Climate Change, Energy and Sustainability: Lessons from the Toronto-Niagara Region

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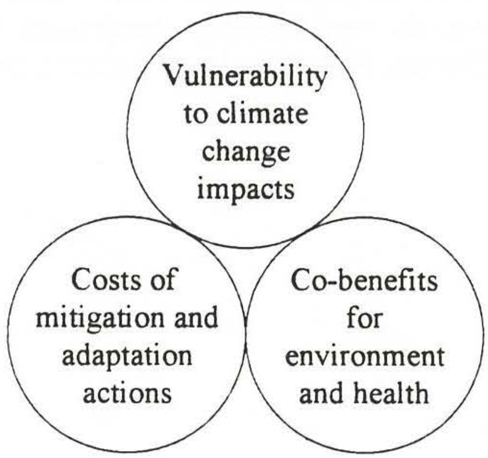
ABSTRACT

It is widely recognized in the discourse on global environmental change that anthropogenic activities, and particularly the combustion of fossil fuels, are having a discernible impact on the earth's climate. Concern over a looming environmental crisis has led to an international response, initially with the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, followed by the Kyoto Protocol in 1997. Much of the national debate on climate change has focused predominantly on the technological options to reduce greenhouse gas (GHG) emissions, and more directly on the costs associated with taking mitigation actions. However, this focus has come at the expense of not fully considering other dimensions of climate change, specifically the costs associated with climate change impacts and effects, the costs of adaptation actions, and the co-benefits for environment and health that could result from GHG plus related emission reductions. This is perhaps most apparent in the discourse on climate change and energy, especially in regards to electricity generation, where there is greater attention directed at the implications of climate change policies rather than the actual impacts and effects arising from climate change.

Figure 1: Climate Change and Energy - Components of a sustainable energy system



In this paper it is argued that the issue of climate change and energy needs to be examined within a broader conceptual framework (Figure 1). Situating climate change and electricity generation within this broader context is essential in developing a sustainable energy system. The paper is organized into four sections. In section one, the conceptual framework is described, highlighting the importance of considering all dimensions of climate change (vulnerability, co-benefits and costs) in developing a sustainable energy system. Section two focuses more directly upon the relationship between climate change impacts and the energy sector, specifically in terms of generation (nuclear, hydro, fossil fuel, and alternatives), distribution and transmission (electricity and natural gas), and the demand for energy. Climate factors considered include changes in the mean, but more importantly variability in temperatures and changes in extreme weather events. This part of the discussion draws upon extensive research in the Toronto-Niagara Region, which has been supported through the Federal Interdepartmental Panel on Energy Research and Development (PERD). Emphasis is placed on identifying what aspects of current climate have had the greatest impact on the energy sector, and the adaptation options that will be necessary to reduce future vulnerability in face of inevitable climate variability and change.

In section three, the emphasis shifts towards actions to reduce GHG plus related emissions, within the context of environmental and health benefits. The co-benefits of reducing GHG plus related emissions includes the implications for ecosystems and biodiversity, environmental health (managed (forestry) and unmanaged (agriculture) systems), social welfare and human health. This discussion is based on research conducted on co-benefits as part of the multi-stakeholder process to develop a national strategy on climate change. The paper concludes by providing a preliminary assessment of the various mitigation options currently being proposed to help reach emission targets set out in the Kyoto Protocol, as they apply to the Toronto-Niagara Region The assessment, which will be undertaken in greater depth as part of Phases III through V of the PERD supported project, considers the vulnerability of an altered energy system to climate change impacts, and the potential co-benefits for environment and health This includes changes brought about by fossil fuel switching, the inter-provincial transmission of electricity, alternative technologies, and energy efficiency, amongst other mitigation actions.

