A NEW METHODOLOGY TO PREDICT THE GHG EMISSION REDUCTIONS DUE TO ELECTRICITY SAVINGS IN THE RESIDENTIAL SECTOR

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ABSTRACT

The objective of this research is to develop a realistic and viable methodology to predict the amount of greenhouse gas (GHG) emission reductions associated with the reduction in electricity consumption in the residential sector due to implementing solar and other renewable energy technologies, as well as energy efficiency measures. Since electricity savings will be within the marginal generation, a marginal GHG intensity factor (g/kWh), which is the amount of GHG emissions produced as result of producing one kWh of electricity on the margin, will be estimated for each province based on published information on the fuels used for marginal generation.

INTRODUCTION

Energy consumption and the associated greenhouse gas emissions, and their potential effects on the environment have been extensively studied in the last two decades. National and international efforts are underway to mitigate or reduce GHG emissions. However, the total anthropogenic[1] GHG emissions are projected to increase due to a variety of reasons, one of the most important of which is the increasing demand for electricity generation. Since a substantial proportion of electricity is generated by combusting fossil fuels, electricity generation is a substantial source of greenhouse gas emissions.

In Canada, the residential sector presents an important component of the energy consumption as it accounts for approximately 17% of the national energy consumption and about 16% of the GHG emissions [OEE, 2006]. Consequently, adressing the electricity consumption in this sector persents a powerful method to reduce GHG emissions.

Each province in Canada has its own electric utility system, and each system is responsible for meeting the demand of its customer base. Since electricity demand in all provinces is highly variable throughout the day as well as during the year, a mix of base load and peaking load power plants are used in order to achieve a good match between electricity demand and generation. Due to the operational characteristics and requirements of base load and peaking load power plants, a variety of fuel sources are used to meet the demand for electricity.

When a solar or other renewable energy technology or an energy efficiency measure is implemented on a wide scale in the residential sector that results in electricity savings, the electricity savings are reflected in the peak (marginal) electricity generation. Thus, the GHG emission reduction due to a reduction in electricity demend (and consequently, marginal electricity generation) corresponds to the reduction in GHG emissions from fuel used to generate the electricity at the margin.

The magnitude of and the fuel used for marginal electricity generation vary from province to province and from hour to hour. To estimate the reduction in GHG emissions, it is necessary to have information on both the magnitude of the marginal electricity generation, and the fuel used to generate the marginal electricity in each province.

OBJECTIVE

The objective of this research is to develop a realistic and viable methodology to predict the amount of GHG emission reductions associated with the reduction in electricity consumption in the residential sector due to implementing solar technologies and/or energy efficiency measures. Thus, this work entails the following:

(i) Determination of the magnitude of the marginal electricity generation in each province as a function of time,
(ii) Determination of the fuels used for marginal electricity generation in each province as a function of time,
(iii) Development of a methodology to predict the GHG emissions due to marginal electricity generation based on (i) and (ii),

[1] Anthropogenic: refers to greenhouse gas emissions that are preduced as result of human activities or as a result of natural processes that have been affected by human activities.

(iv) Comparison of the GHG emission reductions predicted by the methodology developed in (iii) with the estimates obtained from previous studies that utilize average GHG intensity factors and GHG intensity factors for only fossil fuel fired power plants.

(v) Demonstration of the capabilities of the methodology developed by applying it to a number of scenarios that involve solar and other renewable energy technology applications and/or energy efficiency measures in the Canadian residential sector.

PREVIOUS METHODS USED TO PREDICT GHG EMISSION REDUCTIONS FROM ELECTRICITY GENERATION

The primary greenhouse gases emitted during the combustion of fossil fuels are carbon dioxide (CO_2), water (H_2O), methane (CH_4), and nitrous oxide (N_2O). Of these only water is not considered an anthropogenic GHG as its atmospheric levels are controlled by temperature resulting in precipitation. GHGs are characterized by a global warming potential (GWP). The GWP is referenced to the strength of CO_2 (i.e. equivalent CO_2, or CO_2e) as it is the dominant gas emitted during combustion. Considering the GWP of CO_2 to be unity, CH_4 and N_2O have 100 year GWPs of 25 and 298 by mass, respectively (Forster et al. 2007). Thus, CO_2e can be determined as follows:

$$CO_2e = CO_2 + 25\ CH_4 + 298\ N_2O$$

In the rest of this paper, all GHG emissions and emission intensity factors are expressed in terms of CO_2e emissions.

