Impacts of Climate Change on the Power Industry and How It is Adapting

James S McConnach[1], Ahmed F Zobaa[2] and David Lapp[3]
[1]Energy Consultant, Ontario
[2]Senior Lecturer in Power Systems at Brunel University, West London
[3]Manager Professional Practice, Engineers Canada, Ottawa
[1,3]Canada
[2]UK

1. Introduction

The Electrical Power and Energy Industry (the Power Industry) is facing great challenges with the transition to renewable energy options and sustainability (the Green Revolution) and the growing incidence of intelligent grid technology developments to encourage Customer-side responses (Smart Grid). At the same time, there is the definite need to meet continued demand growth (albeit slower) on top of the need for refurbishment and replacement of ageing assets and human resources (the looming Skills Gap) while coping with Climate Change and maintaining reliable and price competitive energy services in a safe and healthy environment and economy.

On the other hand, great challenges and needs bring with them great opportunities for radical thinking and innovation; "necessity being the mother of invention". For example the transition to a renewable and sustainable energy world needs to happen regardless of the Climate Change debate. If the desire to reduce greenhouse gas (GHG) emissions to mitigate climate change is driving **Mitigation Technologies** and market forces/programs such as Cap and Trade with a resultant speeding up of the green revolution then surely this is a good thing. Further information on the impacts of GHG mitigation programs and Markets can be found in the first Reference listed (*McConnach, Hammons & Duffey, 2009*). This reference paper provides an overview of the global responses to Climate Change and of the established and emerging GHG Markets and Programs arising from this. The impacts on the electrical power industry and how it is taking advantage of these programs and markets is discussed. This includes the impacts on policy, strategy and decision-making of major players such as governments, manufacturers, utilities, contractors and consultants and how they are leading by example within their own operations.

There is strong evidence of global warming and climate change that has already happened and that will continue to happen in future. Thus the Power Industry needs to focus efforts on technologies and measures for assessing, adapting to and coping with the risks of these climate changes (**Adaptation Technologies**). With Canada's vast land, water, infrastructure and natural resources, measures and initiatives for adapting to climate change and extreme weather are critically important for the protection and use of these resources. This makes sound risk management sense. The presentation of the second Reference listed reviews some of the programs, initiatives and measures being pursued by climate scientists, researchers and developers for forecasting and adapting to climate change, with particular attention to those impacting the electric power industry in Canada (*McConnach, 2010*). The review takes into account papers and presentations made at recent major Climate Change Technology Conferences held in Canada, notably "The 2nd Climate Change Technology Conference" held in Hamilton Ontario in May 2009 (CCTC2009 - see: www.cctc2009.ca) organized by the Engineering Institute of Canada (EIC) and the North American Symposium, "Engineering in a Climate of Change" held in Toronto April 29, 2010 and organized by the Ontario Society of Professional Engineers (OSPE). See: www.ospeclimatechange.ca

This Chapter of the book focuses on how the Power Industry is adapting to the great challenges and changes it is facing and the measures, tools, processes and technologies that are available for coping with these challenges and changes. Of particular interest is the climate risk assessment protocol in development by the Public Infrastructure Engineering Vulnerability Committee (PIEVC) as part of the National Engineering Vulnerability Assessment Project (NEVAP) led by Engineers Canada (*Engineers Canada*, 2008). See the third Reference listed. The PIEVC Engineering Protocol has great potential as a tool for assessing the risks of Climate Change to the Electrical Power Industry Infrastructure and progress to date with development of the Protocol is described in this Chapter.

2. Need and definition of adaptation

Mitigation measures to reduce the emissions of Greenhouse Gases (GHGs) into the atmosphere will simply slow the changes in Global Climate. Changes have already occurred and the Fourth Assessment Report: Climate Change 2007 (AR4) of the Intergovernmental Panel on Climate Change (IPCC) forecasts steadily increasing temperatures and increased frequency and magnitude of: - (See: http://en.wikipedia.org/wiki/IPCC_Fourth_Assessment_Report)

- Precipitation and flooding
- Droughts
- Severe wind intensities (cyclones, hurricanes, tornadoes, etc.)

