The Role of Nuclear Energy in Reducing Climate Change

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Abstract

Nuclear energy can play a role in minimizing climate change, and in achieving Canada's carbon dioxide (CO_2) reduction targets, where emissions reductions are limited by habitual behaviour. Three major components of Canadians' carbon footprint affected by behaviour are: electricity use, home heating and transportation. The effectiveness of policies and regulations designed to change our behaviour is limited by technology, infrastructure, and lack of personal engagement. Further CO_2 reduction can be achieved through reducing the CO_2 intensity of the energy sources by including clean power sources such as nuclear in the supply mix. Nuclear power is thus a key tool for reducing CO_2 emissions during the transition to renewable sources of power.

Keywords: nuclear energy, low carbon intensity, electricity generation

Résumé

Mots clés :

1. Introduction

There is an overwhelming scientific consensus that climate change due to human activities is already occurring; global temperatures have risen by 0.85°C in the 130 years since the industrial revolution. Aggressive mitigation efforts are required to limit the temperature rise to 2°C. The business as usual scenario would result in a 4°C temperature rise, with major global consequences.

Initiatives to limit global warming have been driven by the United Nations through the UN Framework Convention on Climate Change (UNFCCC), an international treaty signed by 190 countries (parties) in Rio de Janiero in 1992. International meetings to reach a climate accord have included: Kyoto 2007, and Copenhagen 2009. Annual Conferences of the Parties (COP), working towards a universal climate agreement continue with COP 21 in Paris 2015. Locally there is a Western Climate Initiative between several Canadian provinces and US, states.

The three messages in this paper are: 1) As Canadians, our personal contribution to CO_2 emissions, our carbon footprint, is amongst the highest in the world, 2) Reduction of personally

controlled emissions is lagging for various reasons such as the difficulty in changing habitual behaviour and barriers to green behaviour created by existing infrastructure and limits in current technology, and 3) nuclear power can reduce the carbon intensity of the electricity that we use and reduce our carbon footprint beyond what can be achieved by behaviour change alone.

2. Canada's Global Commitment

Canada has made a global commitment for CO_2 reduction. In 2007, the Canadian government signed the Kyoto Protocol, passed the Kyoto Protocol Implementation (KPI) Act and developed "A Climate Change Plan for the Purposes of the Kyoto Protocol Implementation Act" (Government of Canada) with 20 federal government initiatives, most of which ran from 2007 to 2011. In 2012 Canada withdrew from the Kyoto Protocol and repealed the KPI Act. Canada remains a signatory of the United Nations Framework Convention on Climate Change (UNFCCC) and is required to report annually on greenhouse gas (GHG) emissions (UNFCCC United Nations Framework Convention on Climate Change, 2014). Canada signed on to the Copenhagen Accord in 2009 and accepted carbon emission targets of 17% below 2008 levels or 607 MT by 2020 as shown in Figure 1. As of the 2014 National Inventory Report, emissions were 699 MT and not on track to achieve these reductions (Environment Canada 2013).

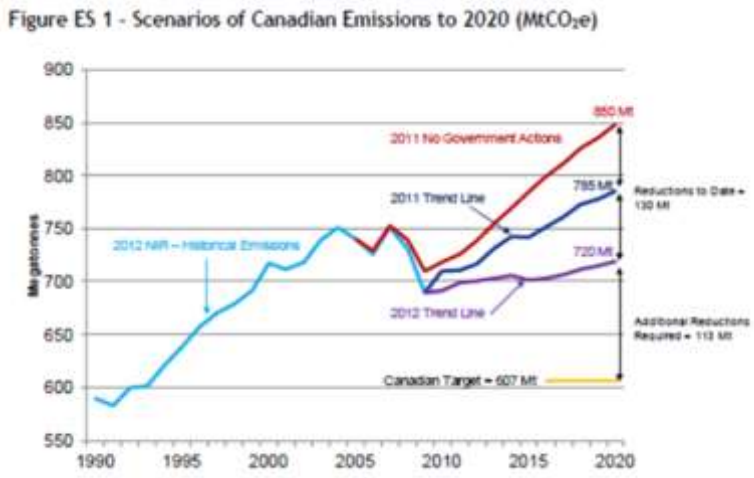

Figure 1 Scenarios of Canadian Emissions to 2020.

