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CLIMATE CHANGE AND EXTREME CLIMATE EVENTS:

VULNERABILITY AND ADAPTATION OF THE CANADIAN ENERGY SECTOR

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ABSTRACT: There are two specific "reasons for concern" for the stakeholders of the Canadian energy sector about the seriousness of climate change impacts. They are the relationships between the global mean temperature increase and the distribution of impacts; and the probability of extreme weather events. Energy production, supply and demand are sensitive to climatic variability and change and sea level rise in Canada. Power generation, transmission and distribution components of the energy sector are presently vulnerable to extreme weather events. Power output loss due to low lake levels in 1964 was estimated at 4.4 million megawatt hours. During the ice storm of 1998, power transmission and distribution suffered a total insured loss estimated at CAN$3 billion. The damage to high voltage transmission towers, distribution systems and transformers raised serious questions about the robustness of the power distribution systems in Ontario and Québec. In general, the measures to cope with the situations were found to be inadequate. In the future, there are possibilities of more heat waves, ice storms and drought conditions in Canada due to climate change. Therefore the energy sector may become more vulnerable unless adequate adaptation measures are designed and implemented.

Keywords: climate change, adaptation, energy, water levels, ice storm

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) indicated about possible changes in climate and increases in extreme weather events in the future (IPCC, 2001). The sensitivity of the Canadian energy sector to future changes in climate and climate extremes may be more pronounced. Mirza (2004) discussed the major impacts of climate variability and change on various components of the Canadian energy sector. Energy production, supply and demand are sensitive to climatic variability and change, and sea level rise. With changes in precipitation and lake levels, hydro-electric power generation may be affected across Canada.

Available assessments show that future warming will reduce heating energy demands in the winter. On the other hand, cooling energy use in the summer will increase. A rise in sea level and possible increases in the number of extreme weather events (such as high winds and storm surges) may cause adverse effects on the offshore oil industry in terms of damage to platforms and riskier investments. Increased winter storms may cause serious damage to transmission and distribution of electrical energy. Coastal energy supply infrastructure may also be impacted as a result of storm surge and sea-level rise. Changes in permafrost in northern Canada will cause stability problems for fossil fuel transmission pipelines. High summer temperatures may reduce transmission capabilities although the magnitude of such a reduction is not known. Extreme events such as severe winter or summer storms can cause extensive damage to power transmission lines and other infrastructure.

The future vulnerability of the Canadian energy sector to changes in climate and extremes is highly dependent on its present state. It is therefore necessary to assess the present vulnerability and performance of the measures to adapt to climate change and climate extremes. It is also necessary to examine potential adaptation measures that will help reduce vulnerability. This paper addresses these in two steps. First, two extreme climate events are selected and vulnerability of the energy sector and the adequacy of adaptation measures are analyzed. Second, a range of adaptation options are suggested to reduce the sensitivity of key assets to changes in climate and extremes, designing resilience and flexibility into the energy infrastructure on appropriate time scales, and managing energy systems and institutions in a climate-resilient manner.

2. Extreme Weather Events and Vulnerability of the Canadian Energy Sector: Two Case Studies

2.1 Case Study: Ice Storm 1998

Eastern Canada (Québec, Ontario and the Maritimes) is susceptible to ice storms – the result of the ice formation process greatly influenced by general weather patterns. The ice storm which hit eastern Canada in 1998 was the worst in recent history. Three previous storms are well documented During the ice storm of February, 1961, the Montreal area was without power for several days, and the estimated damage was CAN$41 million in 1998 dollars (CAN$7 million in 1961) (Mahaffy, 1961). The March, 1972 ice storm affected the Ottawa Valley and the Laurentian foothills (Chaîné, 1973). Damage was estimated at CAN$6 million (CAN$1.5 million in 1972 dollars) and included 900 fallen wooden hydro poles (Chaine and Skates, 1974; Bergeron et al., 1997). During the December, 1983 ice storm, southwestern Québec was plunged into darkness. The ice storm deprived half a million Montreal residents of power for a period of at least 36 hours (Bergeron et al., 1997).