Introduction

It is widely recognized in the discourse on global environmental change that anthropogenic activities, and particularly the combustion of fossil fuels, are having a noticeable impact on the earth's climate. Concern over a looming environmental crisis has led to an international response, initially with the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, followed by the Kyoto Protocol in 1997, and most recently with the Bonn amendments in 2001. Much of the national debate on climate change has focused predominantly on the technological options to reduce greenhouse gas (GHG) emissions and the costs associated with taking mitigation actions. For example, the national implementation strategy on climate change has focused largely on mitigation options and their costs. This focus has come at the expense of not fully considering other dimensions of climate change into the decision-making process. In particular, the costs associated with climate change impacts and effects, the costs of adaptation actions, and the co-benefits for environment and health that could result from GHG plus related emission reductions. This is perhaps most apparent in the discourse on climate change and energy, especially in regards to electricity generation, where policy-makers and decision-makers have also directed considerable attention towards the implications of climate change policies rather than the actual impacts and effects arising from climate change.

In this paper it is argued that the issue of climate change and energy needs to be examined within a broader conceptual framework (Figure 1). Following the model of sustainable development defined by the Bruntland Report (WCED, 1987), a framework to assess the energy sector is outlined, incorporating economic, social and environmental elements of the climate change – energy relationship. First, the costs associated with climate change impacts and effects; second, the costs of mitigation and adaptation actions; and third, the co-benefits for environment and health that could result from GHG plus related emission reductions. Situating climate change and electricity generation within this broader context is essential to develop a sustainable energy system.

In addressing these issues, the paper is organized into four sections. Although preliminary in scope, it draws extensively from published research or studies in-progress, and readers are directed to this work for further detail of the issues (e.g. Chiotti and Urquizo, 1999; Chiotti *et al.*, 2001). In section one, the conceptual framework is described, highlighting the importance of considering all dimensions of climate change (vulnerability, co-benefits and costs) in developing a sustainable energy system. Section two focuses more directly upon the relationship between climate change impacts and the energy sector, specifically in terms of generation (nuclear, hydro, fossil fuel, and alternatives), distribution and transmission (electricity and natural gas), and the demand for energy. Climate factors considered include changes in the mean, but more importantly variability in temperatures and changes in extreme weather events. This part of the discussion draws upon extensive research in the Toronto-Niagara Region, which has been supported through the Federal Interdepartmental Panel on Energy Research and Development (PERD) (Chiotti *et al.*, 2001). This research is based on an extensive literature review, supplemented by interviews with key informants in the energy sector, and a workshop that engaged regional energy stakeholders. Emphasis is placed on identifying what aspects of current climate have had the greatest impact on the energy sector, and the adaptation options that will be necessary to reduce future vulnerability in face of inevitable climate variability and change.

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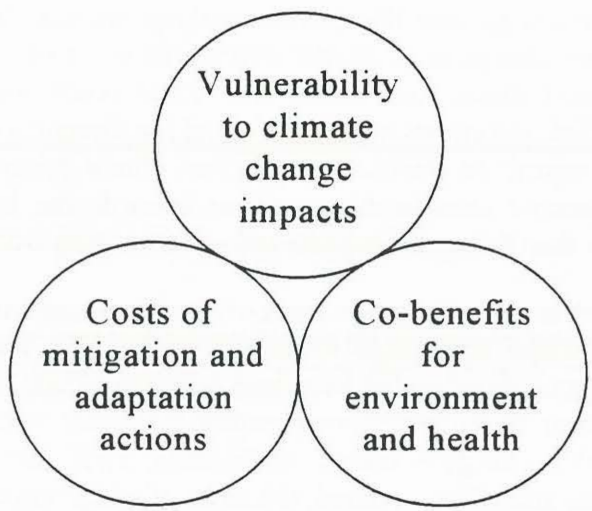

In section three, the emphasis shifts towards actions to reduce GHG plus related emissions, within the context of environmental and health benefits. The co-benefits of reducing GHG plus related emissions includes the implications for ecosystems and biodiversity, environmental health (managed (forestry) and unmanaged (agriculture) systems), social welfare and human health. This discussion is based on research conducted on co-benefits as part of the multi-stakeholder process to develop a national strategy on climate change (Chiotti and Urquizo, 1999). It is argued that energy choices should be evaluated beyond their impacts on GHG via life-cycle analysis, and must also include a fuller spectrum of environmental and health effects. The paper concludes by providing a preliminary assessment of the various mitigation options currently being proposed to help reach emission targets set out in the Kyoto Protocol, as they apply to the Toronto-Niagara Region. The assessment, which will be undertaken in greater depth as part of Phases III through V of the PERD supported project, considers the vulnerability of an altered energy system to climate change impacts, and the potential co-benefits for environment and health. This includes changes brought about by fossil fuel switching, the inter-provincial transmission of electricity, alternative technologies, and energy efficiency, amongst other mitigation actions.