2.1 Personal Contribution (Carbon footprint)

What is the individual contribution to CO_2 emissions in Canada? This is also called the 'carbon footprint'. In developed nations, over one-third of a country's CO_2 emissions typically come from private transportation and domestic energy use and so are within citizens' personal control (Whitmarsh, 2011). The remaining emissions are from sources such as industry, commercial transport, farming, etc. With 699MT for 34.8 million people (2012), Canadians' personal carbon footprint is about 6.7T.

Personal carbon footprints were calculated using the GHG emissions data from twelve developed countries, as reported to the UNFCCC in National Inventory Reports (NIR), Figure 2. Canadians' carbon footprint is second to Australia (8.4T) and significantly higher than France (2.2T) and Sweden (1.2 T). In 2013, 73.3% of France's electricity came from nuclear power and in Sweden it was 42.7% (World Nuclear Association).

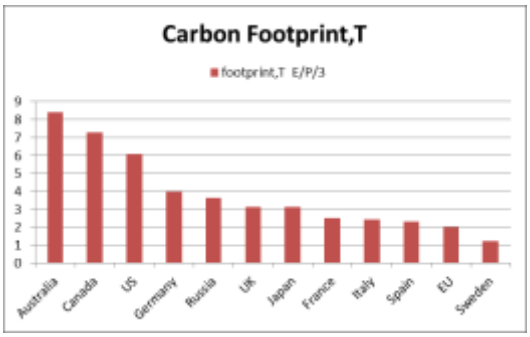

Figure 2 Individual carbon footprints

Table 1 and Figure 3 show the variation in these 12 countries of amount of energy use for: home electrical use, home heat (UNFCCC United Nations Framework Convention on Climate Change, 2014) and transport (International Energy Agency, 2009). Sweden and France, with very low carbon footprints, Figure 2, have significant transportation and home electricity use.

Table 1 Personal Energy Consumption in Selected Countries

Country	Home electrical use	Transport (IEA 2009)	Home Energy per household	
	kWh/household	km/person	T/person	GJ
Australia	10,286	13,357	3.2	53
Canada	15,137	15,266	3.9	106
US	13,394	14,853	5.1	101
Germany	7,215	11,347	1.7	74
Russia	6,430	369	0.85	n/a
UK	5,733	12,090	2.0	23
Japan	8,394	7,193	1.7	41
France	7,728	12,190	2.0	74
Italy	5,384	14,688	2.0	n/a
Spain	6,155	8,969	2.2	n/a
Sweden	14,939	11,803	2.3	14

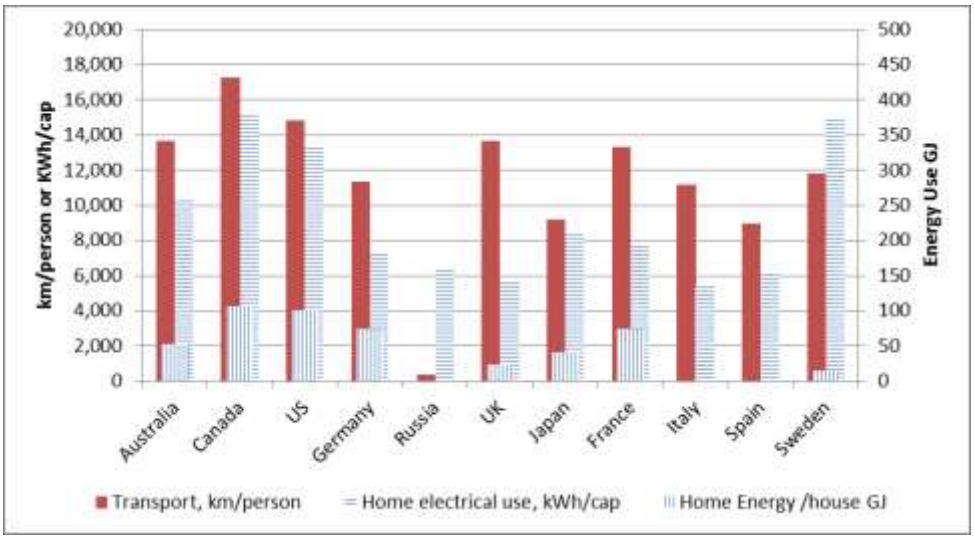

Figure 3 Personal Energy Consumption in Selected Countries

Figure 4 shows the carbon intensity of the electricity in 26 major countries. The lowest carbon intensity occurs in countries with significant nuclear power.