Milton and Bourque (1999) analyzed precipitation data to identify areas in Canada susceptible to freezing precipitation (see Table 1). The analysis shows the highest days of freezing precipitation occur in Newfoundland followed by Québec. In the case of Newfoundland, this is due to the formation of freezing drizzle initiated by frequent contact of cold air masses with the Atlantic Ocean (Phillips, 1990). Western Canada is only moderately susceptible to freezing precipitation.

The 1998 ice storm inflicted heavy damage to the transmission and distribution infrastructure of the power sector in the Canadian provinces of Québec, Ontario, New Brunswick and Nova Scotia. Table 2 demonstrates the damage that occurred during the ice storm.

Table 1 Average annual number of days with freezing precipitation for the period 1961-1990.

CITY	MEAN ANNUAL NUMBER OF DAYS
Gander, Newfoundland	51
St. John’s, Newfoundland	36
Halifax, Nova Scotia	19
Ottawa, Ontario	17
Vald’Or, Québec	16
Québec City, Québec	15
Montreal/Dorval, Québec	13
Bagotville, Québec	13
Saint-Hubert, Québec	12
Shefferville, Québec	12
Winnipeg, Manitoba	12
Sherbrooke, Québec	10
Toronto, Ontario	10
Sept-Îles, Québec	9
Mont-Joli, Québec	8
Edmonton, Alberta	8
Vancouver, British, Columbia	1

Source: Milton and Bourque, 1999.

Table 2 Damage caused to transmission and distribution lines of Hydro-Québec

VOLTAGE CLASS KILO VOLTS (KV)	NUMBER OF DAMAGED LINES	NUMBER OF COLLAPSED STRUCTURES
Transmission		
735	10	150
315	12	60
230	13	300
120	67	1,100
49	14	1,500
Total	116	3,110
Distribution		
25	350	16,000

Source: Hydro-Québec, 1998a

It appears that much of the damage was caused to the main transmission lines. Out of eleven 735 kilo Volt lines, 10 were completely damaged (91%). Lines of smaller voltage class were also damaged significantly. Comparatively, damage of distribution lines was only 12 percent. A disproportionate collapse of high voltage towers might have been due to under-designing for ice load. The highest number of collapsed structures belonged to distribution lines.

There are several factors leading to the vulnerability to ice storms of the energy sector infrastructure in Quebec including the spatial location of power lines; the overdependence on electricity as an energy source; the long distance lines that transmit energy; the design criteria of their transmission lines; the availability of climatological data; the reliance on single line transmission and; and the use of overhead transmission lines. Each factor will be addressed briefly.

In terms of the spatial location of power lines, historical losses from freezing rain and ice storm events across Canada and the United States of America occur in a band of territory that stretches from northern Texas, USA to Newfoundland, Canada. The Hydro-Québec transmission lines are a powerful high voltage network covering long distances, parts of which lie in these areas prone to heavy icing (Hydro-Québec, 1998a).

In terms of overdependence on electricity, the abundance of natural waterways and the pursuit of a 30-year-old policy of promoting electricity over other forms of energy have left Québec overly dependent on hydro-electric power (Environment Index, 2000). Québec is also close to being the most electricity-dependent jurisdiction in the world. Electricity provides over 40 percent of Québec's energy needs compared with 23 percent in other Canadian provinces. As many as 75 percent of the homes and more than 90 percent of newly built residence-depend on electric heat in Québec. Natural gas and oil, more widely used in other Canadian provinces, cannot compete against Hydro-Québec's subsidized rates.

In terms of long distance transmission lines, Hydro-Québec supplies power to Montreal, the most densely populated area in Québec, from generating stations in James Bay and Churchill Falls located as far away as 1,600 kilometers. This is not typical for North American urban centres which get most of their power from local generating facilities (Environment Index, 2000). In order to maintain required power efficiencies over such lengthy distances, Hydro-Québec operates its transmission lines at a high voltage of 735 kilo Volts. As a comparison other utilities such as Ontario Hydro operates at 500 kilo Volts, and both New England and New York operate at 345 kilo Volts. In fact, only 2 other utilities in all of the United States and Canada use the 735 kilo Volts lines and not nearly to the same extent as Hydro Québec (Environment Index, 2000). This requires heavier, more expensive cables, higher transmission towers and more space between transmission lines.

