ADAPTING TO CLIMATE CHANGE

STATE OF PLAY AND RECOMMENDATIONS FOR THE ELECTRICITY SECTOR IN CANADA

Canadian Electricity Association | Association canadienne de l'électricité

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Inclusion of names of individuals is for acknowledgement purposes only and does not constitute an endorsement of the material.

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EXECUTIVE SUMMARY

The long-term climate change trend is clear. Global atmospheric levels of anthropogenic greenhouse gas emissions are expected to continue to rise, and climate impacts are expected to become more frequent and more intense. This reality has precipitated discussions around the need to prepare for climate change via adaptive measures.

A substantial and growing body of evidence indicates that the costs of inaction will exceed those of an evidence-based commitment to adaptation investments.

Canada's electricity sector is on track to spend approximately $350 billion between 2010 and 2030[1] to renew or replace aging infrastructure, with massive capital projects underway or planned in every part of Canada. Climate adaptation considerations must inform this infrastructure renewal process. Like other sectors of the Canadian economy, the electricity sector has begun to incorporate adaptation considerations in a systematic way.

Electricity infrastructure is already experiencing a range of minor and major impacts from climate change, which are likely to increase.

Climate model data analysis completed for this report[2] focuses on potential changes in mean temperature and precipitation for the 2041–2070 period[3].

FINDINGS SUGGEST THAT:

1. Under various modelling outcomes average annual temperatures will increase by 2.0–3.5 degrees Celsius in southern parts of Canada. For all four seasons the average temperature is likely to increase by more than 2 degrees Celsius throughout Canada.
2. Under specific modelling assumptions, spring and fall seasons will see increases in precipitation of 5–15 percent across the country. There will also be a significant increase in mean winter precipitation across the country with some regions more strongly affected than others.

In addition to the climate model results presented in this report, the current scientific literature on extreme events stresses the increasing frequency and magnitude of warm days and heat waves, more frequent precipitation extremes, and potential drought changes (reduced aridity in winter, increased aridity in summer).

1 "Shedding Light on the Economic Impact of Investing in Electricity Infrastructure," *Conference Board of Canada*, 2012, 1, available: http://www.conferenceboard.ca/e-library/abstract.aspx?did=4673.
2 Ouranos, a Montréal -based expert consortium on climate change, completed the climate model data analysis.
3 This is relative to data from 1976–2005.

Climate impacts for the electricity sector, including both risks and opportunities, may be inventoried into three areas: electricity demand, electricity generation, and electricity transmission, distribution and infrastructure. While increased electricity demand from the United States and changes in water availability may present opportunities, climate change presents considerable risk to service reliability.

The data is unequivocal. Low probability, high impact scenarios are increasing in likelihood. The electricity sector is entering a more complex, dynamic and uncertain environment and risk management strategies must be revised accordingly.

Toronto Hydro Corporation's crews working during the 2013 ice storm. *Photo courtesy of Toronto Hydro Corporation.*

CEA member companies stress that greater clarity and confidence in climate change data and modelling methods is needed. This will support better incorporation of adaptation considerations into planning and infrastructure investment decisions.

Development of corporate governance tools and structures is the second requirement for improved integration of adaptation into sector management and investment practices. CEA's Climate Change Adaptation Management Planning Guide, and Engineers Canada's Public Infrastructure Engineering Vulnerability Committee Protocol (PIEVC Protocol) are gaining traction. CEA members developed the Adaptation Guide in 2015, in parallel with the development of this report. The PIEVC Protocol was first developed in 2008, and has been applied to risk assessments for almost 40 infrastructure systems in Canada, including several electricity projects.

Beyond improved availability and understanding of climate data and the development of corporate governance tools to turn data into business decisions, many actions should be undertaken to further Canada's commitment to adaptation. Federal, provincial and territorial governments, municipalities, system operators, electricity companies, electricity regulators, and customers and citizens are all stakeholders and they must be part of the conversation and of the solution. The following recommended actions include both contributions and opportunities for collaboration for each stakeholder[4].

4 The recommended actions are from the Canadian Electricity Association and its members.

CEA MAKES THE FOLLOWING RECOMMENDATIONS:

FEDERAL GOVERNMENT

- Develop a national adaptation strategy
- Improve national understanding of climate risks and opportunities
- Support scientific research and climate data at a regional level
- Ensure cross-border coordination and risk management

MUNICIPALITIES

- Develop adaptation action plans
- Ensure integrated participation from multiple stakeholders
- Pursue comprehensive energy efficiency actions

ELECTRICITY GENERATORS, TRANSMITTERS AND DISTRIBUTORS

- Develop climate adaptation management plans
- Exchange best practices in climate adaptation, including models and methods
- Review electricity system standards and revise as necessary
- Promote demand response and improve system flexibility
- Optimize use of water resources and watersheds

PROVINCIAL AND TERRITORIAL GOVERNMENTS

- Establish a position on climate risks
- Ask municipalities to develop adaptation plans
- Strengthen building codes and standards
- Update flood plain maps

SYSTEM OPERATORS

- Incorporate climate scenarios into load forecasts
- Maintain a climate dialogue with other system operators

ELECTRICITY REGULATORS

- Establish policies and practices that recognize the importance of addressing climate risks in electricity
- Encourage collaboration to identify cost-effective solutions

CUSTOMERS AND CITIZENS

- Support and engage in community discussions around climate change and critical infrastructure
- Contribute to demand response

Despite the need for shared ownership of this issue, Canada's electricity companies must initiate the development of systematic approaches to climate change adaptation and mitigate priority risks.

To help drive this process, CEA has developed this report with three objectives in mind:

- Communicate the importance of climate change adaptation as a critical issue for the electricity sector;
- Provide an overview of current adaptation perspectives and practices among electricity companies; and
- Recommend actions to advance adaptation efforts in the electricity sector and with its key stakeholders.

1 INTRODUCTION

This report is the first national level discussion of climate change adaptation related to electricity generation, transmission, and distribution. The Canadian Electricity Association (CEA) started this project in February 2014, with support from Natural Resources Canada (NRCan), and ongoing participation from CEA's Corporate Utility Members.[5]

A. OUTLINE AND APPROACH

The report combines qualitative and quantitative inputs.

Chapter II discusses temperature and precipitation, two parameters of climate change, and summarizes scientific literature discussing projections for extreme events in Canada.

Chapter III discusses climate change risks and opportunities for the electricity sector. The discussion draws on two principle sources:

- A review of literature on adaptation and electricity; and
- Input from CEA member organizations.

This chapter also provides:

- An inventory of significant risks and opportunities for the electricity sector;
- A discussion of high impact weather events over the last decade and their impacts; and
- An examination of the increasing likelihood of high impact scenarios.

Chapter IV provides the results of a CEA member survey on adaptation and electricity. Survey respondents include 10 of CEA's largest Corporate Utility members. In addition, the chapter discusses the following two tools that can support integration of adaptation into sector management and investment planning:

- CEA's newly developed *Climate Change Adaptation Management Planning Guide*; and
- The Engineers Canada's Public Infrastructure Engineering Vulnerability Committee Protocol (PIEVC Protocol).

Lastly, **Chapter V** draws together the main themes of **Chapters II–IV** to propose climate change adaptation recommendations for the electricity sector and other stakeholders, and highlight immediate next steps for the 2016 CEA's Adaptation Working Group.

B. CONTEXT AND RATIONALE

The following elements taken together make a strong case for adaptive action:

1. Climate change science and worrisome emissions trends;
2. Increased policy focus on adaptation;
3. Growing evidence that the cost of inaction will far exceed the cost of adaptation;
4. Ongoing infrastructure renewal requirements in Canada; and
5. Successful adaptation efforts to date in Canada's electricity sector.

5 Refer to *Appendix 1* for the list of participating organizations.

1. CLIMATE CHANGE SCIENCE AND EMISSIONS TRENDS

The link between anthropogenic emissions and climate disruption is well established.[6]

Based on a comprehensive review of the relevant scientific literature, the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report concludes:

> It is extremely likely [95 percent confidence] that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together.[7]

Climate change increases mean temperature, but it also causes greater *variability* in weather patterns, intensifying extremes. Given this combination, some commentators prefer the term "climate disruption" over "climate change."[8] As the IPPC comments in its 2014 report on impacts, adaptation and vulnerability: "Climate-change-related risks from extreme events, such as heat waves, extreme precipitation, and coastal flooding, are already moderate (high confidence) and high with 1°C additional warming (medium confidence). Risks associated with some types of extreme events (e.g., extreme heat) increase further at higher temperatures (high confidence)."[9]

In short, the science affords no reason for complacency. On the contrary, global anthropogenic emissions are expected to continue to rise in the coming decades, and climate impacts are expected to become more frequent and intense.[10]

2. EVOLUTION OF CLIMATE POLICY: A GROWING FOCUS ON ADAPTATION

Traditionally, climate change policy and action focused on **mitigation** efforts: capping and ultimately reducing carbon emissions. While such efforts continue, in recent years the need to adapt to climate change has become an increasingly apparent reality.

Adaptation focuses on adjusting practices in response to experienced climate change impacts or expected future climate parameters. The IPPC defines "adaptation needs" as "the gap between what might happen as the climate changes and what we would desire to happen."[11]

The gap is widening.

Adaptation focuses on adjusting practices in response to experienced climate change impacts or expected future climate parameters.

6 R.K. Pachauri and L.A. Meyer Geneva (ed.), "Climate Change 2014: Synthesis Report – Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change," *International Panel on Climate Change*, 2014.

7 Ibid, 48.

8 Tom Rand makes the point, "Throughout this book I refer to *climate disruption* rather than *climate change*. The term helps circumvent the nonsense that this warming is part of a natural cycle and emphasizes our contribution to the coming changes and the speed at which they are approaching;" Tom Rand, *Waking the Frog: Solutions for Our Climate Change Paralysis,* ECW Press, 2014, 9.

9 Climate Change 2014: Impacts, Adaptation and Vulnerability, Intergovernmental Panel on Climate Change, http://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf, 12.

10 As the International Energy Agency comments, "The world is off course to prevent two degrees C of warming;" http://www.worldenergyoutlook.org/pressmedia/quotes/#d.en.25166; also see e.g., Mark Kinver, "2014 warmest year on record, say US researchers," *BBC News,* January 16, 2015, http://www.bbc.com/news/science-environment-30852588.

11 Intergovernmental Panel on Climate Change, *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects*, (New York: Cambridge University Press, 2014), 836.

Insurance companies, whose business depends on accurate risk assessments based on historical data, have been among the first to sound the alarm that adaptation needs are growing. Swiss Re, which has been studying climate change for more than two decades, was among several contributors to a 2009 report arguing that climate adaptation is "an urgent priority for the custodians of national and local economies, such as finance ministers and mayors."[12] Risk experts describe a phenomenon in which events that were expected to occur only once in 100 years are now occurring with much greater frequency. An insurance giant, Lloyds commented in a report, "we have tended to think of climate change as a gradual phenomenon … with the impact expected to be felt evenly over time, and any increase in loss taking place incrementally."[13] In reality, they argue, "the latest science … suggests that climate change is likely to bring increasingly dramatic, and possibly rapid, effects at a local level… In addition, a growing number of potential feedback mechanisms within the climate have the capacity to cause tipping points … and speed change further."[14]

In the United States, several reports warning of growing risks and adaptation needs have been published:

- In June 2014, former United States Treasury Secretaries Paulson and Rubin, and New York Mayor Michael Bloomberg, together released a report entitled *Risky Business: the Economic Risks of Climate Change in the United States*. The report examines the total financial cost of climate change, suggesting that "hundreds of billions of assets and property [are] at risk in the coming years."[15]
- In October 2014, the Pentagon released a report claiming that climate change "poses an immediate threat to national security…It also predicted rising demand for military disaster responses as extreme weather creates more global humanitarian crises."[16]
- A 2015 report directed by President Obama, the *Quadrennial Energy Review*, identifies "almost $22 billion (USD) in total losses from a range of weather events in 2013, excluding self-insured losses," and points out that "extreme weather events resulting in more than $1 billion (USD) in damages are increasing,"[17] as illustrated in ***Figure 1***.

12 *Shaping Climate-Resilient Development: a Framework for Decision-Making*, report of the Economics of Climate Adaptation Working Group (Ottawa: 2009), 10, available: http://media.swissre.com/documents/rethinking_shaping_climate_resilent_development_en.pdf

13 *Lloyds 360 Risk Project: Catastrophe Trends, Rapid Climate Change*, (London: Lloyds, 2006), 3, available: http://www.lloyds.com/~/media/lloyds/reports/360/360%20climate%20reports/360_rapidclimatechangereport.pdf

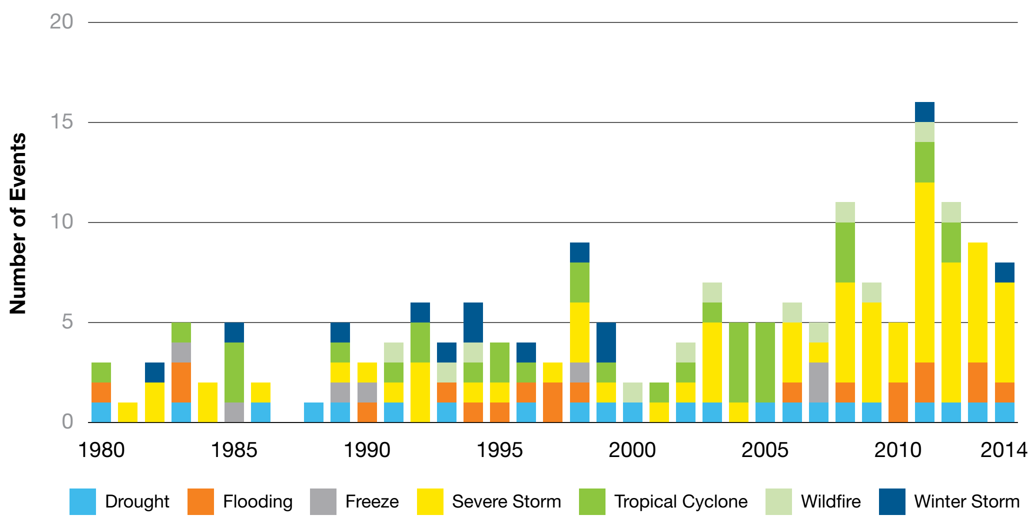
14 Ibid.

15 As described by Andrew Winston, "Two Forces Moving Business Closer to Climate Action," *Harvard Business Review*, September 24, 2014, https://hbr.org/2014/09/two-forces-moving-business-closer-to-climate-action/.

16 As US Defense Secretary Chuck Hagel commented: "The loss of glaciers will strain water supplies in several areas of our hemisphere … Destruction and devastation from hurricanes can sow the seeds for instability. Droughts and crop failures can leave millions of people without any lifeline, and trigger waves of mass migration;" from Coral Davenport, "Pentagon Signals Security Risks of Climate Change," The *New York Times*, October 13, 2014, http://www.nytimes.com/2014/10/14/us/pentagon-says-global-warming-presents-immediate-security-threat.html?_r=0.

17 Office of Energy Policy and Systems Analysis, *Quadrennial Energy Review Report: Energy Transmission, Storage, and Distribution Infrastructure*, Chapter 2, p. 2-6, April 2015, available: http://energy.gov/sites/prod/files/2015/08/f25/QER%20Chapter%20II%20Resilience%20April%202015.pdf.