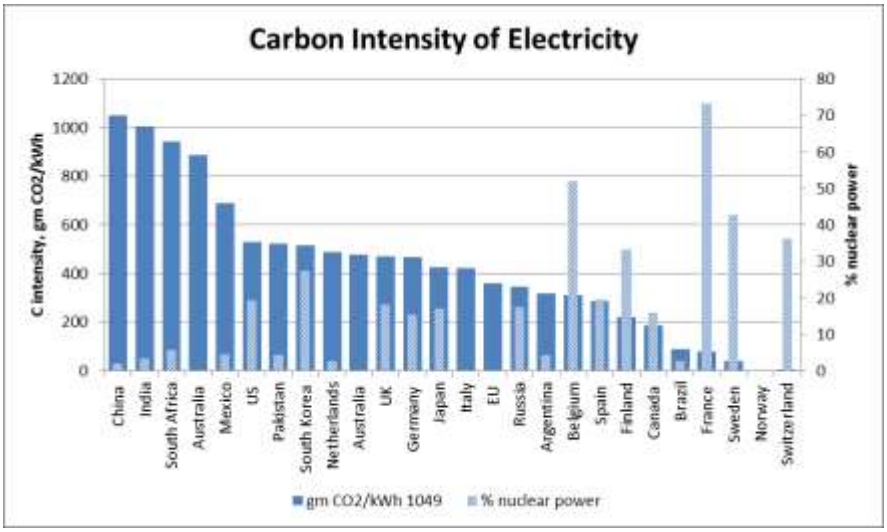

Figure 4 Carbon intensity of electricity and nuclear power use

2.1.1 Personal Electricity Use

Home electricity use is about 6920 kWh per person per year in Canada. According to surveys (Parekh & Wang, 2012), appliances on average consume 2700 kWh, home entertainment 1500 kWh and lighting 1100 kWh. The appliances that use the most electricity are: refrigerators, clothes dryers, ranges and freezers.

There are provincial policies and programs to reduce electricity use focussing on conservation behaviour, recycling old appliances, increasing awareness through labelling, and time of use rates. In Ontario, responsibility for electricity conservation policies is with the Ontario Power Authority (OPA). The Ontario Energy Board provides the Local Distribution Companies (LDCs) with targets for conservation as part of their license. Programs for residents include: the peakSaver program to reduce air conditioning load, programs for metering, and fridge and freezer pickups. Quebec has programs for electronic thermostats on baseboard heaters, geothermal, and recycling fridges. Policies in other provinces include refrigerator recycling programs, fridge buyback programs, net metering, clothes washer rebate assistance, electric baseboard heater programs, alternative energy, small renewable, energy efficiency, and wind prospecting.

There are also electricity efficiency improvements being made through codes and standards for appliances (Energy Star), banning incandescent lighting, revising building codes, and new technologies such as Light Emitting Diode (LED) bulbs. Provincial governments periodically revise Building Codes including the sections relevant to electricity use, and these revisions will improve energy efficiency of new construction. As part of the federal Clean Air Regulatory Agenda, Energy Efficiency Standards (Government of Canada nd b) encourage the use of energy efficient products by regulation, through the Energy Efficiency Act (1995). Stricter regulations should lead to inefficient products disappearing from the market. ENERGY STAR labelling complements these standards by highlighting the best performing equipment. A recent survey found that 84% of Canadian consumers who bought or who were planning to buy home electronics were influenced by ENERGY STAR qualified products.

Widespread labelling of energy use has proven effective in of the top 10 countries for energy efficiency (Zumbrun, 2008).

Home electricity use in Canada is trending upwards despite these policies, conservation programs and improvements in efficiency of major appliances, due to the proliferation of new electronic devices (Parekh & Wang, 2012).

The size of the carbon footprint in each province due to home electricity use depends on the carbon intensity of the electricity, which varies by province depending on the source of supply (Figure 6). Wind, solar, nuclear and hydro power are zero emission sources. Coal emits 0.7 lb C/kWh and natural gas is about 50% cleaner (0.4 lb C/kWh) (Natural Resources Canada nd a). Using the average carbon intensity for electricity, home electrical use is typically the second largest component of Canadians' carbon footprint, (Nakagami, 2008).

