**A new methodology FOR predictING the ghg emission reductions due to electricity savings in the residential sector**

by

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**To**

**The spirit of My unforgettable father ….. Who lives in my heart...**

**My merciful mother..... Who always loves me…**

**My brothers and sisters....Who always support me…**

**\*\*\***

**My beloved husband..... Who lightens my life…**

**My special pearl ..Marwan…. Who sweetens my life...**

**To all of them I dedicate this work**

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# LIST OF ABBREVIATIONS

AESO Alberta Electric System Operator

AREG Annual reduction in electricity generation (MWh/year)

DDm Monthly degree days

DDy Yearly total degree days

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

FFNEG Net electricity generation from only fossil fuel fired power plants in one year (kWh/year)

GHG Greenhouse gas emission

GHGIF Greenhouse gas intensity factor

GHGIFA Average GHG intensity factor (g CO2eq/kWh)

GHGIFM GHG Intensity Factor for fossil fuel (g CO2eq/kWh)

GWP Global warming potential

HO Heavy oil

ICF International Consulting Firm

IESO Independent Electricity System Operator

IPM Integrated Planning Model

MEGMFi Marginal electricity generation using marginal fuel i (MWh)

NG Natural gas

NSP Nova Scotia power

RSI Thermal resistance (m2 ºC /W)

SaskPower Saskatchewan power

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

TEGMFi  Total electricity generation using marginal fuel i (MWh)

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

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# 

# ABSTRACT

In Canada, each province has its own electric utility system, and each system is responsible for meeting the demand of its customer base. Electricity demand in all provinces is highly variable throughout the day, as well as during the year, and the electric utility system operators must ensure that electricity demand is met continuously. In order to achieve a good match between electricity demand and generation, a mix of base load and peaking load power plants are used, which use different fuel sources.

When a solar technology or an energy efficiency measure is implemented on a wide scale in the residential sector that results in electricity savings, the electricity savings reflect in the peak (marginal) electricity generation. Thus, the greenhouse gas emission (GHG) reduction due to the reduction in electricity generation corresponds to the 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 for each province on an hourly time scale. However, this information is regarded confidential by most utilities and is not made public. In addition, due to the continuously changing operational and economic conditions, 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.

The objective of this research is to develop a realistic and viable methodology to calculate the amount of GHG emission reductions associated with the reduction in electricity consumption due to implementing solar technologies or energy efficiency measures. Since electricity savings will be within the marginal capacity, a marginal GHG intensity factor (g CO2eq/kWh), which is the amount of GHG emissions produced as result of producing one kWh of electricity on the margin, is estimated for each province based onpublished estimates of marginal generation magnitude and fuels used for marginal generation.

The results obtained are compared with the estimates obtained from previous studies that utilize average GHG intensity factors and GHG intensity factors for only fossil fuel fired power plants.

# 

# 1. INTRODUCTION

Rising energy prices and increasing awareness of the impacts of fossil fuel use on the environmental have led to increasing energy conservation and renewable energy substitution efforts.

Since the 1980s, energy consumption based on fossil fuels, the associated greenhouse gas emissions, and their potential effects on the environment have been extensively studied and became a main focus of the populace as well as the politicians and the media. National and international efforts are underway to mitigate or reduce GHG emissions. However, the total anthropogenic[[1]](#footnote-2) 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.

The global concern about the GHG emissions and their potential effects on the environment is the initiative behind the Kyoto Protocol. Under this protocol, Canada must reduce its GHG emission by 6% below 1990 level by 2010. But as it can be seen in Figure 1, the actual GHG emissions are increasing continuously due to economic and population growth which leads to increase the energy consumption hence the associated GHG emissions. In 2005 the actual GHG emission was about 25% above the 1990 level and close to 33% above the Kyoto target [1].

In Canada, a substantial proportion of electricity is generated by combusting fossil fuels. Therefore, electricity generation is a substantial source of greenhouse gas emissions. In 2005, electricity generation and heat production were responsible for about 17% of the total GHG emissions . However, the levels of GHG emissions vary considerably from province to province due to the variance of the availability of energy resources which is reflected on the electricity generation system.