All have significant impacts on public infrastructure and communities, including power grids and these impacts need to be either addressed or steps taken to prevent them from happening.

For example, where rising peak ambient temperatures impact the maximum ampacity loading capability of overhead lines, underground cables, transformers, switchgear and other equipment and components of the electrical power grid, this needs to be recognized and appropriate steps taken to establish the revised lower ampacity of these components for the higher ambient temperatures. On the other hand, where events such as extreme wind storms and hurricanes cannot be avoided, then the adaptation measures need to focus on enhancing emergency response and disaster management capabilities to mitigate the impacts on communities, physical infrastructure and human life.

Of course not all climate changes are necessarily detrimental. For example, there will be parts of the world and situations where warming will be welcome and mitigate the extreme cold temperatures and frost levels that need to be taken into account in infrastructure design.

Thus adaptation may be defined as any measure or activity that reduces the risk from negative impacts of climate change and/or takes advantage of the change for the benefit to society and/or the environment. Adaptation may be proactive, as in the example of derating the capability of electrical power grid elements, or reactive, as in the example of enhancing risk assessment and emergency response capabilities. Both may be planned, but reactive measures may sometimes have to be spontaneous.

Planned proactive adaptation measures and maintenance in general will incur less risk and result in lower long term costs over the life or service cycle of infrastructure.

3. Evidence of Canadian climate change and associated impacts

Some of the noteworthy evidence of Climate Changes in Canada are:

- Reduced mass and area of glacial cover
- Reduced extent and duration of snow and ice cover
- Deeper thaw of permafrost due to warming
- Changes in levels and timing of river high flows, with subsequent floods (e.g. recent floods in Manitoba and Saskatchewan)
- Increased frequency and intensity of extreme weather and storms
- Increased frequency of freeze-thaw and icing events
- More frequent and extended periods of high temperatures
- Earlier onset and longer season for plant growth
- Changes in fish species due to warming of water habitats
- Accelerated coastal erosion on eastern seaboard

The major impacts of these changes on power systems are:

- Warming peak and average temperatures impact on:-
  - Demand patterns and peak loading
  - Equipment plant ratings and grid security
  - Reduced equipment performance and reliability
- Increased frequency and severity of extreme weather events give rise to:-
  - Increased risk of failure of power grid, telecommunications and system control centers
  - Increased needs and costs for emergency response and disaster management capabilities
- Increased risks and costs to power grid infrastructure due to forest fires and floods
- Hydro-electric generation production impacted by changes in water levels and flows
- Increased ice accretion on power lines and transmission towers

4. Vulnerability and adaptive capacity

Engineering vulnerability to Climate Change impacts is the degree to which an item or system of infrastructure is susceptible to failure and unable to cope without some adaptation measures. Adaptive capacity is the extent to which modifications can be readily made or use patterns changed to cope with or take advantage of the impacts of Climate Change. In the earlier example of the impact of rising average and peak ambient temperatures on the loading capability of power grid system elements, the rated ampacity of the elements may need to be reduced to prevent failures. Where this is unacceptable, it may be necessary to install additional load carrying capacity to maintain reliability of supply.

Since 2005, Engineers Canada has led the National Engineering Vulnerability Assessment Project (NEVAP). This is a long-term project to assess the engineering vulnerability of infrastructure to the changing climate. Interim results from NEVAP were presented in the first assessment report (*Engineers Canada, 2008*) and concluded that adaptive capacity of infrastructure in Canada is generally high but unevenly distributed. Vulnerability of some regions and population groups is high, particularly where there is increased risk of flooding. On the other hand, some regions and populations may see opportunities to benefit from adapting to Climate Change, particularly where severe winter temperatures are moderated. Therefore a more complete definition of engineering vulnerability is the shortfall in the ability of public infrastructure to absorb the negative effects and benefit from the positive effects of changes in climate data and conditions used to design, operate and maintain public infrastructure.