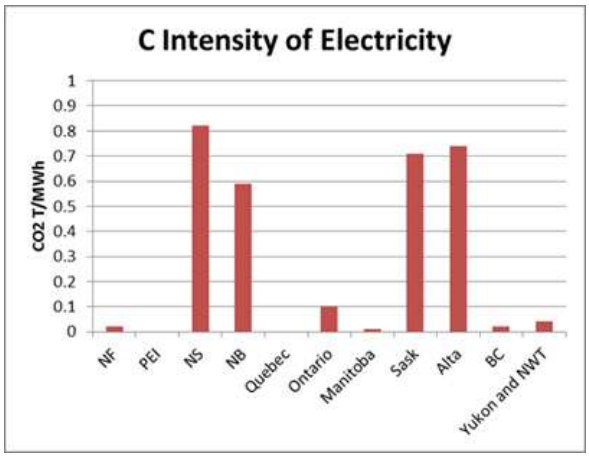

Figure 5 Carbon Intensity of electricity by province

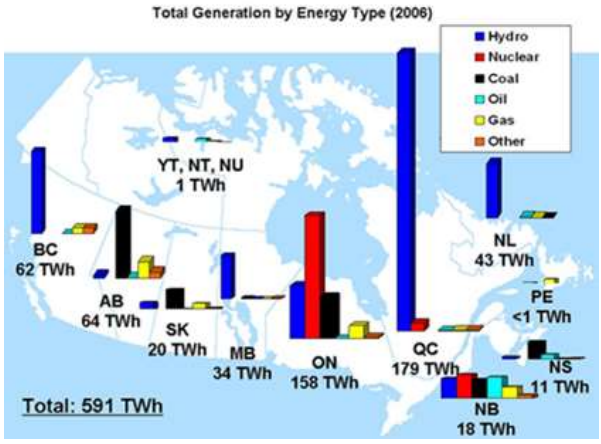

Figure 6 Fuel source across Canada for electricity generation

2.1.2 Personal Transportation

The largest component of Canadian's carbon footprint is usually personal transportation. There are about 14 million personal cars on the road in Canada, and the average car is driven 15,000 km/year, emitting about 4T CO_2 per year based on 100-200 gm/km.

Depending on the size of car and distance driven, the emissions range from 2T to 12T CO_2 per year. Carbon calculators for specific makes, models and years are available from the Canadian Automobile Association (CAA). Emissions from personal transportation are about 56MT or 45% of Canada's overall transportation emissions (Bromley, 2005). Fuel is almost entirely carbon based petroleum.

In Canada there are regulations to reduce carbon emissions from personal transportation. Revised emission standards require model years in 2017 and beyond to reduce vehicle emissions by 50% from 2008 levels by 2025 (Environment Canada, 2013), to match the American corporate average fuel economy (CAFE) standards. Regulations require gasoline to contain at least 5% renewable fuel. Canadian and American cars are currently among the least fuel efficient in the world: 9.4L/100km in the US compared to 5.2L/100km in the European Union (EU).

The success of behaviour changes to reduce driving by using carpools, car sharing, transit, or non-motorized transport is limited in Canada. This is due to climate, urban design that has created residential communities catering to automobiles at the expense of cycling or walking, and resistance to changing habitual behaviour. Carpools or car shares lack flexibility. Public transit is limited, especially in rural areas. There is a perceived lack of safety and risk of theft in bicycling. Subsidies to oil and gas companies keep gasoline prices low, and do not reflect the externalities of fossil fuel use.

If people cannot change their behaviour, technology changes are required so that habitual behaviour emits as little GHG as possible. Electric vehicles (EVs) may be the long term solution to reducing emissions from personal transportation. Programs to promote electric vehicle use include subsidies for purchasing these vehicles and installing charging stations. Currently the market penetration of hybrids and EVs is low due to issues with the emerging technology: EV price, range, battery life and battery replacement cost. Ontario's target is to have 1 in 20 electric vehicles by 2020 (Burpee, 2013). Infrastructure is needed to support EV adoption such as more and higher powered charging stations. For example, the time to charge a 20 kW battery at 120V, 16 amps, is over 10 hours; a 240 V charging station with 32 amps can charge this battery in 3 hours.