1.0 Climate Change and Energy – Components of a Sustainable Energy System: Science and Policy Context

The extraction, processing and transportation of energy in the oil and gas industry accounts for 18% of Canada's GHG emissions. Electricity generation is responsible for a further 17%, while buildings (excluding industry) account for 10%. Not surprisingly, the energy sector, along with transportation, industry, forestry and agriculture, are considered key sectors that make a significant contribution to Canada's efforts to reach their Kyoto target. However, when assessing the relationship between climate change and energy, it is important to recognize that other issues can also be considered, beyond simply the costs of mitigation actions or their potential for reducing GHG emissions. The relationship also consists of the impacts of climate change <u>on</u> the energy system, and the ancillary or co-benefits that may accrue due to actions which reduce GHG-related emissions.

1.1 Climate Change and Potential Impacts in Canada

Anthropogenic induced climate change is a global phenomenon, caused in part through the buildup of GHGs in the atmosphere. Main GHGs are carbon dioxide (CO_2), water vapour (H_2O), methane (CH_4), chloroflurocarbons (CFCs), ozone (O_3) and nitrous oxide (N_2O). These gases are generated from both natural and anthropogenic sources, with the latter largely due to the combustion of fossil fuels (coal, oil, natural gas and biomass), industrial processes and land use change. In the last 200 years, the concentration of GHGs in the atmosphere has been steadily rising, and if current trends continue, then a doubling of CO_2 will occur by the middle of this century, resulting in a global warming of between 1.4°C to 5.8°C (Houghton *et al.*, 2001). Based on tree ring and ice core data, this change in temperature is greater than anything experienced during the past 10,000 years. Beyond changes in the mean, changes in the variability of temperature and precipitation is also a concern. In the case of extreme weather events, for example, a 'storm of the century' could occur once every four years with climate change (Francis and Hengeveld, 1998).

It is projected that northern latitudes will experience the greatest temperature change, with greater average warming occurring over land than over oceans, and in winters relative to summers. Although climate change is projected to be variable across Canada, there is high confidence regarding the direction of change in temperature and precipitation, as well as the coarse regional patterns across the country (Maxwell *et al.*, 1997). There is likely to be greater warming in interior regions compared to areas along the coastlines, and greater winter warming in the Arctic compared to southern Canada. Net average warming for central and northern Canada could reach between 4-6°C by 2050 AD, decreasing to 3-4°C along its western and eastern coastlines. Temperature increases could double these values by the end of this century, representing a warming that is nearly three times the global average.

These predicted changes in climate are expected to have a wide range of impacts and effects upon natural and human systems across Canada. The extent of these effects in terms of their regional and sectoral significance is well illustrated in a recent Environment Canada led assessment of the impacts from, and adaptation to, climate change and variability (Maxwell *et al.* 1997). The first phase of the Canada Country Study covers six regions across the country, twelve sectors and eight cross-cutting issues. Although the study represents a monumental effort to assess the current state-of-knowledge, many gaps remain which limit our understanding of the range and extent of climate change impacts on sectors and regions across Canada. Impacts are likely to be greatest in areas such as the natural environment, water resources and human health. There will be a mixture of adverse impacts and opportunities in sectors dependent upon natural resources and sensitive to climate – such as agriculture, fisheries, and forestry. The least impact will be in the more industrialized and less climate-related sectors of the economy, such as transportation, the energy sector, and building and construction. However, in the latter sectors and in some areas where opportunities exist (e.g. northern expansion of agriculture, reduced energy demand during warmer winters, etc.), there is still a risk of severe impacts occurring because of extreme events. Furthermore, it is possible that indirect losses imposed on Canada as a result of impacts occurring in other countries could be as great as, if not greater than, direct impacts. Just as there may be potential benefits to Canada from adverse impacts elsewhere (e.g. new and expanded markets for Canada's energy, forestry, or agricultural exports). The economic impact of climate change in Canada has been estimated to be 1.5% of GDP (Tol, 1995), which represents a cost of between $8 to $12 billion. However, it has been suggested that the range could be much broader, with a cost of somewhere between $3.5 to $24.5 billion to the Canadian economy (Chiotti and Urquizo, 1999; Demeritt and Rothman, 1998).