Figure 1: Billion Dollar Disaster Event Types by Year, United States (USD)



As a 2013 report by the Canadian Climate Forum observes:

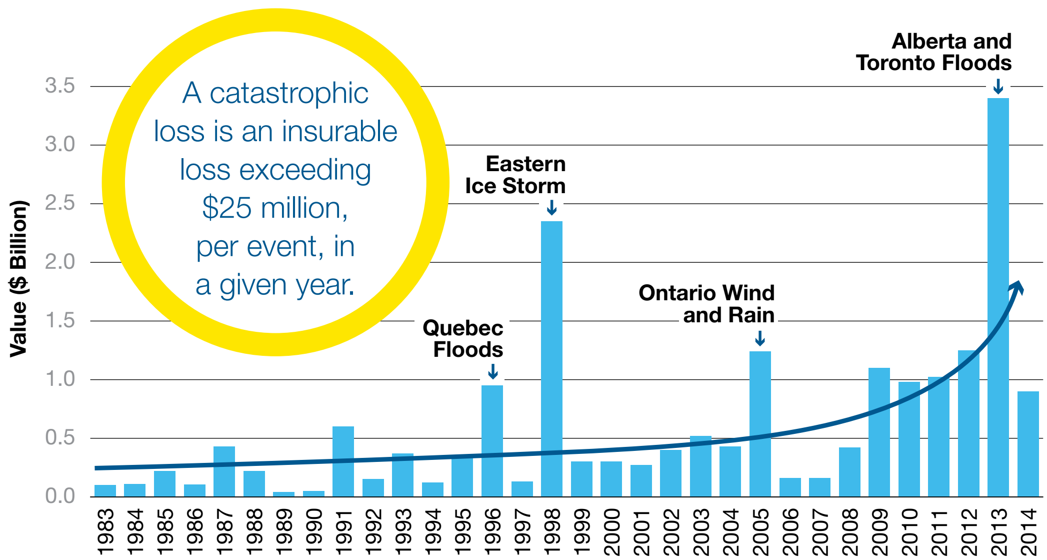
> "Extreme weather … is by definition rare … and is often violent with severe impacts … But these days [in Canada], extreme weather events are less rare, a consequence consistent with climate warming. In some regions, weather events that used to happen once every 40 years now occur every six. And the increase is gathering momentum with severe weather … expected to become even more frequent." [18]

Previously, rare events are becoming less rare.

18 Canadian Climate Forum, *Extreme Weather* (Ottawa: Canadian Climate Forum, 2013), Vol. 1 No. 1. Available from http://www.climateforum.ca/wp-content/uploads/2014/02/Issues-Paper-Final-CCF-1f.pdf.

Previously, rare events are becoming less rare. The 2013 Calgary flood was a reminder of a shared need to expand the boundaries of imagination, scenario planning, and risk assessment. As with the United States, extreme weather events are generating catastrophic losses in Canada well beyond historical patterns demonstrated in ***Figure 2***.

Figure 2: Annual Catastrophic Loss Claims for Canada, 1983–2014*



*Source: G. Robinson, Insurance Bureau of Canada, March 26, 2015. All data is normalized to 2012.

For the period from 1983–2008, catastrophic loss claims in Canada grew from a typical range of $200-$500 million per year (Quebec floods in 1996 led to higher than usual claims) to greater than $1 billion per year for every year from 2009 onward. An analysis of the period from 2009 forward considered several variables, including changes in intensity and duration of rain fall events, aging house infrastructure, aging urban infrastructure, finished vs. unfinished basements, permeability of locations, and elevation. The analysis found that the most plausible factor accounting for the change was the increase in intensity and duration of rainfall events for Canada over this period.[19]

19 G. Robinson, personal communication, Insurance Bureau of Canada, March 26, 2015, and Blair Feltmate, personal communication, September 13, 2015.

3. COSTS OF INACTION EXCEED COSTS OF ADAPTATION

For the electricity sector, climate change may increase costs across all steps in the value chain: extraction, processing, generation, transmission and distribution. Costs may increase as a result of damaged infrastructure, higher insurance premiums, water constraints, increased regulatory obligations, and legal liabilities. Similarly, revenues may decrease through the increased frequency and/or duration of outages, reduced supply availability (especially hydro), and through reduced infrastructure efficiencies.

Adaptation practices may help avoid these increased costs and reduced revenues. While some adaptation practices will have implementation costs, they will be lower than the costs of inaction. As the evidence builds through multiple studies, the business case for adaptation grows ever stronger:

- There is some evidence that proactive investment in climate-resilient assets at the design stage is less costly than retrofitting in response to climate-related damage.[20]
- A study from New York State's Energy Research and Development Agency estimated the cost of inaction in the energy sector (electricity and gas), taking into account the impact on energy supply, demand and infrastructure. The study found that the incremental impact costs of climate change without adaptation would be between $37-$73 million (USD) per year. In contrast, the annual cost of incremental adaptation measures would be $19 million, with benefits estimated to $76 million.[21]
- A Hydro-Québec study of the cost-benefit of adaptation compared to inaction on the Peribonka River system found that "the price of inaction is high, with a reduced hydropower output of about 14 percent, while adaptation action could increase hydroelectric production by about 15 percent."[22]
- A 2011 study by Canada's National Roundtable on Environment and Economy found that proactive adaptation provided benefits far outweighing costs. The ratio of benefits to costs was 9:1 in a scenario with lower GDP growth (1.3 percent) and slower growth in emissions and as high as 38:1 for a scenario with higher GDP growth (3 percent) and higher growth in emissions.[23] The report also found huge potential savings if a proactive adaptation strategy is developed around potential flooding in coastal areas.[24]
- Other studies have established that some simple adaptation measures, particularly measures to improve energy efficiency, have a "negative cost" or in other words, they provide a return on investment.[25]

In short, adaptation measures to strengthen resilience or reliability can help avoid or reduce significant costs and may also provide a range of benefits.

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20 See e.g. Nicholas Stern, "The Economics of Climate Change," *American Economic Review*, 98 (2), 2008, 1-37; also see Samuel Fankhauser and Ian Burton, "Spending adaptation money wisely," Centre for Climate Change Economics and Policy, Working Paper No. 47, (2011), Grantham Research Institute on Climate Change and the Environment, available: http://eprints.lse.ac.uk/36255/1/Spending_adaptation_money_wisely.pdf, and "Climate Change Adaptation Project," *Adapt Now Canada*, available: http://adaptnowcanada.ca/.

21 Robin Leichenko et al, "Economic Analysis of Climate Change Impacts and Adaptations in New York State" 2011, 76-77, available: http://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/EMEP/climaid/ClimAID-Annex-III.pdf.

22 Jane Ebinger and Walter Vergara, *Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation,* World Bank, (Washington D.C, 2011), https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/E-Book_Climate%20Impacts%20on%20Energy%20Systems_BOOK_resized.pdf, 60.

23 The report used the IPCC's "A2" scenario for its high climate change scenario and the "B1" scenario for its low climate change scenario. See *Paying the Price: The Economic Impacts of Climate Change for Canada*, National Round Table on the Environment and the Economy (Ottawa: National Roundtable on the Environment and Economy), 2011, 17, 2 7 and 28, available: http://www.fcm.ca/Documents/reports/PCP/paying_the_price_EN.pdf.

24 Ibid, 17.

25 See e.g. McKinsey & Company's work on greenhouse gas cost abatement curves: http://www.mckinsey.com/client_service/sustainability/latest_thinking/greenhouse_gas_abatement_cost_curves. While McKinsey's analyses were originally developed in the context of climate mitigation discussions, improved efficiency measures are also helpful tools that are often discussed in the context of adaptation, and in particular, planning for higher temperatures.

4. INFRASTRUCTURE RENEWAL IN THE ELECTRICITY SECTOR

In 2011 and 2012, the Conference Board of Canada released two reports examining projected investments between 2010–2030 in Canada's electricity generation, transmission, and distribution industries, as well as the economic impact of these projected investments.

The 2011 report pointed out that Canadian infrastructure, including electricity, has experienced "underinvestment" since the 1980s. It also stated, "as infrastructure comes to the end of its operational life, there is a strong need to rebuild and invest in new facilities as refurbishment costs grow."[26] The research found that in order for the electricity sector to maintain assets and meet expected electricity demand, it would need to spend $350 billion in infrastructure investment by 2030 (in 2012 dollars), or $15 billion per year. Approximately two-thirds of that investment would be for required generation investment, 20 percent for distribution, and the balance for transmission investments.

There is another way to illustrate the scale of Canadian infrastructure renewal. Every year Renew Canada publishes a list of the largest public infrastructure projects in Canada (by cost).[27] In its 2015 *Top 100 Projects* list, 32 are electricity projects with a combined value of over $63 billion (an average value of almost $2 billion per project).[28] The top ten projects according to cost out of the 32 are summarized in ***Table 1***.[29]

Table 1: Top Ten Electricity Projects in Canada in 2015 (by Cost)

#	Project	Cost ($)	Location	Owner(s)
1	Site C Clean Energy Project	8,775,000,000	Near Fort St. John, British Columbia	BC Hydro and Power Authority
2	Muskrat Falls Project	6,990,000,000	Muskrat Falls, Newfoundland and Labrador	Nalcor Energy; Emera Inc.
3	Romaine Complex	6,500,000,000	Havre-Saint-Pierre, Quebec	Hydro-Québec
4	Keeyask Hydroelectric Project	6,500,000,000	Lower Nelson River, Split Lake Resource Management Area, Manitoba	Manitoba Hydro; Keeyask Hydropower Ltd
5	Bipole III Transmission Line	4,600,000,000	Winnipeg, Manitoba	Manitoba Hydro
6	Lower Mattagami Hydroelectric Complex	2,600,000,000	Northeast of Kapuskasing, Ontario	Ontario Power Generation; Moose Cree First Nation
7	Darlington Refurbishment Project (Definition Phase)	2,500,000,000	Clarington, Ontario	Ontario Power Generation
8	Western Alberta Transmission Line	1,650,000,000	Genesee area west of Edmonton to Langdon area east of Calgary, Alberta	AltaLink
9	Beauharnois Hydroelectric Station Renovations	1,600,000,000	Melocheville, Quebec	Hydro-Québec
10	Fort McMurray West Transmission Project	1,600,000,000	Edmonton to Fort McMurray, Alberta	Alberta Electric System Operator

Source: "Top 100 – Canada's Biggest Infrastructure Projects," *ReNew Canada*, 2015, http://top100projects.ca.

26 Barbara Baker, *Canada's Electricity Infrastructure: Building a Case for Investment*. (Ottawa: The Conference Board of Canada, 2011), 2.
27 The projects are located in every province except Prince Edward Island.
28 "Top 100 – Canada's Biggest Infrastructure Projects," *ReNew Canada*, 2015, http://top100projects.ca.
29 Refer to *Appendix 3* for the full listing of 32 electricity projects and the map indicating their locations.

While both the Conference Board reports and the annual Renew Canada rankings highlight the scale and diversity of required electricity infrastructure renewal investment in Canada, they do not address climate change adaptation as a potential cost and/or benefit in the context of those investments. However, given the current situation, it is clear that adaptation must form part of the electricity sector's investment analysis.

5. ADAPTATION EFFORTS IN CANADA'S ELECTRICITY SECTOR

Considering climate science and emissions trends, the resulting evolution of climate policy and action, and the scale of infrastructure investment planned for the coming decades in Canada, there is a need for a more systematic approach to adaptation in the electricity sector.

Since 2009, CEA member organizations have reported on high level adaptation activities through CEA's Sustainable Electricity™ program. In January 2013, CEA established a Climate Change Adaptation Working Group to further CEA members' technical understanding of climate modelling and potential infrastructure impacts of a changing climate. The working group has identified the need for active climate change adaptation management planning across the sector as a key priority.

C. REPORT OBJECTIVES

Based on the context and background considerations, this report has three key objectives:

1. To communicate the importance of climate change adaptation as a critical issue for the electricity sector.
2. To provide a preliminary baseline understanding of current perspectives and practices with respect to adaptation in the electricity sector.
3. To put forward key recommendations for how to improve climate change adaptation in the electricity sector, especially (but not exclusively) with reference to investment planning.

The audience for these objectives includes utilities and the full range of electricity stakeholders, including governments, regulators, electricity companies, system operators, electricity customers, and citizens. Robust efforts towards climate adaptation in the electricity sector will require effective understanding, communication, and coordination among multiple constituencies.

The report was made possible through collaboration with Natural Resources Canada (NRCan). In 2012, NRCan, recognizing the importance of supporting adaptation responses to climate change, launched an 'Adaptation Platform.' As NRCan describes it, the Adaptation Platform "brings together key groups from government, industry, and professional organizations, to collaborate on adaptation priorities. By providing the structure to pool knowledge, capacity, and financial resources, the Platform aims to get work on adaptation done, and to ensure the results of that work, such as information, tools and recommendations, reach the right audiences." [30]The Adaptation Platform's Energy Working Group has provided financial and advisory support for several projects in the energy sector in order to improve understanding of adaptation risks and opportunities, to establish the business case for investing in adaptation, and to help integrate adaptation into planning.

30 "Adaptation Platform," Natural Resources Canada, last modified July 20, 2015, http://www.nrcan.gc.ca/environment/impacts-adaptation/adaptation-platform/10027.

2 CLIMATE SCIENCE AND CANADA'S FUTURE

Climate change will bring two kinds of change: changes in *average* annual and seasonal variables (relative to historical patterns) as well as increased *variability*, and especially, increased frequency, intensity and duration of extreme weather events. This chapter discusses these two aspects through the following:

A. A review of climate model results for Canada with a focus on changes in mean temperature and precipitation in the future; and

B. A brief summary of scientific literature discussing projections for extreme events in Canada.

A. CLIMATE MODEL RESULTS AND KEY FINDINGS

In early 2014, CEA commissioned Ouranos[31] to do an analysis of current climate observations and future climate scenarios in Canada. Ouranos focused on three main themes: climate science, vulnerabilities, and impacts and adaptation.

The data discussed within the report is taken from a Global Climate Model (GCM). GCMs track the state of numerous variables including atmospheric pressure, wind, precipitation, and temperature. These variables, taken together, create "a mathematical representation of the climate system, based on equations that drive the physical processes governing the climate, including the role of the atmosphere, hydrosphere, biosphere, etc."[32] GCMs allow climate scientists to study the response of the climate system to changes in greenhouse gas concentrations in the atmosphere and to quantify future climate changes.[33]

This report focusses on temperature and precipitation to express the potential impacts of climate change because climate scientists are confident that GCMs are especially adept at modelling these two variables.

The maps of Canada (***Figures 3-5***) included below highlight the regional and temporal variations for each of the two variables. The maps illustrate both the current state of the climate, derived from observed data from1976–2005, and possible future states from 2041–2070. Findings from the climate modelling is summarized in ***Table 2***.

31 Ouranos is a consortium on regional climatology and adaptation to climate change that brings together 450 scientists and professionals from relevant disciplines.

32 Isabelle Charron, A *Guidebook on Climate Scenarios: Using Climate Information to Guide Adaptation Research and Decision.* (Montréal: Ouranos, 2014), 78, available: http://www.ouranos.ca/media/publication/352_GuideCharron_ENG.pdf.

33 More specifically, data in this chapter were derived from greenhouse gas (GHG) emission scenarios used in phase 5 of the Coupled Model Intercomparison Projects (CMIP5). Results from CMIP5 served as the basis of the Fifth Assessment report from the Intergovernmental Panel on Climate Change (IPCC). For more information, please see http://www.ipcc.ch or http://www.ouranos.ca.

A NOTE ON METHODOLOGY AND MODELLING ASSUMPTIONS

The climate is complex, a range of phenomenon need to be accounted for including clouds, aerosols, and biological processes, and permafrost. This report aims to reach a general audience, and cannot do justice to all such variables in a single chapter. It therefore focuses on two variables in particular: temperature and precipitation. These two variables are key determinants of local weather as well as long-term modelling outcomes, their processes are well understood, and data on them are readily available. In other words, they provide an accessible introduction to climate variables for the purpose of a policy report.

Climate projections come with intrinsic uncertainty. Climate scientists consider an ensemble of many projections to mitigate this uncertainty and seek to make use of the valuable information contained in climate projections. In the maps below, the 25th, 50th and 75th percentiles are used to represent the range of possible futures as low, medium and high climate change scenarios[34].