Emissions from electric vehicles vary by province depending on the carbon intensity of the electricity, Figures 5, 6. To achieve the most benefit from the widespread adoption of electric vehicles, a clean, reliable source of base load power is required. For example, driving a Toyota Prius for 5 years in Ontario would emit 1.8T of GHG, while in Alberta the emissions would be 9.7 T (compared to about 4T/y for an average gasoline fuelled car). Drivers in New Brunswick could reduce CO_2 emissions by 84% by switching to EVs.

Electricity requirements for electric vehicles are estimated at 2000-3000kWh per car for yearly travel of 12,000-20,000 km. It has been predicted that if all the vehicles in British Columbia were electric, the increase would be 19% to base load.

2.1.3 Home Heating

The third major portion of the personal carbon footprint is from home heating and hot water. Home energy use in Canada is amongst the highest in the world (Table 1), 106 GJ for the average household (Statistics Canada, 2007) compared to 23 GJ in the UK and 14 GJ in Sweden. The energy needed for heating is a function of dwelling type, age, size, house area/ person and degree days (Parekh & Wang, 2012). The high usage in Canada is due to our

cold climate; and relatively few people per home. For example household heating demand in Montreal (65 GJ) with an average winter temperature of -10C is higher than in Florida where the average is 20C (5 GJ) (Nakagami, Murakoshi, & Iwafune , 2008).

Policies and programs to reduce home heating energy use include: improvements to the Canadian Building Code, CMHC guidelines for home retrofits for increased energy efficiency (CMHC), ecoEnergy for renewable heat, ecoEnergy retrofit initiatives to improve insulation and reduce heat loss, and Energuide for homes (Government of Canada nd b). Existing buildings can be retrofitted to reduce energy use by one-half to two-thirds according to the Pew Centre for Global Climate change[i], but due to the Canadian climate and size of homes, Canadians will continue to require significant energy for home heating.

The carbon footprint from home energy use has a significant regional variation, being highest in Alberta and Saskatchewan and lowest in Ontario (UNFCCC United Nations Framework Convention on Climate Change, 2014), depending on the fuel source. Figure 7 shows the provincial variation in the fuel used for heating: electricity, or the direct combustion of fossil fuels such as oil, natural gas or wood. 79% of households in Quebec use electricity to generate heat. Ontario, Alberta and BC homes are heated primarily with natural gas. The Maritime Provinces use oil, wood, and light fuel oil. The CO_2 produced by combustion of the major conventional fuel sources is: coal 90.8 g/MJ, natural gas 49.9 g/MJ, fuel oil 74.4 g/MJ, propane 59.8 g/MJ, gasoline 68.6 g/MJ, biodiesel 8.3 g/MJ, biomass 4.6 g/MJ, and ethanol 4 g/MJ.

Overall, 38% of Canadian homes use electricity for heating (Statistics Canada, 2007). Emissions from electric heating depend on the source of fuel for electricity. CO_2 emitted per MWh is: natural gas (0.4 lb), oil (0.5 lb), propane (0.7 lb), coal/wood 0.75 lb (Natural Resources Canada nd a). Hydro and nuclear are almost carbon free. The carbon intensity of electricity by province is shown in Figure 5: Nova Scotia 0.82 T/MWh, Alberta 0.74T/MWh, Ontario, Quebec and PEI 0.1T/MWh (Environment Canada 2013). The low carbon intensity of electric heat in Quebec is due to extensive hydroelectric resources. An average home heated entirely with electricity would emit 24T CO_2 in Nova Scotia compared to 2.9T CO_2 in Ontario