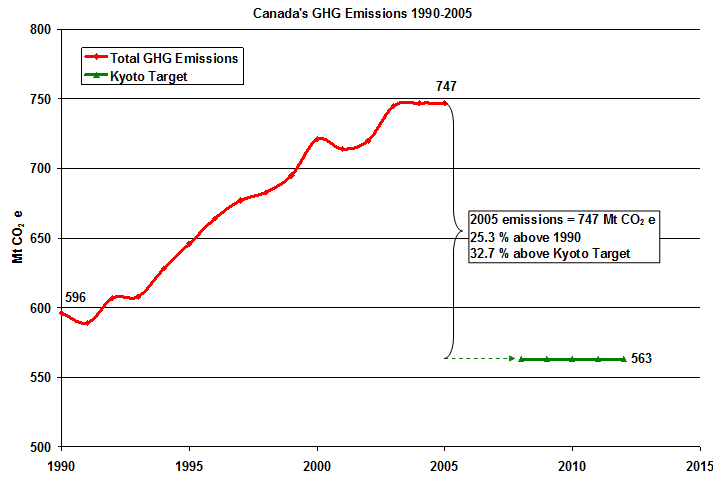


Figure 1. Canada’s GHG Emissions and the Kyoto Target [1]

In Canada, the residential sector presents an important component of the energy consumption as it accounts for approximately 17% of the national energy consumption as shown in Figure 2. This is responsible for about 16% of the total GHG emissions [3] as shown in Figure 3. Consequently, addressing the electricity consumption in this sector presents an effective method to reduce the total GHG emissions in Canada.

There are numerous options to reduce the GHG emissions in all sectors of the economy. These include increasing the efficiency of energy consumption, and reducing the energy consumption by structural changes and fuel substitution (e.g. using less carbon intensive fuels or renewable energy resources).

When a 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 reductions due to a reduction in electricity demand, and consequently, marginal electricity generation, corresponds to the reduction in GHG emissions from the fuels 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 actual 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.

Figure 2. Annual Energy Consumption by Sector [3]

Figure 3. Annual GHG Emission by Sector [3]

## 1.1 Performance of the Electricity Grid

The performance of the electricity grid can be summarized in three major components: electricity generation, transmission and distribution. The voltage of the electricity generated by power plants is increased using transformers, and the high voltage electricity is delivered through the electricity transmission and distribution lines to transformer stations where the electricity voltage is reduced to a lower level, and transmitted over local distribution grids to the consumers [4].

The demand for electricity changes considerably from hour to hour through the day, as well as throughout the year. In order to have a reliable electricity system, the balance between electricity production and costumer demand must be ensured. In order to satisfy the electrical demand in the most economical fashion, electric utilities use complex rules to dispatch their generating units based on demand forecasts, cost of production, unit availability and export/import considerations. This is known as "optimal power dispatching".

Utilities use a mix of base load, intermediate load, and peaking load power plants (or units) to satisfy the variability of the demand while minimizing the cost of generation. Base load power plants are designed to operate at full capacity on a continuous basis, and have high fixed costs and low operational costs, resulting in the lowest cost electricity generation within a utility system. Commonly, coal fired power plants, nuclear power plants and hydro power plants are used as base load plants. Intermediate load power plants have moderate fixed costs and their operational costs are higher than those of base load units. These power plants run during the daytime, filling the gap in supply between base load and peak load power. Their output can change more easily than base load power plants. Commonly oil, combined cycle natural gas and hydro plants are used as intermediate load power plants. The most expensive electricity is produced by peaking load power plants that operate only at peak demand periods this is also known as “marginal generation”. Thus, power plants whose output can be changed easily and quickly to match fluctuations in demand are used as peaking plants. They can also be started up and shut down quickly. Peaking power plants have lower capital costs and higher operating costs, and they commonly use natural gas or oil (in combustion turbine or steam cycle plants), and if available, hydro or pumped hydro. Electricity supply mix in terms of base load, intermediate load and peaking load power plants are shown in Figure 4.

Figure 4. Electricity supply mix in terms of base load, intermediate load and peaking load power

In addition to these kinds of power plants, there are also non-dispatchable power plants. These plants include wind and tidal power plants, and they cannot be counted on to produce at specific times. Their output depends on the availability of the energy source. The electricity generated by these power plants is usually fed to the grid whenever it becomes available [4].

## 

## 1.2 Distribution of the Energy Sources in Canada

Canada is the second largest country in the world with substantial and diverse natural resources, which are reflected in its electricity generating system as shown in Figure 5 .