How climate impacts the energy sector, however, is more difficult to ascertain. It is known, for example, that changes in temperature, precipitation and extreme events could affect the entire energy cycle, impacting (i) production and generation, (ii) transportation, transmission and distribution, and (iii) the demand for energy, but the nature and severity of effects at the regional scale are still poorly understood. Moreover, the preponderance of literature to date has focused on production and generation, and to a lesser degree upon transmission and distribution, and the demand for energy (e.g. Mercier, 1998). The implications of climate change impacts on exploration and production in the Arctic, the tar sands in Alberta, and off-shore locations such as Hibernia have tended to receive the majority of attention, relative to other regions across Canada. The uneven attention in the literature to these issues may be due more to the nuances of research priorities to date, rather than reflect an actual disproportionate degree of impact or vulnerability. Research has also tended to focus on specific segments of the fuel cycle (e.g. generation or transmission or demand), ignoring potential interactions between them.

The impacts from climate change are just as likely to be determined by the nature of the regional energy mix, as due to changes in regional climate conditions. In Canada the regional pattern of production is quite distinct. In 1996, coal-fired plants were prominent generators of electricity and by extension major sources of air pollutants in Alberta, Saskatchewan, Ontario, Nova Scotia and New Brunswick. This differs quite noticeably from the relative importance of hydro in Quebec, Manitoba and British Columbia, as well as nuclear energy in Ontario. As a dose-response relationship, the severity of climate change impacts upon the energy sector at the regional scale will be determined by the intensity of the climate stress, as well as the technical and institutional environment shaping the vulnerability and resilience of the system being impacted. In the case of the TNR, the literature suggests that impacts on production and generation would only apply to the latter, especially reductions in hydroelectricity due to changes and water availability. Alternative energy sources such as wind, solar and small scale hydroelectric could also be adversely impacted by climate, although the specific nature and degree are not well documented in the literature. Research on climate impacts upon transmission and distribution has predominantly focused on the electrical grid, where the capacity of transmission lines drop at higher temperatures (Columbo, 1997). The 1998 ice storm in Quebec and eastern Ontario also clearly demonstrated the vulnerability of our current electricity transmission and distribution system to extreme events (Kerry et al., 1999). In terms of demand, climate can have a significant influence on patterns of energy consumption (both in terms of total and peak demand), with milder winter temperatures reducing energy needs for space heating and higher summer temperatures increasing electricity demand for air conditioning.

1.2 The Co-benefits of Mitigation Actions

Responses to climate change include policies directed at 'mitigation' and 'adaptation'. Mitigation refers to measures designed to reduce human-induced emissions and atmospheric concentrations of GHG, whereas adaptation refers to measures designed to reduce impacts from and vulnerability to climate change. Although both mitigation and adaptation actions are incorporated in the UNFCCC and Kyoto Protocol, actions to reduce GHG emissions have received much greater attention in the science and policy literature (e.g. Watson *et al.*, 1996). In the Kyoto Protocol, for example, most of the discourse has focused on the need for developed countries to collectively reduce greenhouse gases to 5.2% below 1990 levels by 2008-2012. Canada has set an even lower target of 6%, although the Bonn amendments may reduce the reduction to approximately 2% when the carbon sinks of forests are taken into account.