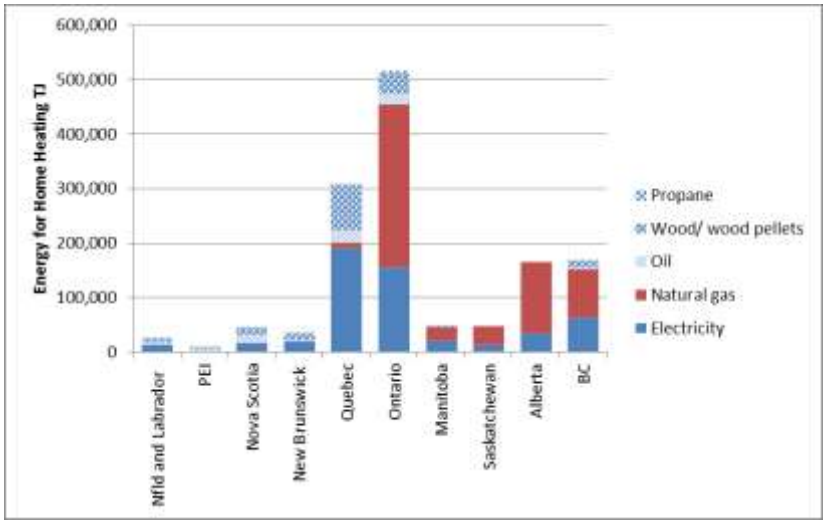

Figure 7 Source of Energy for Home Heating in Canadian provinces

Table 2 Households and Environment Energy Use (Stats Canada 2007 Catalog 11-526-S)

Units, TJ	Electricity		Natural gas		Oil		Wood/ pellets		Propane		All fuel
		%		%		%		%		%	
Canada	520,250	38	587,183	43	76,773	6	176,107	13	8,642	1	1,368,955
Nfld, Labrador	12,518	54	F	F	4,680	20	5,746	25	273	1	23,216
PEI	1,667	25	F	F	3,064	45	1,890	28	134	2	6,777
Nova Scotia	14,822	33	F	F	15,613	35	12,864	29	354	1	44,369
New Brunswick	18,240	53	F	F	4,343	13	10,729	31	291	1	34,273
Quebec	189,948	61	10,805	3	21,899	7	84,996	27	1,619	1	309,266
Ontario	154,995	30	298,893	58	21,722	4	35,411	7	4,146	1	515,166
Manitoba	20,215	42	23,671	49	F	F	3,370	7	F	F	48,093
Saskatchewan	11,699	24	33,956	70	F	F	F	F	F	F	48,482
Alberta	33,704	20	130,037	77	F	F	5,738E	3 E	F	F	169,800
BC	62,442	37	88,415	52	3,678	2	13,750	8	F	F	169,511

3. Changing Behaviour is Difficult

The Canadian public has not reduced their carbon footprint sufficiently to support international commitments. Changing behaviour is difficult, even amongst people directly affected by climate change. Changing habitual behaviour is very difficult (Verplanken, 2011). Technological innovations such as renewable energy and electric vehicles are only partially effective because people have yet to change their behaviours and adopt these new technologies in large numbers.

Barriers to changing behaviour to reduce our carbon footprint are due to effects discussed in the literature on behavioural science and energy policy. The **Endowment Effect** is where people are reluctant to forego something such as driving that they have done in the past. The **Rebound Effect** in conservation and energy economics is operating when a person increases consumption of a good, such as driving more or leaving lights on, because of the lower cost of use of fuel efficient cars and energy efficient lights. The **Status-quo Bias** is a preference for the current state of affairs, or continuing to live life as usual. And finally, if neighbours, friends and other countries are not taking action, they are **free riders** and so negate our actions.

Traditional drivers or techniques for changing behaviour are: 1) Knowledge, information or awareness, such as labelling, or on-line monitoring of energy use; 2) Positive motivation such as financial incentives or High Occupancy Vehicle (HOV) lanes, as opposed to negative motivational involving a sense of duty or guilt, or negative comparisons (Rabinovich, Morton, & Duke, 2011); and 3) Coercive, such as energy efficiency regulations, emissions standards, and building codes.

Surveys show (Transport Canada, 2009) that a majority of Canadians are aware of climate change, are concerned, have taken some action to reduce the GHG emissions for which they are personally responsible, but agree that there is more that they could do. This awareness has not translated into effective action, as indicated by increasing emissions from transportation and residential electricity use. The next level of change requires modifying habitual behaviour, such as reducing driving, or involves additional time, effort or cost, such as installing home insulation, requiring a higher level of engagement (Hoppner & Whitmarsh, 2011), (Wolf, 2011).

The change in behaviour to reduce our carbon footprint is also hampered by existing policies, technologies and infrastructure, and requires enabling infrastructure and technology to be successful. Environmental problems have been created by the state through infrastructure such as cities and suburbs designed for the car, and a dependence on fossil fuels (Davidson, 2011). People are locked into the structure of the life they have built that determines their patterns of behaviours, for example living in suburban neighbourhoods far from places of work or shopping.