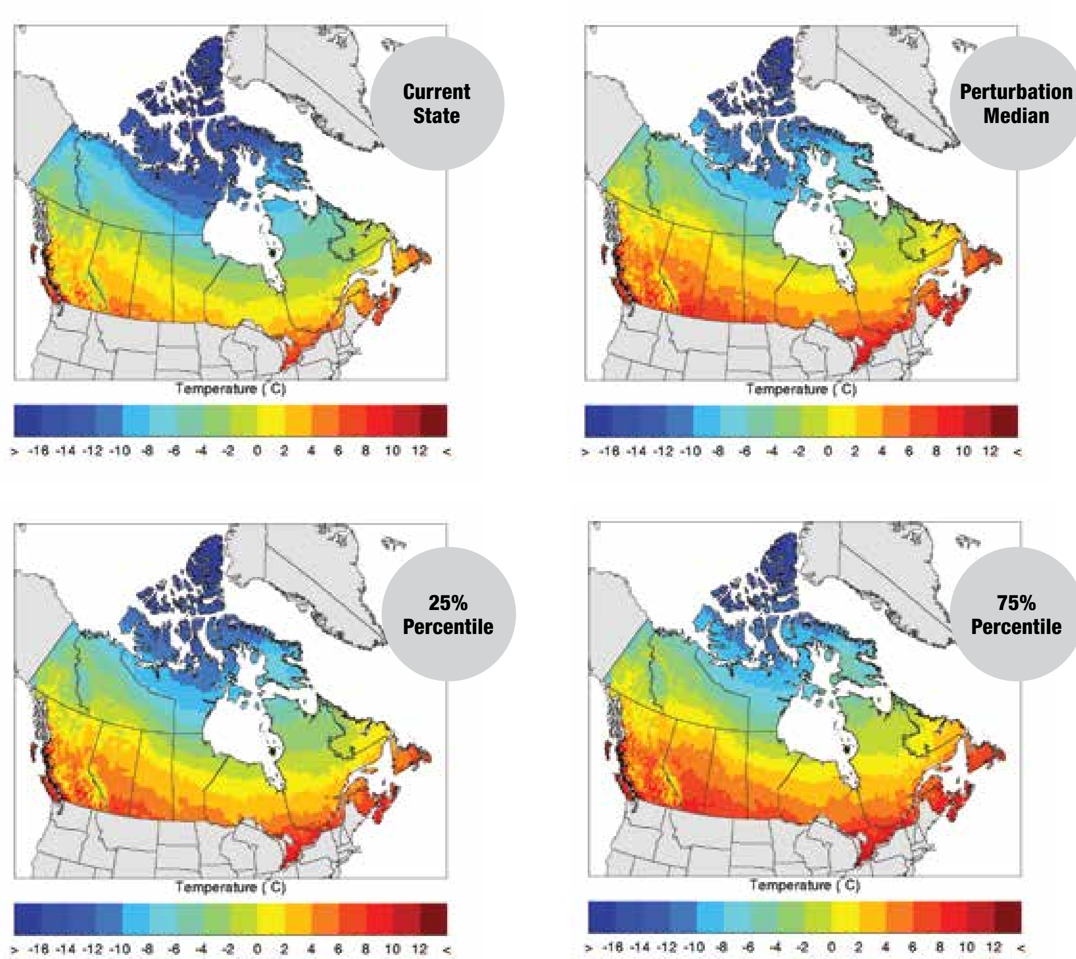
Electricity sector stakeholders are advised to consider other variables in project planning including runoff rates, wind speeds, number of icing days, heat waves, and analyze temperature and precipitation scenarios in greater detail (e.g. including additional percentiles) and with more attention to regional variations[35].

34 For additional information on Ouranos and how it develops climate scenarios, see *A Guidebook on Climate Scenarios: Using Climate Information to Guide Adaptation Research and Decisions,* Ouranos Consortium on Regional Climatology and Adaptation to Climate Change, September 2014.

35 In the interest of brevity, this chapter only provides a small subset of available information and scenarios from climate models and scientific research. For additional information on climate science, global models, and scenarios for Canada, please refer to *Appendix 4*.

Figure 3: Annual Mean Temperature for Current State and Future State (2041–2070)

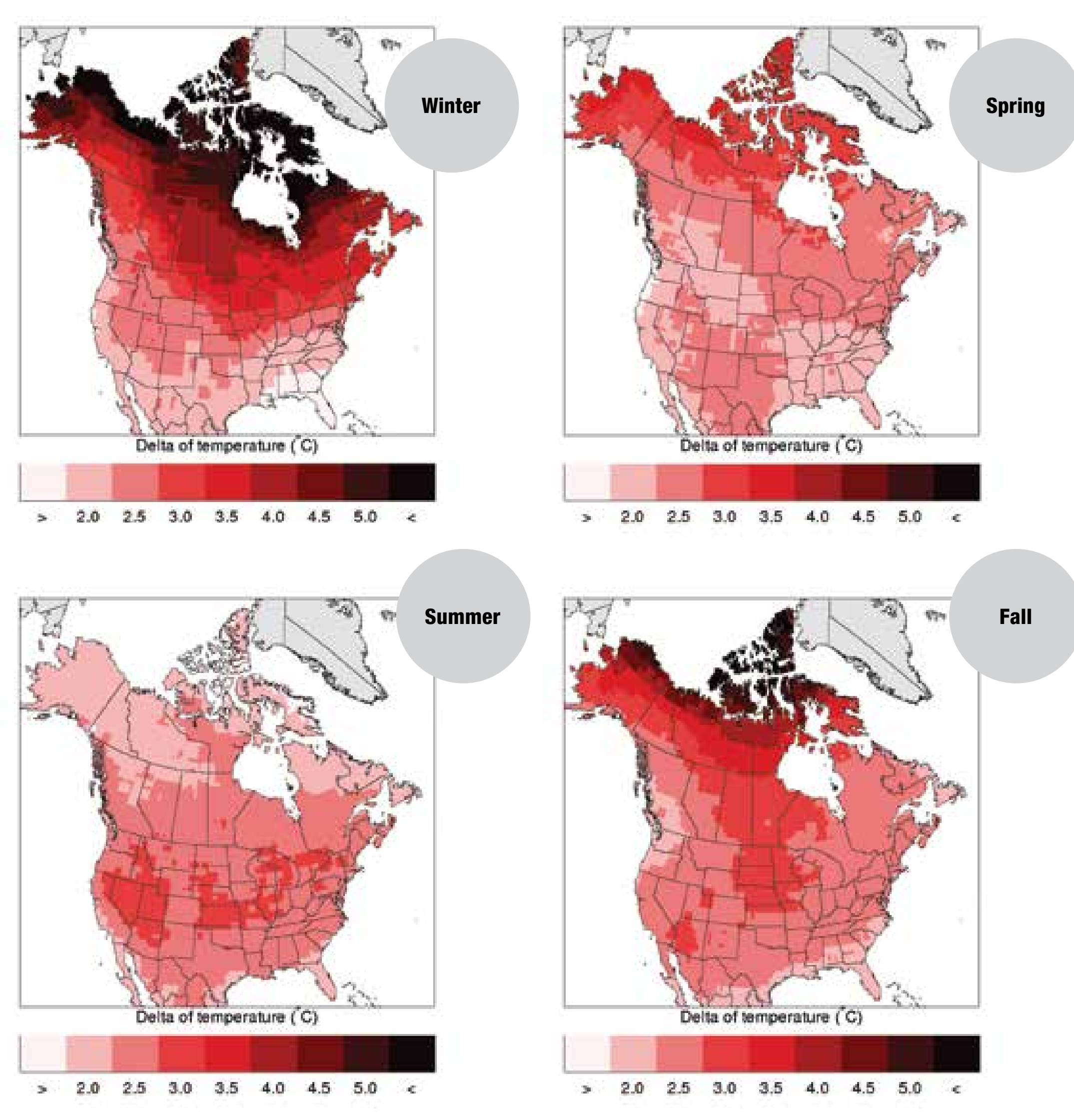
The current state is derived from observed data and the 25th, 50th, and 75th percentiles are low, medium and high climate scenarios over the period 2041–2070.



KEY FINDINGS

- At the 25th, 50th, and 75th percentile, there will be an average annual temperature increase of 2.0–3.5 degrees Celsius in southern parts of Canada and more at northern latitudes.

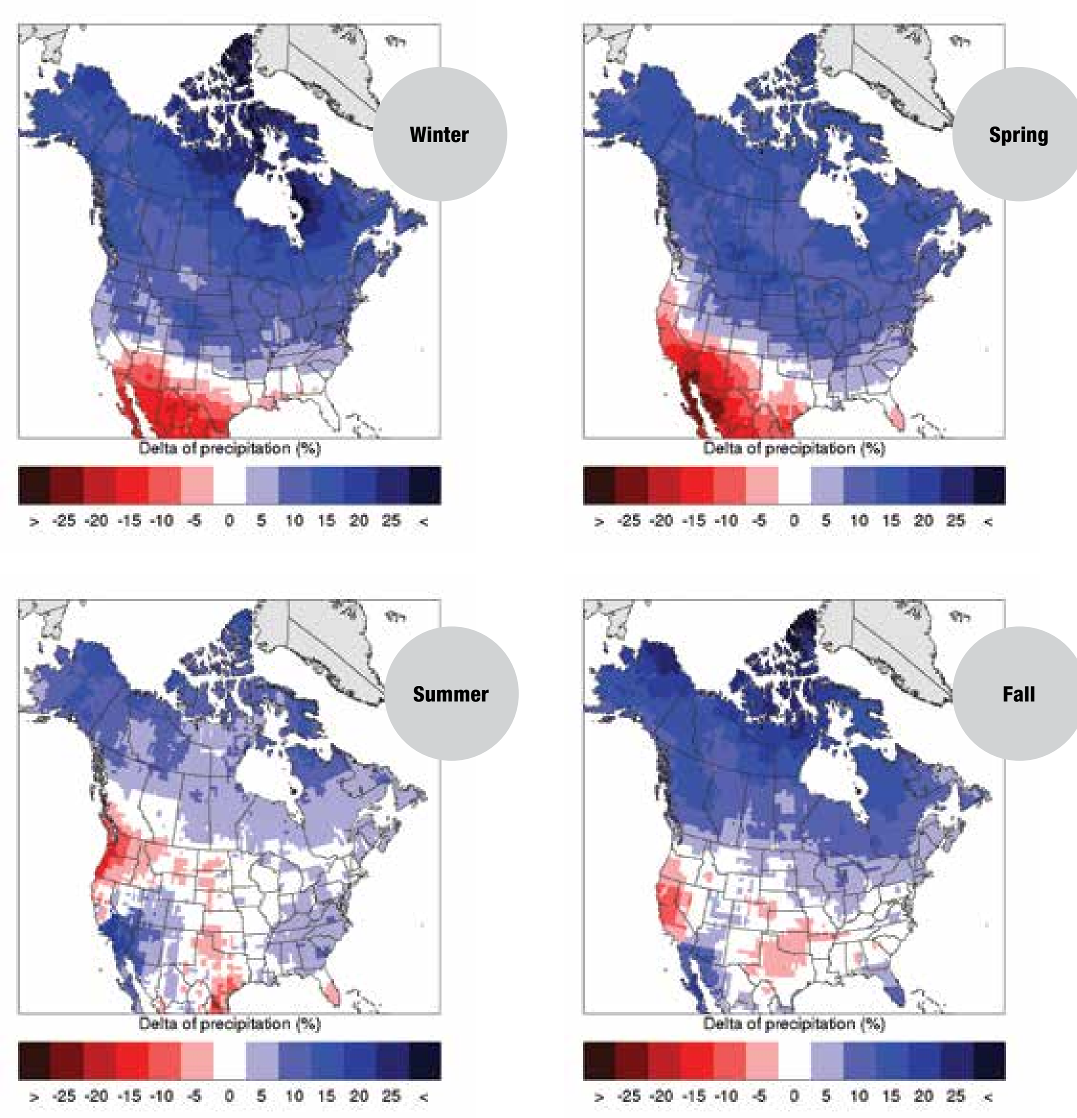
Figure 4: Change in Mean Seasonal Temperature for 50th Percentile of Future State (2041–2070)



KEY FINDINGS

- In all four seasons, the average temperature may increase by more than 2 degrees Celsius throughout Canada.
- The most significant seasonal temperature change is in the winter, with an average increase of 3.5 degrees Celsius in the south, and 5 degrees Celsius or more in the far north.

Figure 5: Change in Mean Seasonal Precipitation for 50th Percentile of Future State (2041–2070)



KEY FINDINGS

- For the 50th percentile, the spring and fall seasons see moderate to significant increases in precipitation, from 5–15 percent, across the country.
- The 50th percentile also shows a significant increase in mean winter precipitation: 10–15 percent for the country overall, and as much as 25 percent in several parts of northern Canada.

Table 2: Summary of Climate Model Findings

Variable	Key Findings
Temperature	**Annual:** At the 25th, 50th, and 75th percentile, there will be an average annual temperature increase of at least 2.0–3.5 degrees Celsius in southern parts of Canada.
	Seasonal: For all four seasons, the average temperature may increase more than 2 degrees Celsius throughout Canada. The most significant seasonal temperature change is in the winter, with an average increase of 3.5 degrees Celsius in the south, and 5 degrees Celsius or more in the far north.
Precipitation	Delta of mean seasonal precipitation for 50th percentile: the spring and fall seasons see moderate to significant increases in precipitation, from 5–15%, across the country. There is also a significant increase in mean winter precipitation: 10–15% for the country overall, and as much as 25% in several parts of northern Canada.

B. SUMMARY OF PROJECTIONS FOR EXTREME EVENTS

In addition to scientific models showing potential for annual and seasonal changes for mean temperature and precipitation, other scientific analyses indicate that extreme events are also likely to occur with increased frequency, duration and magnitude. NRCan's 2014 report titled *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* summarizes some of the IPCC's discussion of changes in extreme events:

- **Warm Days and Heat Waves.** There is a 99–100 percent probability that the 21st century will see warm days and nights with increased frequency and magnitude, cold days and nights with decreased frequency and magnitude, and that there will be increased "length, frequency, and/or intensity of warm spells, including heat waves."[36]
- **Precipitation Extremes.** For precipitation, the literature suggests that "one-in-20-year extreme daily precipitation events would become a one-in-10 year event by mid-century for mid to high latitude regions."[37] However, NRCan cautions that regional models may reveal "important details about spatial patterns of change not evident in global studies."
- **Potential Drought Changes.** Similarly, "available studies suggest a strong tendency towards reduced aridity in winter and increased aridity in summer over large areas of the Canadian landmass." though However, NRCan notes that "the lack of model agreement in the direction of projected change over many areas of Canada, including south-central Canada, indicates that these results should be interpreted cautiously."[38 39]

36 Warren, F.J. and Lemmen, D.S., editors, *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*; Government of Canada, Ottawa, 2014, p. 36, available: http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2014/16309.
37 Ibid.
38 Ibid.
39 See *Appendix 4* for more resources.

3 CLIMATE RISKS AND OPPORTUNITIES FOR THE ELECTRICITY SECTOR

Climate change presents both risks and opportunities for the electricity sector. To identify climate change adaptation solutions, ensure appropriate allocation of resources, and improve the resilience of Canada's electricity system, these risks and opportunities must be considered. This chapter provides an assessment of climate change risks and opportunities for Canada's electricity sector from three perspectives:

A. An inventory of significant risks and opportunities for the electricity sector in Canada arising from climate change impacts, which is grouped into three areas: electricity demand; electricity generation; and electricity transmission, distribution and infrastructure;

B. A discussion of high impact weather events over the last decade and their impacts, in order to highlight the importance of building a system that is as resilient as possible; and

C. An examination of the increasing likelihood of high impact scenarios, and the need for the electricity sector to incorporate the risk of high impact, low frequency events in investment planning and operations management.

A. RISKS AND OPPORTUNITIES FOR ELECTRICITY IN CANADA

This section considers potential risks and opportunities for electricity in Canada arising from climate impacts.

Discussions with CEA members identified many more risks than opportunities. Even so, two key opportunities may arise for electricity: increased electricity demand from the United States could lead to the increased exportation of Canadian electricity, and increased water availability in some regions may increase hydroelectric capacity.[40]

Potential climate change impacts for the electricity sector will vary by region, and vary in their material importance (financial sensitivities, insurance exposure, etc.) for individual companies and stakeholders. Individual projects will require targeted regional climate projections and scenarios.

Some climate drivers may present issues that are both risks and opportunities depending on the circumstances, and on how those issues are managed by various interdependent stakeholders. For this reason, it would be misleading to attempt to create a ledger with risks on one side and opportunities on the other.

40 For a useful table of "recent studies concerning hydrologic impacts on river basins of importance for hydroelectricity generation in Canada, see ibid, p. 86.