In response to the Kyoto Protocol, the Federal Government has engaged provinces, municipalities and key stakeholders in a process to develop a national implementation strategy for Canada. By 1997, however, Canada's GHG emissions were 14% higher compared to 1990 levels. Furthermore, scenarios of emission trends project a gap of 140 – 185 Mt between the Business as Usual case and the Kyoto Protocol target, thereby requiring a reversal in emissions of almost 25% by 2010 if Canada is to meet its reduction commitment. However, even if all of the signatories to the Kyoto Protocol achieve their targets, such reductions in GHG emissions will only delay a doubling of CO_2 by 6 years (Houghton *et al.*, 2001); consequently, some degree of climate change is inevitable. It has been estimated that global emissions of GHGs will need to be reduced by more than 50% over the next century (Haites, 1996), if atmospheric concentrations are to be stabilized. This implies that more aggressive emission reductions may become necessary in the future.

As a country that contributes approximately 2.1% of the global emissions of GHGs, Canada is unlikely to reduce climate change to any significant degree by unilateral action. This might imply that action internationally is needed by Canada to convince other countries to act accordingly, or that adaptation should take an increased role in the national response strategy (where benefits can be captured locally). It is also important to recognize that mitigation actions can themselves produce a wide range of benefits that accrue more positively in terms of time and space. The ancillary benefits associated with mitigation can be assessed in two ways. First, reductions in emissions from baseline projections will generate reduced damages that would otherwise have occurred in the absence of action. These avoided damages, which are often referred to as "abatement benefits", accrue at the global level and are expected to increase over time, generating greater benefits in the future than at present (Pearce *et al.*, 1996). Second, there are the benefits of GHG abatement that spill over into other sectors, specifically through the enhancement of sinks to sequester carbon, and via actions which reduce GHG emissions. The latter recognizes that actions to reduce GHG emissions can also reduce other "conventional" environmental pollutants which contribute to other air issues.

While it may be possible to achieve significant reductions of non-energy GHG emissions through technological advancements (CHEMinfo Services Inc. and Margaree Consultants Inc., 1998), given existing technology, the most cost-effective method of reducing energy generated GHG emissions is through actions to reduce fossil fuel combustion. This includes energy conservation, energy efficiency, agricultural practices and fuel switching. Reductions in emissions from fossil fuel combustion will also function to reduce a wide range of pollutants. Among them are sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), particulate matter (PM), ground-level ozone (O_3), volatile organic compounds (VOCs), heavy metals (e.g. lead, mercury) and other toxic pollutants (e.g. acetaldehyde, formaldehyde, organic aromatics, polycyclic aromatic hydrocarbons (PAH), and chlorinated dioxins and furans) (Pearce *et al.*, 1996; Administration Economic Analysis, 1998). In Canada, fossil fuel use accounts for about 55% of SO_2, 90% of NO_x, 55% of VOCs, and 90% of CO.

These pollutants are also precursors for other atmospheric issues, such as stratospheric ozone depletion (and increasing UV-B radiation), acid deposition, smog, and hazardous air pollutants. All of which are known to have a wide range of adverse impacts upon aquatic and terrestrial ecosystems, as well as effects upon environmental, social and human health. SO_2 and NO_X are precursors for acid deposition, which have adverse effects upon aquatic and terrestrial ecosystems. SO_2 and O_3 can cause foliar damage in crops and trees, with the latter known to reduce agricultural yields. Particulate matter and secondary pollutants such as sulphates and nitrates are particularly hazardous to human health, impairing both respiratory and cardiovascular systems. Pollutants are also known to impair visibility and damage materials, accelerating the decay of infrastructure (roads and bridges), buildings, statues and monuments. The size of these effects (and therefore the size of the benefits) depends upon the magnitude and duration of exposure to specific pollutants, and the sensitivity of the exposed population, among other factors. Benefits from actions to reduce GHG-related emissions will therefore accrue in the near term, and accrue largely in regions where the mitigation actions occur.

In addition to improving regional air quality and reducing the adverse impacts and effects from other atmospheric issues, the actions themselves could also generate additional "external" benefits. Modal shifts in transportation that involve the movement of drivers from single occupant vehicles into public transit or car-pooling, for example, could result in fewer traffic accidents or congestion, while lower gasoline consumption could reduce the risk of tanker accidents and oil spills (Pearce *et al.*, 1996). Abatement avoidance costs are another possible benefit. There are many policies already in place that address specific pollutants and atmospheric issues, which require technological solutions (and capital investments) to reduce emissions. If emission reductions of other atmospheric pollutants are achieved through GHG emission reductions, then emission controls would be unnecessary, and potentially substantial costs for controlling pollution would be avoided. Such costs are estimated to be $1 billion per year in the U.S. (Administration Economic Analysis, 1998).