The GHG emission intensity factor, i.e. the total CO_2e GHG emissions generated per unit of electricity generation (g/kWh) is a function of the properties of the fuel used to generate electricity and to a lesser extent, on the combustion technology [Environment Canada, 2007]. The GHG emissions as a result of combusting fuels used in the electric utility sector are given in Table 1 [Environment Canada, 2007]. Using these factors, the GHG emission intensity factor for electricity generation can be determined based on the amount of fuel combusted and the amount of electricity generated.

Table 1
GHG emissions due to the conversion of fuels to generate electricity

Fuel Used	CO_2 (g)	CH_4 (g)	N_2O (g)
Natural gas (m3)	1891	0.49	0.049
Heavy Fuel Oil (L)	3080	0.034	0.064
Bituminous Coal (kg)	1852-2254	0.022	0.032

Two methods have been used to predict the GHG emission reductions associated with reductions in electricity consumption due to energy efficiency and renewable energy measures [Guler et al., 2001, Guler, 2000]. These are summarized as follows.

1. Average GHG Intensity Factor ($GHGIF_A$)

The Average GHG Intensty Factor "$GHGIF_A$" can be defined as the amount of GHG emissions produced as a result of generating one kWh of electricity:

$$GHGIF_A = \frac{TGHG}{TEG} \tag{1}$$

where,

TGHG = Total GHG emissions from electricity generation in one year (Tons/year)

TEG = Total electricity generation in one year (kWh/year)

$GHGIF_A$ can be calculated for the whole country, or for each individual province. Since each province uses a substantially different fuel mix for electricity generation, the $GHGIF_A$ is substantially different from one provnce to another.

Generally, base electrical load is satisfied by large scale power plants that are difficult to modulate, and produce the least expensive electricity, using energy sources including nuclear and hydro which produce no GHG emissions. Therefore, depending on the fuel mix used, this method may result in highly conservative estimates of GHG emission reduction because it assumes that electricity savings is distributed among all types of power plants.

2. GHG Intensity Factor for Fossil Fuels ($GHGIF_M$)

The GHG Intensity Factor for fossil fuel "$GHGIF_M$" can be defined as the amount of GHG emission produced as a result of generating one kWh of electricity from only fossil fuel power plants:

$$GHGIF_M = \frac{FFGHG}{FFEG} \tag{2}$$

where,

FFGHG = GHG emissions from electricity generation from only fossil fuel fired power plants in one year (Tons/year)

FFEG = Electricity generation from only fossil fuel fired power plants in one year (kWh/year)

Since in some provinces, and during parts of the year, marginal electricity generation can be from hydro resources, this method may result in liberal estimates of GHG emission reductions because it assumes electricity savings come only from the fossil fuel power plants.

As result, the GHG emission reductions predicted using $GHGIF_A$ represent the lower limit of the GHG emissions reduction, whereas the emission reductions predicted using the $GHGIF_M$ represent the upper limit of GHG emission reductions. Therefore, the actual GHG reduction will be somewhere between these two limits.

To demonstrate the magnitude of the differences between the two methods, the $GHGIF_A$ and $GHGIF_M$ values for each province for 2004 and 2005 are presented in Table 2. These values were calculated using the latest available Statistics Canada data on electricity generation and fuels used [Statistics Canada, 2006, 2007].

Table 2
$GHGIF_A$ and $GHGIF_M$ values (g/kWh) for each province for 2004 and 2005

	2004		**2005**	
Province	**$GHGIF_A$**	**$GHGIF_M$**	**$GHGIF_A$**	**$GHGIF_M$**
BC	23	498	21	478
AB	932	1066	887	1025
SK	846	1106	766	1119
MB	14	1155	14	1232
ON	195	897	215	861
PQ	10	852	4	867
NB	463	815	452	851
NS	678	830	669	842
PEI	303	1670	168	2429
NFL	34	725	27	736

As seen in Table 2, the values of $GHGIF_A$ and $GHGIF_M$ are highly variable from one province to another. The lowest value of $GHGIF_A$ is for Quebec where electricity generation is primarily from hydro power plants, while other provinces such as Alberta and Saskatchewan have higher values of $GHGIF_A$ due to their dependency on fossil fuel power plants.

PROPOSED METHODOLOGY

The magnitude of and the fuel used for marginal electricity generation vary from province to province and from hour to hour. To estimate the reduction in GHG emissions, it is necessary to have information on both the magnitude of the marginal electricity generation, and the fuel used to generate the marginal electricity for each province as a function of time. However, this information is regarded confidential by most utilities and is not made public.

