Implications of Long-Term Climatic Changes for Transportation in Canada

NEAL A. IRWIN AND WILLIAM F. JOHNSON

A preliminary, strategic assessment of the implications of long-term climatic changes due to the greenhouse effect for future conditions in Canada and the likely impacts of such developments on Canadian transportation are presented. It is assumed that emissions of greenhouse gases will be controlled through international cooperation so that their concentrations in the atmosphere stabilize by about 2050 at conditions equal to the "2 × CO_2" scenario (equivalent to twice the preindustrial concentration of carbon dioxide) and that longer-term responses (e.g., melting of ocean ice cover and northward movement of permafrost, the tree line, and agriculture) will reach equilibrium during the following decades. The most significant changes affecting Canadian transportation would probably be increased marine and air services followed by a northward extension of road and rail networks and a new equilibrium between marine and land transportation that would reflect the longer shipping season in the St. Lawrence Seaway and year-round operation of the Port of Churchill on Hudson Bay. Major expenditures would be required to protect coastal transportation facilities from floods and possibly to maintain navigation in the face of lower water levels on the Great Lakes. In general, however, if global temperatures stabilize as assumed, the implications for Canadian transportation of the postulated scenario will probably be, on balance, positive for Canadian transportation. There would, however, be significant costs in adapting to the new circumstances, and a number of implications for policy and research and development are outlined.

A continuing warming trend due to increasing atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases (GHGs) that transmit incoming solar radiation but capture the outgoing infrared (heat) radiation from the earth would have significant impacts on average global temperatures and precipitation patterns. Simulations of future conditions under the "2 × CO_2 scenario," in which the concentration of CO_2 would be twice as high as the preindustrial level (it has already increased 25 to 30 percent above that level), indicate that average global temperatures would be 1.5°C to 4.5°C higher than at present. Increased absorption of solar radiation due to reduced ice and snow coverages would cause greater winter temperature increases (3°C to 12°C) in high latitudes. Though less reliable than the temperature estimates, climate model estimates of precipitation patterns suggest that there may be a relative reduction in precipitation in mid-latitudes (i.e., southern Canada) and an increase in the mid-north (i.e., between 55 and 65 degrees north latitude).

There is also considerable uncertainty regarding the rate of temperature increase. Whereas industrial, space heating and cooling, transportation, and other activities of modern society emit GHGs at increasing rates, other factors, such as atmospheric chemical reactions and the rate of absorption of CO_2 by the ocean, may act to retard or accelerate the rate of increase of these gases in the atmosphere. Recent estimates suggest that an increase in the mean global temperature of 3°C could be experienced within 30 years (by 2020) or possibly not until 200 to 300 years from now; the "most probable" estimate falls somewhere in the latter half of the 21st century, about 60 to 100 years from now. Past trends in average global temperatures and future projections (illustrating the wide range of uncertainty in the latter) are given in Figure 1.

In the absence of concerted and effective action to limit the rate of GHG emissions, there is every likelihood that global warming trends will continue as GHG concentrations increase beyond the level of the 2 × CO_2 scenario. Though "equilibrium" conditions reflecting that scenario are the basis for this paper and its broad conclusions regarding Canadian society and transportation, the longer-term consequences of continued global warming would be ominous for the viability of Canadian society.

PHYSICAL AND BIOSPHERE CHANGES IN CANADA UNDER THE 2 × CO_2 SCENARIO

A number of important changes affecting Canada in terms of permafrost, snow and ice cover, water levels, growing seasons, and vegetation regimes would be expected to accompany such climate changes:

- The southern limit of permafrost areas would move northward 200 to 600 km. This expectation is based on an estimated migration of 100 to 150 km per 1°C warming. Methane emissions from rotting muskeg in these areas might increase.
- The mean ocean level would increase in the Atlantic, Arctic, and Pacific oceans by about 1 m (with a range in the estimated increase of 20 to 140 cm by 2050). In addition, average sea surface temperatures would increase by 2°C to 3°C; Hudson Bay, the Gulf of St. Lawrence, and the Great Lakes–St. Lawrence basin would be generally free of ice; numbers and sizes of icebergs would not change predictably; the Labrador Current would become stronger and have a correspondingly increased influence on the eastern seaboard; and surface salinity on the shelf areas of Canadian coastal waters would decrease.
- In the absence of level control measures that could be taken and would probably be at least partially effective, water levels in the Great Lakes would be reduced by about 30 cm in Lake Superior; 70 cm in Lakes Michigan, Huron, St. Clair, and Erie; and 70 cm or more in Lake Ontario.

N. A. Irwin, IBI Group, 250 Richmond Street West, Toronto, Ontario, Canada M5V 1W1. W. F. Johnson, Transport Canada, Tower C, Place de Ville, Ottawa, Ontario, Canada K1A 0N5.