Figure 5. Electricity Generation in Canada by Fuel Source 2005 [1]

However, the fuels used and their shares in electricity generation are quite different at the provincial level due to the variation of energy resources from province to province. For example, Newfoundland and Labrador, Quebec, British Columbia, and Manitoba rely mostly on hydroelectric resources, which generally supply the base load generation. About 90% of nuclear power generation in 2005 was used to provide base load generation in Ontario, while the remainder was used in Quebec and New Brunswick. Coal-fired power plants are primarily operated in Alberta and Saskatchewan, and they also play a significant role in electricity generation in both Ontario and Nova Scotia. Natural gas fired power plants are part of the electricity supply mix in most provinces across Canada, primarily in Ontario and Alberta, followed by British Columbia and Saskatchewan. Natural gas fired power plants have been recently introduced into Quebec, and the Atlantic region where natural gas became available only since 2000. Natural gas power plants are usually used at peak times to meet demand fluctuations. Refined petroleum products are used mostly in Nova Scotia and New Brunswick, where they represent 14% and 37%, respectively, of the total supply mix in 2005. These percentages vary from year to year depending on the price difference between the refined petroleum products and coal. Refined petroleum products are also used in Alberta and Quebec. Biomass resources are mainly used in British Columbia, Alberta, and New Brunswick. Electricity generation in Canada by region and fuel source used in 1990 and 2005 is presented in Figure 6 .

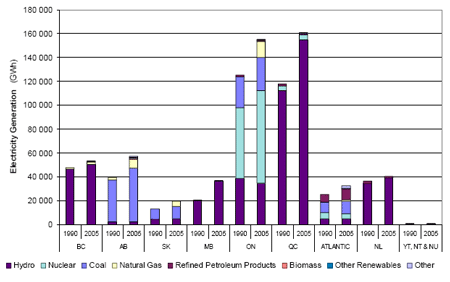


Figure 6. Electricity Generation by Region and Source for 1990 and 2005 [1]

# 

# 2. 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 :

1. Gather information on marginal electricity generation and fuel used from the open literature as well as electric utilities through personal contacts and utility websites.
2. Based on the information obtained in (i), determine the magnitude of the marginal electricity generation in each province as a function of time.
3. Based on the information obtained in (i), determine the fuels used for marginal electricity generation in each province as a function of time.
4. Develop a methodology to predict the GHG emissions due to marginal electricity generation based on (ii) and (iii).
5. Compare the GHG emission reductions predicted by the methodology developed in (iv) with the estimates obtained from previous studies that utilize average GHG intensity factors and GHG intensity factors for only fossil fuel fired power plants.
6. Demonstrate 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.

# 3. ELECTRICITY GENERATION AND DISPATCH IN CANADA

In Canada, each province has its own electric utility system, and each system is responsible for meeting the demand of its customer base. A review of the electric power supply mix and fuels used in each province is presented in the following sections.

## 3.1 Newfoundland and Labrador

Newfoundland and Labrador Hydro is the main electricity provider in Newfoundland and Labrador. Newfoundland and Labrador Hydro has installed generating capacity of 7,289 MW generated by ten hydroelectric plants, one oil fired power plant, four natural gas fired power plants, and 26 diesel plants .

The peak demand for electricity in Newfoundland is during the winter months. The peaking generation capacity is provided by the province’s largest thermal power plant that utilizes heavy fuel oil. This power plant has a generating capacity of 500 MW. At peaking time, this power plant runs at full capacity to meet the peak demand. In addition to the thermal generation, about 900 MW is supplied to the grid by several hydro power plants . The total electricity generation for years 2004 to 2006[[2]](#footnote-3) in Newfoundland, as well as the types and amounts of fuel used for electricity generation are given in Table 1.

Table 1. Electricity generation in Newfoundland and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel**  **Input** |
| Light fuel oil | -4,629\* | -0.01 | 681kL | -6,331\* | -0.02 | 1,217kL | -9,480\* | -0.02 | 1,679kL |
| Heavy fuel oil | 1,647,586 | 4.14 | 419,385kL | 1,326,672 | 3.29 | 339,876kL | 738,835 | 1.81 | 200,098kL |
| Diesel | 53,204 | 0.13 | 15,579kL | 44,257 | 0.11 | 15,017kL | 43,991 | 0.11 | 14,395kL |
| Hydro | 38,101,914 | 95.74 | N/A | 38,949,551 | 96.62 | N/A | 40,056,901 | 98.11 | N/A |
| Total | 39,798,075 | 100 | - | 40,314,149 | 100 | - | 40,830,247 | 100 | - |

\* The reason for the negative number for the electricity generation from light fuel oil in Newfoundland is due to the fact that a number of large combustion turbines are kept running and therefore they consume light fuel oil but are not generating electricity for a variety of reasons [11].