Estimates of the impacts upon the atmosphere from GHG-related emission reductions are usually expressed as a percentage or as a measure of per metric tonne of carbon reduced. Complainville and Martins (1994) estimate that reductions in CO_2 from the 1990 baseline of between 4-21% will result in corresponding reductions in SO_X and NO_X of between 4-29% and 3-32% respectively. Scheraga and Leary (1994) present somewhat more modest estimates for the U.S., where a reduction of 8.6% in CO_2 using a carbon tax would generate the following reductions in other pollutants: SO_X (1.9%), NO_X (6.6%), CO (1.5%), TSP (1.8%), and VOCs (1.4%). Despite the appearance of relatively small improvements in emissions of GHG-related pollutants, it is important to note that even small amounts can generate avoided damage estimates from ten to several hundred times larger than those for CO_2. In their review of co-benefit studies for the Intergovernmental Panel on Climate Change (IPCC), Pearce *et al.* (1996) discovered that the value of avoided damages range from US$2 to US$500 per tonne of carbon reduced. On average, the value of co-benefits offsets 30% of the initial abatement costs of GHG emission reductions, although in some cases savings could be much higher (Burtraw and Toman, 1997; Pearce *et al.*, 1996). It has been estimated that co-benefits could offset between 30-50% of the initial abatement costs in Norway (Alfsen *et al.*, 1992), and over 100% in the UK (Barker, 1993) and Japan (Amano, 1994).

As in the case of climate change impacts on the energy system, it is expected that in Canada the co-benefits for environment and health will also be regionally differentiated.

Emissions from electricity generation, for example, are directly related to the fuel type and energy mix, and in Canada the regional pattern of production will likely produce differential opportunities for co-benefits. In regions that are dominated by hydro-electricity, co-benefits will be less than areas where coal-fired power plants already contribute significant amount of air pollutants.

2.0 Climate Change Impacts on the Energy Sector in the TNR

In assessing the potential impacts of climate change on the energy sector in the TNR, Wheaton and MacIver (1999) provide a useful framework. Their framework focuses on recent climate experience, with emphasis on vulnerability and how natural and human systems respond to current climate stresses. This approach is extended to include climate variability (rather than just changes in the mean) and extreme weather events, in addition to recognizing the importance of considering how climate stimuli can operate at different spatial scales. Existing vulnerability and adaptation measures to current climate can then be evaluated within the context of projected future climate change. In this approach, how stakeholders perceive and interpret impacts, and value the effectiveness of adaptation options, is considered to be especially important. This involves addressing the following questions:

1. What climate [change] stress must the energy system adapt to?
2. What part of the energy system is being impacted?
3. What are the impacts?
4. Who is adapting?
5. What is the adaptation response? and
6. How well will the energy system adapt to climate change?

The last question is particularly important to the analysis, as it addresses the efficacy of current adaptation actions to present climate stresses that may have to be improved to withstand climate change.

In 1997, 82 power stations with a combined 30,284 megawatts of installed capacity generated 145 terawatt-hours in Ontario. The energy mix consisted of 25% from hydroelectric (Niagara, Ottawa-St. Lawrence), 17% thermal (mostly 5 coal-fired power plants), 48% nuclear (Darlington and Pickering), and 10% from other sources (e.g. independent power producers, other utilities). Heating for buildings was provided by electricity, but also by natural gas and oil. Based upon an extensive review of the literature, and supplemented by stakeholder input, climate change impacts and adaptation options for the energy system in the TNR can be categorized as follows:

- Climate impacts on electricity generation, including alternative sources;
- Climate impacts on the transportation of natural gas and heating oil;

- Climate impacts on the transmission and distribution of electricity and natural gas; and
- Climate variability and demand.