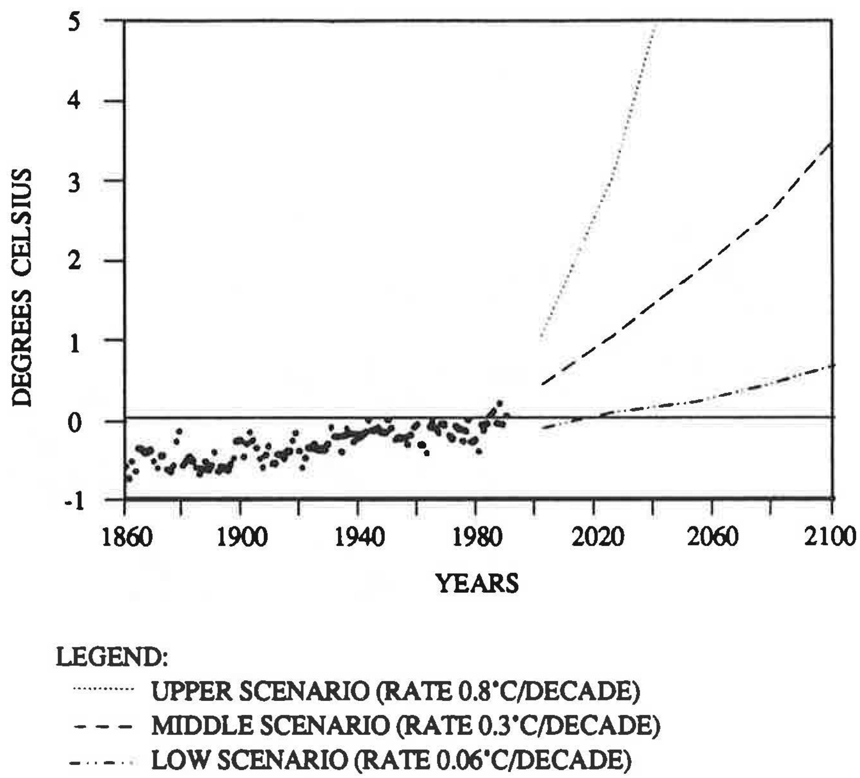

FIGURE 1 Trends in average global temperature, 1860–2100 (*1*).

• Air quality would be reduced because of increased intrusions of polluted air masses northward from industrial basins in the United States, increases in regional pollution episodes, and increases in acidic deposition (acid rain).

• Water quality would be reduced because of reductions in stream flows and basin levels. Aquatic plant growth would increase because of increases in water temperature. Some wetlands bordering lakes and oceans would dry out, and other wetlands would migrate toward lower-level coastal areas.

• Mean winter snowfall would be reduced by 20 to 80 percent in areas south of 60 degrees latitude; the greatest change would occur north of the lower Great Lakes. The snow-covered season would shorten by 2 to 10 weeks in mid-latitudes. "No snow areas" in southern Ontario would significantly increase. Sub-Arctic (e.g., in the latitude of Yellowknife, Churchill, and Ungava) snowfall would increase by 10 to 20 percent, but the snow-covered season would be reduced by 30 to 40 days owing to earlier spring and later fall seasons.

• As shown in Figure 2, the boreal (coniferous) forest would migrate northward (possibly by 200 to 600 km). The deciduous forest and other major ecosystems would move northward correspondingly and replace coniferous growth. The overall size of boreal forest coverage would probably be reduced, but the reduction would be offset at least partially by increased rates of tree growth.

• Growing seasons would lengthen. Increases would range from up to 40 days in the northern prairies to as much as 61 days in southern Ontario. Droughts might become more frequent and severe and particularly affect the southern prairies and southern Ontario regions. Grain production in the Palliser triangle of southern Saskatchewan might become marginal, and slight drops in agricultural produce might occur in other parts of the southern prairies and in southern Ontario. The increased precipitation and growing season in areas farther north, however, might produce substantial increases in agricultural yields in northern Ontario (e.g., the clay belt area around Sudbury), northern Quebec, Labrador, the prairie provinces, and British Columbia. The primary limitations would be soil availability and quality in many of these northern areas. Adaptation of farming methods and crop types (e.g., a change from spring to winter wheat in the southern prairies and to corn in portions of Ontario and Manitoba) might produce increases in these areas as well, although increases in drought frequency could introduce greater uncertainty regarding farm viability.

• Increases in vegetation productivity (up to 50 percent) and drought resistance due to direct biological impacts of 2 × CO_2 concentrations have not been taken into account in the preceding impact assessment. These may more than offset the tendencies to reduced agricultural and forest production. Net increases may result instead.

• Average winter temperatures would trend substantially upward throughout Canada, especially in the sub-Arctic and Arctic areas. Summer temperature increases throughout Canada would be smaller but still significant. The frequency and length of summer heat waves would increase; for example, the climate in southern Ontario would more closely approximate that of southern Ohio at present.

Some of these responses to climatic change, in particular the migration of permafrost areas and forest types, would lag many decades behind the date at which 2 × CO_2 atmospheric conditions might occur owing to factors such as thermal inertia