Electric utilities determine the source of marginal electricity to dispatch as the demand for electricity changes using complex and dynamic dispatch rules that take into consideration operational and economic conditions. Since these conditions change on a continuous basis, it is practically impossible to predict with precision the magnitude of the marginal generation and the fuel used on a time scale of hours, or even days. Therefore, three methods are proposed here to estimate the GHG emissions from marginal electricity generation in each province on an annual or on a monthly basis.

Method 1. Annual Marginal GHG Intensity Factors

Through the information that was made publicly available or has been obtained through personal communication on electricity generation and fuels used, the mix of fuel sources used to generate the marginal capacity for each province has been identified as shown in Table 3.

Table 3
Fuels used for marginal electricity generation

Province	**Fuels Used for Marginal Electricity Generation**
BC	Natural gas, imports
AB	Natural gas, hydro, coal, imports
SK	Natural gas, hydro
MB	Natural gas, imports
ON	Coal, hydro, natural gas, imports
PQ	Hydro, natural gas, oil
NB	Coal, oil
NS	Oil, Natural gas, hydro
PEI	To be determined
NFLD	To be determined

The range of GHG emission intensity factors from marginal electricity generation based on the fuels identified in Table 3 are given in Table 4. In calculating the range of GHG intensity factors, imported electricity is assumed to have no GHG emissions attributable to Canada. Similarly, electricity obtained from hydro resources is assumed to be free from GHG emissions.

For British Columbia, Alberta and Manitoba the lower limit of the marginal GHG intensity factor (0 g/kWh) reflect the emission factor for imported electricity, whereas the lower limit (0 g/kWh) for Saskatchewan, Ontario, Quebec and Nova Scotia reflect the emission factor for hydroelectric generation.

In the absence of detailed data on the amounts of marginal electricity generated from each fuel, it can be assumed that the fuel mix used for marginal electricity generation has the same ratio as the mix of these fuels in the annual generation, i.e.

$$\frac{MEGMF_i}{\sum_{i=1}^{n} MEGMF_i} = \frac{TEGMF_i}{\sum_{i}^{n} TEGMF_i} \qquad (3)$$

where,

$MEGMF_i$ = Marginal electricity generation using marginal fuel i (MWh)

$TEGMF_i$ = Total electricity generation using marginal fuel i (MWh)

n = number of fuels used for marginal electricity generation

The GHG intensity factors calculated based on this assumption are given in Table 4. The values of $TGEMF_i$ were obtained from the latest available Statistics Canada data on electricity generation and fuels used [Statistics Canada, 2006, 2007].

Table 4
Range of GHG intensity factors and annual marginal GHG Intensity Factor

Province	Year	Range GHG Intensity Factor (g/kWh)	Annual Marginal GHG Intensity Factor (Method 1) (g/kWh)
BC	2004	0 ~ 455	112
	2005	0 ~ 436	122
AB	2004	0 ~ 590	570
	2005	0 ~ 546	525
SK	2004	0 ~ 563	289
	2005	0 ~ 562	274
MB	2004	0 ~ 711	23
	2005	0 ~ 796	33
ON	2004	0 ~ 943	393
	2005	0 ~ 927	431
PQ	2004	0 ~ 796	10
	2005	0 ~ 843	4
NB	2004	795 ~ 870	820
	2005	809 ~ 887	835
NS	2004	0 ~ 763	501
	2005	0 ~ 763	459

Method 2. Monthly GHG Intensity Factors based on ICF Estimates

In a study conducted for the Pilot Emission Removals, Reductions and Learnings (PERRL) Initiative of Environment Canada, ICF Consulting developed monthly estimates of the magnitude of marginal electricity generation (MWh) and the fuel mix used for marginal electricity generation for the period of 2004-2007 for each province [ICF, 2003].

The estimates developed by ICF will be analysed and "representative" estimates of fuel mix used for marginal generation in each province for each month will be developed. Using these representative estimates, monthly GHG intensity factors will be developed.

Method 3. Monthly GHG Intensity Factors Estimated Based on Reported Data

The electric utility sectors in Ontario and Alberta are deregulated. Consequently, compared to the data available from the utilities in other provinces, substantially more data on generation and fuels used are publicly available from the Ontario Independent Electricity System Operator (IESO) and Alberta Electric System Operator (AESO). Ontario IESO reports hourly generation data, including the fuels used, on its website, while AESO has on its website several reports identifying the fuels used on the margin.