In terms of generation, the most obvious impact will be upon hydro capacity, where variations in Great Lakes water levels have been known to cause a 20% variance in generation. In fact, the lowest generation by hydro plants in the history of Ontario Hydro (now Ontario Power Generation) occurred in 1999, which coincided with near record lows in water levels. Under climate change Great Lakes water levels are projected to drop by as much as 1 metre (Mortsch and Mills, 1996). Low lake levels will also reduce vessel draft, thereby requiring an increase in coal deliveries. A 1-metre drop in lake levels translates into a 10% loss in draft for most vessels. Hanging dams caused by ice build-up have also been known to restrict river flow and reduce hydro capacity along the Ottawa River and St. Lawrence Seaway. Nuclear and thermal (coal) plants are also affected by changes in water temperature, which could increase along with lower water levels. Warmer water temperatures are known to reduce condenser efficiency, while higher air temperatures could also affect draft fan efficiency. This could result in a loss of generation capacity of between 1-3%. Indirect effects could also occur from increased water temperatures, such as bio-fouling (e.g. algae, zebra mussels), although their extent are unknown. The impact on alternative sources such as wind and solar power are less conclusive. Changes in cloud cover are difficult to project at the regional scale, which could affect the capacity of solar power. Wind turbines could be at risk to extreme weather events, such as hurricanes or ice storms.

The 1998 ice storm clearly demonstrated the vulnerability of the electricity transmission grid, yet less publicized were the impacts on the transportation of natural gas. Back-up generators using natural gas fuel have recently been installed at gate stations across Ontario as part of a massive Y2K retrofit, but electricity failure in individual homes will continue to render natural gas furnaces ineffective (e.g. without the use of forced air fans). Transmission capacity is also known to drop at higher temperatures, where a 3-5% loss in transmission could occur. A 30% variation in efficiency can occur between the summer and winter seasons. Variation in efficiency is a function of ambient air temperatures and demand, both of which are expected to increase significantly with climate change. On average Toronto currently experiences approximately 10-15 days which reach 30°C or over, based on 1961-1991 averages. However, with climate change, this number could reach 50 days by the year 2050 (Chiotti and Mills, 2001). Even underground distribution systems are subject to overheating during heat waves. With climate variability, there may also be a decrease in the length of shoulder seasons (spring and autumn), thereby placing more stress upon maintenance schedules for electricity transmission.

Perhaps the most significant changes will occur in the demand for energy. Until recently peak power generation and demand for the province occurred during the winter, but in the past few years this has shifted to the summer. Many municipalities in the TNR have already experienced summer peaking for the past 10 years, where demand is largely driven by air conditioning. Since maximum demand for air conditioning occurs at 26°C and above, it is expected that demand will increase substantially under climate change. To some degree increased demand for electricity during the summer will be off-set by lower demand for heating from electricity, natural gas and oil with warmer winters. However, it is important to note that a 1°C increase in temperature has 4-5 times greater impact on energy demand in the summer, compared to a corresponding 1°C drop in winter temperatures. Further, if climate becomes more variable, then extreme cold temperatures may still occur, albeit less frequently. During the extremely cold winter of 1995-1996, increased residential demand resulted in disruptions of supply for natural gas, specifically to industrial users who were on interruptible contracts.

3.0 Energy and Co-benefits for environment and health

Electricity is essentially clean at the end point use, but as was noted above its generation via the combustion of fossil fuels entails some adverse impacts and effects. Not all of the effects, however, are restricted solely to emissions at the point of generation. If the life-cycle of energy is considered, then a full accounting of effects would include all potential impacts that occur at each stage of the energy system and fuel cycle, which could be substantial and varies considerably within and between energy groups (Ottinger *et al.*, 1991; International Expert Group 3, 1991). The life-cycle sequence considers the risk of fatalities, diseases and injury to workers (occupational health) and the public, from activities involved in the fuel extraction (mining, drilling and harvesting), construction, transportation, treatment, storage, utilization or conversion (including waste management), and decommissioning of energy generation facilities. Even hydroelectric power will generate impacts and effects upon environmental and human health. Relative to electricity generation from fossil fuel combustion, hydroelectricity has the advantage of not producing air pollutants or GHGs apart from that created during material preparation and facility construction. As Ottinger *et al.* (1991) point out, environmental impacts result from (i) changes in river flow characteristics; (ii) changes in the ecosystems of land flooded to form reservoirs; and (iii) erection of barriers which interfere with the natural movements of fish and wildlife.

