Calculating Residential Carbon Dioxide Emissions -- A New Approach

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Abstract

All Annex 1 Parties are required to submit an annual national greenhouse gas inventory to the United Nations Framework Convention on Climate Change using the Common Report Format. The inventory is to include a sectoral report for energy, listing different sectors and their associated greenhouse gas emissions (principally carbon dioxide, methane, and nitrous oxide). The sectors and their associated emissions can be used as a benchmark to show changes in emissions over time. In certain cases, these changes can be misleading, since an apparent emission reduction in one sector can result in a significant increase in the emissions of another, typically electricity production. Applying the emissions to the sector responsible for the final energy demand (as opposed to the sector that generates the energy) allows researchers and policy makers to develop reduction strategies that are targeted to the demand.

This paper demonstrates this by removing the equivalent residential emissions from category A.1.a (Public Electricity and Heat Production) and applying them to category A.4.b (Residential) in Nova Scotia, a Canadian province that relies heavily on fossil fuels for electrical generation. The shift in emissions changes an apparent 4.1 percent decrease in Nova Scotia's residential emissions between 1991 and 2001 to an 8.2 percent increase.

Keywords: UNFCCC, Greenhouse gas inventories, Climate change, Nova Scotia

1 Introduction

Each year, every Annex 1 Party of the United Nations Framework Convention on Climate Change (UNFCCC) is required to submit a summary report for national greenhouse gas inventories [27]. These reports are required to follow a Common Reporting Format that consists of a series of tables relating to national sources and sinks of greenhouse gases (principally carbon dioxide, methane,

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and nitrous oxide [9]) expressed in terms of their carbon dioxide equivalent or CO_2e. For example, Table 1 is the sectoral report for energy, while Table 4 is the sectoral report for agriculture. Each table consists of a number of categories; the energy table includes categories such as A.1.a (Public Electricity and Heat Production) and A.4.b (Residential).

By examining the Common Reporting Format tables, it is possible to determine the changes in a specific sector over a period of years since 1990 (the Kyoto base year). In certain cases, these changes can be misleading, since an apparent emission reduction in one sector can result in a significant increase in the emissions of another. For example, if residential consumers shift their space heating demand from oil to electricity, the emissions shift from A.4.b (Residential) to A.1.a (Public Electricity and Heat Production).

As an Annex 1 Party, the federal government of Canada is responsible for creating a report on its national greenhouse gas inventories. The federal government has taken this one step further by creating a series of greenhouse gas inventory reports expressed in terms of carbon dioxide equivalents (CO_2e) for each of Canada's ten provinces and three territories. Not surprisingly, the provincial emissions inventories vary widely; for example, British Columbia and Quebec have low per-capita emissions because of their reliance on hydro-electricity, whereas Alberta has the high per-capita emissions because of its fossil-fuel industries [5].

One province that is of particular interest to this report is Nova Scotia, with a small, stable population (less than one million inhabitants), declining industrial, manufacturing, and agricultural sectors, and a heavy reliance on fossil fuels for the generation of electricity.

Nova Scotia's greenhouse gas emissions for 1990 (Canada's Kyoto base year), and 2001 (the most recent inventory year) are shown in Table 1. The total provincial emissions grew by about 7.7 percent during this period, from 19,400 to 20,900 kilotonnes (kt). Despite the decline in its industrial sector and limited population growth, Nova Scotia's per capita emissions increased by 5.1 percent from 21.3 to 22.2 tonnes.

From Table 1, one can see that almost 80 percent of Nova Scotia's annual greenhouse gas emissions are attributable to four sectors:

Electrical generation. Greenhouse gas emissions from electrical generation are due primarily to carbon dioxide from the combustion of coal, refined petroleum product (notably heavy oil, light oil, and diesel), and natural gas. In Nova Scotia, Nova Scotia Power Incorporated (NSPI) is responsible for about 97 percent of the province's electrical generation. In 2001, NSPI's generating mix was coal (1267 MW), oil and natural gas (546 MW), and hydroelectric (371 MW). That year, NSPI supplied 11,646 GWh from the following sources: coal (8,855 GWh), natural gas (1,129 GWh), oil (691 GWh), hydroelectric (692 GWh), and interprovincial purchases (279 GWh) [2]. Between 1990 and 2001, emissions from electrical generation increased by 27.5 percent.