The need for the NEVAP became evident when considering how to account for Climate Change in infrastructure design. Most notably, there was a low level awareness of climate impacts and vulnerabilities at the local level and the attendant gap between science, engineering and local planning. Available protocols, strategies and tools had focused on mitigation measures to reduce GHG emissions, while measures to increase adaptive capacity have been more limited and developed more slowly. Therefore there were few examples of comprehensive adaptation strategies and tools. This combined with uncertainties and competing priorities resulted in unwillingness to take action and no sense of urgency.

Engineers need to understand and assess the risks of Climate Change and account for it through changes in design and retrofitting of public infrastructure so as to minimize the risks of deterioration or failure and disruption throughout its lifecycle. There is the need to develop and/or revise policies, standards and tools to guide professional engineers in their day to day practice. In response to these challenges Engineers Canada proposed the NEVAP to the Canadian Federal government, specifically Natural Resources Canada's Climate Change Impacts and Adaptation Program. The primary objectives of the NEVAP were:

- To assess the risk of destruction, disruption or deterioration of civil infrastructure due to changing climatic conditions.
- To understand climate change and account for it in the design and retrofitting of public infrastructure.
- To develop or revise policies, standards, protocols, and tools to guide and help engineers in their day to day practice.

In this regard, public infrastructure (including the power grid infrastructure) is defined as those facilities, networks and assets, designed, installed and operated for the collective public benefit, including the health, safety, cultural and economic well-being of a country's population, whether operated by government and/or non government agencies.

Canada's engineers are on the front lines in helping ensure infrastructure adapts to the impacts of anticipated climate changes. Reliable studies, including those by the United Nations-backed Intergovernmental Panel on Climate Change (IPCC), report statistical trends of global warming – evidenced by increasing global average air and ocean temperatures. These trends cast doubt on the validity of applying historic climate data when designing infrastructure. In the face of climatic changes, engineers may have to reconsider existing assumptions relative to infrastructure capacity and vulnerability.

Based on this concern, Engineers Canada has focused the NEVAP towards engineering vulnerability assessment of four categories of Canadian public infrastructure:

- storm-water and wastewater;

- water resources;
- roads and associated structures; and
- buildings.

While acknowledging that Canada's inventory of public infrastructure extends far beyond the four selected categories, this work stressed the importance of initiating the process of assessing the engineering vulnerability of infrastructure to climate change. These infrastructure categories were considered by the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to be the ones where the impact of climate change poses higher risks to public health and safety. Moreover, examples of the four selected categories of public infrastructure are widely dispersed throughout Canada. Seven infrastructure case studies in the four categories were completed by April 2008 under Phase II of the NEVAP. In Phase III, to be completed by the spring of 2012, another 15 case studies will have been completed and additional ones sought in the four categories as well as other types of infrastructure.

A progress report on NEVAP summarizing the results of the work of Phase II was issued in June 2008 (*Engineers Canada, 2008*). It includes the seven case study reports as well as recently completed literature reviews for each of the initial four categories of infrastructure covered by the project. Preliminary findings and conclusions, based on a limited number of case studies and expert opinion from a national workshop, comprise the first assessment report.

The work presented in the report was started in January 2007 and completed in March 2008. Further assessments, including further infrastructure systems, were to follow from the findings, conclusions and recommendations of this report. and the work was continued in Phase III which commenced in April 2009. Subsequently the PIEVC has extended the scope to include other categories of infrastructure now that the PIEVC Engineering Protocol has been successfully applied to the four different categories of infrastructure. There is full confidence in its application to other infrastructure categories, and the electrical power industry infrastructure is a prime candidate.