Although a comparative risk assessment of different energy systems must be treated with extreme caution, some general trends are demonstrated in the literature. The fossil fuel group (coal, oil and natural gas) has relatively high accident rates that dominate occupational risks, and the burning of fossil fuels produces relatively large amounts of gaseous and solid wastes that dominate public health risks. Coal-plants in Ontario have been particularly cited by public health officials as having a significant impact on human health (Perrotta and de Leon, 1999). The renewable group (wind, solar and thermal) is characterized by low public risk and relatively high occupational risk from the construction phase. In contrast, while the nuclear group generates relatively small amounts of GHGs (Andseta *et al.*, 1998), it also has occupational risks that are dominated by mining and power production related accidents. Public risk is relatively low during normal operations, but long term waste management and the potential for severe accidents add considerable risk and uncertainty to this energy option. Recent events of terrorism raises this isue beyond the 'hypothetical' stage, into the mainstream public discussion regarding the vulnerability of nuclear energy. Currently, life-cycle analysis is not well equipped to deal with radioactive releases to the environment, including the fact that land used for mining and preparation of uranium cannot be used for other purposes for 80,000 years after decommissioning, although Michaelis (1998) suggests that this could be addressed using risk assessment techniques.

Due to the complexity of the task, there have been few attempts to assign values to the effects from each stage of the life-cycle. Krewitt *et al.* (1998) attempt to do so in terms of human health effects, and demonstrate that solid and liquid fossil fuels have the highest loss of life expectancy. Combined cycle natural gas has the lowest risk amongst fossil fuels, and its effects are even lower than those attributed to the photovoltalics fuel chain, as the latter generates adverse effects during the material supply and component production stage. Nonetheless, it is becoming more widely accepted that a combination of natural gas, renewable and actions that involve energy conservation and efficiency are the most environmentally safe options currently available. Lastly, other factors should also be considered that could affect the climate change – energy relationship. This includes the role of alternative adaptation measures directed at reducing the urban heat island effect, and thereby helping to reduce the demand for air conditioning. Urban forestation in particular can have a significant impact in reducing urban temperatures during the summer.

4.0 Discussion

In the recent action plan on climate change, options proposed to help Canada reach its Kyoto target include fuel switching (from coal to natural gas), an increase in the inter-provincial trade of hydroelectricity, energy conservation and residential energy efficiency, and greater use of emerging renewable energies such as wind and solar (Government of Canada, 2000). These proposed actions should be examined in the context of the proposed sustainable energy framework that includes co-benefits for environment and health, in addition to the vulnerability and adaptive capacity of energy options to climate change impacts. A cursory review suggests the following, although it is important to note that many of the vulnerabilities cited could be reduced through effective adaptation measures:

- Fuel switching from coal to natural gas could result in co-benefits for environment and health.

- Greater reliance on inter-provincial transmission of electricity could increase risk to catastrophic failure of the electricity grid due to extreme weather events.

- Increased demand for air conditioning could lead to greater air pollution, depending upon the importance of coal in the energy mix. The frequency of smog episodes is projected to increase by a factor of 5 – 8 due to climate change (Kalkstein and

Smoyer, 1993; Wilson and Sousonunis, 2000), regardless of any changes in emissions of air pollutants.

- The impacts of residential energy efficiency must be examined within the context of indoor environments. Improper installation of energy efficiency measures could actually increase exposure to indoor pollutants.

- Alternative energy options should be carefully assessed regarding externality costs, and how they may be impacted by climate change.

In considering these factors in developing a sustainable energy system for the TNR, future research over the next 2-3 years will address the following issues in the TNR:

1. The production of scenarios on climate and energy demand;

2. Estimating the costs of climate change impacts on the energy system;

3. An evaluation of the fuel mix under climate change;

4. An assessment of the costs and benefits of mitigation options; and

5. The development of a plan for a sustainable energy system that incorporates mitigation and adaptation strategies.

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