Hydro-Québec made a complete review of its design criteria for the entire province following the 1969 and 1973 major line failures caused by in-cloud icing on the Manic-Churchill lines. The ice carrying capacity of the lines was raised from 35 to 45 millimeters of radial ice (Canadian standard was 12 millimeters). In addition to radial ice, the process of transmission line failure is accelerated by high wind speeds. Design wind speed specifications for the Hydro-Québec are not known; however, Ontario Hydro uses 100 kilometers per hour for its main transmission lines (Street et al., 2002). The vast majority of energy transmission lines built in Quebec after 1976 include modified design features to help its carrying capacity. The 1998 ice storm raised several questions regarding climatalogical data such as the gathering of historical data on atmospheric icing, the reliability of the instruments used for measurement of ice accumulation, the models applied for transforming ice accumulation data into radial ice thickness, the method of producing iso-line contour maps, and the applicability of such data for line design (Hydro-Québec, 1998a). Data from Hydro-Québec and Environment Canada are of different types. Whereas Hydro Québec's ice measurements are converted into equivalent radial ice thickness, Environment Canada's measurements are expressed in equivalent liquid precipitation. While the information from both sources regarding location and geometry of the storm is consistent, these two sets of data are difficult to reconcile with respect to ice thickness.

Some regions of Québec, including urban areas, rely on a single transmission line for its electrical energy source. For example, the South Shore region along the St. Lawrence River in Quebec is served by a single line which, if put out of commission by natural processes or emergencies, will not be able to deliver electricity to these areas (*Kerry et al., 1999*). The South Shore area was severely affected when the single feeding line was lost during the 1998 ice storm.

Over 90 percent of Hydro-Québec's distribution system is not buried underground, but is overhead. This makes the power distribution system very vulnerable to natural disasters such as ice storms and tornadoes. The weight of ice accumulation on the cables could add 15 to 30 kilograms per meter to the wire.

2.2 Case Study: Low Lake Levels

The Great Lakes are the world's largest body of fresh water comprised of five lakes: Superior, Michigan, Huron, Erie, Ontario and their outlet rivers. Their water levels are of concern to hydropower, navigation, coastal landowners, and environmental interest groups. Over 820 billion kilowatt hours of hydropower are produced annually at the outlets of Lakes Superior, Erie and Ontario (Beranek, 2000). In 1964, water levels in the Great Lakes dropped to extremely low levels. This caused significant impacts on hydropower generation in Canada and the USA. In Canada, total generation in the Niagara Falls and St. Lawrence River dropped by 20 percent.

Periods of low or high water levels in the Great Lakes occur over several years (Brotton, 1995). However, strong evidence shows a yearly high-to-low cycle; and a second, larger cycle with deeper peaks and depths occurring roughly every thirty years. Low water levels were recorded in 1934, and 1964 but not 1994. A third theory is extremely deep low Great Lakes levels arriving every 150 years (MSU, 2002).

Annual or seasonal variations in water levels are based mainly on changes in precipitation, evaporation and runoff to the Great Lakes. Generally, the lowest levels occur in winter when much of the precipitation is locked up in ice and snow on land, and dry winter air masses pass over the lakes enhancing evaporation. Levels are highest in summer after the spring thaw when runoff increases. However, low precipitation in winter together with higher evaporation and temperatures can cause lower water levels, which occurred in 1964, 1997, 1998, 1999, 2000 and 2001 (GLERL, 2000). Wind and atmospheric pressure may also cause temporary changes in the surface levels of the Great Lakes (Koshida, 1989). An example of water levels at one of the Great Lakes - Lake Ontario - are presented in Figure 1 for the period 1900-2000.