Other provinces provide varying levels of less detailed data.

To develop monthly GHG intensity factors for each province, all data available from the provincial electric utilities will be collected and analysed, and a suitable methodology will be developed for each province to calculate the monthly GHG intensity factors for each province based on the data available.

For example, the generation data for the period of April 1-8, 2008 obtained from Ontario's IESO are plotted in Figure 1. As seen in this figure, nuclear power plants operate close to their full capacities continuously (i.e. are operated as base load plants), while the generation output of hydro, coal and others (oil and gas) fluctuate with time, indicating that these power plants are used to supply the marginal load for the province.

A technique was developed to identify the energy sources that are on the margin in Ontario by performing an analysis of the contribution of each energy source that responds to a change in the total output. The following conditions were used when analyzing the marginal energy sources:

- The minimum change in the total electricity generation in Ontario during one hour was set to 250MW for consideration of marginal sources,
- A marginal energy source must contribute at least 20% of the change in total generation to be considered of significance,
- During the periods when total generation remain constant, the previously determined marginal energy sources are considered to remain on the margin,
- If the generation from a fuel source changes in the opposite direction to the change in the total generation (i.e. not following load), that fuel source is not considered to be on the margin.

The hourly marginal energy sources were averaged over individual days to identify the significant components. These daily average marginal generation energy source components are shown in Figure 2. Both coal and hydro play a significant role in providing electricity on the margin. Natural gas (Other) is not on the margin on April 6, in agreement with the constant natural gas output shown in Figure 1. As expected, at no point during the period is nuclear or wind on the margin.

Using a daily average of the energy source components of the entire Ontario generation, the marginal components shown in Figure 2, and the GHG factors for fossil fuel electricity generation from Table 1, the average and marginal daily GHG intensity factors for the April 1-7, 2008 period were calculated for Ontario. These results are presented in Table 5.

Table 5
Average and marginal daily GHG intensity factors for Ontari0, April 1-7, 2008

Date	Average Daily GHG Intensity Factor (g/kWh)	Marginal Daily GHG Intensity Factor (g/kWh)
April 1	189	399
April 2	201	326
April 3	199	313
April 4	189	341
April 5	151	434
April 6	142	489
April 7	194	440

From these results, it is apparent that during the week in question, the average electricity energy source mix of Ontario, consisting of both the base and margin generation, produced significantly less GHGs per generated kWh than the marginal sources. This is primarily due to the heavy reliance on nuclear base generation, which produces minimal GHG emissions. The marginal GHG intensity factor fluctuates by 20% from the mean throughout the week. It is at its highest value of the period over the weekend due to coal being the dominant marginal energy source.

The data for the remainder of the year has yet to be analyzed. It is expected that significant seasonal affects will become apparent and additional trends or patterns may be identified which will help to develop marginal GHG intensity factor estimates that can be used to predict future reductions in GHG emissions resulting from electricity savings due to renewable energy or energy efficiency technologies in Ontario.

Depending on the level of detail of available data for each province, suitable methods will be developed to estimate the marginal GHG emission intensity factors for each province.

CONCLUSION

New methodologies are being developed to estimate the marginal GHG emission intensity factors for each province in Canada that will be used to calculate the GHG emission reductions due to electricity savings resulting from solar and other renewable energy and energy efficiency technology applications in the residential sector.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support provided to this project through the NSERC funded Solar Buildings Research Network. Ms. Mohmed is grateful to the Libyan Government for her scholarship. The authors also acknowledge Lukas Swan in the development of the analysis methodology for the Ontario IESO data.