The PIEVC Engineering Protocol (the Protocol) was one of the pivotal outcomes of the Phase II work. The five-step protocol provides a procedure for sifting through data for developing relevant information on specific elements of the climate and characteristics of a given infrastructure. The Protocol then considers how this information might interact and result in the infrastructure being vulnerable or adaptive to climate change. A general description of the Protocol is provided below.

5. The importance of vulnerability and risk assessment

There are many uncertainties in assessing the effects of Climate Change. Forecasting future climate conditions is a very inexact science fraught with unknowns and complications, particularly when trying to forecast local conditions. The impacts of climate change on public infrastructure such as the power grid are better known but still leave room for doubts in vulnerabilities depending upon the original design, ageing effects and level of maintenance throughout its life-cycle. Socio-economic conditions can vary and impact the ability of communities to respond to climate induced disasters.

Sound risk management strategies and assessment tools can help decision makers to deal with these uncertainties, prioritize the risks and make prudent decisions on preventive or adaptive measures against Climate Change. A proven vulnerability and risk assessment tool has been developed and tested as part of the Canadian NEVAP and is described in the following sections. These sections closely follow the details of a presentation by Joel R.

Nodelman, P.Eng. at the May 2011 PIEVC Training Workshop, jointly organized by Professional Engineers Ontario and Engineers Canada.

5.1 Principles of infrastructure vulnerability and risk assessment due to climate change

Three basic beliefs held by design engineers are:

- The past predicts the future
- Scientific principles always apply (e.g. Thermodynamic laws don't change; Newtonian physics are constant.)
- Problems can be solved with logical reasoning

However, in the case of Climate Change we can no longer rely on past climate data and records to predict future conditions on which to base designs. The current trends in temperatures and the frequency and severity of extreme weather events are following a significantly different track to a simple extrapolation of historical records. The wide variation in possible outcomes between historical norms and the extrapolation to the future is a large un-quantified risk.

Scientific principles, although constant, must be applied in the proper context and this cannot always be predicted with certainty. Solving problems using logic and scientific principles only works when our assumptions are correct.

Another key observation when considering the impacts of climate change on public infrastructure is the fact that small increases in the forces/loads due to weather and climate extremes have the potential to result in large increases in failure and damages. The engineering resiliency of an infrastructure element is the safety margin between the forecast capability or capacity of the element and the loading imposed on it by climate extremes. This safety margin is susceptible to erosion from both sides. Ageing of the infrastructure and poor maintenance practices can reduce the capability/capacity of the element. On the other side, the increased loading on the element can occur due to warming temperatures or more extreme weather forces. The small increases in climate conditions can push the element from positive engineering resiliency to negative engineering vulnerability and possible failure.

The process to determine the resiliency and vulnerabilities of infrastructure elements was developed by the Public Infrastructure Engineering Vulnerability Committee (PIEVC) of NEVAP. The PIEVC Engineering Protocol leads practitioners through a formal, documented process and applies standard risk assessment tools to this new concern. Vulnerability assessment is predictive – it is contemplating **potential** risk of failure modes based on forecast information. Therefore in order to effectively address the risk issue with confidence we need to assess the likelihood of the event occurring and the level of service disruption. Risk assessment tools and techniques help to quantify the risk level. In the PIEVC Protocol, Risk level (R) is defined as the product of Probability (P) of an event occurring and the Severity Level (S) of disruption of an event given it has happened. **R = P x S**

Since risk is the combined effect of probability and severity both elements must be considered. Very low likelihood and high severity can still be a serious risk. Very high likelihood and low severity may be a low risk. Most people have an intuitive understanding of risk but need guidance to sort out and assess the relevant significance of Probability and Severity. The Protocol guides practitioners through the process of assessing both Probability and Severity in a rigorous manner.