## 3.2 Prince Edward Island

For economic reasons, more than 90% of the electricity supplied in Prince Edward Island is imported from New Brunswick. The electricity purchased from New Brunswick is transmitted by using an undersea cable of 200 MW capacity . This electricity is primarily generated from nuclear and fossil fuel fired power plants. The remaining electricity generation is from oil fired power plants and wind turbines in the province operated by Maritime Electric Company.

The peak demand for electricity in Prince Edward Island is during the winter months. The minimum load is about 100 MW, and the peak load is 210 MW . The peak demand in the province is supplied by imported electricity in addition the province’s thermal power plant which can be used as supplemental capacity at peak demand, but this power plant is usually idle . The total electricity generation for years 2004 to 2006 in Prince Edward Island, as well as the types and amounts of fuel used for electricity generation are given in Table 2.

Table 2. Electricity generation in Prince Edward Island and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel Input** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel Input** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel Input** |
| Light fuel oil | 853 | 1.84 | 181kL | 243 | 0.53 | 278kL | 2,633 | 6.24 | 252kL |
| Heavy fuel oil | 7,718 | 16.65 | 3,911kL | 3,075 | 6.76 | 2,182kL | 372 | 0.88 | 1,141kL |
| Diesel | 508 | 1.10 | 498kL | 68 | 0.15 | 24kL | 0 | 0 | 0 |
| Wood | 2,583 | 5.57 | 1,096Mg | 1,977 | 4.35 | 1,037Mg | 2,927 | 6.94 | 1,012Mg |
| Wind and tidal | 34,703 | 74.85 | N/A | 40,104 | 88.2 | N/A | 36,249 | 85.94 | N/A |
| Total | 46,365 | 100 | - | 45,467 | 100 | - | 42,181 | 100 | - |

## 

## 3.3 Nova Scotia

Nova Scotia Power (NSP) has been the main electricity provider in the province for more than 80 years. It provides 97% of the electrical generation, transmission, and distribution in Nova Scotia (the remaining 3% comes from several small-scale producers, primarily utilizing hydro sources) . NSP owns and operates about 2,293 MW of electricity generation capacity, which uses a mix of fossil fuels and renewable energy. The generating fleet includes five thermal power plants, one tidal and 33 hydro power plant, as well as four combustion turbines and two wind turbine sites .

In Nova Scotia, electricity generation from fossil fuels comes from three major sources: coal, natural gas (NG), and heavy (#6) oil (HO). The four coal-fired power plants in Nova Scotia produce 75% of the electricity in the province. NSP was dependent on locally mined coal until 1999; however, recently, most of its coal comes from international markets .

NG represents 13% of NSP's generating capacity. It is considered as a clean fossil fuel because it produces less air pollution compared to the other forms of fossil fuels. In 2000, NSP modified its Tuft's Cove power plant to burn either HO or NG. Furthermore, two additional NG-fired gas turbines were added to Tuft's Cove . The plant can produce 450 MW of electricity.

The third form of fossil fuel used for electricity production in Nova Scotia is oil. NSP owns several oil-fired power plants around the province. In the renewable energy segment, NSP owns two wind turbine sites with a peak generating capacity of 60 MW of clean energy, as well as 33 hydro power plants with a capacity of up to 360 MW. NSP also owns and operates a tidal power plant, which can produce up to 20 MW of power .