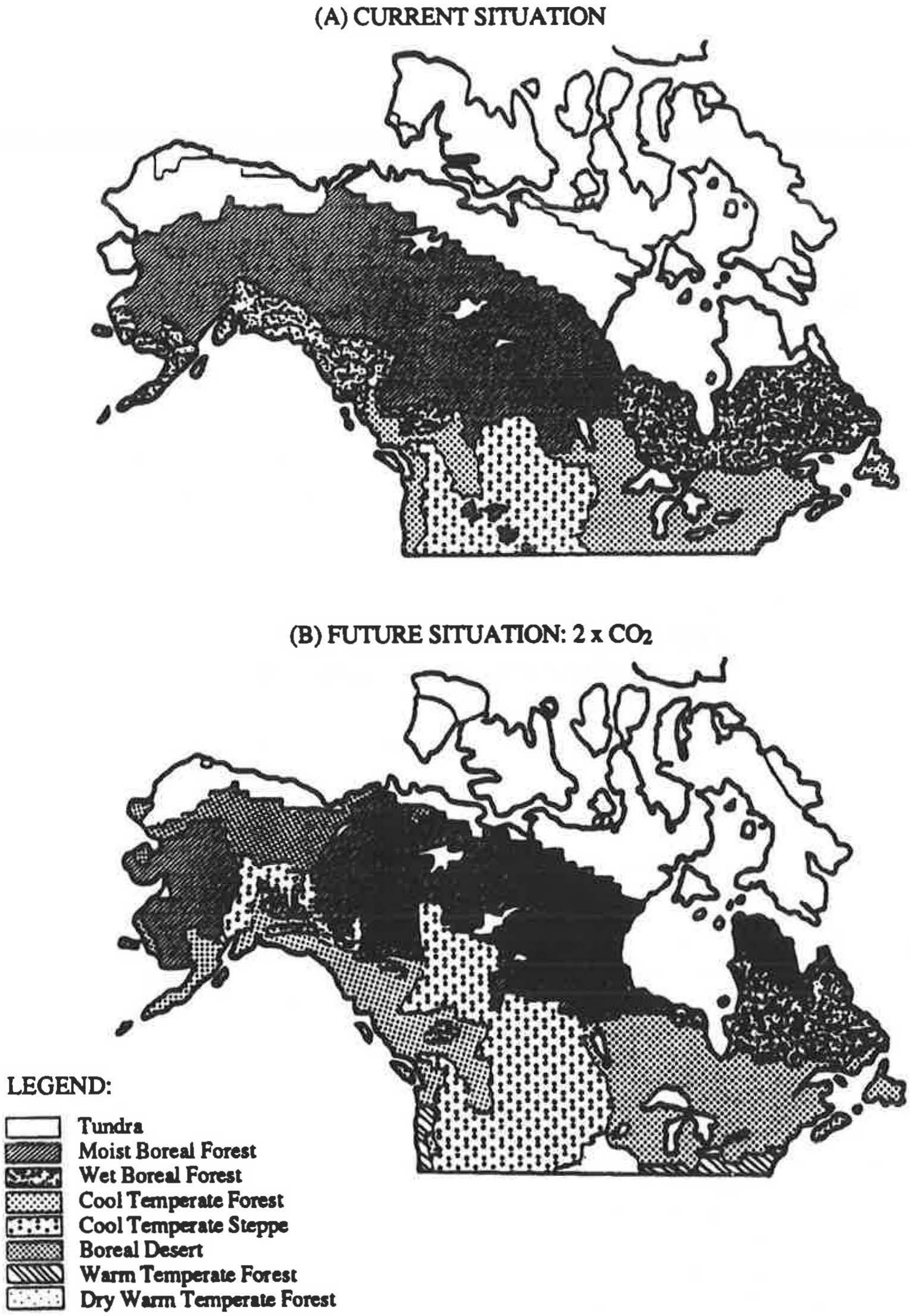

FIGURE 2 Projected changes in major ecosystem distributions under 2 × CO_2 scenario (*2*).

and biological response times. The 2 × CO_2 scenario discussed is based on the assumption that policies to limit GHG emissions result in a leveling off of CO_2 and other GHGs at double their preindustrial concentrations and that sufficient time thereafter passes to allow physical and biological responses, such as the migration of permafrost areas and forest types and the melting of some ice cap areas, to reach equilibrium with the new climate conditions.

IMPACTS ON HUMAN ACTIVITIES

The above physical and biosphere changes would be expected to have a number of impacts on societal activities in Canada. The impacts would include the following:

- Areas suitable for agriculture and forestry activities may spread northward by 200 to 600 km or 120 to 400 mi, which could substantially increase the north-south dimension of settled, agricultural areas in parts of Canada, subject to the suitability of soil types and coverage for such activities. Shorter, warmer winters and a northward migration of sea ice would also contribute to year-round mining, shipping, and related activities in sub-Arctic and Arctic areas and expansion of settlements in many northern areas of the country.

- Resettlement from low-lying coastal areas subject to increased flooding due to rising ocean levels may occur, and accompanying public works may protect such areas and related transportation facilities.
- Hydroelectric power generation could be reduced in southern areas (e.g., by about 10 percent in southern Ontario) owing to reduced flow levels but could be increased substantially in northern areas (e.g., by about 30 percent in the James Bay–Quebec power generation project with similar increases in Labrador, the northern prairie provinces, and British Columbia).
- Energy consumption for heating purposes may be reduced (by about 40 percent in most parts of Canada), and energy consumption for summer air-conditioning may be increased (by 5 to 10 percent, mainly in southern Canada).
- Agricultural output in southern Canada may be reduced, remain the same, or increase. Agricultural production may significantly increase farther north (existing areas of agriculture may experience a 10 percent increase, and new areas may come under cultivation).
- Forest production and logging may be reduced or increased, with increases more likely on balance. A shorter logging season in some areas may result from shorter winters.
- Commercial downhill skiing operations in southern Ontario and Quebec will probably disappear. Skiing seasons in northern Ontario and Quebec and in Rocky Mountain areas will probably be shorter.
- Summer tourism may increase owing to longer summers and incentives to travel farther north into cooler areas.

IMPLICATIONS FOR TRANSPORTATION IN CANADA

Transportation Supply and Cost

Table 1 summarizes the possible impacts of climate changes on supply and cost aspects of Canadian transportation—that is, on the ease with which transportation ways and terminals can be established and vehicles and other equipment operated and the overall capital and operating cost of providing transportation that results.

As indicated, there could be substantial impacts on all modes of transportation. Some of the more significant would affect ocean shipping, particularly in Arctic areas. Some of these impacts would be beneficial (e.g., deeper drafts in harbors and channels and longer shipping seasons, potentially year-round, in the Great Lakes–St. Lawrence system, Hudson Bay, and the Labrador coast area). Some would probably lead to increased costs (e.g., flooding of harbor facilities, greater need for navigation aids owing to increased precipitation and storm frequencies, and probable increases in requirements for search and rescue activities). Shipping on the Great Lakes might experience increased costs owing to reduced drafts in harbors and channels, which would require vessels to carry reduced payloads and make more trips. It seems likely, however, that this could be mitigated by structures and systems to control lake levels at close to current levels under possible conditions of reduced river flows and greater evaporation losses.

Automotive transportation (the road mode) is the dominant mode for passenger transportation, carrying 70 to 90 percent of this traffic in most parts of the country. It is also extremely important for freight transportation, particularly in southern Canada, where it carries more than half of the freight by value of commodities and about half of the tonnage. A beneficial effect of the climate trends described earlier would be substantially reduced winter maintenance activities and expenses (e.g., snow removal), particularly in southern Canada, where the shorter winter season would possibly be combined with less snowfall. In the mid-north, the benefits of a shorter winter season might be offset by greater winter maintenance activities during the season to remove increased snowfall. Impacts that would increase costs for the road mode include the need for realignments and measures to avoid flooding of coastal roads owing to increased sea levels, a shorter season during which winter roads can be used in northern areas, and a general reduction in the efficiency of heat engines caused by warmer temperatures. In urban areas, this latter effect would probably be offset by a reduction in winter warm-up times for automotive engines, which would contribute to the overall efficiency of energy use for the relatively short trips in urban areas.

