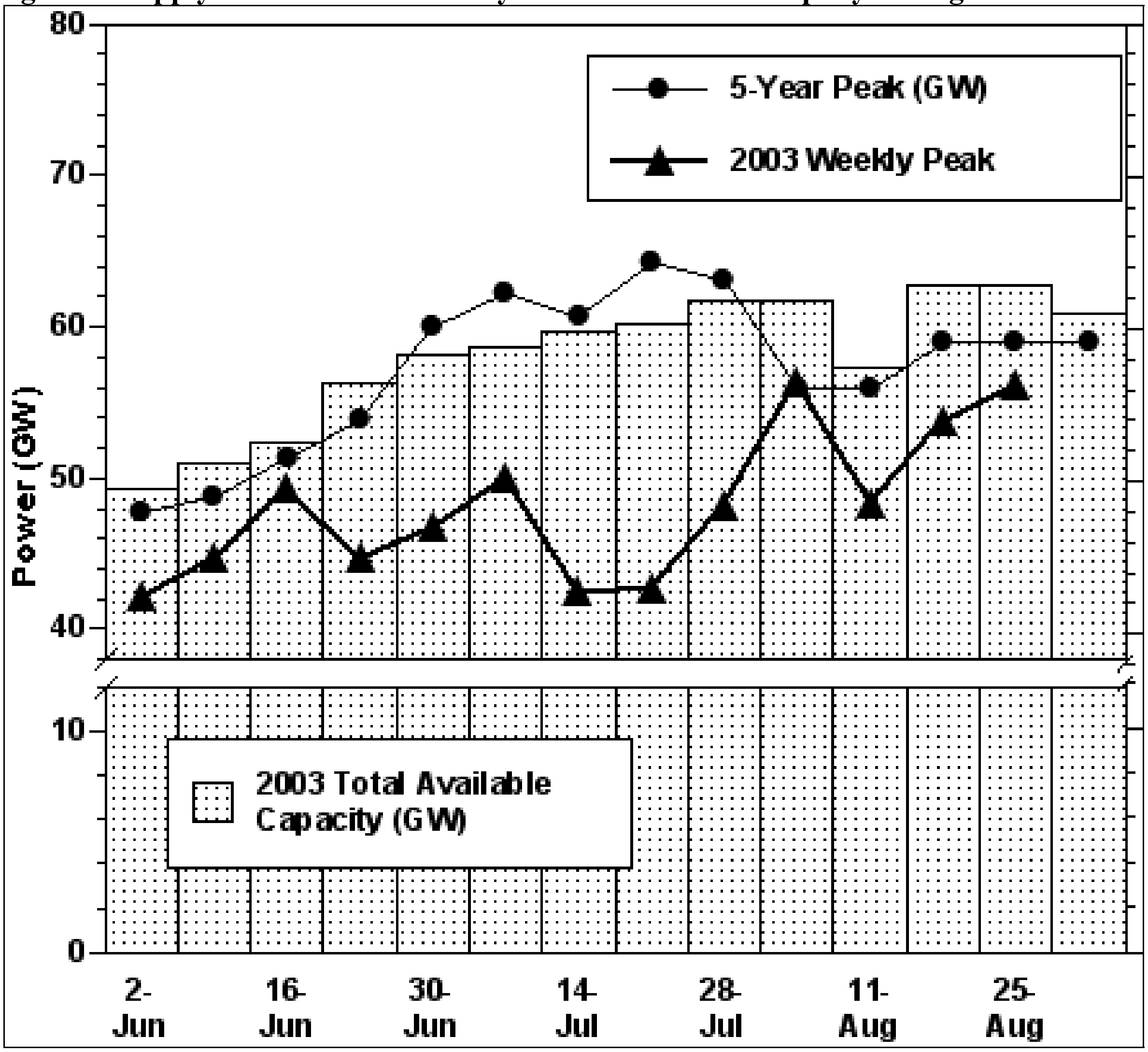


Source: Almeida 2004

At 3%, the savings in Tokyo were among the smallest achieved. Some evidence suggests that actual savings were larger (and were possibly hidden by the unusually cool summer) (The Japan Times Online 2003). These modest savings may nevertheless have prevented blackouts. Figure 2 shows the course of the electricity supply and demand during the summer of 2003. For most weeks, TEPCO had sufficient capacity to meet demand. However, for the week of 16 June, the energy savings roughly equaled the difference between actual demand and available capacity; without conservation, a blackout may have occurred.

These results do not reveal two important aspects of the electricity crises. First, how much did the conservation programs cost? Some data are available for direct government expenditures but these costs are probably dwarfed by individual and corporate investments that were in part stimulated by the government programs. Second, these results do not indicate the extent to which normal economic activity continued during this period. This would not have been possible if blackouts had occurred. The experiences in Italy stand in contrast to those in countries with successful conservation programs. There, large industrial customers periodically (and without warning) lost power. When these demand reductions were insufficient, regions were randomly and without warning blacked out—"spots of the leopard" in Italian—causing widespread confusion and inconvenience. California experienced limited blackouts in the months leading up to the major crisis period. These events gave a preview to the chaos and economic losses that would occur in the event of widespread blackouts.

Figure 2. Supply and Demand for Tokyo Electric Power Company during Summer 2003



Source: TEPCO 2003

What happens when a *second* shortfall occurs soon after the first? Will the public be motivated to again conserve? New Zealand is perhaps the only country that has endured two once-in-a-century droughts in four years (leading to electricity supply shortfalls). The savings during the second crisis were actually larger than in the first; however, this improvement may also be attributed, among other things, to a more sophisticated media campaign and greater price flexibility in electricity pricing.

Conclusions

The temporary shortfall in electricity supply is a distinct phenomenon and each region's experience is unique. Nevertheless, the combined results from several regions have demonstrated that it is possible to reduce electricity demand quickly for short periods. These regions achieved reductions ranging from 3–20%. Estimates of net benefits and costs are not available; however, the reductions in demand were typically accomplished without major economic disruption or hardships.

These results (and the policies that achieved the savings) are important because temporary shortfalls in electricity supply are likely to occur more often. De-regulation and market liberalization have led to reduced reserves and safety margins through the whole electricity supply chain. This, in turn, makes the electricity supply system more vulnerable to unusual weather events or other disruptions. Global climate change, appearing in the form of increased weather variation, is likely to provide these disruptions.

Policies to reduce electricity demand quickly are no substitute to fixing the problems on the supply side. However these policies provide time for those repairs to occur while protecting the economy from permanent damage.

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