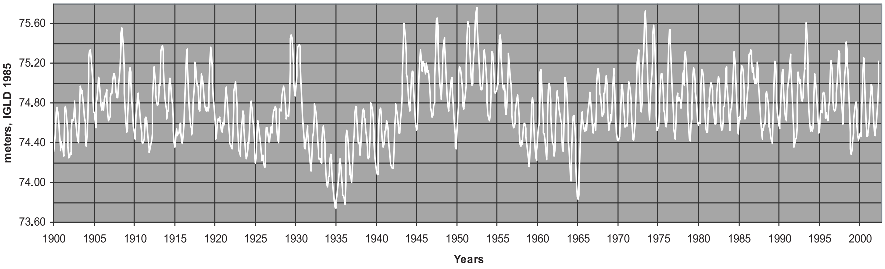

FIGURE 1

Lake Ontario water levels, 1900-2002. *Source: Environment Canada, 2003.*

Correlations of hydro-meteorological variables - runoff, overlake precipitation, evaporation, temperature, outflow and net basin supply - with lake levels have were conducted and are presented in Table 3. Runoff shows strong correlation with lake levels for Lake Huron and Lake St. Clair; while a low negative correlation is found for Lake Superior. Overlake precipitation is found to be important for Lake Ontario and Lake Superior with negative correlations for Lake Huron and Lake St. Clair. Temperature and outflow show positive correlation with water levels which needs further investigation. Net basin supply demonstrates the strongest correlation for Lake Superior and an almost similar level of correlation for Lake Ontario and Huron.

Table 3 Correlation between lake levels and various hydro-meteorological variables

HYDRO-METEOROLOGICAL VARIABLES	ERIE	HURON	ONTARIO	SUPERIOR	ST. CLAIR
Runoff	0.44	0.68	0.52	-0.25	0.98
Overlake Precipitation	0.36	-0.04	0.58	0.75	-0.15
Evaporation	0.15	0.06	0.24	-0.07	-0.18
Temperature	0.35	0.30	0.57	-0.23	0.56
Outflow	0.92	0.91	0.67	0.62	0.46
Net basin supply	0.39	0.55	0.59	0.8	0.44

In the 1960s Ontario Hydro had major power development capacities on the Great Lakes system at Niagara and on the St. Lawrence River. The installed capacity was of the magnitude of 3,000 Mega watts and the total investment was in the range of CAN$3-4 billion (in 1964 dollars). Driven by low water levels in the Great Lakes, power generation in 1964 was one of the worst years on record. The Hydro-Electric Power Commission of Ontario (1964) compared the power output of 1963 with that of the average of 100 years. Table 4 illustrates the effects of the low water event for power production.

Table 4 Power output at Niagara Falls and on the St. Lawrence River

ITEMS	AVERAGE 100 YEARS	1963	1964
Power output (million megawatt-hours)	19.64	16.16	15.24
Loss in output (million megawatt-hours)		3.48	4 .40
Equivalent volume of coal needed for replacement (million tonnes)		1.40	1.76
Value of replacement power (million dollars in 1994 prices)		55.80	82.50

Sources: Boyer, R.J. 1964. Hydro-Electric Power Commission of Ontario, 1964; Statistics Canada, 1995.

Hydropower generation is dependent on lake levels which is broadly dependent on the amount of precipitation that falls in a region. It is also sensitive to variations in temperature and wind. Ontario Hydro assumes that decreases in hydropower generation due to inadequate precipitation are not expected to occur more than 2% of the time (Lawford, 1977). The implication of such probability is that the generation station may be below capacity for six months every 25 years or for two years every century. While historical streamflow data are used in the design of each station, the length of record at many stations precludes a consideration of the effects of a five- to ten-year drought. A drought can also cause broader regional impacts; it can affect a number of hydraulic stations in a region simultaneously. Therefore, it becomes impossible for the regional generation stations to satisfy the demands without tapping alternative power sources or importation of electricity from elsewhere (Lawford, 1977). Both options lead to increases in the cost of electricity (Brotton, 1995).

Great Lakes' water is also used for cooling and steam condensing purposes; its temperature is increased a small amount as a result. Any interruption to the supply of this fresh water will result in the curtailment or interruption of delivery of power (McKeran, 1964). It is believed that certain severe wind conditions, coupled with existing low levels, could create conditions that would interrupt water supplies (McKeran, 1964).

2.3 Adaptation Measures and Policies

2.3.1 Case Study: The Ice Storm 1998

Southern Canada has a long history of ice storms and records are available from 1942. Economic damages due to ice storms since that time are significant. The storms also caused human sufferings in terms of power disruption, relocation, and physical and mental trauma. Records demonstrate that the pattern of historical damage is similar to the 1998 storm. However, the magnitude of the earlier ice storms were not as large.