Transportation. In the transportation sector, carbon dioxide is the principal greenhouse gas emission, produced almost exclusively from gasoline and diesel combustion. In Nova Scotia, as in much of North America, emissions from light-duty gasoline vehicles (i.e., automobiles) have dropped by about 14 percent since 1990, while emissions from light-duty gasoline trucks (notably Sports Utility Vehicles) have increased by almost 50 percent [6]. The trend towards shipping goods by heavy-duty diesel truck is also evident in Nova Scotia, with emissions increasing by almost 35 percent since 1990 [6].

Residential. Residential greenhouse gas emissions in Nova Scotia are caused by fossil fuel usage for space and water heating. Space and water heating emissions are caused by the combustion of coal and oil; there is no district heating in Nova Scotia nor has there been widespread penetration of natural gas [18]. Nova Scotia's residential emissions recorded a decline of over 15 percent between 1990 and 2001.

Fugitive sources. Fugitive emission sources are from coal mining (methane) and oil and gas production (carbon dioxide and methane). Of the top four emission sectors in 1990, fugitive sources have shown the greatest decrease because of the widespread closure of coal mines in the north of the province due to the removal of government subsidies [7]. However, with the extraction of offshore natural gas, Nova Scotia's fugitive emissions have started to increase again [6].

The understandable temptation is to blame electrical generation for the increase in provincial emissions [10]; however, doing so overlooks the fact that apparent decreases in emissions in one category can be at the expense of increases in another. For example, the decline in residential emissions is often attributed to fuel substitution that reduces the need for petroleum products and improvements in end-use efficiency [20]. While this may be true, it can mask the actual emissions associated with a sector, giving a false sense of improvement. This can be an issue in a jurisdiction such as Nova Scotia that has a significant reliance on fossil fuels for electricity.

The remainder of this paper examines the residential energy sector in Nova Scotia and shows how its apparent decline in greenhouse gas emissions actually masks a significant increase in emissions. To illustrate this point, 1991 and 2001 Canadian government data for Nova Scotia is examined since detailed residential data and greenhouse gas emissions data exists for each of these years.

This research suggests that by considering all emission sources within a sector, policy makers can create more meaningful emissions reduction strategies. Furthermore, by including all emissions within a sector (such as residential), users can understand the true impact of their energy usage.

2 Nova Scotia's demographics

Nova Scotia's population has grown slowly compared to most other regions of Canada, increasing about 3 percent between the 1991 and 2001 census (see Table 2). This Table also highlights the fact that the province has an ageing population, with declines in all age categories between 0 and 44 and increases in those sectors above the age of 45.

The ageing population has had a significant impact on the residential housing market. Table 2 also shows that the number of households is growing at a faster rate (10.4 percent) than the overall population (3 percent), while at the same time, the number of people per household has decreased. These changes can be attributed to a variety of factors, including a decline in the number of families with children, a decline in the birthrate, and a decline in family size [14].

3 Residential energy demand

According to Statistics Canada, residential energy demand in Nova Scotia is met from four energy sources: coal, propane (or natural gas liquids), electricity, and refined petroleum products. Coal, propane, and refined petroleum products are used almost exclusively for space and water heating, whereas electricity is used for most appliances and lighting [19].

It should be noted that two energy sources, wood and natural gas, are not included in the list of energy sources used to meet Nova Scotia's demand:

Wood. The data for residential wood heating usage is unreliable. The reason for this is quite simple: all fuel sales in Canada are subject to both provincial and federal taxes, meaning that tracking a fuel's consumption is a relatively easy matter. However, many people obtain wood for space heating or domestic hot water from their own wood lot or from individuals and do not pay tax, meaning that wood fuel demand data is, at best, an estimate [8].

Natural gas. Nova Scotia has an estimated five TCF (trillion cubic feet) of marketable natural gas in the offshore Atlantic. Since early 2000, about 500 MMCF (million cubic feet) is being extracted daily, primarily for sale in the northeastern U.S. market. With the exception of dual-fuel boilers at one of the NSPI generating stations, limited amounts of natural gas are being made available to the Nova Scotian market.

Table 3 shows the changes in energy sources between 1991 and 2001. Propane has seen a considerable drop in popularity because of its cost relative to other fuels (for example, see [12]). Coal's decline can be attributed to a decline in its availability due to the closure of most of the province's coal mines. Of the two remaining fuels, refined petroleum products have shown little change over this period, while electricity usage has increased dramatically by almost 20 percent. The increase in energy use over this period has kept pace with the growth in population.