5.2 The PIEVC engineering protocol

Figure 1 illustrates the overlap between infrastructure elements and climate parameters. There will be a subset of both that will interact and this is the focus of the vulnerability assessment. The Protocol is a five step evaluation process derived from standard risk management methodologies but tailored to climate change vulnerability. Data quality and availability is assessed throughout and it is recognized that there may often be gaps in the data, records, models and technical expertise available to a specific study. This need not deter practitioners from completing an assessment. The Protocol identifies which questions to ask and does not dictate the method to be used to answer those questions. Figure 2 shows the five steps and their sequence. There are a number of loops that may be necessary as the need for information and data becomes better understood.

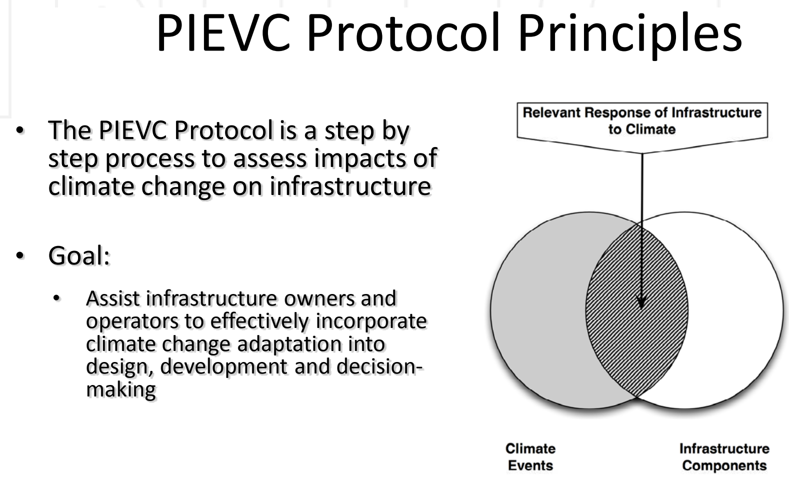

Fig. 1. The PIEVC Engineering Protocol Principles

To fill gaps it must be recognized that engineering vulnerability assessment is a multidisciplinary activity. A team approach is essential to filling gaps in data and resources. The combined resources of the team must have:-

- Expertise in risk/vulnerability assessment
- Directly relevant engineering knowledge of the infrastructure under study
- Climatic and meteorological expertise relevant to the region under study
- Operational experience and knowledge
- Hands on management knowledge of the infrastructure under study
- Local knowledge

The last item, local knowledge, filtered through the expertise of the team, can often be critical in compensating for data gaps and provide a basis for professional judgment of the vulnerability of the infrastructure.

The PIEVC Engineering Protocol has been rigorously and successfully applied with success to engineering vulnerability assessments of over 20 infrastructure case studies across Canada. Details of these case studies are available upon request to Engineers Canada. While the categories of infrastructure in these examples did not include Power Grid Infrastructure, the protocol is equally applicable. However, the availability of power was always considered as a part of the impacts of climate on an infrastructure. Without power a public infrastructure may not operate reliably, safely or within prescribed levels of service without back-up power generation.

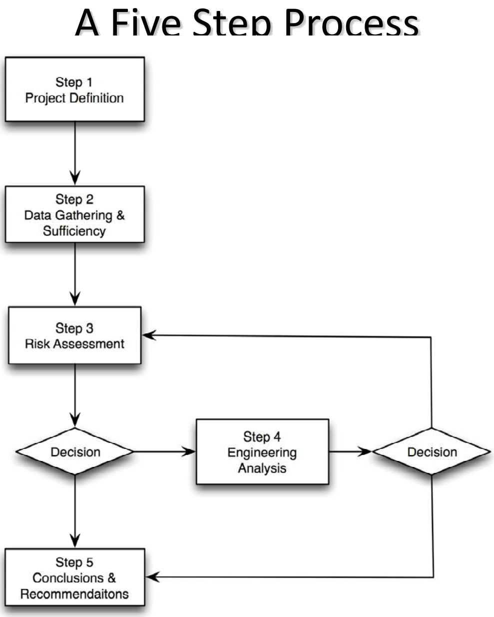

Fig. 2. The PIEVC Engineering Protocol Five Step Process

The evolutionary nature of the process must be stressed. Innovations and improvements to the process will be added as more and more experience is gained in its broader application, including to Power Grid Infrastructure.