It will be important for each company and stakeholder to go through its own robust risk assessment taking all considerations into account. The objective of the matrices below is simply to provide a broad inventory of significant potential risks, issues and opportunities (compiled with input from CEA members) to set the stage for more tailored analysis and planning among individual companies and other stakeholders. Risk assessment and management will remain an iterative process.[41]

Potential climate change impacts can be grouped into three broad categories:

- Electricity demand;
- Electricity generation; and
- Electricity transmission, distribution, and infrastructure.

1. ELECTRICITY DEMAND

Major patterns in future climate changes may generate the following overall changes in electricity demand (and energy demand more generally), see ***Table 3***.

Table 3: Canadian and American Electricity Demand

Climate Driver	Potential Risks, Issues, and Opportunities for Electricity Demand	
Increases in Air Temperature	In Canada: • Increased summer demand in many regions for cooling purposes. • Increased peak demand in summer, especially in large cities as a result of rising temperatures in combination with the urban heat island effect (UHI).[43] • Conversely, higher winter temperatures may mean reduced winter demand for electric heating, where applicable.[44]	In the United States: • Increased summer demand as a result of temperature increases, resulting in increased demand for electricity exports from Canada. • Reduced winter demand for exports from Canada for space heating.
Changes in Water Availability	• Higher water availability variability. In the summer months, potential exists for decreased runoff, decreased precipitation and increased evaporation, resulting in reduced water availability. In the fall and winter, increased precipitation and runoff may result in increased water availability. • Water is a shared resource across sectors and between Canada and the United States. Reduced water availability for a variety of uses – such as energy resource extraction, power plant cooling, or agriculture – may result in the need to divert water from farther afield, potentially by using electricity.[45]	

41 The US literature could also inform risk identification and assessment. See e.g. *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather, "Figure 1*. Selected events over the last decade illustrate the U.S. energy sector's vulnerability to climatic conditions," pp. 1-3: http://energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector%20Vulnerabilities%20Report.pdf.

43 An urban heat island is a city or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities. See: https://en.wikipedia.org/wiki/Urban_heat_island.

44 It is important to emphasize, however, that many other factors will also influence future electricity demand levels, including demand side management, electric vehicle adoption, oil prices, and GDP growth in both the United States and Canada.

45 "Water – how we use it," *Environment Canada*, last modified July 19, 2013, available: http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=0BBD794B-1. Also see e.g., Derrel L Martin et al, "Evaluating Energy Use for Pumping Irrigation Water." Paper presented at the proceedings of the 23rd Annual Central Plains Irrigation Conference, February 22-23, 2011. available: http://www.k-state.edu/irrigate/oow/p11/Kranz11b.pdf. A recent paper also found that drought may increase electricity demand, though it is unclear how much of this increase was directly attributable to the decrease in water availability, as opposed to the increase in air temperature. See Bridget R. Scanlon et al., "Drought and the water-energy nexus in Texas," *Environmental Research Letters* 8:4 (2013), available: http://iopscience.iop.org/1748-9326/8/4/045033/article.

2. ELECTRICITY GENERATION

Climate change carries with it significant risk for Canada's electricity generation system. Impacts to resource availability, operating efficiencies and environmental sustainability could limit the sector's ability to operate at full capacity (see ***Table 4*** for details).

Table 4: Electricity Generation

Climate Driver	Potential Risks, Issues, and Opportunities for Electricity Generation
Increases in Air and Water Temperature	• An increase in ambient temperature can reduce the efficiency of various forms of thermal generation by decreasing the difference between ambient and combustion temperature.[46] The loss of efficiency may be trivial in some cases but significant in others.[47] An increase in ambient air temperature can also impact nuclear generation by reducing thermal efficiency.[48] • As summer peaks increase in certain jurisdictions, the balance of long-term energy contracts could be impacted (e.g., the mix of "diversity agreements" between winter-peaking and summer-peaking jurisdictions). • Thermal and nuclear stations withdraw, use, and discharge significant amounts of water for cooling purposes. As air and water temperatures increase, plants may need more water for cooling, but they may also be more constrained by regulations in how they can use and discharge water, potentially even leading to plant deratings or shutdowns.[49]
Changes in Water Availability	• Changes to water levels could have implications for the environmental licensing process, since the allowable impacts (lake levels, flow limits) from hydroelectric plants are based on historical information. If there is an overabundance of water projected, generators may be required to reengineer their spillways. • Almost 65% of Canada's electricity production is hydroelectric. Changes to water availability could have significant impacts throughout the electricity system. • Hydro generation relies on a resource with competing uses: lakes and rivers are also used for fishing, recreation, transportation, water consumption, etc. A change in water availability (e.g. an extended drought in the summer) may impact several or all of these uses at once, creating the potential for tensions and conflict. • Changes to water availability in the United States would also have an impact on Canadian generators. Even moderate changes are likely to impact the electricity trade balance.
Ice Storms	• Ice storms may damage wind blades.[50] • Ice storms may lead to increased use of road salt, causing additional cleaning requirements and premature rusting of some equipment. • Biomass generation may benefit from ice storms by using damaged wood as a feedstock.[51]

46 Asian Development Bank, *Climate Risk and Adaptation in the Electric Power Sector.* (Mandaluyong City, Philippines: Asian Development Bank, 2012), 9, available: http://adb.org/sites/default/files/pub/2012/climate-risks-adaptation-power-sector.pdf.

47 Ibid.

48 As one report notes: "a 1˚C rise in ambient air temperature can reduce nuclear power output by about 0.5% because of reduced thermal efficiency;" Asian Development Bank, *Climate Risk and Adaptation in the Electric Power Sector*, 15. Significantly, however, as the report also notes, "during droughts and heat waves, the loss may exceed 2% per degree Celsius because cooling systems are constrained by physical laws, environmental regulations, and reduced access to cooling water;" ibid.

49 See e.g. Matthew L. Wald, "Heat Shuts Down a Coastal Reactor," *The New York Times*, August 13, 2012: http://green.blogs.nytimes.com/2012/08/13/heat-shuts-down-a-coastal-reactor/?_r=0. Also see e.g., Asian Development Bank, *Climate Risk and Adaptation*, 4.

50 Ibid., 25.

51 See e.g., "Ameresco Biomass Plant Uses Damaged Wood from Ice Storm," Ameresco Press Release, April 8, 2014, available: http://www.ameresco.com/press/ameresco-biomass-plant-uses-damaged-wood-ice-storm#sthash.uNJPakfl.dpuf.

Climate Driver	Potential Risks, Issues, and Opportunities for Electricity Generation
Sea Level Rise and Storm Surges	• In Canada, a rise in sea level could impact generation facilities in coastal areas, particularly in Charlottetown, PEI, and parts of Nova Scotia.[52] • One report found that the United States has "more than 280 electric power plants, oil and gas refineries, and other energy facilities located on low-lying lands vulnerable to sea level rise and flooding."[53] • Among other damaging effects, storm surges[54] can hinder the ability of emergency teams to respond quickly and effectively, thus prolonging outages.
Climate Impacts on Biodiversity/ Invasive Species	• Changes to temperature and water availability and levels may have second order impacts on local biota. These changes in biota may in turn impact how generators are regulated. • Warmer environments may result in conditions that support unfavorable growth in biota including algal blooms and the growth of invasive species such as zebra mussels. • Changes to water temperature and levels may also impact fish populations, leading to regulatory changes for hydroelectric plants. • Changes in migratory bird patterns may also impact wind turbine public acceptance and operational requirements.

Toronto Hydro Corporation's linesman in a bucket truck during the 2013 ice storm. The storm ravaged the City of Toronto over the winter holiday season. *Photo courtesy of Toronto Hydro Corporation.*

52 "Water and Changes," *Environment Canada,* last modified August 3, 2010, available: http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=3E75BC40-1. The issue is already a major concern in Nova Scotia. See: https://www.novascotia.ca/coast/documents/state-of-the-coast/WEB_SLRSE.pdf.

53 Ben Strauss and Remik Ziemlinski, "Sea Level Rise Threats to Energy Infrastructure," *Climate Central*, April 19, 2012, available: http://slr.s3.amazonaws.com/SLR-Threats-to-Energy-Infrastructure.pdf, and Jennifer Morgan, "How Climate Change Impacts America's Energy Infrastructure," *World Resources Institute*, Feb. 5, 2013, available: http://www.wri.org/blog/2013/02/how-climate-change-impacts-america%E2%80%99s-energy-infrastructure.

54 A storm surge is defined as a rising of the sea as a result of atmospheric pressure changes and wind associated with a storm. Hurricane Sandy, for instance, experienced significant damage from storm surges.

3. ELECTRICITY TRANSMISSION, DISTRIBUTION, AND INFRASTRUCTURE

The potential risks to transmission, distribution, and supporting infrastructure for the electricity system, including information and communications technology (ICT) and relevant transportation infrastructure is detailed in ***Table 5***.

Table 5: Electricity Transmission, Distribution, and Infrastructure

Climate Driver	Potential Risks, Issues and Opportunities for Electricity Transmission, Distribution, and Infrastructure
Increases in Temperature	• Higher ambient temperatures may reduce transmission and distribution efficiency.[55] In particular, higher temperatures may result in de-rating or failure for air cooled transformers, and in sag and annealing for overhead conductors.[56] • More frequent heat waves will place more stress on the distribution system. Distributors and system planners/operators may need to respond by managing energy demand in real time, building in more system redundancy and revising maintenance and component replacement strategies.
Ice Storms	• Ice storms can snap power lines, break or bring down utility poles, and significantly increase tree contacts leading to widespread infrastructure damage and power loss.
Changes in Precipitation, Runoff, and Ground Conditions	• Changes in precipitation and runoff may cause or exacerbate storm surges and flooding. Substations may be particularly vulnerable to flooding.[57] • Flooding may also impact the supporting infrastructure – for example, copper and fiber-optic cables used in ICT systems.[58] • Fluctuations in winter precipitation and temperatures may lead to an increased number of "freeze/thaw" cycles. These cycles can damage concrete through the expansion and contraction of moisture,[59] and can also "cause cracking and deterioration of underground vaults and cable chambers over time."[60] Freeze/thaw cycles may also cause sinkholes, exacerbating travel challenges faced when making repairs in remote transmission locations.
Permafrost Melt and Ice Reductions	• Higher temperatures in winter months in northern parts of Canada may result in the loss of permafrost in some areas. • Reductions in permafrost may impact transmission and distribution infrastructure in northern areas where infrastructure was designed and installed for permafrost conditions. • Ice cover reductions could also present a challenge to trucks that use ice roads to transport diesel to remote locations for power generation.
Higher Winds	• High winds can damage wires and distribution systems, especially through tree contact damage.[61]

55 For a related discussion, see *Climate Risk and Adaptation*, Asian Development Bank, 37-38.
56 Ibid.
57 Ibid.
58 Ibid, 38.
59 Laura Zizzo et al., *Understanding Canadian Electricity Generation and Transmission Sectors' Action and Awareness on Climate Change and the Need to Adapt.* Toronto: Zizzo Allen Professional Corporation, 2014, 7. available: https://uwaterloo.ca/school-environment-enterprise-development/sites/ca.school-environment-enterprise-development/files/uploads/files/understanding_canada_electricity_generation.pdf.
60 AECOM, *Toronto Hydro-Electric System Public Infrastructure Engineering Vulnerability Assessment Pilot Case Study* (2012), 24, available: http://www.pievc.ca/sites/default/files/toronto_hydro_pievc_pilot_case_study_final_report.pdf.
61 Asian Development Bank, *Climate Risk and Adaptation*, 37.

Climate Driver	Potential Risks, Issues and Opportunities for Electricity Transmission, Distribution, and Infrastructure
Wildfires	• Wildfires are increasing in number and severity in both the United States[62] and Canada[63], and present several risks for electricity: – Fires in and around transmission lines can burn down the lines and damage transmission poles. – Conductors can become annealed or damaged and subsequently fail. Lines can be damaged simply by the heat of the fire, even if they are not burned directly. – Fires can create a "flashover" from electricity infrastructure. As the Union of Concerned Scientists explains, "the greatest risk comes from smoke and particulate matter [which] can ionize the air, creating an electrical path away from transmission lines. This can shut down the lines and produce power outages."[64]
Climate Impacts on Biodiversity/ Invasive Species	• As discussed under generation impacts, changes to temperature and water availability and levels may have second order impacts on local biota. These changes in biota may also impact on transmission, distribution and infrastructure. For instance, changes in the seasonal migrations and nesting behaviours of species of birds protected under legislation could present new environmental challenges for constructing or maintaining transmission lines. Changes in vegetation growth and/or the introduction of new invasive species may require changes in vegetation management practices.

An AltaLink transmission line in Canmore during the 2013 flood. *Photo courtesy of AltaLink.*

62 Michelle Davis and Steve Clemmer, *Power Failure: How Climate Change Puts Our Electricity at Risk*. (Cambridge, MA: Union of Concerned Scientists, 2014), 2. http://www.ucsusa.org/global_warming/science_and_impacts/impacts/effects-of-climate-change-risks-on-our-electricity-system.html#.VPyFXXyUeSo. California in particular faces enhanced wildfire risks from extremely dry winds known as Santa Ana winds.

63 Bill Gabbert, "Acres burned in Canada in 2014 were three times the average," December 24, 2014, referencing an Environment Canada report, http://wildfiretoday.com/2014/12/24/acres-burned-in-canada-in-2014-was-three-times-the-average/.

64 Michelle Davis and Steve Clemmer, *Power Failure: How Climate Change Puts Our Electricity at Risk*, 5.

B. HIGH IMPACT WEATHER EVENTS

High impact weather events over the last decade have significantly impacted public safety, the economy and infrastructure in Canada and in other countries. These events (documented in ***Table 6***) underscore the importance of continuously improving system resilience.

Linesman from New Brunswick Power Corporation is repairing a line during the 2014 ice storm. *Photo courtesy of Tony Crawford and New Brunswick Power Corporation.*

Table 6: Weather Events and Electricity Impacts

Factor	Event	Mortality, Health and Ecosystem Impacts	Electricity Impacts and Economic Costs
Ice Storms	December 2013 ice storm Canada and U.S.	10 deaths in Canada and 17 deaths in the U.S.[65]	• Extensive power transmission damage • Over $200 million (USD) in damages.[66] • Loss of power to more than a million residents.[67]
	New Brunswick's 2013 and 2014 ice storms	Swift power restoration mitigated public health risks	• The series of storms resulted in the most significant outage event in New Brunswick Power Corporation's recent history.[68] • Approximately 88,000 NB Power customers were affected. Many customers lost power more than once, and some as many as six times.[69] • The total cost of New Brunswick Power Corporation's restoration process was estimated at $12 million.[70]

65 Rachel Katz, "Ice storm power outages lead to carbon monoxide deaths," *ABC News*, December 26, 2013, available: http://abcnews.go.com/US/ice-storm-power-outages-lead-carbon-monoxide-deaths/story?id=21341326.

66 Madhavi Acharya-Tom Yew, "Ice storm pushed weather losses to record $3.2 billion: Insurance Bureau," *The Toronto Star*, January 20, 2014, available: http://www.thestar.com/business/2014/01/20/severe_weather_losses_hit_a_record_32_billion_in_2013.html.

67 David J. McFadden, *The response of Toronto Hydro-Electric System to the December 2013 ice storm: Prepared for the Toronto Hydro Independent Review Panel*, Davies Consulting, June 19, 2014, available: https://www.torontohydro.com/sites/corporate/Newsroom/Documents/TorontoHydro_%20Final%20Report%20of%20the%20Independent%20Review%20Panel.pdf.

68 NB Power, "Ice Storms Outages 2013–2014: Lessons Learned." *NB Power*, Fredericton, 2014, available: https://www.nbpower.com/media/1603/d-html-en-about-publications-annual-lessonslearned_storms_13_14.pdf.