Since the number of households has grown at a faster rate than the population, there has been a decrease in residential energy demand per household and, to a lesser extent, per person, by 6.7 and 0.5 percent, respectively (see Table 3).

Other factors that can account for the decline in per household residential energy use include:

- Temperature variations over this period. Table 4 shows the number of heating and cooling degree days for Nova Scotia between 1991 and 2001. The data suggests that for 2001, Nova Scotia was slightly warmer than in 1991, meaning that there would be less demand for heating, thereby reducing energy demand.
- An increasing number of elderly people. Although ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) comfort charts for heating and cooling comfort levels suggest that elderly people require higher heating levels [1] (resulting in higher energy demands), many elderly are on fixed incomes, meaning that some are unable to afford higher fuel costs. For example, during the winter of 2002-2003, the Nova Scotia government offered $50 cheques to those on low and fixed-incomes who were unable to pay for home heating fuel that had increased in price due to instability in Venezuela and the run up to the Gulf War.
- There is a gradual increase in newer housing stock in Nova Scotia, with almost thirty percent built since 1981 [14]. Most new house construction follows more stringent insulation guidelines that should result in lower space heating demand [19]; however, offsetting this is the 14 percent increase in house size since 1981 [19].

The increase in electrical demand is due to two factors [19]. First, an increasing demand for large appliances such as dishwashers, clothes washers, and clothes dryers. Second, a rapid growth in the demand for small appliances such as videocassette recorders, videodisc players, and home computers.

4 Residential emissions

Each year, the Canadian government creates an inventory of the greenhouse gas emissions for each Canadian province and territory. These inventories are in the Common Reporting Format used in national inventories submitted to the UNFCCC.

Table 5 shows the total residential emissions from carbon dioxide, methane, and nitrous oxide for Nova Scotia. The dominant emissions source is carbon dioxide from the combustion of oil, propane, and refined petroleum products. The total residential emissions are based upon these fuels; emissions associated with electricity are not included in the inventory. The result is a 4.1 percent decrease in emissions in the residential sector.

When considering the emissions per person and per household, significant emissions reductions are also achieved as shown in Table 5, with per person and per household reductions of 7 percent and 13.6 percent, respectively.

5 Residential emissions from electrical generation

All emissions associated with the electricity used by a sector (such as residential) are 'hidden' in that they are assigned to the utility generating the electricity. This is deceiving in that a sector can be made to appear to be making reductions in emissions when in fact they are increasing.

To illustrate this point, it is necessary to determine the utility's energy intensity in terms of its greenhouse gas emissions per unit of electricity generated. Ideally, utility data regarding generation merit order and the sectoral demand would be publicly available, allowing an accurate allocation of fuel types (and hence associated emissions) with demand. However, as this information is not available from NSPI, it is necessary to determine the energy intensity from the CO_2e from the electricity generated and the overall annual energy generated.

Table 6 shows the CO_2e associated with NSPI's electrical generation during the two census years. The slight improvement in the energy intensity, from 207.5 to 204.6 tonnes per terajoule (TJ) despite the 26 percent increase in electrical production, is explained by NSPI's decision to substitute natural gas for oil in one of its larger generating stations [2].

By applying the energy intensity (tonnes CO_2e per TJ) to residential demand, the residential emissions associated with electrical generation can be determined. In Table 7, the 19.5 percent growth in electrical demand results in a 17.8 percent growth in CO_2e emissions.

6 Total residential emissions

By combining the residential emissions inventory data with the electrical emissions associated with the residential sector, the total residential emissions can be obtained. The total residential emissions for Nova Scotia are shown in Table 8.

Not surprisingly, the total residential emissions are considerably higher when compared to the residential inventory data if emissions from electrical generation are included. This results in a 12 percent increase in residential emissions (from -4.1 percent to +8.2 percent).

Similarly, there are corresponding increases in the emissions per person and per household when residential electrical emissions are included in the total residential emissions. In Table 8, per person and per household emissions are determined to be a 6.2 percent increase and a 2.5 percent decrease, respectively. These are both more than 10 percent greater when compared to inventory emissions that excludes emissions associated with electricity shown in Table 5.