Canada's railways play an extremely important role in the movement of freight, particularly bulk commodities, in both east-west and north-south directions. Coupled with marine transportation on the Great Lakes and at ocean ports, they play a central role in carrying major export commodities such as grain, forest products, and mineral products, as well as various types of manufactured goods, such as automobiles and automobile parts. Beneficial climate effects on the railways could include decreases in winter maintenance costs and, with the northward retreat of permafrost areas, an enhanced ability to stabilize the roadbed of northern lines (e.g., the line to Churchill, Manitoba). Effects leading to increased net costs could include losses of winter bulk traffic owing to year-round navigation on the Great Lakes–St. Lawrence system, realignment or protection to avoid flooding of coastal lines, and lower efficiency of heat engines owing to higher average temperatures.

The air mode would experience similar impacts of warmer temperatures, both on engine efficiency and on the lift of aircraft in warmer, less dense air, which marginally reduces allowable payloads. Although float planes would benefit from a longer season (owing to reductions in the duration of winter ice on northern lakes), the length of the season in which winter air strips could be used would be correspondingly shorter. Increases in precipitation in the mid-north could lead to more downtime or increased costs for improved navigation aids, or both.

Transportation Demand

Potential impacts of climatic change on the demand aspects of Canadian transportation are summarized in Table 2. As

TABLE 1 POTENTIAL IMPACTS OF CLIMATIC CHANGE ON SUPPLY ASPECTS OF CANADIAN TRANSPORTATION

MODE/AREA	CLIMATIC CHANGE	TRANSPORTATION IMPACTS
Marine-Ocean	Rise in ocean level	- deeper draft in harbours and channels - possible flooding of harbour facilities during storms, high tides, etc.
	More precipitation/winds	- greater need for navigation aids
	Reduction in ice formation	- winter navigation in St. Lawrence may not require ice-strengthened vessels; more winter traffic
Marine-Arctic	Reduction in ice cover	- longer shipping seasons in Labrador, Hudson Bay, etc; more use of Port of Churchill for grain, arctic resupply, etc. - more shipping in high arctic; possible greater need for icebreaking (although lower class?), search and rescue, navigation aids, etc.
Marine-Great Lakes	Lower lake levels	- reduction in available draft and efficiency of lake fleet leading to higher shipping costs - possibly could be mitigated by structures to control lake levels
	Less ice cover	- makes 11 month or year round navigation much more feasible
Marine-Mackenzie	Less ice cover, higher water levels	- longer season, increased draft and payloads
Roads-South	Generally higher temperatures	- less efficiency of heat engines (offset by less requirement for "warming up")
	Higher winter temperatures and greater precipitation	- less winter maintenance (e.g. snow removal) in southern areas - possibly more winter maintenance further north - better drainage required

	Increase in ocean levels	- flooding of some coastal roads, with resulting need for realignments, improvements and/or protection measures
Roads-North	Higher winter temperatures	- less use of winter roads; more demand for air cargo movements - shorter seasons for winter maintenance but greater snow removal effort (increased snow fall) during the snow season
Railways	Generally higher temperatures	- lower efficiency of heat engines - possible decrease of winter maintenance although offset by greater precipitation - year-round navigation on Great Lakes will even out seasonal demand for eastbound grain transportation and remove/reduce winter peak "at and east" movements
	Reduction in permafrost	- change in new roadbed requirements for certain lines, e.g. Churchill; could be lower or higher cost
	Increase in ocean levels	- floodings at some coastal lines leading to need for realignment, improvements and/or protection measures on coastal routes
Air	Generally higher temperatures	- lower "lift" of aircraft - lower efficiency of heat engines - less use of winter airstrips - longer season for float planes
	More precipitation/winds	- more down time and/or need for navigation aids

TABLE 2 POTENTIAL IMPACTS OF CLIMATIC CHANGE ON DEMAND ASPECTS OF CANADIAN TRANSPORTATION

INDUSTRY/AREA	CLIMATIC CHANGE AND EFFECT	TRANSPORTATION IMPACTS
Agriculture-B.C. and Prairies	Increase in temperature may result in slightly increased (or decreased) agricultural volume and probably increased variety of products	- possibly greater volume but more specialized transportation requirements - possibly more exports from prairies and B.C. - possible year-round use of Churchill and Thunder Bay as grain export ports
	Change in precipitation patterns will change relative productivity of agricultural areas with northward extension of agricultural areas where soils allow and with possible higher frequency of drought conditions in southern areas	- changes in gathering system for agricultural products will be required - possible increase in annual demand fluctuations and resulting need for transportation flexibility and cost reduction
Agriculture-South Central and Eastern Canada	Increase in temperature may reduce or increase volume of products from existing agricultural areas; northward extension of agricultural areas where soils allow will add new production; possible increase in frequency of drought conditions with likely greater variety of products	- possibly more exports from Ontario, Quebec, Atlantic Provinces - likely year-round use of Great Lakes/St. Lawrence seaway transportation system for exports and other traffic - possible increase of trucking and intermodal services for flexibility and efficiency in serving changing demands, both E-W and N-S
Agriculture-Mid-North	Increase in temperature and precipitation will likely increase volume and variety of products	- greater development of clay belt, northern prairies and Peace River areas will require transportation improvements in the north