69 Ibid, 8.

70 Ibid.

Factor	Event	Mortality, Health and Ecosystem Impacts	Electricity Impacts and Economic Costs
Heat Waves	France's 2003 maximum recorded temperature of 40°C and low precipitation	• Approximately 14,800 casualties.	• 17 nuclear reactors were "forced to shut down or reduce their production due to water withdrawal and discharge restrictions."[71]
	California's heat waves (2002, 2006, 2007, 2010, and 2014)	• For example, the 2006 heat wave resulted in an estimated 650 "heat related deaths," with 16,166 "excess visits" to hospital emergency departments	• In Los Angeles in 2006, "more than 80,000 people were left without electricity for several days and 860 transformers were malfunctioning or stopped operating." [72, 73] • In northern California, "1.2 million PG&E customers experienced electricity shortages when 1,150 distribution line transformers failed to cool down and stopped operating."[74]
Droughts and wildfires	California's 2007 wildfire caused the Southwest Powerlink transmission system to go out of service," and another fire "caused two [additional] high-voltage transmission lines to trip offline."[75]	• The 2007 California wildfires displaced nearly 1 million people, destroyed thousands of homes, and resulted in the death of 10 people[76]	• The California Independent System Operator asked local utilities to reduce electric load by 500 MW among other measures. In total "the fires knocked more than two dozen transmission lines out of service," such that "only one 230-kilovolt transmission line was serving San Diego. Estimates indicate that more than 1,500 utility poles were burned, more than 35 miles of wire were damaged, and nearly 80,000 SDG&E customers in San Diego lost power."[77]
	2015 British Columbia wildfires	• In July 2015, B.C. had had 1,300 fires, burning more than 295,000 hectares (the 10-year average for the same time period is 708 fires affecting 41,000 hectares).[78]	• $143-million spent fighting forest fires as of late July 2015 ($63 million was budgeted for the year).[79]

71 Sofia Aivalioti, *Electricity Sector Adaptation to Heat Waves*. (New York: Columbia Law School Sabin Center for Climate Change Law, January 2015), 9, available: http://web.law.columbia.edu/sites/default/files/microsites/climate-change/white_paper_-_electricity_sector_adaptation_to_heat_waves.pdf.

72 Ibid, 9.

73 Ibid, 14.

74 Ibid, 14.

75 Edward Vine, *Adaptation of California's Electricity Sector to Climate Change*. San Francisco: Public Policy Institute of California, 2008, available: http://www.ppic.org/content/pubs/report/R_1108EVR.pdf.

76 California Department of Forestry and Fire Protection (CAL FIRE) et al., "California Fire Siege 2007: An Overview", 3, available: http://www.fire.ca.gov/fire_protection/downloads/siege/2007/Overview_CompleteFinal.pdf.

77 US Department of Energy, US Energy Sector Vulnerabilities to Climate Change and Extreme Weather, DOE/PI-0013. (Washington, DC: US Department of Energy, 2013), 2, available: http://energy.gov/sites/prod/files/2013/07/f2/20130710-Energy-Sector-Vulnerabilities-Report.pdf.

78 Mark Hume, "Premier warns B.C. in for more wildfires, blames climate change," *The Globe and Mail,* July 22, 2015, available: http://www.theglobeandmail.com/news/british-columbia/bc-wildfire-fight-aided-by-cool-weather-but-winds-complicate-efforts/article25628547/.

79 Ibid.

Factor	Event	Mortality, Health and Ecosystem Impacts	Electricity Impacts and Economic Costs
Droughts and wildfires	2015 Alberta drought	• "Farmers across almost two-thirds of Alberta are coping with some of the driest conditions in decades." [80]	• The vice-president of the Alberta Federation of Agriculture warned that "unless the province gets substantial rain and snow over the next few months, 2016 could be even worse for farmers: 'If we don't see a substantial rebuilding of the deeper moisture layer, next year farmers will be living shower to shower. The effects of this could be long-lasting.'"[81]
Hurricanes, floods and major storms	Hurricane Katrina, August 2005	• Estimated 1,836 deaths, and millions left homeless.	• Property damage is estimated at $81 billion (USD).[82] • In terms of electricity damage, all of Mississippi Power's customers "lost power, nearly two-thirds of the transmission and distribution system was damaged or destroyed, and all and all but three of the company's 122 transmission lines were out of service."[83]
	Hurricane Sandy, October 2012	• 285 deaths, including at least 125 in the United States.[84]	• "More than 8 million customers lost power in 21 affected states," and there was "damage to over 7,000 transformers and 15,200 poles."[85] • "[P]orts and several power plants in the Northeast, including all nuclear power units, petroleum/natural gas refineries and pipelines, and petroleum terminals, were either damaged or experienced temporary shutdowns due to high winds and flooding."[86]
	Alberta floods of June 2013	• 32 local councils declared a "state of emergency" • Five deaths as a direct result of the flooding • Over 100,000 people displaced throughout the region[87]	• Total damage estimates have reached as high as $6 billion.[88] • The cost of the flood to ENMAX Corporation was calculated at $4.7 million in operational costs and capitalized costs of $4.9 million.[89]

80 Justin Glovannetti, "In Alberta, farmers fear long-lasting effects from brutal drought," *The Globe and Mail*, July 19, 2015, available: http://www.theglobeandmail.com/news/national/in-alberta-farmers-fear-long-lasting-effects-from-brutal-drought/article25588883/.

81 Ibid.

82 Kim Ann Zimmermann, "Hurricane Katrina: Facts, Damage, and Aftermath," Live Science, August 20, 2012, available: http://www.livescience.com/22522-hurricane-katrina-facts.html.

83 Billy Ball, "Rebuilding Electrical Infrastructure along the Gulf Coast: A Case Study," The Bridge 36:1. (Washington, DC: National Academy of Engineering, 2006), available: https://www.nae.edu/File.aspx?id=7393.

84 Tom McCarthy, "'Sandy' to be retired as hurricane name by World Meteorological Organization," *The Guardian*, April 12, 2013, available: http://www.theguardian.com/world/2013/apr/12/hurricane-sandy-name-retire.

85 US Department of Energy, *US Energy Sector Vulnerabilities to Climate Change and Extreme Weather*, DOE/PI-0013. (Washington, DC: US Department of Energy, 2013), 6, available: http://energy.gov/sites/prod/files/2013/07/f2/20130710-Energy-Sector-Vulnerabilities-Report.pdf.

86 Ibid.

87 Bob Weber, "Alberta Flooding 2014: Some Evacuations, While Others Hold Ground," *The Canadian Press*, June 18, 2014, available: http://www.huffingtonpost.ca/2014/06/18/alberta-flood-evacuations_n_5507617.html.

88 Ibid.

89 "The Economic Impact of the Flood," *ENMAX Corporation*, available: https://www.enmax.com/about-us/corporate-responsibility/cr-and-economics/impact-of-flood.

Factor	Event	Mortality, Health and Ecosystem Impacts	Electricity Impacts and Economic Costs
Hurricanes, floods and major storms	Toronto flood of July 2013	• Record rainfall of 126 mm, causing major flooding in the metropolitan area[90]	• "Insurers paid out nearly $1 billion to cover the cost of the Toronto flood."[91]
	Post Tropical Storm Arthur, Nova Scotia and New Brunswick, July 5, 2014	• In Fredericton, the storm brought 100 km/hour winds which took down over 4,000 trees[92] • Winds of 139 km/hour were recorded in Nova Scotia[93]	• Over 250,000 customer outages at the storm's peak[94] and 140,000 customers without power following the storm[95] • Over 200 utility poles in Fredericton had to be repaired or replaced[96] • New Brunswick Power Corporation deployed more than 300 crews, including contractors, for restoration efforts. This was the largest mobilization of crews for restoration efforts in the utility's history. The final cleanup cost (in New Brunswick alone) was estimated at $23 million.[97]

AltaLink employees helping with the 2013 flood recovery efforts in Southern Alberta. *Photo courtesy of AltaLink.*

90 "Toronto floods leave power system 'hanging by a thread'," *CBC News*, July 9, 2013, available: http://www.cbc.ca/news/canada/toronto/toronto-floods-leave-power-system-hanging-by-a-thread-1.1304807.

91 Dana Flavelle, "A year after the Toronto flood," *The Toronto Star*, July 5, 2014, available: http://www.thestar.com/business/personal_finance/investing/2014/07/05/a_year_after_the_toronto_flood.html.

92 "NB Power pushes service restoration estimates into next week," *CBC News*, July 10, 2014, available: http://www.cbc.ca/m/touch/canada/newbrunswick/story/1.2702010.

93 Andrew Russell, "Maritimes cleaning up after post tropical storm Arthur ravages region", *Global News*, July 6, 2014,available: http://globalnews.ca/news/1434951/maritimes-cleaning-up-after-post-tropical-storm-arthur-ravages-region/.

94 Ibid.

95 "Blackout in Atlantic Canada could last for days as city officials face weeks of cleanup in Arthur aftermath," *National Post*, July 7, 2015, available: http://news.nationalpost.com/news/canada/blackout-in-atlantic-canada-could-last-for-days-as-city-officials-face-weeks-of-cleanup-in-arthur-aftermath.

96 "Storm Arthur's cost for NB Power estimated at $23M," *CBC News*, December 3, 2015, available: http://www.cbc.ca/news/canada/new-brunswick/storm-arthur-s-cost-for-nb-power-estimated-at-23m-1.2858540.

97 Ibid.

Highway during the Toronto flood of July 2013. The flood had a record rainfall of 126 mm, causing major flooding in the metropolitan area, which caused damage to electricity infrastructure. *Photo courtesy of Toronto Hydro Corporation.*

C. ARE HIGH IMPACT SCENARIOS INCREASING IN LIKELIHOOD?

Extreme weather events raise concerns that the likelihood and frequency of high impact scenarios[98] are increasing.

There are three issues worth highlighting in connection with these concerns:

1. The potential exacerbating impact of aging infrastructure;
2. The interconnected nature of electricity; and
3. The potential for low probability, high impact events (black swans).

1. POTENTIAL VULNERABILITY OF AGING INFRASTRUCTURE

Aging infrastructure may be more vulnerable to damage from some climate change effects than recently built infrastructure.[99] As the U.S. General Accounting Office (GAO) comments, "most energy infrastructure was engineered and built for our past or current climate and may not be resilient to continued and expected increases in the magnitude and frequency of extreme weather events."[100] The GAO points out that "most of the U.S. electricity transmission system was designed to last 40 to 50 years; yet, in some parts of the country, it is now 100 years old … Changes in climate [could] further strain these already aging components by forcing them to operate outside of the ranges for which they were designed."[101] The U.S. Department of Energy's supports these findings and notes that "aging infrastructure is more susceptible than newer assets to the hurricane-related hazards of storm surge, flooding, and extreme winds, and retrofitting this existing infrastructure with more climate-resilient technologies remains a challenge."[102]

Canadian electricity infrastructure is aging as well, with most non-hydro assets needing replacement or renewal by 2050.[103] As a result, Canada's infrastructure is subject to similar risks, particularly for assets designed in line with older weather-related assumptions.

98 High impact scenarios can be defined as scenarios that represent dramatic increases relative to historical norms in terms of cost, damage or safety.

99 For example, aging infrastructure compounded problems in the 2009 heat wave. See Sofia Aivalioti, *Electricity Sector Adaptation to Heat Waves*, 44.

100 United States Government Accountability Office, *Climate Change: Energy Infrastructure Risks and Adaptation Efforts,* GAO-14-74. Published: Jan 31, 2014. Publicly Released: Mar 4, 2014. 10, available: http://www.gao.gov/products/gao-14-74.

101 Ibid.

102 Ibid.

103 "Shedding Light on the Economic Impact of Investing in Electricity Infrastructure," *Conference Board of Canada*, 2012, 1, available: http://www.conferenceboard.ca/e-library/abstract.aspx?did=4673.

The electricity system is not just defined by its own internal interdependencies: electricity inputs and outputs are also inextricably connected to other municipal services, as well as to the larger ecosystem.

2. THE INTERCONNECTED NATURE OF ELECTRICITY

The 2003 North American electricity blackout began with overgrown trees in Ohio and ended with 50 million people losing power. While electricity reliability in North America has been strengthened since then (through coordinated reliability policies and standards), interconnectedness remains a central feature of the system.[104] In addition to internal interdependencies, electricity sector inputs and outputs are also inextricably connected to other municipal services, as well as to the larger ecosystem. Electricity, urban centers, and the climate are all highly complex, interconnected systems where changes can combine and cascade into magnified multi-sector impacts:

- Water is needed for energy and land (e.g., power plant cooling and agriculture); energy is needed for water and land (e.g., water treatment and resource extraction); and land is needed for energy and water (e.g., power lines and watersheds).[105]
- The electricity distribution system is connected to many municipal service systems such as housing and municipal sewer systems. The severity of the 2013 flash flood in Toronto, which caused power outages for thousands of customers, was in part due to the city's aging water infrastructure.[106]
- If transmission capacity is lost or reduced, generation facilities will either need to trip their systems (e.g. thermal generation) and then start up again, or run sub-optimally (e.g. hydro systems may need to spill water). In either case, this could potentially impact service to customers and revenues.

Cumulative impacts within the various manifestations of climate change are equally challenging, consider for instance the risks of drought, extreme heat, and wildfire. While any one of these present a challenge in its own right, the system impacts may expand exponentially when taken together.

- Adding further complexity, information and communications technology (ICT) is playing an increasingly important role as part of this complex interchange. As an Asian Development Bank report sums up: "… energy, transport, and water infrastructure tend to be highly interconnected with each other and with ICT which increasingly monitors and controls electricity operations … Understanding the … potential effects of multiple hazards [caused by climate change impacts] is critical for the energy sector."[107]

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104 After the Blackout: Implementation of Mandatory Electric Reliability Standards in Canada, Energy and Mines Ministers' Conference, Halifax, Nova Scotia, July 15, 2015, available: http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/www/pdf/publications/emmc/15-0137%20EMMC-After%20the%20Blackout-e.pdf. New threats and risks are also emerging. On this point, see Adam Miller, "A decade after North American blackout, power grids more reliable, but still vulnerable to failure," *The Globe and Mail,* August 13, 2013, http://www.theglobeandmail.com/news/national/a-decade-after-north-american-blackout-power-grids-more-reliable-but-still-vulnerable-to-failure/article13748261/.

105 US Department of Energy, *US Energy Sector Vulnerabilities to Climate Change and Extreme Weather,* 5.

106 Laura Kane, "Toronto must overhaul aging infrastructure to meet dramatic climate change projections, study shows," *The Toronto Star,* January 28, 2013, available: http://www.thestar.com/news/gta/2013/01/28/toronto_must_overhaul_aging_infrastructure_to_meet_dramatic_climate_change_projections_study_shows.html.

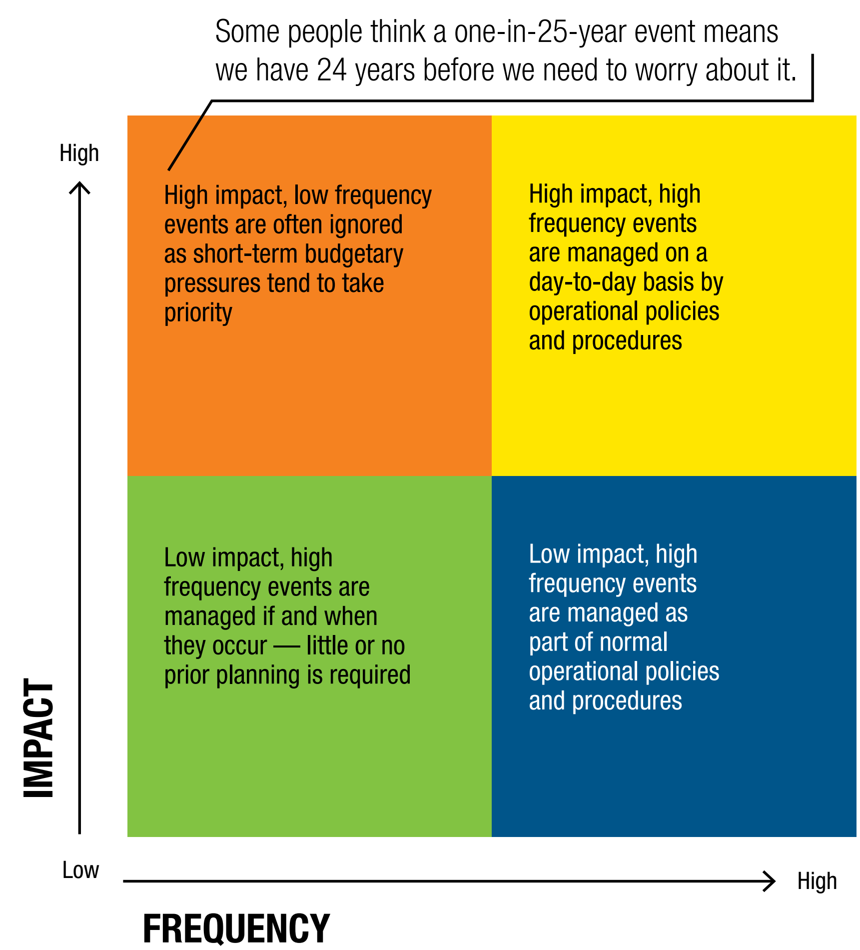
107 Asian Development Bank, *Climate Risk and Adaptation*, 5. Or, as the United States Department of Energy warns, "Compounding factors may create additional challenges. For example, combinations of persistent drought, extreme heat events, and wildfire may create short-term peaks in demand and diminish system flexibility and supply, which could limit the ability to respond to that demand;" *US Department of Energy, US Energy Sector Vulnerabilities to Climate Change and Extreme Weather.* July, 2013, available: http://energy.gov/sites/prod/files/2013/07/f2/20130710-Energy-Sector-Vulnerabilities-Report.pdf.