6. Other studies and considerations

In addition to the research and developments in Canada relating to adapting to Climate Change, there are many such activities being undertaken in other countries and via international groups. A prime example is the study work by the Australian Government reported in the Position Paper on Adapting to Climate Change in Australia (*Australian Government, 2010*). The abstract from the Position Paper states:-

"This paper sets out the Australian Government's vision for adapting to the impacts of climate change and proposes practical steps to realise this vision. Adapting to the impacts of climate change will be a substantial ongoing challenge for all Australians well into the future. Meeting this challenge will require contributions from governments at all levels, businesses, communities and individuals. Individuals and businesses will adapt to developments as they unfold. However, governments have an important role to play in creating the right framework and in providing appropriate information to allow the private sector to make well-informed decisions. To this end, the Australian Government proposes to work through the Council of Australian Governments (COAG) to develop a national adaptation agenda. This agenda will clarify roles and responsibilities for adapting to the impacts of climate change and identify priorities for collaborative action between governments to position Australia to manage the unavoidable impacts of climate change."

Two of the authors of this Chapter reviewed international activities and presented a Paper providing an overview of the international response for mitigation and adaptation to climate change at the 2006 General Meeting of the IEEE Power & Energy Society (*Zobaa & McConnach, 2006*). This identified considerable international effort aimed at adaptation to climate change already occurring.

The risks of climate change are not limited to public infrastructure, communities and societies. Another major consideration is risks to private companies, the financial sector and the global economy. Extreme weather events can ruin companies and destroy asset values. The sixth Reference listed is an IEEE Paper which provides an overview of the risks that climate change can pose for the financial sector and the global economy (*Zobaa, 2005*).

7. Some adaptation measures for the energy sector

The following are a few examples of the adaptation measures available to the Power Industry.

- Applying risk assessment tools such as the PIEVC Engineering Protocol to quantify the risks from Climate Change.
- "Hardening" of grid systems to increase their capability to withstand extreme events. This includes developing grid equipments resilient to extreme environments and weather.
- Coping with changed loading patterns and reduced equipment ratings due to climate change.
- Strengthening and enhancing grid emergency response and restoration plans.
- Improving back-up telecommunications and grid control (as part of Smart Grid developments).
- Extending and incorporating climate monitoring and recording stations.
- Undergrounding critical circuits and interconnections.
- Revising codes and standards to reflect harsher climate conditions.
- Adaptation strategies for Energy Utilities and Municipalities
- Engineering in Extreme Climates – Policy Considerations
- Building climate changes into infrastructure Codes & Standards
- Extreme Weather Management: Planning, Preparation and Operations
- Using Smart Grid technology developments to adapt/respond to Climate Change.
- Strategies for adapting to the vulnerabilities and interdependencies of critical infrastructure facilities such as energy, transportation and telecommunications.
- Hydro Power and Climate Change
- Thermal protection of transmission line foundations against thawing of permafrost.
- Improvements to Disaster Management responsiveness and capabilities.

With regard to the latter item, the World Conference on Disaster Management (WCDM) was held in Toronto, Ontario, Canada in June 2011 (*WCDM, 2011*). The WCDM is the pre-eminent conference of its kind - providing the opportunity to gain valuable education, training and best practices to assist disaster management professionals, organizations and communities to mitigate, prepare for, respond to and recover from emergencies and disaster.

Many other adaptation opportunities exist in the Power Industry and this is a ripe area for further study.

8. Conclusions and recommendations

Significant impacts of Climate Change are evident across Canada and their frequency and severity are forecast to increase. Planning and development of adaptation measures in the Power Industry is needed and urgent.