Forest Industries	Changes in temperature and rainfall will alter growing patterns	- possibly more production in north and less in south, with changes in transportation demand
Fossil Fuels	Increase in winter temperatures will reduce demand for space heating Increase in summer temperatures will increase demand for air conditioning	- lower demand for transportation of oil and gas and of coal for electricity generation - somewhat greater demand for heavy oil and coal for electricity generation in summer months
Arctic Resource Extraction	More activity	- greater demand for transportation: air, sea and land
Settlement Patterns	More dispersion of population and employment into mid-north and arctic areas	- dispersion of transportation demand with more demand in mid-north and arctic areas
Leisure Industry	More summer recreation, less skiing in south and more in north	- changes in passenger transportation demand
Global Concern About Greenhouse Effects	Possible restrictions on emissions of CO_2, CO, No_2, and other GHG's	- changes required in vehicle and heating technology (e.g. hydrogen-fuelled engines and on-board storage; electric vehicles with improved batteries or fuel cells for urban use, drawing on nuclear-generated electric energy from central plants for recharging)

noted earlier, the most significant general impact of this type would probably be from a northward spreading of agricultural, forestry, and mining activities, which would result in increased population and intensified settlement patterns in Canada's mid-north and Arctic areas. In some respects, the shape of Canada's major settled area could be changed from a ribbon (a few hundred kilometers wide from north to south and 5000 km long) to more of a rectangle. The settled area could approximate 1000 km or more in the north-south direction. The marine, road, rail, and air modes would have to expand their facilities and service coverage accordingly. This would entail substantial capital and operating costs, but on balance it would represent an economic opportunity because revenues from the increased northern traffic should more than offset the increased costs.

As indicated in Table 2, an increase (or decrease) in prairie grain production coupled with a northward expansion of production (where allowed by soil types and coverage) could lead to greater (or lower) export volumes. There would probably be an eastward trend in export movements if Thunder Bay or Churchill, or both, were able to operate 12 months per year owing to reduced ice coverage. The prairie gathering system for agricultural products would have to be extended northward. This would probably be combined with consolidation of country elevators into inland terminals, greater use of trucking on an expanded road system to the inland gathering points, unit and solid trains for rail movement to the ports, and possibly a northward expansion of rail lines.

Changes in the level of agricultural output from south, central, and eastern Canada would be less certain. Increases or decreases could be experienced in various areas, and crop types might be changed to adapt to the new conditions. There could be more exports from Ontario, Quebec, and the Atlantic provinces because year-round navigation on the Great Lakes–St. Lawrence Seaway system and a possible increase in trucking and intermodal services would provide greater flexibility and efficiency in serving changing demand for both east-west and north-south movements of agricultural products.

There would probably be enhanced agricultural development in northern areas, such as the Peace River district in northwestern Alberta and the clay belt area in northeastern Ontario, which would contribute to the requirements and changes. This is true also because of the probable northward extension of forestry activities (by as much as 200 to 600 km as noted earlier). Coniferous trees and other northern species would be logged in areas not previously forested as the tree line moves north. Hardwood and deciduous production would increase as the southern limits of the boreal forest move north and coniferous growth is largely replaced by deciduous forest in those areas.

As mentioned earlier, there would be a substantial lag (on the order of 50 to 100 years following establishment of the new climate regime) in the response of forests to the changed conditions owing to the time required for tree growth and regeneration.

Fossil fuels, such as coal, oil, and natural gas, require transportation from their areas of production, particularly in western Canada, to other parts of the country. Reductions of energy demand for space heating (by as much as 30 to 50 percent per household) would lead to reduced demand for the movement of coal by rail, although this would not be a major impact owing to the substantially greater importance of natural gas and oil as fuels for space heating in Canada. Reduced demand for movements of the latter fuels by pipeline would also be likely. The reduction in winter demand for space-heating energy would also be slightly offset by an increase in summer energy demand for air-conditioning (on the order of 10 percent according to some estimates), which would probably lead to some increase in fossil fuel consumption for electricity production during the summer season.

As noted at the end of Table 2, global concerns about greenhouse effects may lead to national and international energy policies aimed at reducing the consumption of fossil fuels, which produce CO_2, CH_4, N_2O, and other greenhouse gases. Steps in this direction would also have the effect of reducing transportation demands for fossil fuels.

Finally, passenger transportation may be affected, particularly by changes in the patterns and extent of leisure travel. There would probably be more summer travel to cottage and camping areas in cooler northern areas and to take advantage of the longer summer season. Reduced skiing opportunities in southern areas could also lead to increased winter travel to skiing areas farther north.

In general, it appears likely that there will be an increased in the geographic extent and possibly the volume of demand for both freight and passenger transportation resulting from these effects and particularly from the northward extension of agricultural, forestry, mining, and other activities.

Transportation Implications

Table 3 gives a broad assessment of the impacts of the above conditions on Canadian transportation. The first two columns in the table describe the mode/area and transportation impacts and are a slightly condensed version of the types of supply and demand impacts illustrated in Tables 1 and 2. The other six columns in the table summarize, in broad terms, other ways of describing the impacts. These may be summarized as follows:

- The geographic extent of a northward expansion of settlement and related activities in Canada could be major and would affect all four modes (marine, roads, rail, and air), leading to substantial northward extensions of facilities and services.
- Additional capital costs to maintain and restore transportation facilities affected by flooding and other climate impacts would, in general, be modest or moderate. A possible exception could be major public works to prevent decreases in water levels in the Great Lakes due to possible substantial decreases in river flows and increases in evaporation rates.
- There would be major capital costs to expand transportation systems and services into northern areas, particularly for the road and rail modes. Significant or major capital costs would also be likely for expansions to the ocean marine mode (depending on whether Canada decides to expand its own merchant marine fleet), for increased coastal trade, and for increased coast guard and defense activity in the context of substantially increased northern marine, air, and other forms of transportation.