3. BLACK SWANS

Risk management has evolved to include not only an analysis of probabilities based on historical patterns, but also a consideration of low probability, high impact events, or black swans.[108] In the case of climate change, black swans are starting to resemble grey swans (improbable, perhaps, but conceivable). As author and investor Tom Rand argues, "we now know sudden, catastrophic changes in climate are a real possibility … Neither the precise timing of these catastrophic events, nor their effects, can be treated with any degree of certainty, but we do know they're worth worrying about."[109]

When considering scenarios, even if incremental change will be the norm for most locations most of the time, extreme events are likely to occur in a few locations on some occasions. Thus electricity investment planners and infrastructure experts will need to find ways to identify the potential for such extreme events and ask how they will be managed if they do occur, so as to minimize their

Table 7: Impact Frequency Assessment Chart



108 For the argument that popularized this metaphor, see Nassim Nicholas Taleb, *The Black Swan: The Impact of the Highly Improbable*. (New York: Random House, 2007).

109 Tom Rand, *Waking the Frog: Solutions for Our Climate Change Paralysis*, ECW Press, 2014, 120.

unwanted effects. In a July 2015 opinion piece Arunabha Ghosh and David King argue for the importance of considering worst case scenarios: "A country's national security adviser would rarely be criticized for considering the worst case military, intelligence or terrorist threats … Similarly, an insurance firm would not be faulted for assessing the worst-case risks … We have to plan for the worst, not merely hope for the best."[110]

Unfortunately, however, high impact, low frequency events are often ignored (see ***Table 7***):[111]

D. KEY FINDINGS ON RISKS AND OPPORTUNITIES

Climate change presents a wide range of risks and vulnerabilities for the electricity sector. While there may be some opportunities in some areas for some actors, on balance the sector's risk profile is increasing.

Through this report's analysis of high impact weather events, potential climate change impacts for electricity, and the increasing likelihood of high impact scenarios, a number of key findings emerge:

- Climate impacts may vary dramatically by region. Additionally, impacts may be experienced very differently by different constituencies and communities within the same region.[112]
- Opportunities may become risks, and risks may become opportunities, as circumstances and/or perspectives change.
- Some potential impacts may be anticipated by planning processes and historical analogies, and others will be the unexpected result of cascading effects in interdependent systems, or of high impact, low frequency events for which organizations are often poorly prepared.

While it may be tempting for risk managers to continue to focus on moderate potential risks as a defensible, middle-of-the-ground planning assumption for the sake of future investments, the extreme events of past years suggest that another step is needed for improved system resilience. Managers will need to establish mechanisms and processes (or revise existing ones), to try to anticipate unpredictable events.

In short, the world is becoming less predictable, and electricity stakeholders will need to prepare for a more dynamic and uncertain environment.

110 Arunabha Ghosh and David King, "Climate risks – the worst cases matter," *Business Standard*, July 20, 2015, available: http://www.business-standard.com/article/opinion/arunabha-ghosh-david-king-climate-risks-the-worst-cases-matter-115072001245_1.html. As an example of a worst case scenario that deserves our attention, Ghosh and King reference a recent analysis of India, finding "that under a worst-case scenario, Delhi, Ahmedabad, Bangalore, Mumbai and Kolkata are projected to experience the highest absolute increases in heat-related mortality this century."

111 As one example, see Henry Renteria, *British Columbia Earthquake Preparedness Consultation Report.* December 2014, available: http://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/emergency-preparedness-response-recovery/embc/renteria_eq_consultation_report_2014.pdf. As Renteria argues, "In B.C., the lack of significant seismic activity near highly populated areas has resulted in widespread apathy. This has meant that earthquake preparedness has not received the day-to-day attention that other pressing needs have received. Consequently, earthquake and disaster preparedness programs have been cut or restricted in growth and resources have been devoted to other priorities and programs," p.2.

112 US Department of Energy, *US Energy Sector Vulnerabilities to Climate Change and Extreme Weather,* DOE/PI-0013. (Washington, DC: US Department of Energy, 2013), i.; also see Rosemary Lyster and Rebekah Byrne, "Climate Change Adaptation and Electricity Infrastructure," in *Research Handbook on Climate Adaptation Law*, ed. by J. Verschuuren. (Cheltenham: Edward Elgar Publishing, 2013), 4.

4 SECTOR PERSPECTIVES AND PRACTICES ON ADAPTATION

The evidence is growing that climate change adaptation ought to be a priority issue for the electricity sector, especially as it relates to operations management and investment planning. How is the sector responding? This chapter provides an overview of current perspectives and practices from two sources:

A. An overview of a survey of CEA members on adaptation; and

B. A discussion of important tools to integrate climate change adaptation into investment planning processes.

A. SURVEY ON ADAPTATION AND ELECTRICITY

In 2014, CEA conducted a member survey to learn more about the current state of awareness, dialogue, and action on climate change adaptation in the electricity sector. The survey was undertaken as an input to this report, to supplement member contributions from workshops and meetings with CEA's Climate Change Adaptation Working Group. Altogether, 10 CEA member companies[113] responded and completed all 23 questions.[114]

The survey forms a snapshot of current practices in the electricity sector with regard to three critical issues:

1. Investment planning practices;
2. Climate change adaptation awareness and management; and
3. The intersection of climate change adaptation and investment planning.

Summary results are as follows:

1. INVESTMENT PLANNING PRACTICES

- **Diversity in investment planning:** Some companies project investment requirements over much longer time horizons than others, and the allocation of capital investment dollars varies considerably according to company-specific prioritization.
- **Load changes expected in next 10–15 years:** 7 out of 10 companies anticipate a significant load profile change (i.e. overall increase in peak demand), in the next 10–15 years.
- **Central focus on asset renewal and asset condition:** When asked about areas they are investigating in support of meeting future expected reliability levels, 9 out of 10 highlighted "asset renewal."

2. CLIMATE ADAPTATION AWARENESS AND MANAGEMENT

For Canadian electricity companies, climate adaptation is a new consideration:[115]

- **Corporate policies still at early stage:** four out of 10 companies have a formal corporate policy indicating a commitment to climate change adaptation.

113 While the list of respondents is confidential, they represent a subset of member organizations identified in *Appendix 1: Participating Organizations*.

114 See *Appendix 2* for more details on the survey.

115 For further evidence that climate adaptation is new for Canadian electricity companies, see http://sustainableelectricity.ca/en/annual-report/annual-report-2014/climate-change/.

- **Priority of issue increasing, but still low to medium priority:** The priority given to climate change has increased in the last two or three years, but most still consider climate change adaptation to be a low to medium priority issue.[116]
- **Responsibility for issue varies widely:** There is no sector consistency as to which function or part of the organization has primary responsibility for climate change adaptation.
- **Adaptation considerations not integral to investment planning**: When companies were asked about the extent to which they incorporated adaptation considerations into investment planning, seven out of 10 said they did so only "occasionally" (one said "often," and two said "always").
- **Limited in-house capabilities:** To the extent that companies incorporate climate data, only one indicated that it has in-house modelling capabilities, while five others indicated that they obtain climate data from various external sources.
- **Regional data, but limited confidence:** Four companies responded that their climate data sets are more regional/local than national/international. Even so, no company had high confidence in its incorporation of climate data into its investment analysis process.

In summary, many CEA member companies do not yet have formal policies on climate adaptation awareness and management, and the issue is not yet deemed as a high priority. Primary responsibility for the issue varies widely among companies, and most "only occasionally" incorporate adaptation considerations into investment planning. Utilities do not have a high level of confidence in climate data, nor do they have a high level of confidence in how they incorporate climate data into their investment analysis process.

3. INTERSECTION OF CLIMATE CHANGE AND INVESTMENT PLANNING

While climate change adaptation may be a new or emerging issue among member companies, robust investment planning practices are in place. In particular:

- Companies' projected investment requirements are developed through a range of sophisticated and complementary methodologies;
- For supply and demand planning, companies also use a range of methods to enhance system resiliency and reliability; and
- All surveyed companies have restoration/emergency plans in place as preparation for extreme weather events.

The robustness of existing investment planning, including methods designed to ensure high levels of reliability, suggests that some climate adaptation considerations may already be finding their way into company decision-making through less formal processes. For instance, most companies consult with various stakeholders on different components of their long-run demand forecast, where temperature sensitivities are considered alongside Gross Domestic Product trends. Companies also have emergency plans in place for extreme events. While these plans may not explicitly discuss climate change, they may help anticipate some of its impacts.

116 Some respondents chose both low and medium priority at the same time; hence the total number of responses under medium and low exceeds 10.

To more effectively incorporate climate change considerations into existing investment practices, CEA member companies highlighted two key requirements:

- **Confidence around reliability and geographic scale of data:** As one respondent commented, "higher confidence" will come "with improved data and models. Many climate models do not agree on the magnitude (or direction) of change in some hydrologic variables." Another respondent called for "more climate modelling at the regional or local level around the utility and its micro-climate." And another wrote that there was a need for "provincially based climate modelling on the frequency and severity of extreme weather/climatic events (versus median increases) and secondary consequences (i.e. extended droughts could lead to increased fire risk/hazards)." The respondent felt that such modelling would "allow for consistent decision making among agencies, regulating entities and utilities."
- **Need for a more defined process to connect adaptation and investment planning:** In the words of one respondent, "there is some work underway to incorporate climate change information into decision making. Advances in decision making methods can help advance incorporation of climate change into investment planning."

In short, further defining and developing climate change adaptation data and methods will allow adaptation considerations to be incorporated more fully into investment forecasting and planning.

B. BRIDGING THE GAP: TOOLS TO INTEGRATE ADAPTATION INTO INVESTMENT PLANNING

This section highlights two important tools to support the integration of climate change into management practices and especially investment planning:

1. CEA's *Climate Change Adaptation Management Planning Guide;* and
2. Engineers Canada's Public Infrastructure Engineering Vulnerability Committee Protocol (PIEVC Protocol).

CEA members developed and approved the *Climate Change Adaptation Management Planning Guide*[117] in late 2015. The PIEVC Protocol was first developed in 2008, and has been applied to risk assessments for almost 40 infrastructure systems in Canada, including several electricity projects.[118]

1. CEA'S CLIMATE CHANGE ADAPTATION MANAGEMENT PLANNING GUIDE

This guidance document supports the creation of effective climate change adaptation management plans, and outlines a risk-based guidance framework which defines the characteristics and considers key aspects of adaptation planning. It takes an approach similar to ISO management standards by providing a framework to allow users to flesh out the details in a manner specific to their business circumstances. The framework can be readily incorporated into existing enterprise risk management (ERM) processes. In the absence of ERM processes, it supports the creation of an adaptation management process.

117 The development of CEA's *Climate Change Adaptation Management Planning Guide* was done in concert with the development of this report.

118 Public Infrastructure Engineering Vulnerability Committee (PIEVC) website: http://www.pievc.ca/protocol.

The framework is not intended to be an exhaustive treatment of the subject, but rather outlines management approaches and illustrates them with some implementation suggestions. It is not intended to prescribe outcomes but rather stimulate critical thinking on the part of industry practitioners. It recognizes the fact that management strategies may vary based on the uniqueness of each electricity company's risk profile and tolerance.[119]

2. ENGINEERS CANADA'S PUBLIC INFRASTRUCTURE ENGINEERING VULNERABILITY COMMITTEE'S PROTOCOL

Between 2008 and 2014, Engineers Canada's Public Infrastructure Engineering Vulnerability Committee's Protocol (PIEVC Protocol) has been applied to risk assessments for almost 40 infrastructure systems in Canada. The protocol has been applied to a range of assessments including buildings, water systems, roads, electricity distribution and airports.[120] The PIEVC Protocol works by assessing "the nature, severity and probability of future climate changes and events," and then establishing "the adaptive capacity of an individual infrastructure as determined by its design, operation and maintenance."[121] The assessment includes an analysis of potential impacts on various infrastructure components and identification of higher risk components, so as to support "informed engineering judgments on what components require adaptation as well as how to adapt them e.g. design adjustments, changes to operational or maintenance procedures."[122]

Although the PIEVC Protocol is only in an early stage of adoption, Engineers Canada recommends its use "for all types of infrastructure going forward," and has made it available at no charge through a license agreement.[123] As a helpful case study for CEA members, the final report for Toronto Hydro Corporation's *Electrical Supply and Delivery Infrastructure* assessment under the Protocol was completed in September 2012[124].

119 Refer to *Appendix 3* which includes two excerpts from the *Climate Change Adaptation Management Planning Guide* to inform managerial planning and decisions: 1. Adaptation process elements; 2. Sequence of steps in adaptation planning

120 From the Public Infrastructure Engineering Vulnerability Committee (PIEVC) website discussion of "The Protocol," available: http://www.pievc.ca/protocol.

121 Ibid.

122 Ibid.

123 Ibid.

124 Refer to the PIEVC Protocol website: (http://www.pievc.ca/protocol) to view this report.

5 RECOMMENDATIONS

Effective climate adaptation in electricity will require leadership, action, and coordination across multiple stakeholder groups:

FEDERAL GOVERNMENT

PROVINCIAL AND TERRITORIAL GOVERNMENTS

MUNICIPALITIES

SYSTEM OPERATORS

ELECTRICITY COMPANIES

RATEPAYERS AND CITIZENS

All stakeholders must be actors in a broader system in which cross-sector communication and collaboration are essential for optimal planning and action in response to current and future climate scenarios.

A. FEDERAL GOVERNMENT

The federal government has a critical leadership role to play in supporting a national vision and common understanding of climate change, and in coordinating dialogue with the United States and between various levels of government in Canada. CEA recommends that the federal government:

- ***Develop a national adaptation strategy:*** No sector, and no province or territory, will be able to adapt to climate change on its own. Building on the 2011 Federal Adaptation Policy Framework, the federal government should take the lead in championing a comprehensive climate change adaptation strategy for Canada. The strategy should provide concrete guidance for federal and provincial policymakers.[125]
- ***Improve national understanding:*** The federal government should provide a strategic voice to support greater climate literacy among citizens, industry sectors, and regions.
- ***Support scientific research and climate data at a regional level:*** Scientists and researchers play a critical role in advancing the complex science behind climate change. It is important that Canadian scientists in universities, think tanks and research consortia receive appropriate financial support to continue their research as part of ongoing efforts to advance scientific understanding. It is equally important that industry sectors, including the electricity sector, have access to high quality, regional climate data in a usable format for use in investment planning.

125 See: "Helping Canadians adapt to Climate Change, Government of Canada, last modified October 1, 2010, available: http://climatechange.gc.ca/default.asp?lang=En&n=2B2A953E-1.

Advances in scientific research will also help industries refine the business case for action over inaction.[126] The federal government has a key role in supporting organizations that can provide the data and associated tools required.

- ***Cross-border coordination and risk management:*** In May 2015, Canada, the United States and Mexico established a ministerial-level working group on climate change and energy issues, with plans to examine adaptation among other topics.[127] CEA encourages the working group to examine climate adaptation risks and practices in areas of shared concern, including critical infrastructure vulnerabilities in cities, cross-border transmission issues, and scenarios for hydropower water use.