Nova Scotia has a winter peaking load, and the peak load is supplied by the Tuft's Cove power plant, which is fuelled by HO or NG, as well as the hydro plants in different part of the province. The Tuft's Cove plant has three steam cycle thermal units; they can produce up to 350 MW. These units can burn either HO or NG, and they can switch from one fuel to another in a matter of hours. In addition, the Tuft's Cove plant has two 50MW gas turbine units that can burn only NG. The plant is normally started in the early morning (6-7 AM) and shut down at night (10-11 PM) to meet the daytime peaking loads. NSP has a long-term contract to buy a certain amount of NG from the Sable off-shore NG field. Every day, depending on the spot market cost of oil and NG, NSP decides which one of the two fuels it will use in the thermal units of the Tuft's Cove plant to meet the peak load. If it is able to make more profit by selling its NG allocation to the Eastern Seaboard of the US, it sells the gas, and uses heavy oil in its thermal units; otherwise, it uses the NG in the thermal units, and if necessary in the gas turbine, to meet the peak load.

Occasionally, NSP uses hydro units for peak power supply as well. In addition, NSP has non-dispatchable power plants such as wind and tidal which generate power only when the energy source is available . The total electricity generation for years 2004 to 2006 in Nova Scotia, as well as the types and amounts of fuel used for electricity generation are given in Table 3.

Table 3. Electricity generation in Nova Scotia and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated (MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** |
| Canadian bitum. | 1,001,570 | 10.21 | 437,577Mg | 826,513 | 8.37 | 359,452Mg | 886,333 | 10.07 | 386,505Mg |
| Imported bitum. | 4,995,331 | 50.92 | 1,850,817Mg | 4,908,846 | 49.73 | 1,907,42Mg | 5,671,452 | 64.41 | 2,155,488Mg |
| Imported subbitum. | 932,057 | 9.50 | 346,858 Mg | 1,032,824 | 10.46 | 403,420 Mg | 0 | 0 | 0 |
| Light  fuel oil | 15,888 | 0.16 | 4,564kL | 15,440 | 0.16 | 4,400kL | 16,952 | 0.19 | 4,519kL |
| Heavy fuel oil | 1,650,432 | 16.83 | 406,063kL | 1,558,644 | 15.79 | 383,875kL | 860,920 | 9.78 | 125,718kL |
| Diesel | 128,443 | 1.31 | 44,920kL | 198,955 | 2.02 | 70,157kL | 105,840 | 1.20 | 35,279kL |
| Natural gas | 13,795 | 0.14 | 3,760k.m3 | 12,767 | 0.13 | 3,476k.m3 | 0 | 0 | 0 |
| Wood | 178,346 | 1.81 | 133,088Mg | 167,960 | 1.70 | 134,625Mg | 156,491 | 1.78 | 122,225Mg |
| Hydro | 864,526 | 8.81 | N/A | 1,036,471 | 10.50 | N/A | 978,661 | 11.11 | N/A |
| Wind and tidal | 28,961 | 0.30 | N/A | 113,088 | 1.15 | N/A | 128,679 | 1.46 | N/A |
| Total | 9,809,349 | 100 | - | 9,871,508 | 100 | - | 8,805,328 | 100 | - |

## 3.4 New Brunswick

In New Brunswick, electricity is generated from 16 power plants distributed throughout the province. NB Power Group is the main electricity provider in the province. NB Power Group is an integrated system that is responsible for electricity generation, transmission and distribution throughout the province. The NB Power Group has two generating companies; the first one is NB Power Nuclear. It operates a 635 MW reactor, which provides about 25% of New Brunswick's electrical requirements. It also sells 5% of its energy production to Maritime Electric Company of PEI. The second company is NB Power Generation. It produces 75% of the electricity generation in the province, and exports energy to the neighbouring New England, Quebec, Prince Edward Island and Nova Scotia markets. NB Power Generation owns 15 power plants with total installed capacity of 3,324 MW. Seven of these are hydro plants, two are coal-fired power plants, three are oil-fired power plants, and three are diesel power plants. 1,903 MW of the total capacity is from thermal plants, whereas 895 MW is from hydro, and 526 MW is from combustion turbine .

Similar to the most other provinces in Canada, New Brunswick has a winter peaking load. This is as a result of electric space heating, especially in the residential sector, where more than 60% of the homes are heated by electricity . The peak load in the province is primarily generated from a mix of coal and oil , while the base load is provided by nuclear, hydro and coal. Heavy oil and Orimulsion are used to provide either base or intermediate load [23]. The total electricity generation for years 2004 to 2006 in New Brunswick, as well as the types and amounts of fuel used for electricity generation are given in Table 4.