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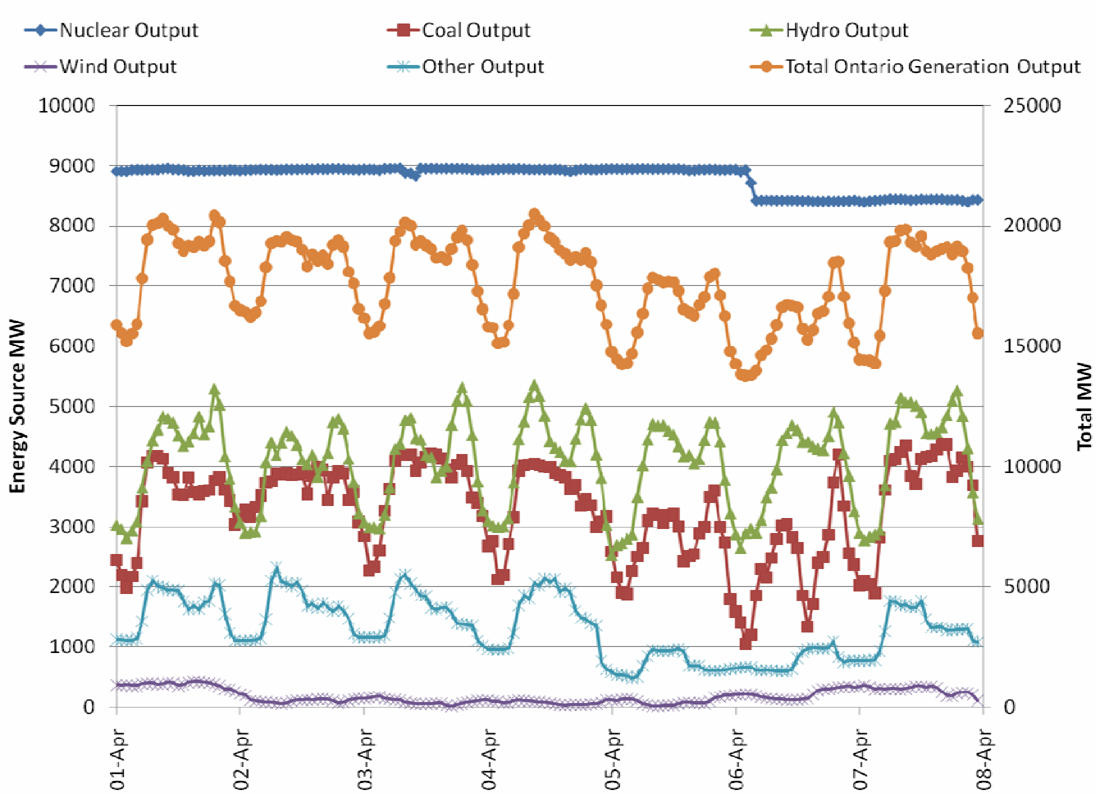

Figure 1. Electrical generation energy source components for Ontario for April 1-8, 2008

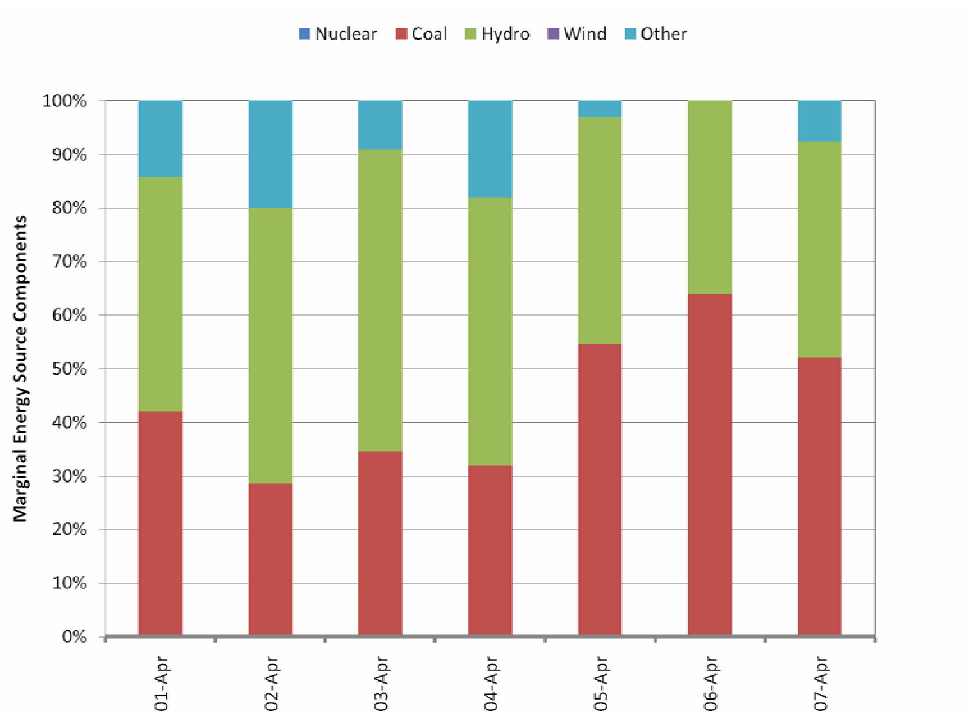

Figure 2. Energy sources for the marginal electricity generation of Ontario for April 1-7, 2008