TABLE 3 ASSESSMENT OF IMPLICATIONS FOR CANADIAN TRANSPORTATION

MODE/AREA	TRANSPORTATION IMPACTS	GEOGRAPHIC EXTENT	ADDITIONAL CAPITAL COST		CHANGE IN UNIT OPERATING COST	SCALE OF SOCIO-ECONOMIC IMPLICATIONS	NATURE OF IMPACT
			To Maintain/ Restore System	To Meet Expanded Area and/or Demand			
Marine-Ocean and Marine Arctic	Increased Export Trade	Major	N/A	Minor-Significant	Minor Decrease	Significant	Net Benefit
	Increased Coastal Trade	Major	N/A	Significant	Moderate Decrease	Significant	Net Benefit
	Ice-Free Labrador/Hudson Bay	Major	N/A	Moderate	Significant Decrease	Moderate	Net Benefit
	Harbour/Dock (Re)Construction	Limited	Moderate	Moderate	Neutral	Modest	Net Cost
	Increased Coast Guard Activity	Major	N/A	Significant	Significant Increase	Moderate	Net Cost
	Increased Defence Activity	Major	N/A	Significant-Major	Significant Increase	Moderate	Net Cost
Marine - Great Lakes	Increased Export/Import/Coastal Trade	Significant	N/A	Moderate	Neutral	Modest	Net Benefit
	11 or 12 Month Operations	Significant	N/A	Modest	Minor Decrease	Moderate	Net Benefit
	Expanded Water Level Control System	Significant	Major	N/A	Moderate Increase	Moderate	Net Cost
Roads - South	Decreased Winter Maintenance (Snow Removal)	Major	N/A	N/A	Moderate Decrease	Modest	Net Benefit
	Realignment/Protection from Coastal Flooding	Moderate	Significant	N/A	N/A	Modest	Net Cost
Roads - North	Expanded System to Serve Northern Areas	Major	N/A	Major	Modest Increase	Major	Net Benefit
	Realignment/Protection from Coastal Flooding	Modest	Moderate	N/A	N/A	Minor	Net Cost
	Shorter but Heavier Snow Removal Season	Major	N/A	N/A	Modest Increase	Modest	Neutral
	Shorter Season for Winter Roads	Significant	Modest	N/A		Modest	Net Cost
Railways	Expanded System to Serve Northern Areas	Major	N/A	Major	Modest Increase	Major	Net Benefit
	Realignment/Protection from Coastal Flooding	Modest	Moderate	N/A	N/A	Modest	Net Cost
	Reduced Winter Traffic Due to Ice-Free Great Lakes	Significant	N/A	N/A	Neutral	Modest	Neutral
	Improved Operations on Northern Lines	Moderate	Moderate	N/A	Moderate Decrease	Modest	Net Benefit
	Net Decrease in Winter Maintenance	Major	N/A	N/A	Modest Decrease	Modest	Net Benefit
Air	Expanded System to Serve Northern Areas	Major	N/A	Significant	Modest Increase	Major	Net Benefit
	Expanded Navigation Aids (or Down Time)	Major	Moderate	Moderate	Modest Increase	Modest	Net Cost
	Lower Lift and Engine Efficiency	Major	N/A	N/A	Modest Increase	Minor	Net Cost
	Shorter Season for Winter Airstrips	Significant	Modest	N/A	Moderate Increase	Modest	Net Cost
	Increased Coast Guard and S & R Activity	Major	N/A	Significant	Significant Increase	Moderate	Net Cost
	Increased Defence Activity	Major	N/A	Significant-Major	Significant Increase	Moderate	Net Cost

Legend:

Five Point Impact Scale in Declining Order: Major; Significant; Moderate; Modest; Minor

Net Benefit = Transportation revenues may increase relative to costs, possibly in the context of an overall increased transportation role

Neutral = Costs and Benefits offset each other

Net Cost = Transportation costs may increase relative to revenues

N/A = Not applicable

- Increased coast guard, search and rescue, and defense activity would also contribute to significant increases in unit operating costs. These would be partially offset by significant decreases in unit operating costs owing to extended ice-free navigation in northern waters. Other minor, modest, and moderate increases and decreases are also identified.
- The northern expansion of road, rail, air, and marine transportation services would have major socioeconomic impacts. Other changes, including a shorter winter season and its various implications, would have more moderate socioeconomic impacts.
- As indicated in the last column of Table 3, the preliminary assessment suggests that, on balance, there might be net benefits to Canadian transportation under the estimated 2 × CO_2 scenario conditions. Although a substantial number of entries in the table are expected to lead to an increase in net costs, these items tend to be less important in geographic extent, increased capital and operating costs, and scale of socioeconomic implications. A number of the more important impacts (in particular, those related to the northward extension of transportation systems) are seen as leading to a net benefit, increased revenues more than making up for increased costs.

Environmental protection in Canada's north could be an important issue and would have to be addressed. Also, as stated earlier, continuing warming beyond the scenario described here would eventually be fatal to human beings and the entire biosphere. The preliminary findings of this paper should not, therefore, be taken as an endorsement of "no action" to reduce GHG emissions. On the contrary, early and sustained action will be required if the warming trend is to be halted, and it may already be too late to achieve equilibrium at the 2 × CO_2 level instead of a higher level.

SYNTHESIS AND CONCLUSIONS

Likelihood, Timing, and Importance of Canadian Transportation Implications

On the basis of the assumption that international policies to limit GHGs stabilize climate conditions by about 2050 as described for the 2 × CO_2 scenario, Table 4 presents a summary of the likelihood, timing, and relative importance of the various types of Canadian transportation implications described earlier. A five-point scale is used, the terms in declining order of importance or likelihood being high, medium-high, medium, medium-low, and low.

The approximate timing ranges shown in the table reflect the assumption that the rate of temperature increase will be somewhat greater than the most probable trend discussed earlier (that is, that an average global temperature increase of about 3°C to 4°C will be experienced by 2050).