4. Role of Nuclear Power

Where behaviour change is limited, technology and infrastructure improvements are needed in order to reduce our carbon footprint. As shown in Figure 8, Ontario and Quebec have carbon footprints of 10-13T, much lower than Alberta and Saskatchewan (63-69T). This is primarily because the electricity fuel mix (Figure 6) produces lower carbon intensity, Figure 5. (Note that Figure 6 is from 2006, and recent changes are that the coal fired plants in Ontario have been shutdown, as has the nuclear plant in Quebec). In provinces such as Alberta where electricity is generated mainly by coal, the CO2 emissions from the electricity sector are significantly higher than in provinces where electricity is generated by hydroelectric or nuclear such as Ontario.

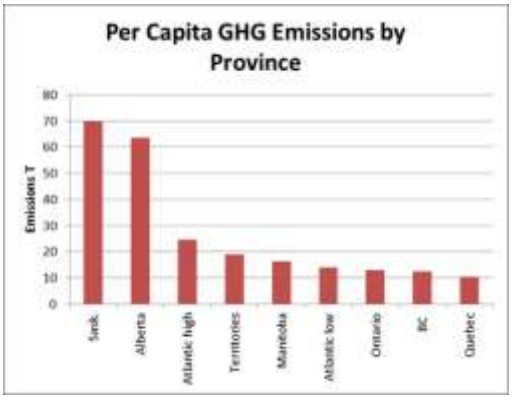

Figure 8 Personal Carbon Footprint by Province

Where behaviour change has stalled, energy policies that reduce the CO2 intensity of the electricity source are effective in reducing GHG emissions, as seen by CO2 emissions in France, Sweden and Germany (Talbot, 2012). France has 77% nuclear power and Sweden 53% (World Nuclear Association). These countries have low carbon footprints despite high electricity use, Figure 4.

Policies, such as a maximum carbon content of the electricity source, can be effective in reducing GHG emissions where behaviour change is stalled. Efforts to reduce the carbon intensity of electricity are being made. Canada has new regulations to reduce emissions from the coal fired electricity sector; effective July 2015 emissions are to be reduced by 214 MT over 21 years.

Renewables such as wind, biomass, low-impact hydro, geothermal, solar photovoltaic, and ocean energy are producing a larger share of Canada's electricity, but it will be many years before they significantly reduce the carbon intensity of the electricity. Renewables, excluding hydro and nuclear, provided 0.36% of Canada's total electricity generation in 2005, and are expected to increase to 4% by 2020. In Ontario, the Long Term Energy Plan has a target of

20,000 MW renewables by 2025. New Brunswick Power currently has an energy mix of 65% non GHG emitting fuel sources and a target of 75% by 2020.

Federally, the four-year ecoENERGY for Renewable Power (ecoRP) program was launched in April 2007 and ended on March 31, 2011 (Government of Canada nd b). ecoRP for small businesses provided incentives to increase Canada's supply of clean electricity from renewable sources. The program provided an incentive of 1 cent/kWh for up to ten years to qualifying projects. In 2007, at the time of program design, it was estimated that the program would encourage about 14.3 terawatt-hours of electricity annually, or about 4,000 megawatts (MW) of renewable power capacity.

There has been success in other countries such as Germany in reducing the cost of, and contribution by, renewables. However, Germany is balancing its renewables with coal after closing its nuclear plants and so has relatively high overall carbon intensity, Figure 4. Nuclear power is recognized as an important bridge to renewable energy, and the World Nuclear Association (WNA) reports that 45 countries including China, South Korea, Poland and India are planning an expansion of nuclear power.

8. Conclusion

In Canada, behaviour change alone cannot be expected to accomplish significant GHG emission reductions. There is significant change needed from the population, but the size of the country, temperature, infrastructure, and size of homes are barriers to personal GHG emission reductions. Emissions reductions in the electricity sector could be achieved by adding nuclear to the supply mix in provinces other than Ontario and New Brunswick and maintaining or increasing its share in provinces where it is currently used. This would support widespread use of electric vehicles, which requires a clean source of base load electricity for charging stations. A sustained or increased role for nuclear power would be an effective policy to meet our global commitment for CO_2 reduction during the transition to renewable sources of power, such as wind and solar.

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10. Biography

P. Watson is a professional engineer who, after a career in providing engineering services to the electricity generation industry in Ontario, is currently retired and volunteering in areas that promote sustainable energy policy, including the Canadian Nuclear Society.

[i] http://www.pewtrusts.org/our_work_detail.aspx?id=327744, 2005