Fortunately Canada has a high capability to assess, adapt to and deal with the impacts and consequences of Climate Change. There are many opportunities for the Power Industry to show leadership in developing technology, tools and processes for coping with Climate Change. In particular vulnerability and risk assessment processes, tools and strategies and associated technical expertise have a major role to play in this work.

Barriers and knowledge gaps to adaptation actions need to be addressed. This includes addressing limitations in awareness and availability of information and decision-support tools, such as vulnerability assessment and risk management tools. However, existing knowledge and capabilities are sufficient to undertake adaptation studies and activities in most situations.

Finally, the Power Industry and Governments must work together to address barriers and knowledge gaps in adaptive capacity and so reduce the impacts of climate change by applying sound risk management strategies and practices. The Conclusions and Recommendations from **Canada's First National Engineering Assessment Report** (*Engineers Canada*, 2008). are very relevant in this regard and are quoted here:-

Conclusions: A central finding from the first National Engineering Assessment of the Vulnerability of Public Infrastructure to Climate Change is that the Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment works (now referred to as the PIEVC Engineering Protocol). As such it has great potential for application to Climate Change risk assessment of the Electrical Power Industry infrastructure.

In its general conclusions and recommendations, this work also draws attention to the Interdependence of infrastructure in Canada. Generally, that infrastructure is designed to withstand extreme events. However, that does not mean the impact of climate change can be ignored. The conclusions from this study break out into seven themes.

Theme 1: Some infrastructure components have high engineering vulnerability to climate change. In the case studies a number of components demonstrated high vulnerability to climate change. More work is required to confirm the applicability of these conclusions to infrastructure located elsewhere in Canada(and which is now underway since the first assessment report was published).

Theme 2: Improved tools are required to guide professional judgment. Better consensus is needed regarding the definition of what is considered critical loss of infrastructure as well as what constitutes a catastrophic failure. These definitions are needed for each of the four infrastructure categories assessed.

Theme 3: Infrastructure data gaps are an engineering vulnerability. Many of the case studies reported significant gaps in the availability of infrastructure data. Thus engineers, operators and decision-makers have no clear definition of the capacity and resiliency of the system. These data gaps contribute to the overall vulnerability of infrastructure.

Theme 4: Improvement is needed for climate data and climate change projections used for engineering vulnerability assessment and design of infrastructure. The seven case studies revealed significant gaps in the types and nature of historical climate data needed to conduct engineering vulnerability assessments. The historical data establishes the baseline to compare future changes derived from the climate change projection models.

Theme 5: Improvements are needed in design approaches. There is a need to systematically document the climatic data that has been used to establish climatic design values in existing codes and standards in the four infrastructure categories. It is much easier to apply results of an engineering vulnerability assessment during design than to existing, mature facilities. It is important to apply assessment of climate change vulnerability to new technologies, many of which have unknown performance capabilities relative to the effects of climate change on infrastructure.

Theme 6: Climate change is one factor that diminishes resiliency. In recent years, concerns have been raised in Canada about present level of maintenance and future needs for infrastructure. Factors affecting the resiliency of infrastructure may include the age of the asset; level of maintenance and monitoring of facilities; changes in populations; and the amount of use the infrastructure receives. Climate change is likely to intensify the engineering vulnerability if current levels of maintenance continue. Properly maintained infrastructure enables the infrastructure and its components to function as designed, which includes accounting for changing climate events. A holistic approach is needed to deal with the issue, including consideration of financial, managerial and social factors as well as climate change.

Theme 7: Engineering vulnerability assessment requires multi-disciplinary teams. Assessment of vulnerability to climate change requires interdisciplinary approaches involving a range of expertise, including, but not limited to, engineers, climatologists, architects, hydrologists and others. Ideas on the vulnerability of a piece of infrastructure may differ between engineers and managers, on the one hand, and personnel involved in day-to-day hands-on operation of infrastructure on the other.

Recommendations: Five recommendations arise from the work completed to date:

Recommendation 1: Revise and update the engineering vulnerability assessment protocol.