Hydro-Québec's claims that its transmission system has been designed and developed over the years according to reliability criteria that generally exceed recognized standards in North America. Exceedences in standards were made because of the exceptional climatic conditions and great importance of electricity in Québec. However, a commission examining the 1998 ice storm in Quebec disagreed with this claim. Expert analysis by the Nicolet Commission (1999) has revealed that Hydro-Québec had designed, constructed, operated and maintained an unstable and unreliable system. The power grid might have saved money in construction and maintenance, but only at the cost of reliability when tested by conditions that could have been reasonably expected (Young, 1999). The Nicolet Commission reported that: "…transmission and subtransmission lines collapsed at vertical load levels that were below their theoretical design ice-load limit. In fact, since the winds at the time could be classified as no more than moderate, the commission's experts, in their evaluation, termed these raptures premature." (Nicolet, 1999).

Hydro-Québec did not introduce uniform design criteria for all transmission lines. For example, old steel tower lines built prior to 1974 were designed in accordance with the Canadian Standard Association criteria of their time. Variable performance was observed in the recently built transmission lines during the storm. These lines are supported on anti-cascading towers which limit the effect of a collapse in series to 10 towers at the most. During the storm, some new lines even seem to have performed better than expected (Hydro-Québec, 1998a). In terms of performance, wooden poles were the worst. However, wooden poles are chosen for transmission purposes due to economics (Hydro-Québec, 1998a).

The choice of a Gumbel distribution by Hydro-Québec for extreme value analysis of the climate data was criticised by the Nicolet Commission. The Commission was of the opinion that application of the Gumbel method may lead to an underestimation of the amount of freezing rain for long periods of return (Hydro-Québec, 1998b). However, Hydro-Québec disagreed with the Commission's view. Hydro-Québec explained that it used pooled data from stations to form a triad and doing so, the Gumbel distribution fit appeared to be very satisfactory with the adjustment of error by 10 to 15 percent (Hydro-Québec, 1998b). Reliability of the model used for converting ice data to radial values was also questioned after the 1998 ice storm. In addition to this, there is a procedural difference in terms of climatological data collection, transformation and interpretation between Hydro-Québec and Environment Canada (Hydro-Québec, 1998a).

De-icing of power transmission lines can save millions of dollars in repair costs and can reduce risk of collapse of the lines and resultant power outages (*McCurdy et al.,* 2001). Ice-melting is the process of placing a short circuit at one end of a sub-transmission line, essentially turning the line into a heating element which melts the ice. Generally, the temperature on the line is raised to just a few degrees above freezing. Hydro-Québec does not use the de-icing method at all. Exceedence of international standards for capacity, voltage level and design criteria prevented Hydro-Québec to apply the deicing technology.

Considering the magnitude of the damage caused by the 1998 ice storm to the power transmission and distribution systems in Québec, Ontario and the Maritimes, the concerned authorities and field workers worked day and night to restore power supply. However, the restoration process unveiled a number of problems faced especially by Hydro-Québec and Ontario Hydro in terms of human and material resources. Over 220 lineman arrived from British Columbia and Manitoba to help rebuild Québec's power grid (Lecomte et al., 1999). While this kind of cooperation is useful, it has risks too. If a storm would affect vulnerable provinces with the magnitude similar to Québec, this kind of manpower help may not be available.

Supply of hardware materials also experienced a shortfall. On January 27, 1998, Hydro-Québec announced that in just three weeks, it had exhausted its normal five-year supply of materials (Lacomte et al., 1999). In a normal month, as many as 150 truckloads of supplies arrive at Hydro-Québec's complex in Saint-Hyacinthe. During the ice storm and after, more than 2000 trucks carrying goods from all over North America to repair Hydro-Québec's downed power network had rolled into the complex's yard (North, 1998).

When the power system collapsed providing emergency power supplies to hospitals, water utilities and gas stations became a difficult problem to handle. Power supply authorities did not have enough high power generators. On January 9, 1998, power supply was cut to the water filtration plant of Montreal and the water supply was almost depleted. Hydro-Québec shifted power to the water supply system. This system had no back up generators (Environmental Index, 2000).