  Both Canada and the United States will need to ensure that the use of water for hydropower, especially along the Canada-U.S. border, will be consistent with optimal use of a resource that may see meaningful changes in availability patterns.

B. PROVINCIAL AND TERRITORIAL GOVERNMENTS

Provinces should respond to a renewed national vision around adaptation in the context of their specific market circumstances and issues. In particular, CEA recommends that each province:

- ***Establish a position on climate risks:*** Through consultation with climate scientists and infrastructure engineers, each province should develop a position on climate risks and potential adaptation strategies, including both sector-specific and province-wide strategies.
- ***Require municipalities to develop adaptation plans:*** Action plans align the efforts of key services and stakeholders to avoid gaps and redundancy. While municipalities will have local expertise, the requirement to develop robust local action plans should come from the provincial level.
- ***Strengthen building codes and standards:*** Resilient cities require resilient buildings. Provincial building codes should be strengthened to adapt to climate risk and extreme weather. Design practices should take into account two key themes: "durability," and "disaster resilience."[128] Work is needed to establish the return on investment (ROI) for innovations in resilient and durable design. In cases where the ROI payback is already clear, there should be mechanisms "for enshrining new solutions into codes and standards."[129]
- ***Update flood plain maps:*** To help lower risks in relation to extreme precipitation events, provincial governments should develop up-to-date flood plain maps.[130] These maps could inform plans to locate and build new infrastructure and housing as well as improve adaptation measures for existing locations.[131]

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126 On this point see P. Audinet et al, *Climate Risk Management Approaches in the Electricity Sector: Lessons from Early Adapters*. A. Troccoli et al., editors, Weather Matters for Energy, Part I (pp 17-64).

127 "Canada, US, Mexico agree to establish working group for climate change, energy," *CTV News*, May 25, 2015, available: http://www.ctvnews.ca/business/canada-u-s-mexico-agree-to-establish-working-group-for-climate-change-energy-1.2390202.

128 *Climate Change Adaptation Strategy*, City of Vancouver, 2012, available: http://vancouver.ca/files/cov/Vancouver-Climate-Change-Adaptation-Strategy-2012-11-07.pdf, 25.

129 Adam Auer, "Fight the Future," *ReNew Canada: The Infrastructure Magazine*, December 8, 2014, available: http://renewcanada.net/2014/fight-the-future/.

C. MUNICIPALITIES

Key recommendations for municipalities include the following:

- ***Develop adaptation action plans:*** While provinces should require municipalities to develop adaptation plans, municipalities themselves will need to consider their specific resource situations, including community energy sources, water resources, and land use requirements and constraints.[132]
- ***Ensure integrated participation from multiple stakeholders:*** 2012 Truro floods and 2013 Toronto and Calgary floods highlighted the need for improved critical infrastructure assessment and planning not just within, but also *across*, various municipal functions. For instance, electricity reliability can be connected to sewage systems (and how well those systems are equipped to handle extreme rainfall and runoff) in ways that may not be obvious. Sewage and electricity stakeholders should therefore be collaborators in a cross-stakeholder process for identifying risks and responses. The Greater Toronto Area (GTA) Weatherwise Partnership is a good example of an initiative drawing together multiple GTA stakeholders (including a range of public, private, and non-profit organizations) along with the federal and provincial governments to discuss climate change.
- ***Pursue comprehensive energy efficiency actions:*** Cities are particularly vulnerable to increases in temperatures which are exacerbated by the urban heat island effect. All cities should include comprehensive energy efficiency measures as part of their adaptation plans.

D. SYSTEM OPERATORS

Recommendations for system operators are as follows:

- ***Incorporate climate scenarios into load forecasts:*** System operators should consider climate sensitivities and their potential impact on future demand. They could collaborate with climate modelers to integrate climate change considerations into the determination of appropriate future reserve margins.
- ***Maintain a climate dialogue with other system operators:*** While the system operator in one jurisdiction may be confident that regional climate scenarios are manageable, it will also be important to consider sensitivities arising from neighbouring jurisdictions, including potentially extreme climate change scenarios in the United States that could dramatically impact American demand and, therefore, overall North American demand.

130 For a recent discussion of the need to update Canadian flood plain maps, see Dr. Yi Wang, "Climate Change and Municipal Stormwater Systems," white paper prepared for the Canadian Water Network Research Project, 'An Integrated Risk Management Framework for Municipal Water Systems,' University of Guelph, 2015. Also see the Government of Canada's "National Disaster Mitigation Program (NDMP)" introduced in April 2015: http://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/index-eng.aspx.

131 In response to major floods in 2010-11 in Queensland, Australia, The Queensland Floods Commission of Inquiry made a number of recommendations with applicability to other jurisdictions: "a recent flood study of the most flood-affected catchments and of all urban areas in the State should be initiated and made available. The flood study should be comprehensive … All flood mapping should be displayed [publicly] and property specific information should be available to the general public …" and finally, "[p]rospective purchasers should be alerted to the risk of flooding including by standard contract conditions;" see Rosemary Lyster and Rebekah Byrne, "Climate Change Adaptation and Electricity Infrastructure," 32.

132 For New York's efforts to improve climate resilience, particularly in response to Hurricane Sandy, see US Department of Energy, *US Energy Sector Vulnerabilities to Climate Change and Extreme Weather*, 37.

E. ELECTRICITY COMPANIES

Key recommendations for electricity companies are as follows:

- ***Develop climate adaptation management plans:*** Drawing on CEA's *Climate Change Adaptation Management Planning Guide* discussed in **Chapter IV**, each electricity company should develop and update its own climate adaptation management plan. Each plan should assess system vulnerabilities and identify ways to manage climate risks and opportunities, including cost-effective actions to modify infrastructure.

  Effective adaptation plans could significantly impact the bottom line. Hydro-Québec found in its study of the Peribonka River system that doing nothing could result in reduced power output of 14 percent, while adaptation could increase output by 15 percent.[133] As one commentator argues, "a comprehensive adaptation plan would help to firmly establish the future benefits and the avoided costs of resiliency measures, even if these measures do not pay dividends right away."[134]

  - Building on the broad set of potential risks identified earlier in this report, electricity companies should maintain a tailored inventory of applicable risks[135] and assess, and periodically review and update the sensitivity of their assets to those risks.
  - In addition, companies should consider making use of the PIEVC Protocol for new infrastructure projects. They should also canvass and consider potential engineering solutions that may be applicable to their assets' specific circumstances. For example, thermal and nuclear generation facilities may want to consider design and technology changes to improve water cooling efficiency. Distribution companies, meanwhile, may want to ensure that equipment is designed and rated to withstand structural flooding, and that provisions are in place to improve water flow in underground structures (e.g., effective sump pumps and drainage systems). Hydroelectric generation facilities may want to consider increasing reservoir capacity to reduce sensitivity to changes in water supply.

- ***Exchange best practices in climate adaptation, including models and methods:*** There is an opportunity and need for electricity companies to exchange emerging and best practices with respect to climate adaptation planning, including questions around data and methods. As one survey respondent commented, since adaptation "is such an interdisciplinary and complicated topic," Canadian electricity companies should "collaborate with other utilities and industries that share our region," as well as "with utilities in other regions to share methodologies."

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133 Jane Ebinger and Walter Vergara, *Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation*, World Bank, Washington D.C, 2011, available: https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/E-Book_Climate%20Impacts%20on%20Energy%20Systems_BOOK_resized.pdf, 60.

134 Sam C.A. Nierop, "Envisioning Resilient Electrical Infrastructure: A Policy Framework for Incorporating Future Climate Change into Electricity Sector Planning," Columbia Law School Center for Climate Change Law, December 2013, available: http://www.questcanada.org/sites/default/files/publications/envisioning_resilient_electrical_infrastructure.pdf, 17.

135 Sea level rise and wildfire will not be risks for all assets.

- There are important data-related questions to be resolved, such as: which climate modelling resources/organizations are considered the most credible? What kind of model methodology is considered the most robust? Through CEA, member companies should identify recommended resources and organizations to improve the sector's confidence in incorporating climate models into investment planning considerations. A common theme in the emerging literature on electricity and adaptation, one echoed in comments by CEA members, is the need to provide "higher-resolution models for local and regional impact evaluation." Many electricity investment and operational decisions are based on regional or even quite local considerations.
- With respect to methods, it is important to determine the best ways to factor both moderate and extreme scenarios into decision making. There are also organizational issues to consider: should companies have dedicated functions looking at climate adaptation, or should the assessment be absorbed into existing investment planning practices? Also, should there be standardized ways of communicating and reporting climate adaptation measures? What would these look like? CEA has a facilitative leadership role to play in engaging member companies on options around these questions, and then shaping those options into recommendations.

- ***Review electricity system standards:*** Electricity companies should work with the Canadian Standards Association, the Canadian Dam Safety Association and other relevant experts to ensure infrastructure design and electricity system planning standards reflect current and future potential climate challenges.
- ***Promote greater demand response and overall system flexibility:*** To address the growing risk of unprecedented peaks in summer cooling demand, electricity companies should expand demand reduction programs.
- ***Optimize use of water resources and watersheds:*** Electricity companies should develop integrated plans for future hydropower capacity and cooling water needs for thermal operations taking into account extreme scenarios for changing weather patterns, increased need for summer peaking power, and the potential for intensified competition over water resource use on both sides of the Canada-U.S. border.

F. ELECTRICITY REGULATORS

Key recommendations for electricity regulators are as follows:

- ***Establish policies and practices that recognize the importance of addressing climate risks in electricity:*** Regulators will need to establish principles and processes by which utilities could undertake incremental infrastructure investments, or make changes to planned electricity investments, so as to improve resilience or otherwise address emerging climate risks and issues. Improved resilience must be understood in the context of traditional notions of cost prudence, as well as within emerging ideas around incentive regulation. To establish a systematic basis for this discussion, a report on the U.S. electricity sector argues that "[r]egulators should consider playing a more proactive role in requiring and reviewing utility climate change adaptation activities." More specifically, the report suggests that "regulators may want to require that utilities submit a climate change vulnerability assessment and a plan for reducing those vulnerabilities."[136]
- ***Encourage collaboration to facilitate cost-effective solutions:*** In response to Hurricane Sandy, Con Edison in New York City "applied for a $1 billion (USD) investment in storm hardening measures to reinforce its electrical system" as part of its rate case.[137] To support identification of cost-effective solutions, "a Collaborative was formed comprised of parties to the rate case, including the utility, state and local governments and NGOs. This Collaborative addressed climate change impacts on the utility's infrastructure, design standards and resiliency strategies."[138]

G. CUSTOMERS AND CITIZENS

Electricity customers and citizens also have a critical role to play. They should:

- ***Support and engage in community discussions around climate change and critical infrastructure:*** Climate change raises complex issues at the intersection of science, policy, and economics. Broad-based literacy and engagement on these issues will help the electricity sector identify potential cross-cutting risks, vulnerabilities, dilemmas, and tradeoffs.
- ***Contribute to demand response:*** By reducing loads at peak hours and during extreme weather events, demand response can help electricity providers maintain grid reliability across current and future climate scenarios. Electricity providers can enhance the role of consumers in the electricity market by providing them with incentives to use electricity when it is cheapest and most plentiful.

136 Melissa Higbee, *Climate change adaptation in the US electric utility sector, Massachusetts Institute of Technology,* 2013, available: http://hdl.handle.net/1721.1/81632, 89. In July 2014, Toronto Hydro became the first utility in Canada to cite adaptation studies and extreme weather events as part of its application for a five year rate plan with its provincial economic regulator, the Ontario Energy Board. The plan calls for $4 billion in funding for increased maintenance, operational support, and much-needed investments into the system to replace aging assets, meet growing demand, help improve reliability, and safeguard against extreme weather events.

137 Sam C.A. Nierop, "Envisioning Resilient Electrical Infrastructure: A Policy Framework for Incorporating Future Climate Change into Electricity Sector Planning," *Columbia Law School Center for Climate Change Law*, December 2013, available: http://www.questcanada.org/sites/default/files/publications/envisioning_resilient_electrical_infrastructure.pdf, 17.

138 Ibid.

CONCLUSION AND NEXT STEPS

This report is the first national level discussion of climate change adaptation for the electricity sector in Canada. It has attempted to fulfill three objectives: communicating the importance of climate change adaptation for the electricity sector; providing a preliminary understanding of current adaptation perspectives and practices in the sector; and advancing key recommendations for stakeholders.

There are three overarching findings.

1. ***The Range of responses required to adapt to future climate scenarios is not limited to the electricity sector.***

   Problems cut across sectors and geographies, solutions must be equally cross-cutting and holistic, involving a range of stakeholders. Governments at all levels, system operators, regulators and customers all have important roles to play.

2. ***There is an opportunity and need for CEA and individual electricity companies to develop more programmatic approaches to climate change adaptation***.

   It will take time to get this right, as the issue is complex, but the tools needed to begin the process are in place.

3. ***Electricity companies need to improve the incorporation of climate change scenarios into corporate governance, project planning and risk management practices.***

   A key priority for the sector is to ensure that the current $350 billion infrastructure spend is informed by a careful consideration and analysis of potential climate change impacts.

CEA is encouraged by the work underway on all fronts, and is optimistic that Canadian electric utilities will manage climate risk in a pragmatic, informed manner.

Appendix 1

PARTICIPATING ORGANIZATIONS

The following organizations contributed to the development and/or review of this report:

CEA's Climate Change Adaptation Working Group

AltaLink; ATCO Electric; ATCO Power; BC Hydro and Power Authority; Capital Power; ENMAX Corporation; Horizon Utilities Corporation; Independent Electricity System Operator; Manitoba Hydro; New Brunswick Power Corporation; Nova Scotia Power Inc. (Emera Inc.); Ontario Power Generation; PowerStream Inc.; SaskPower; Toronto Hydro Corporation; TransCanada; Yukon Energy Corporation.

CEA's Generation Council

ATCO Power; BC Hydro and Power Authority; Brookfield Renewable Energy Group; Capital Power; Columbia Power Corporation; ENMAX Corporation; Manitoba Hydro; New Brunswick Power Corporation; Newfoundland and Labrador Hydro (Nalcor Energy); Nova Scotia Power (Emera Inc.); Ontario Power Generation; SaskPower; TransCanada; Yukon Energy Corporation.

CEA's Transmission Council

Alberta Electric System Operator; AltaLink; ATCO Electric; BC Hydro and Power Authority; FortisBC; ENMAX Corporation; EPCOR Utilities Inc.; Hydro One Inc.; Hydro-Québec TransÉnergie; Independent Electricity System Operator; Manitoba Hydro; New Brunswick Power Corporation; Newfoundland and Labrador Hydro (Nalcor Energy); Nova Scotia Power (Emera Inc.); SaskPower.

CEA's Distribution Council

ATCO Electric; BC Hydro and Power Authority; City of Medicine Hat Electric Utility; FortisAlberta; FortisBC; ENMAX Corporation; EPCOR Utilities Inc.; Horizon Utilities Corporation; Hydro One Inc.; Hydro Ottawa; Hydro-Québec Distribution; Manitoba Hydro; Maritime Electric Company, Ltd.; New Brunswick Power Corporation; Newfoundland and Labrador Hydro (Nalcor Energy); Newfoundland Power Inc.; Northwest Territories Power Corporation; Nova Scotia Power (Emera Inc.); Oakville Enterprises Corporation; PowerStream Inc.; Saint John Energy; Saskatoon Light & Power; SaskPower; Toronto Hydro Corporation.

For a full list of CEA members, please visit www.electricity.ca.

Appendix 2

TOP ELECTRICITY INFRASTRUCTURE PROJECTS IN CANADA, 2015 (BY COST)

Renew Canada's *Top 100 Projects* list summarizes the largest public infrastructure projects in Canada (by cost). This is an abbreviated version of only electricity infrastructure projects, organized according to projected cost (***Table 8***) and mapped out according to geographical location (***Figure 6***).