Table 4. Electricity generation in New Brunswick and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated**  **(MWh)** | **% of Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel**  **Input** |
| Canadian bitum. | 322,446 | 1.72 | 152,045 Mg | 299,438 | 1.56 | 139,317 Mg | 230,436 | 1.37 | 109,194Mg |
| Imported bitum. | 2,858,731 | 15.24 | 1,061,015 Mg | 261,953 | 13.66 | 995,840 Mg | 2,697,997 | 16.10 | 994,420Mg |
| Light fuel oil | 64,368 | 0.34 | 27,862kL | 20,154 | 0.11 | 10,010kL | 11,457 | 0.07 | 5,228kL |
| Heavy fuel oil | 6,480,139 | 34.55 | 1,653,394kL | 6,084,657 | 31.70 | 1,584,966kL | 3,414,998 | 20.38 | 921,960kL |
| Diesel | 1,604 | 0.01 | 706kL | 4,661 | 0.02 | 1,562kL | 4,028 | 0.02 | 1,302kl |
| Natural gas | 1,777,371 | 9.48 | 374,474k.m3 | 1,966,849 | 10.25 | 592,041k.m3 | 2,319,797 | 13.84 | 533,857 k.m3 |
| Hydro | 2,954,100 | 15.75 | N/A | 3,817,074 | 19.89 | N/A | 3,714,228 | 22.16 | N/A |
| Nuclear | 4,298,814 | 22.92 | N/A | 4,377,987 | 22.81 | N/A | 4,366,463 | 26.05 | N/A |
| Total | 18,757,573 | 100 | - | 19,192,773 | 100 | - | 16,759,404 | 100 | - |

## 3.5 Quebec

The province of Quebec is considered as one of the richer regions in the world for its water and hydroelectricity resources. Over 40% of Canada’s water resources are in Quebec, where the surface water reserves in the province cover about 12% of its territory . Historically Quebec has relied mostly upon hydro electricity to meet its energy needs. Hydro Quebec is responsible for most electricity production in the province; it owns 60 power plants around the province, 54 of which are hydroelectric power plants. Of the remaining six power plants, one is nuclear, four are thermal and one is wind. The highest demand of the electricity in the province is during the winter months, especially during January’s coldest days.

Primarily, hydroelectric power plants are used as base load power plants, with the nuclear power plant also providing base load generation. The thermal power plants, which are fuelled by oil or NG, are used mainly as peak load plants during a few highest load periods. The Tracy oil fired thermal power plant, which has a generating capacity of 600 MW, is operated two weeks per year on average, whereas the NG burning Becancour plant, which has a 428 MW capacity, is used for 200 hours per year. Other thermal power plants work approximately 20 hours per year [25].

Finally, since wind generation is not a reliable source of energy, Hydro Quebec has decided to develop wind generation in tandem with hydroelectricity [25]. The total electricity generation for years 2004 to 2006 in Quebec, as well as the types and amounts of fuel used for electricity generation are given in Table 5.

Table 5. Electricity generation in Quebec and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated**  **(MWh)** | **% of Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of Total Generation** | **Fuel**  **Input** |
| Light fuel oil | 11,654 | 0.01 | 6,697kL | 1,685 | 0 | 3,620kL | 3,973 | 0 | 2,059kl |
| Heavy fuel oil | 1,718,554 | 1.12 | 438,211kL | 567,336 | 0.35 | 151,345kL | 131,047 | 0.08 | 47,799kL |
| Diesel | 99,261 | 0.06 | 27,140kL | 98,703 | 0.06 | 27,051kL | 98,523 | 0.06 | 27,071kL |
| Natural gas | 209,820 | 0.14 | 75,310k.m3 | 212,073 | 0.13 | 75,774k.m3 | 141,377 | 0.09 | 325,013 k.m3 |
| Wood | 350,271 | 0.23 | 171,798Mg | 319,861 | 0.20 | 159,331Mg | 327,881 | 0.21 | 192,584Mg |
| Hydro | 146,157,421 | 95.15 | N/A | 154,677,596 | 96.21 | N/A | 151,792,208 | 96.37 | N/A |
| Wind and tidal | 186,783 | 0.12 | N/A | 416,241 | 0.26 | N/A | 418,791 | 0.27 | N/A |
| Nuclear | 4,877,718 | 1.18 | N/A | 4,483,055 | 2.79 | N/A | 4,595,198 | 2.92 | N/A |
| Total | 153,611,482 | 100 | - | 160,776,550 | 100 | - | 157,508,998 | 100 | - |