TABLE 4 LIKELIHOOD, TIMING, AND IMPORTANCE OF CANADIAN TRANSPORTATION IMPLICATIONS

MODE/AREA	TRANSPORTATION IMPACTS	LIKELIHOOD	TIMING	IMPORTANCE
Marine-Ocean and Marine Arctic	Increased Export/Coastal Trade	Medium	2040-2150	High
	Increased Winter/Summer Navigation	Medium-High	2030-2070	High
	Harbour/Dock (Re)Construction	High	2030-2050	Medium
	Increased Coast Guard/Defence Activity	Medium-High	2030-2070	High
Marine - Great Lakes	Increased Export/Import/Coastal Trade	Medium	2030-2070	High
	11 or 12 Month Operations	High	2020-2050	High
	Expanded Water Level Control System	Medium	2030-2050	Medium-High
Roads - South	Decreased Winter Maintenance	High	2020-2050	Medium-Low
	Realignment/Protection from Coastal Flooding	High	2030-2070	Medium-High
Roads - North	Expanded System to Serve Northern Areas	Medium	2040-2150	High
	Realignment/Protection from Coastal Flooding	High	2030-2070	Low
	Shorter but Heavier Snow Removal Season	Medium-High	2030-2050	Medium
	Shorter Season for Winter Roads	High	2030-2050	Medium-Low
Railways	Expanded System to Serve Northern Areas	Medium	2050-2150	High
	Realignment/Protection from Coastal Flooding	High	2030-2070	Medium-High
	Reduced Winter Traffic due to Ice-Free Great Lakes	High	2020-2050	Low
	Improved Operations on Northern Lines	High	2030-2100	Medium
	Net Decrease in Winter Maintenance	High	2020-2050	Medium
Air	Expanded System to Serve Northern Areas	Medium	2030-2150	High
	Expanded Navigation Aids (or Down Time)	Medium	2030-2070	Medium-High
	Lower Lift and Engine Efficiency	High	2030-2050	Low
	Shorter Season for Winter Airstrips	High	2030-2050	Low
	Increased Coast Guard and S & R Activity	Medium-High	2030-2070	High
	Increased Defence Activity	Medium-High	2030-2070	High

On the basis of Table 4 and in line with the broad assessment in Table 3, it is suggested that the transportation impacts of high importance are related closely to expanded transportation facilities and services to serve northern areas of the country and associated changes in export and coastal trade, year-round marine transportation, and requirements for coast guard, search and rescue, and defense activity.

The likelihood of a substantial northward expansion of Canadian agriculture, forestry, and settlement is considered to be lower than the likelihood of increased ocean levels and winter navigation. Northward expansion depends to some extent on precipitation forecasts, which are considered to be very uncertain. Furthermore, changes in precipitation will take substantially longer to occur because of the lag effects in the northward movement of permafrost, the establishment of forest cover in these areas, and resulting agriculture and settlement activities. This is reflected in the wide timing ranges shown in Table 4; for example, northern expansion of the transportation system is estimated to be most significant in the period 2040 to 2150, increased winter and summer navigation in northern seas is seen as likely during the period 2030 to 2070, and 11- or 12-month navigation on the Great Lakes–St. Lawrence system could occur somewhat earlier (e.g., 2020 to 2050).

Policy Issues

A number of relevant policy issues stemming from these preliminary and tentative findings include the following:

- Control of greenhouse gas emissions;
- Sovereignty and defense;
- Northern environmental protection;
- Transportation system planning and investments;
- Transportation system operation, regulation, and adaptation;
- Transportation cost minimization; and
- Continuing surveillance, research, and forecasting.

Brief comments on each policy issue will be made.

Control of Greenhouse Gas Emissions

It has been estimated that 60 to 80 percent of the measured 25 to 30 percent increase in CO_2 concentrations from preindustrial levels has been due to the burning of fossil fuels for space-heating, industrial, transportation, and other purposes. Recent data for Canada indicate that approximately 25 percent of the fossil fuel energy consumed is used for transportation purposes. This includes gasoline consumption by automobiles, trucks, and buses; diesel and bunker fuel oil consumption by trucks, locomotives, marine engines, oil pipeline pumping stations, buses, and automobiles; coal burned in electric generating stations to produce electricity for electric-vehicle operation (e.g., subways, streetcars, trolley coaches, and elevators); and natural gas and propane (used to a small extent for automotive transportation, with larger consumption of natural gas to fuel pumping stations on natural gas pipelines).

Transportation uses of fossil fuels, therefore, are probably contributing 15 to 20 percent of the emission rate of CO_2 and probably higher percentages of nitrous oxides. These percentages are probably somewhat higher than the average for all countries because of Canada's extended geography and relatively high production and transportation of bulk commodities. Even so, transportation is a significant contributor to the greenhouse effect.

Canada and other countries will undoubtedly be considering changes in their energy policies to reduce the emission of GHGs. These changes, in turn, could lead to mandated restrictions on the use of fossil fuels in transportation. Restrictions could take the form of public education for greater conservation (through fewer trips, use of smaller cars, etc.), increased taxes on such fuels, or even rationing to restrict their use. Measures of this type would, in turn, lead to increased research and development activities to develop practical means of propulsion that reduce or eliminate the production of CO_2 and other GHGs.

One such approach would be intensified development of batteries and fuel cells for electric vehicles. In order to be effective, however, the additional electricity required would have to be produced by nuclear power or some other means that does not require the burning of fossil fuels. Increased use of nuclear power, at least with existing forms of fission reactors, would have other environmental implications (e.g., the safe storage of fission products), which are beyond the scope of this paper. Another possibility, which would also require considerable research and development for practical transportation applications, would be the development of engines and on-board storage systems for the use of hydrogen as a transportation fuel. Hydrogen has the distinct advantage of creating only water vapor (H_2O) from its combustion, so its use as a fuel would probably contribute less to the greenhouse effect than would use of fossil fuels.

Sovereignty and Defense

Increased ice-free navigation in northern waters and a northward movement of settlement and other human activities in Canada and other Arctic countries would make more evident the need to assert Canadian sovereignty and provide effective coast guard and defense in the country's northern and Arctic areas. Policy issues related to transportation include the modal balance and technology used for these purposes; for example, it may be that reductions in Arctic ice could affect the required mix of vessels in Canada's navy. Consideration might therefore be given to using the funding that would have been devoted to that purpose for other types of transportation and surveillance equipment in the context of the settlement, transportation, and economic activity scenario for northern Canada by 2050 that is described earlier in this paper.