Figure 6: Map of Top Electricity Projects, 2015

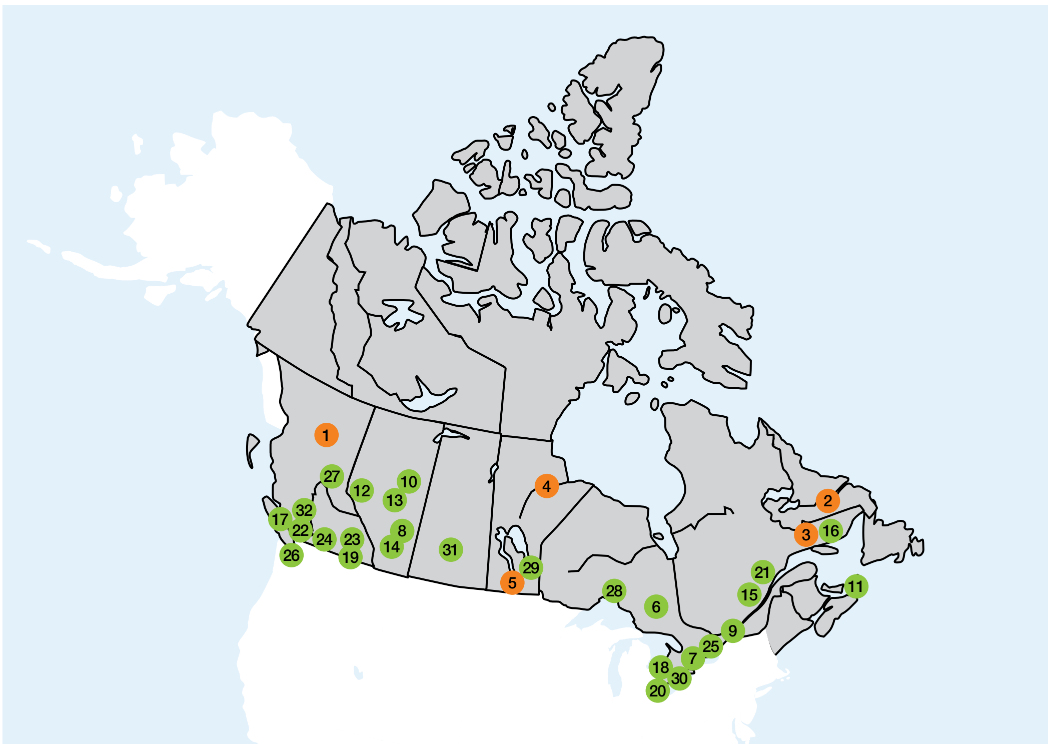


Table 8: Top Electricity Infrastructure Projects According to Projected Cost

#	Project	Cost ($)	Location	Owner(s)
1	Site C Clean Energy Project	8,775,000,000	Near Fort St. John, British Columbia	BC Hydro and Power Authority
2	Muskrat Falls Project	6,990,000,000	Muskrat Falls, Newfoundland and Labrador	Nalcor Energy; Emera Inc.
3	Romaine Complex	6,500,000,000	Havre-Saint-Pierre, Quebec	Hydro-Québec
4	Keeyask Hydroelectric Project	6,500,000,000	Lower Nelson River, Split Lake Resource Management Area, Manitoba	Manitoba Hydro; Keeyask Hydropower Limited Partnership
5	Bipole III Transmission Line	4,600,000,000	Winnipeg, Manitoba	Manitoba Hydro
6	Lower Mattagami Hydroelectric Complex	2,600,000,000	Northeast of Kapuskasing, Ontario	Ontario Power Generation; Moose Cree First Nation
7	Darlington Refurbishment Project – Definition Phase	2,500,000,000	Clarington, Ontario	Ontario Power Generation
8	Western Alberta Transmission Line	1,650,000,000	Genesee area west of Edmonton to the Langdon area east of Calgary, Alberta	AltaLink
9	Renovations to Beauharnois Hydroelectric Station	1,600,000,000	Melocheville, Quebec	Hydro-Québec
10	Fort McMurray West Transmission Project	1,600,000,000	Edmonton to Fort McMurray, Alberta	Alberta Electric System Operator
11	Maritime Transmission Link	1,560,000,000	Cape Breton, Nova Scotia	ENL Maritime Link
12	H.R. Milner Coal Plant Expansion	1,500,000,000	Grand Cache, Alberta	Maxim Power
13	Great Spirit Power Project	1,500,000,000	Lake Wabamun, Alberta	Focus Energy Group; Paul First Nation
14	Shepard Energy Centre	1,400,000,000	Calgary, Alberta	Capital Power
15	Chamouchouane–Bout-de-l'Île Transmission Line	1,350,000,000	Saguenay to Montréal, Quebec	Hydro-Québec
16	Romaine Complex Transmission Line	1,200,000,000	Minganie Region, Quebec	Hydro-Québec
17	John Hart Generating Station Replacement Project	1,093,000,000	Campbell River, British Columbia	BC Hydro and Power Authority
18	Deep Geological Repository	1,000,000,000	Kincardine, Ontario	Ontario Power Generation
19	The Waneta Expansion	900,000,000	South of Trail, British Columbia	Fortis Inc. Columbia Power Corporation; Columbia Basin Trust
20	K2 Wind Project	850,000,000	Township of Ashfield-Colborne-Wawanosh, Ontario	Capital Power LP; Samsung Renewable Energy Systems Inc.; Pattern Renewable Holdings Canada ULC
21	Riviere du Moulin Wind Farm	800,000,000	MRC de Charlevoix and MRC du Fjord de Saguenay, Québec	EDF Energies Nouvelles

#	Project	Cost ($)	Location	Owner(s)
22	Ruskin Dam and Powerhouse Upgrade	748,000,000	Ruskin, British Columbia	BC Hydro and Power Authority
23	Mica Generating Station Upgrade	739,000,000	Revelstoke, British Columbia	BC Hydro and Power Authority
24	Interior to Lower Mainland Transmission Project	709,000,000	Merritt to Coquitlam, British Columbia	BC Hydro and Power Authority
25	Marmora Pumped Storage Project	700,000,000	Marmora, Ontario	Northland Power
26	Juan de Fuca Power Cable	665,000,000	Victoria to Port Angeles, Washington, British Columbia	Sea Breeze Power
27	Gordon M. Shrum Generating Station Refurbishment	600,000,000	Peace River, British Columbia	BC Hydro and Power Authority
28	Ontario East-West Transmission Tie	600,000,000	Thunder Bay to Wawa, Ontario	Enbridge; NextEra Energy Canada; Borealis Infrastructure
29	Pointe Du Bois Spillway Replacement Project	560,000,000	Pointe du Bois, Manitoba	Manitoba Hydro
30	Armow Wind Farm	550,000,000	Kincardine, Ontario	Samsung; Pattern Energy
31	Queen Elizabeth Power Station Expansion	532,000,000	Saskatoon, Saskatchewan	SaskPower
32	Upper Lillooet Hydro Project	434,000,000	Boulder Creek, Upper Lillooet River, British Columbia	Innergex Renewable Energy Inc.

Source: "Top 100 – Canada's Biggest Infrastructure Projects," *ReNew Canada*, 2015, http://top100projects.ca.

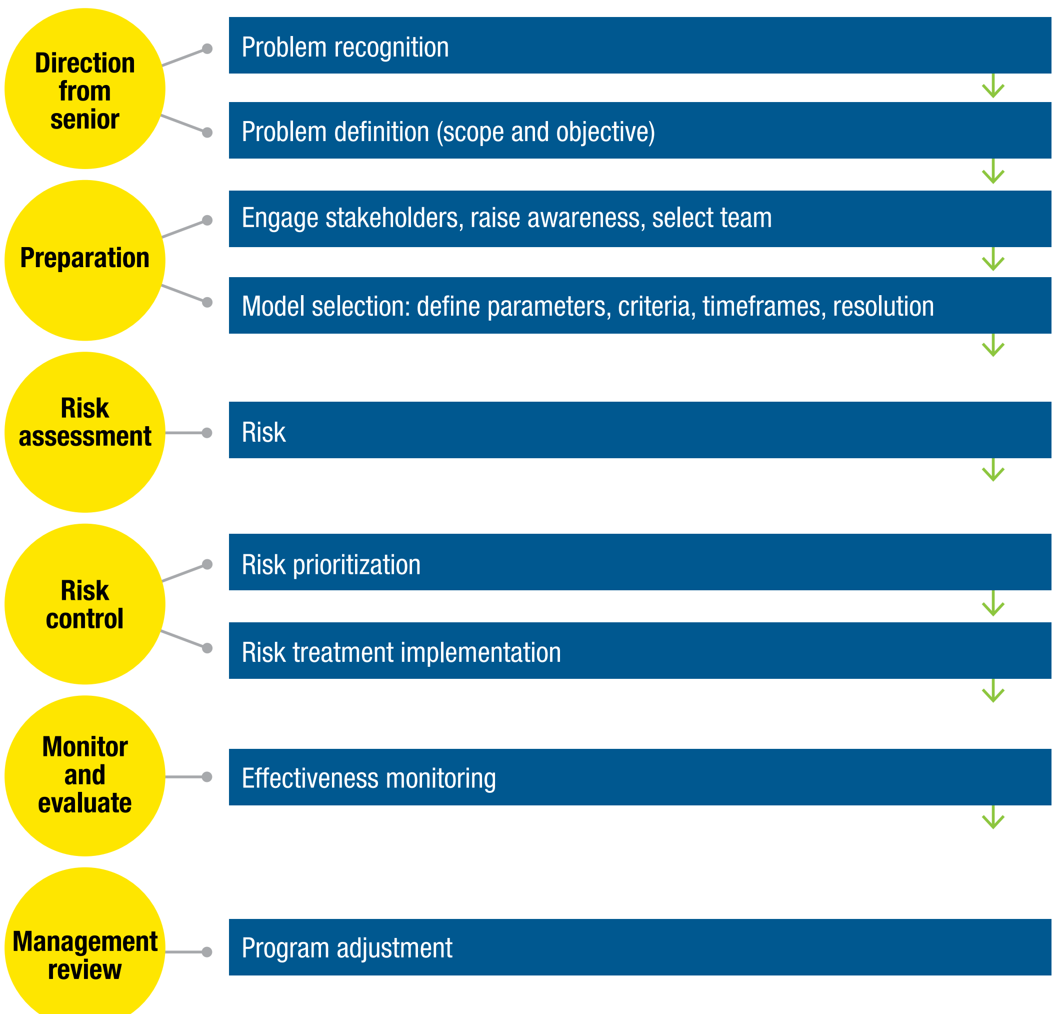
Appendix 3

CEA CLIMATE CHANGE ADAPTATION MANAGEMENT PLANNING GUIDE EXCERPTS

A. ADAPTATION PROCESS ELEMENTS

The adaptation process (detailed in ***Figure 7***) are discussed in detail in CEA's *Climate Change Adaptation Management Planning Guide*:

Figure 7: Adaptation Process Elements



A. Sequence of Steps in Adaptation Planning

Building on the process elements, CEA's *Climate Change Adaptation Management Planning Guide*: identifies 53 sequential steps for effective adaptation planning (documented in ***Table 9***):

Table 9: Steps in Adaptation Planning

#	Steps
	Direction from the Top
	Problem Recognition/Definition
1	Leadership team clearly defines and approves objectives
2	Define scope of climate change adaptation management
	Preparation
3	Engage stakeholders
4	Raise stakeholder awareness
5	Ensure project team competency
6	Define climate-modelling parameters
7	Establish specific climate and weather criteria
8	Identify model timeframe(s) consistent with objectives e.g. near, mid or long term
9	Determine appropriate model resolution (spatial and temporal)
	Obtain Future Climate and Extreme Weather projections:
10	Execute model and/or obtain qualitative descriptions of future climate and weather – as suits utility needs
	Risk Universe:
	Risk Identification
11	Identify key facilities and infrastructure (in scope)
12	Correlate key infrastructure locations with climate hazards
13	Identify equipment *vulnerable* to climate change (extreme weather)
14	Identify equipment *critical* to achieving company objectives
15	Understand both the design criteria and existing response strategies
16	Consider impacts: primary and secondary; direct and indirect; low probability but high consequence
	Risk Assessment
17	Ensure data scales are appropriate to support a meaningful evaluation and prioritization
18	Assess the probability and consequence(s) associated with each risk (or opportunity)
19	Consider potential impacts to all phases of operation including construction and design
20	Evaluate inherent and residual risk(s)
21	Select the value of the most significant consequence to calculate the overall risk

#	Steps
	Risk Control Strategy:
	Risk Prioritization
22	Rank risks in order from most to least critical
23	Understand management's risk appetite (risk tolerance)
24	Consider plotting risks on a heat map for quick visual reference
25	Consider controlling high negative consequence, low probability risks even if they cannot be economically justified
	Risk Mitigation/Implementation
26	Consider the range of risk treatment options including avoidance; sharing/transferring; mitigating; and accepting
27	Consider the extent of control that the organization has over the process and treatment options
28	Consider interdependencies and interconnectedness
29	Benchmark with other jurisdictions for existing design or strategies that address the risk
30	Assess control strategies identified through benchmarking for adoption suitability
31	Consider implementing actions that can be modified as necessary in future
32	Consider implementing a variety of mitigation strategies to experiment and determine which is most effective
33	Identify hard and soft adaptation options as appropriate
34	Ensure response strategies take into account local/regional conditions such as specific climate and extreme weather projections, stakeholder expectations, regulatory regimes and the risk tolerance of individual organizations
35	Identify preferred adaptation measures that reduce the risk to acceptable levels, are socially acceptable, technologically and economically feasible. The prevailing regulatory environment should be taken into account
36	Ensure that new infrastructure design and requests for proposal (RFPs) include climate change risk assessments for consideration by the design engineer
37	Consider the uncertainty related to cost, benefits and effectiveness of the process controls
38	Align climate change adaptation plans with strategic planning priorities
39	Capture actions in the business planning process
	Risk Control *strategies must be planned and implemented*
40	Implement the control strategy. Implement one or more options to mitigate risk(s) requiring additional controls
41	Control risks to within tolerance levels
	Monitor and Evaluate
42	Ensure that the suite of metrics is appropriate to risk. Have leading metrics been considered?
43	At predetermined points (milestones): • evaluate the effectiveness of controls in mitigating risk to acceptable levels • monitor factors that influence the risk profile
44	Track or monitor low risks to ensure that the risk profile does not change with changing circumstances
45	Analyze and learn from events, changes, trends, successes and failures
46	Detect changes that may require revision of the plan and priorities
47	Adopt a cyclical process of assessing risk controls, determining the acceptability of residual risks, generating new risk treatment if residual risks are not tolerable; and assessing the effectiveness of the treatment

#	Steps
	Management Review/Program Adjustment Periodically re-evaluate objectives, risks, and controls. Plans need to be iterative/adaptive in nature to capture feedback on outcomes achieved and lessons learned
48	Determine whether current controls are producing the desired results and whether there is a reasonable expectation that they will continue to do so
49	Consider changes to the risk universe • Are new risks present? • Has the context changed? E.g. Stakeholder expectations, regulatory environment, or adaptive capacity
50	Have there been changes to available information, or projections? What are the implications?
51	Have lessons for transfer been identified? Communicated?
52	Is it time to implement actions previously deferred?
53	Does the plan require adjustment? • Do changes need to be made to the control environment or objectives? • Do modified strategies need to be adopted?

Appendix 4

FOR FURTHER READING

The science of climate change is complex. In the interest of brevity, this chapter only provides a small subset of available information and scenarios from climate models and scientific research. For additional information on climate science, global models, and scenarios for Canada, the reader is invited to visit the following websites:

- *Canada in a Changing Climate: Sector Perspectives in Impacts and Adaptation*, Natural Resources Canada, 2014: http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf.
- *Climate simulation models developed by the Canadian Centre for Climate Modelling and Analysis,* Environment Canada: http://www.cccma.ec.gc.ca/diagnostics/diagnostics.shtml.
- *Climate Change Adaptation: A Priorities Plan for Canada:* http://adaptnowcanada.ca/report. In particular, the precipitation maps for Canada on this website provide additional information on changes towards wetter and dryer conditions.
- *The Intergovernmental Panel on Climate Change's Fifth Assessment report:* https://www.ipcc.ch/report/ar5/index.shtml. Detailed discussions of the physical science basis: http://www.un.org/climatechange/the-science/. Discussions for impacts and adaptation: http://www.un.org/climatechange/the-science/.

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