7 Policy Implications

The UNFCCC's Common Reporting Format requires electrical utilities to assume responsibility for all greenhouse gas emissions from thermal (i.e., fossil fuel) generation. This overlooks the fact that electricity is not generated in isolation, it is generated to meet a demand. This methodology can, and often does, lead to calls for utilities to "clean up their acts", while ignoring those sectors that consume the electricity. In order to make an impact on greenhouse gas emissions, it is necessary to target both utilities and consumers.

Policies that encourage reductions of greenhouse gas emissions from the electricity sector are well know and include:

- Changing to less carbon-intensive fuels for electrical generation; for example, switching from coal to natural gas. This has the advantage of being transparent to the customer, since the customer is not required to make any 'lifestyle' changes. However, the onus is on the utility rather than the customer to make the reductions.
- Improving overall utility efficiency, by increasing generation load factors and decreasing transmission and distribution losses.
- Changing customer consumption patterns to reduce the demand for electricity (that is, placing some of the responsibility for emissions reduction on the customer). This can be done in a number of ways, including pricing (e.g., seasonal pricing or adopting increasing rate structures), subsidies for energy efficient products, and education.

However, policies that target the generator and the consumers of electricity (such as those described above) can be met with resistance from both groups, for a number of reasons:

- Utilities can claim that they have no control over the consumption patterns of their customers;

- Utilities reliant on thermal generation can claim that they and their shareholders are at a disadvantage when compared to utilities with limited thermal generation facilities;
- Customers of utilities reliant on thermal generation could be required to make more changes to consumption patterns than customers of utilities with limited thermal generation facilities.

7.1 Nova Scotia

In Nova Scotia, the approach adopted by NSPI (and encouraged by the provincial government) has been fuel substitution. All three units of an existing 350 MW thermal station have been converted to burn either Bunker C or natural gas, depending upon the price of each [16]. A General Electric LM6000 (natural gas combustion turbine) is presently on-line and public hearings are underway regarding the installation of a second LM6000. Almost all new and replacement generation is scheduled to use natural gas [15].

The driving force behind NSPI's move to natural gas has been pressure from the provincial government to meet the province's SO_2 reduction targets [3].

The provincial government is presently developing legislation for a Renewable Portfolio Standard (RPS) to be imposed upon NSPI. The proposed target is five percent of 2001 generation (about 500 GWh [11]) to be achieved by 2010. The target is voluntary and has no penalties for non-compliance.

NSPI's move to natural gas, the proposed RPS, and projected increases in demand are expected to slow the growth of, as opposed to reduce, emissions from the electrical sector [17].

Neither NSPI nor the provincial government has shown interest in demand side management programmes. Any programmes that successfully reduce consumption patterns could reduce the utility's profits and shareholder value. From the provincial government's standpoint, a reduction in electrical demand could see a fall in tax revenues, and any activity seen to suggest an increase in electricity prices would be unpopular amongst many businesses and the public.

8 Concluding Remarks

The UNFCCC summary reports for national greenhouse gas inventories separates emissions into a series of categories based upon a variety of sectors, such as category A.1.a (Public Electricity and Heat Production) and category A.4.b (Residential). This categorization approach can give a false sense of improvement within individual sectors, especially with regards to electrical generation where there is a growing demand for electricity and the substitution of electricity for other fuels is encouraged. The reason for this is that the UNFCCC requires that all emissions associated with electrical generation be applied to electrical utilities rather than to the sector where the demand actually occurs.

Associating emissions from electrical generation with the generator rather than the user often causes people to blame utilities for the increase in emissions, rather than examining the downstream activities of a specific sector.

This issue was illustrated through an examination of the emissions inventory for the Nova Scotia residential sector compiled by the Canadian government. The inventory's 4.1 percent decrease in emissions between 1991 and 2001 was due solely to decreases in the use of fossil fuels. The emissions associated with the nearly 20 percent rise in the use of electricity by the residential sector was not included in the residential emissions inventory. Consequently, the utility, which relies heavily on thermal generation, has been blamed for increasing provincial emissions.

A clearer picture of the residential sector's emissions was achieved by including the emissions associated with the electrical usage, obtained from the utility's energy intensity (expressed in terms of CO_2e per TJ). Using this approach, the total emissions for the residential sector showed a rise of over 8 percent. Similarly, an apparent decrease in household emissions of almost 14 percent was closer to a decline of only 2.5 percent.