During the execution of the case studies, a number of minor issues were identified with the current version of the Engineering Vulnerability Assessment Protocol (Rev 7.1, 31 Oct. 2007). (Note: Version 9 of the PIEVC Engineering Protocol is the one currently in use (from April 2009 to present) as of the date of this publication, and another revision will be available through Engineers Canada in the spring of 2012)

Recommendation 2: Conduct additional work to further characterize the vulnerability of Canadian public infrastructure to climate change. There is a need to conduct further engineering vulnerability assessments to more fully characterize the vulnerability of Canadian public infrastructure to climate change (This includes power industry infrastructure.)

Recommendation 3: Develop an electronic database of infrastructure vulnerability assessment results. The analysis provided in this report is based on analyzing limited data. As more information accumulates, an electronic database will significantly aid in the analysis of vulnerability trends within a category of infrastructure, regionally and/or nationally.

Recommendation 4: Assess the need for changes to standard engineering practices to account for adaptation to climate change. Some of the case studies determined that the current design codes and practices applicable to the infrastructure under consideration could be improved. In some cases, this was related to dated information used within a standard and in others it was based on the view that climate change should be factored into new designs. In light of this experience, further work is needed to:

- review codes and standards applicable to the four categories of infrastructure that are the current focus of the Public Infrastructure Engineering Vulnerability Committee (PIEVC) and determine specifically where dated climatic information is used;

- maintain a dialogue between engineers, scientists, modellers and climatologists to clarify the climate data needs and formats to support the design and management of engineering;
- maintain a dialogue with codes and standards organizations to communicate the outcomes from this engineering vulnerability assessment in order to evaluate the need to update codes and standards; and
- investigate incorporating the use of the Engineering Protocol for Climate Change Infrastructure Engineering Vulnerability Assessment, or similar assessment processes, into design processes for new infrastructure and major infrastructure rehabilitation in Canada.

Recommendation 5: Initiate an education and outreach program to share learning from this assessment with practitioners and decision-makers. Public infrastructure systems do not function in total isolation. Multiple stakeholders have a role to play in ensuring robust and resilient public infrastructure for assurance of serviceability and public safety. Key learning from this initiative should be shared with other constituencies in order to promote effective infrastructure design, operation and management.

9. Acknowledgements

The authors wish to acknowledge the kind permission of Engineers Canada to include material from their First National Engineering Vulnerability Assessment Report, in particular for the description of the PIEVC Engineering Protocol. The Protocol has great potential as a Climate Change risk assessment tool for the Electrical Power Industry. Further information on the Protocol, including its use for infrastructure engineering vulnerability assessment can be obtained by contacting Engineers Canada (David Lapp, P.Eng.) at the following email address: david.lapp@engineerscanada.ca

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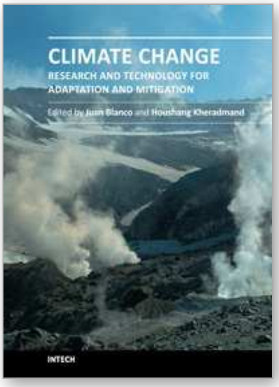

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This book provides an interdisciplinary view of how to prepare the ecological and socio-economic systems to the reality of climate change. Scientifically sound tools are needed to predict its effects on regional, rather than global, scales, as it is the level at which socio-economic plans are designed and natural ecosystem reacts. The first section of this book describes a series of methods and models to downscale the global predictions of climate change, estimate its effects on biophysical systems and monitor the changes as they occur. To reduce the magnitude of these changes, new ways of economic activity must be implemented. The second section of this book explores different options to reduce greenhouse emissions from activities such as forestry, industry and urban development. However, it is becoming increasingly clear that climate change can be minimized, but not avoided, and therefore the socio-economic systems around the world will have to adapt to the new conditions to reduce the adverse impacts to the minimum. The last section of this book explores some options for adaptation.

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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821