During the months of January, February, and March 1998, the Citizens Utility Company transported 64, 507 Mwh of Hydro-Québec power across its transmission system under its Open Access Transmission Tariff. These deliveries were made to alleviate transmission outages in the province of Québec resulting from the severe ice storm. No costs were reported with these ice storm deliveries since Hydro-Québec was both the supplier and recipient of this power (DOE, 2000). Hydro-Québec also imported some electricity from the Vermont Electric Transmission Company, Inc. Tripping of two 735 kV lines, which supply electricity to Des Cantons substation, caused a setback for Hydro-Québec in importing electricity from the USA during the ice storm.

Underground lines constitute only 10% of the distribution lines in Québec. Although the underground lines are considered to be safer and robust, they also pose a significant risk of failure too. After the 1998 ice storm, Hydro-Québec constituted a Task Force to look at the technical and economic aspects of underground cables (Hydro-Québec, 1998b). It also carried out an economic comparison of a German design and its own design. The German design was found to be half the cost of the Hydro-Québec underground design for that type of new installation. The principal reasons for such differences were attributed to: years of experience with undergrounding, network configurations, different voltages, direct-buried cables, standardization, quality control of equipment and installation, costs of cables and coordination of joint use of trenches (Hydro- Québec, 1998a).

2.3.2 ***Case Study: Low Lake Levels***

In the low lake levels on the Great Lakes in 1964, Ontario Hydro required 1.4 million tons of coal to compensate the lost output of electrical power due to low lake levels (Boyer, 1964). In another episode of low lake levels, Ontario Hydro was forced to use more expensive methods (e.g. fossil fuel) of generating electricity in many areas of north-western Ontario during the fall of 1976 and winter of 1976/1977. Flows over and above the normal regulated outflow were discharged in 1964 from Lake Superior to improve extremely low level situation downstream in Lakes Huron-Michigan. This additional inflow assisted in preventing a further decline in the level of these lakes and maintained the inflow into Lake Erie (Hydro-Electric Power Commission of Ontario, 1964).

Other measures that have been suggested but not applied to address low water levels on the Great lakes include cloud seeding to initiate rainfall on specific areas of deficient lakes (Hydro-Electric Power Commission of Ontario, 1964); diversion of additional water flow into the drainage basin but this is enormously expensive; and the construction of regulating structures at the outlets of Lake Huron and Lake Erie to permit all of the Great Lakes to be regulated. However, such a plan would be very complex as all interests are not compatible. For example, too great a compression of the storage range of the lakes for the benefit of riparian interests would reduce the great natural storage effect and would damage other interests such as power (Hydro-Electric Power Commission of Ontario, 1964).

2.4 Climate Change and Future Adaptation

In the past, the effects of climate variability varied from component to component of the energy sector. Responses resulted in the introduction of measures to reduce or eliminate the negative effects, usually in the context that the changes in climate and their effects were short term and both would in most of the cases return to "normal" following the perturbation. In the case of the projected changes in climate associated with an enhanced greenhouse effect, existing coping measures may not be effective and specific adaptation measures and policies will need to be designed, evaluated and implemented to reduce vulnerabilities of the energy sector.

The nature of future impacts is anticipated to be broadly similar to current conditions but the magnitude and frequency are likely to be greater than at present. It is difficult to predict the exact adaptation measures, which will need to be developed and incorporated in various components of the energy sector. Table 5 presents some adaptation measures for the Canadian energy industry. However, adaptation measures that should be implemented at various levels of the energy sector from generation to consumer. The measures have been classified according to the definition of Burton et al., 1993 (see Table 6). They would also vary from region to region depending on climate, socio-economic structure, resources, technology and policy formulation and implementation strengths.