Attributing emissions to the demand is both useful and meaningful, since it allows policymakers to tailor policy towards specific activities within a sector rather than focussing exclusively on the generation of electricity. Developing programmes that reduce demand will, in turn, reduce emissions. Having said this, it is also necessary to have widespread acceptance of the need to address the issue of anthropogenic climate change. Intransigence on the part of utilities, public opposition to change, or the lack of political leadership can all result in maintaining the status quo.

The methodology described in this paper can be applied to any jurisdiction that maintains statistics on residential energy use, electrical generation, and the number of households. Furthermore, it can also be applied to other UNFCCC sectors where electricity is used as a substitute for other fuels, such as manufacturing, commercial, institutional, and agricultural.

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Table 1: Greenhouse gas emissions for Nova Scotia for 1990 and 2001

Category	1990 (kt)	2001 (kt)	% change 1990-2001
Electrical generation	6,830	8,710	+27.5
Transportation Combustion Sources	5,200	5,660	+8.8
Residential	2,210	1,870	-15.4
Fugitive sources	1,170	473	-59.6
Commercial and Institutional	810	1,070	+32.1
Fossil Fuel Industries	714	819	+14.7
Manufacturing Industries	712	516	-27.5
Agriculture (soils and livestock)	609	591	-3.0
Waste	593	718	+21.1
Industrial	300	263	-12.3
Agriculture (Energy)	107	135	+26.2
Total emissions (Nova Scotia)	19,400	20,900	+7.7

Table 2: Demographic changes between 1991 and 2001 [21]

	1991	2001	% change 1991 - 2001
All ages	915,068	942,884	+3.0
0 to 24	323,886	294,298	-9.1
25 to 44	304,099	286,361	-5.8
45 to 64	172,811	235,167	+36.1
65 and above	114,272	127,058	+11.2
Number of Households [13, 14]	324,377	360,020	+10.9
Average number of persons per household [13, 14]	2.7	2.5	-7.4

Table 3: Residential energy supply data

	1991	2001	% change 1991-2001
Coal (TJ) [22]	976	798	-18.2
Propane (NGL) (TJ) [23]	1,029	531	-48.4
Electricity (TJ) [24]	11,968	14,296	+19.5
Refined Petroleum Products (TJ) [26]	22,277	22,384	+0.5
Total residential demand (TJ) [25]	36,251	37,509	+3.5
Demand / Person (GJ)	39.6	39.4	-0.5
Demand / Household (GJ)	111.7	104.2	-6.7

Table 4: Heating and cooling degree days [3]

	1991	2001
Heating Degree Days	4223.6	4073.5
Cooling Degree Days	142.8	156.8

Table 5: Residential CO_2e emissions [6]

	1991	2001	% change 1991-2001
CO_2 from energy sources	1,760	1,680	-4.5
CH_4 emissions	7.7	7.6	+12.9
CO_2e for CH_4 (GWP 21)	160	160	0
N_2O emissions	0.1	0.1	0
CO_2e for N_2O (GWP 310)	28	27	+3.5
Total CO_2e emissions	1,950	1,870	-4.1
Emissions / person (tonnes)	2.13	1.98	-7.0
Emissions / household (tonnes)	6.01	5.19	-13.6

Table 6: NSPI's energy intensity in terms of greenhouse gas emissions

	1991	2001	% change 1991-2001
CO_2e from electricity generated (kt) [6]	7,010	8,710	+24.3
TJ electricity produced [24]	33,786	42,575	+26.0
Tonnes per TJ	207.5	204.6	-1.4

Table 7: Emissions associated with residential electrical demand

	1991	2001	% change 1991-2001
Tonnes CO_2e per TJ	207.5	204.6	-1.4
Electrical demand (TJ)	11,968	14,296	+19.5
CO_2e from electrical generation (kt)	2,483	2,925	+17.8

Table 8: Total residential emissions

	1991	2001	% change 1991-2001
CO_2e emissions inventory data (kt)	1,950	1,870	-4.1
CO_2e from electrical generation (kt)	2,483	2,925	+17.8
Total residential CO_2e emissions (kt)	4,433	4,795	+8.2
Emissions / person (tonnes)	4.84	5.1	+6.2
Emissions / household (tonnes)	13.66	13.32	-2.5