Northern Environmental Protection

As permafrost areas recede to the north, the fragility of the northern environment may be reduced. The environmental impacts of a northward movement of settlement, agriculture, forestry, mining, and related transportation activities into these areas may be more acceptable than at present. This will remain an important policy area, however, and will require careful study and consultation before major actions are taken along these lines.

Transportation System Planning and Investments

Many components of transportation infrastructure have an estimated life of 50 years or more. Given the possible timing of the above impacts, summarized in Table 4, it is therefore important that transportation system planning take these trends and possibilities into account. Major transportation investments and disinvestments should be made with the same long-term trends in mind. Policy makers would be well advised to ensure that alternatives have been considered that, though equally cost-effective during the next 2 or 3 decades, may be more so in the longer range because of a greater ability to meet changing requirements, such as those outlined in Tables 1, 2, and 3. For example, abandonment of the Port of Churchill as a grain export port and of the rail line that serves it might prove to be a costly decision if the port were to become attractive in 30 or 40 years owing to northward extensions of grain production and ice-free year-round navigation in Hudson Bay and Hudson Strait.

Transportation System Operation, Regulation, and Adaptation

Similar considerations apply regarding the shorter-term decisions affecting transportation system operation, regulation, and the possible adaptation of the system to meet such conditions. Certain transportation regulations or subsidies may no longer be applicable under the new conditions (e.g., the "at and east" rail subsidy would be obviated by year-round navigation on the Great Lakes–St. Lawrence system). As another example, it may be desirable to change certain operational requirements or regulations affecting the introduction of new technologies that could limit the GHG emissions of one or more transportation modes.

Transportation Cost Minimization

This is closely related to the preceding two points in terms of both capital and operating costs. Investment and operating decisions should be made after consideration of possible changes that would affect the transportation system if the expected climate trends take place. For example, the proposed bridge linking Prince Edward Island and New Brunswick should be designed so that an increase in the mean sea level (which could be on the order of 1 m but might be substantially more) would not compromise the integrity or safety of the bridge or that of marine traffic passing under the bridge. A modest increase in the initial investment at the time of design and construction could reduce or delay the need for extremely costly repairs or modifications at a later date.

Continuing Surveillance, Research, and Forecasting

Given the uncertainties of the climate trends and related transportation implications discussed in this paper, it is clear that Canada and other countries must continue to watch the situation closely, conduct relevant research, and continue to study and make forecasts in these important areas. Such activities will provide an early warning system that will be essential as a basis for addressing the other policy issues outlined.

Suggested Actions

A number of areas are discussed briefly in terms of suggested actions.

Monitoring of Climate-Related Variables

Clearly, Environment Canada is involved in monitoring and studying climate trends and related socioeconomic implications. The time frame for such impacts is long compared with the lifetime of elected governments and many aspects of physical and economic planning, but the potential importance of these trends is great. It is suggested that consideration be given to increased government support for monitoring of climate-related variables, including not only temperature, precipitation, wind velocities, and so forth, but also concentrations of GHGs and related trends and impacts. The difficulty of separating the "signal" of long-term climate trends from the "noise" of shorter-term fluctuations is such that the quality and coverage of information must be of the highest order.

Climate-Transportation Research Studies

In addition to the climate-modeling and related studies being carried out by Environment Canada and other researchers, it would be desirable to expand the range of studies and research related to Canada's transportation system in the context of a continuing warming trend. The following areas could be studied:

- Propulsion systems that do not burn fossil fuels (e.g., electric vehicles using nuclear electric generation, improved batteries and fuel cells, and hydrogen engines and on-board storage systems);
- Improved designs of ice-strengthened vessels and ice breakers for use in areas with light ice conditions;
- Improved designs of snow-removal equipment for heavier snowfalls in sub-Arctic areas;
- The best methods to extend the road and rail systems into the mid-north, including the most cost-effective roles of the road, rail, air, and marine modes; possible earlier use of marine and air extensions; and subsequent extension of road and rail systems;
- Protection of road, rail, air, and marine facilities from rising sea levels;
- Improved stabilization measures for roads, rail lines, and airport runways in areas of discontinuous permafrost; and
- Control of structures and systems to maintain Great Lakes water levels in the face of reduced flow levels.

Given their relative flexibility, it is likely that the marine and air modes will continue to play a dominant role in Canada's northern transportation, at least in the early years of the expected warming trend. If the trend continues, however, the land modes will also be extended northward. Rail extensions would probably be mainly oriented in a north-south direction, and highways and local roads would form a grid network such as now exists to the greatest extent in Saskatchewan and Alberta.

Environmental Protection Studies

Substantial efforts have already been made in this area regarding northern development impacts, but most have been related to specific mining or transportation projects. It would be desirable to broaden these studies to consider possible migration of permafrost areas, forest coverage, and agricultural areas; the impacts of soil suitability and coverage; and related factors. Study and policy consideration will also be required regarding the challenging issues of northward expansion in the context of native land claims and aboriginal rights.

National and International Cooperation

It is essential that Canada continue to be at the forefront of monitoring, research, and international discussions related to these trends and possible policy responses. Canada is well positioned to support and play a leadership role in such activities. As a northern country that could be profoundly affected by an unprecedented and continuing warming trend, it behooves Canada to play an active role in this important policy area.

ACKNOWLEDGMENT

This paper summarizes a longer report prepared for Transport Canada as a basis for strategic consideration of the trends and implications outlined. The authors acknowledge with thanks the advice and background reports provided by the Atmospheric Environment Service of Environment Canada.

REFERENCES

1. *Developing Policies for Responding to Climatic Change*. Beijer Institute, Stockholm, Sweden, 1988.
2. B. Bolin et al. (eds.). *The Greenhouse Effect, Climatic Change, and Ecosystems*. John Wiley and Sons, Inc., New York, 1986.

Publication of this paper sponsored by Committee on Energy Conservation and Transportation Demand.