Table 5 Major adaptation measures for the Canadian energy sector

MEASURE	IMPACT ADDRESSED	TYPE OF ADAPTATION	COMMENTS
I. Energy Generation/Supply Change in approach to water management vis-a-vis hydroelectric generation	Loss of hydroelectric generation capacity	Loss sharing/use change	Reductions in or changes in patterns of lake/river or stream flows may require changes in approach of water management
Increase energy production in the fossil fuel powered stations	Loss of hydroelectric generation capacity	Loss sharing/use change	This may increase in greenhouse gas emissions. Clean coal technology may be useful.
Operate hydro-plants at different locations	Decommissioning effects; temporary loss of power generation	Change location/Loss sharing	Construction of new plants may cause environmental effects and cost.
Invest in water storage	Potential for secured power supply	Prevent effects	Construction of new storage and creation of capacities in existing storage may cause environmental effects and cost.
Increase number of vessels to maintain level of coal supply for the fossil fuel powered generation units in Ontario	Reduction in power generation due to navigation problem in the Great Lakes caused by falling lake levels	Threat modification	Per unit cost of electricity generation may increase that will have to be shared by the consumers eventually
Buying energy from other sources	May reduce power shortage		Risks involved if the suppliers unable to secure the supply
II. Energy Transmission High-temperature super conducting material can be used to prevent power loss due to increases in temperature	Power loss in the transmission lines due to increase in temperature	Threat modification	Investment in power transmission will increase considerably
Strengthening of transmission structure of the long-distance power lines	Damage of transmission structures and lines during an extreme event (e.g., storms)	Threat modification	Investment in power transmission will increase significantly

Table 5 Major adaptation measures for the Canadian energy sector *...continued*

MEASURE	IMPACT ADDRESSED	TYPE OF ADAPTATION	COMMENTS
III. Energy Use Increase efficiency of air conditioning equipment	Increased cooling electricity cost	Threat modification	Increased air conditioning efficiency will reduce electricity expenditures, but will make initial costs higher. The measure will also reduce greenhouse gas emissions.
Thermal shell standards	Increased cooling costs	Threat modification	Increased insulation is often the most cost-effective measure.
Information Dissemination programmes	Increased space cooling costs	Threat modification	Energy sector agencies can provide information about energy efficiency measures that can save energy use and reduce energy costs.
Voluntary conservation programme	Energy saving possibility	Education/behavioural change	Must be a part of the long-term planning process. Might take a long-time period to yield any result

Sources: Modified from Stern, 1998; Smit, 1993; and Scott and Gupta, 2001.

Table 6 Types of Adaptation

Burton et al. (1993) grouped adaptation types into the following eight categories.

(i) *Bear losses.* Bearing loss occurs when a sector or a person affected has no capacity to respond in any other ways or where the costs of adaptation measures are considered to be high in relation to the risk or the expected damage.

(ii) *Share losses.* This type of adaptation response involves sharing the losses among a wider community.

(iii) *Modify threats.* For some risks, it is possible to exercise a degree of control over the environmental threat itself.

(iv) *Prevent effects.* A frequently used set of adaptation measures involves steps to prevent the effects of climate variability and change.

(v) *Change use.* Where the threat of climate change makes the continuation of an economic activity impossible or extremely risky, consideration can be given to changing the use.

(vi) *Change location.* A more extreme response is to change the location of economic activities.

(vii) *Research.* The process of adaptation can also be advanced by research into new technologies and new methods of adaptation.

(viii) *Educate, inform, and encourage behavioural change.* Another type of adaptation is the dissemination of knowledge through education and public information campaigns, leading to behavioural change.

3. Concluding Remarks

Damage that occurred during the 1998 ice storm to electricity transmission and distribution systems in eastern Canada demonstrates the vulnerability of these systems to extreme weather events. Extensive damaged caused to Hydro-Québec was due mainly to the exceptional nature of the storm. In many areas the combination of ice loads and wind speeds exceeded the recommended design standards. Vulnerability also increased due to the presence of high voltage towers in a region susceptible to ice storms, long transmission lines, and the short length of climatic records.

Although Hydro-Québec worked very hard mobilizing all of its resources, in many cases, the adaptation measures in place were found to be inadequate. As a result, the Nicolet Commission recommended reinforcement of the power network, improvement of network structural features and adapting the energy policy and securing electricity supplies. The commission also recommended an improved emergency preparedness program and that the government considers public control over good design practices. Initiatives have been taken by Hydro-Québec to strengthen their network structural system.

Hydropower generation is also vulnerable to low lakes levels in the Great Lakes. This may result in a drop in hydropower generation in the Niagara Falls and St. Lawrence River by as much as 20%. Low precipitation, high evaporation and high temperatures cause lower water levels. But, their correlation with water levels is not well studied. This is important for avoiding any setback in hydropower generation that is dependent on the Great Lakes water levels. During the 1964 extreme low lake levels a number of adaptation measures were suggested, but none of them were found to be economically viable, especially regulation of the Great Lakes water levels.

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