## 

## 3.6 Ontario

Electricity generation in Ontario comes from three major sources: nuclear, coal, and hydro. In 2007, more than 50% of Ontario's electricity needs were met by nuclear power. There are three nuclear power plants in Ontario with total installed capacity of 11,240 MW. Hydroelectric generation accounts for 21% of Ontario’s generation mix. There are currently about 180 hydroelectric plants in Ontario. The size of these plants are considerably different, with the smallest plants producing less than one megawatt of power, while Ontario's largest hydro power plant, Niagara Falls' Sir Adam Beck 2, generates more than 1,400 MW of electricity.

Coal and NG are the most used fossil fuels in Ontario for electric power generation. Ontario has four power plants fuelled by coal with a total installed capacity of 6,420 MW, which produce about 18% of the electricity production in the province. Currently there are about 60 power plants fuelled by NG that provide approximately 8% of Ontario's generating mix. Wind power provided 1% of the total generation in 2007 . Ontario’s peak demand occurs on hot summer days, when most people rely heavily on air conditioning. Ontario’s base load is generated mainly from nuclear and hydro resource, where the intermediate and peak load supplied by coal, natural gas, oil, and hydroelectric generators with storage [27]. The total electricity generation for years 2004 to 2006 in Ontario, as well as the types and amounts of fuel used for electricity generation are given in Table 6.

Table 6. Electricity generation in Ontario and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated**  **(MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity**  **Generated**  **(MWh)** | **% of**  **Total**  **Generation** | **Fuel**  **Input** | **Electricity**  **Generated**  **(MWh)** | **% of**  **Total**  **Generation** | **Fuel**  **Input** |
| Canadian bitum. | 234,489 | 0.16 | 87,111Mg | 0 | 0 | 0 | 0 | 0 | 0 |
| Imported bitum. | 15,630,797 | 10.41 | 5,796,892Mg | 16,183,127 | 10.43 | 5,896,334Mg | 10,621,771 | 6.88 | 4,018,681Mg |
| Imported subbitum. | 8,456,845 | 5.63 | 4,785,959Mg | 11,511,735 | 7.42 | 6,303,708Mg | 12,022,456 | 7.79 | 6,607,856Mg |
| Lignite | 1,757,382 | 1.17 | 1,276,426Mg | 1,733,513 | 1.12 | 1,267,687Mg | 1,593,196 | 1.03 | 1,180,889Mg |
| Light fuel oil | 43,801 | 0.03 | 14,077kL | 56,751 | 0.04 | 16,620kL | 308,160 | 0.20 | 15,355kL |
| Heavy fuel oil | 617,814 | 0.41 | 183,587kL | 677,790 | 0.44 | 188,332 | 121,950 | 0.08 | 45,756kL |
| Diesel | 2 | 0 | 1kL | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural gas | 8,665,151 | 5.77 | 2,088,723k.m3 | 11,901,579 | 7.67 | 2,832,214k.m3 | 10,693,529 | 6.93 | 2,833,982 k.m3 |
| Wood | 532,576 | 0.35 | 595,472Mg | 431,975 | 0.28 | 505,578Mg | 438,310 | 0.28 | 476,992Mg |
| Hydro | 38,083,122 | 25.37 | N/A | 34,550,848 | 22.27 | N/A | 35,004,137 | 22.67 | N/A |
| Wind and tidal | 25,110 | 0.02 | N/A | 155,596 | 0.10 | N/A | 144,467 | 0.09 | N/A |
| Nuclear | 76,063,313 | 50.67 | N/A | 77,968,854 | 50.25 | N/A | 83,456,853 | 54.05 | N/A |
| Total | 150,110,402 | 100 | - | 155,171,768 | 100 | - | 154,404,829 | 100 | - |

## 

## 3.7 Manitoba

Manitoba Hydro is the main provider of electricity in the province; it generates about 95% of its electricity from hydroelectric resources. The remaining 5% is provided by a combination of thermal plants and electricity imports . Manitoba Hydro operates an integrated system with 14 hydro plants of total generating capacity 4,828 MW, while thermal generating capacity is about 535MW generated by two gas-fired power plants and one coal fired power plant . Manitoba has a winter peaking load similar to the most provinces in Canada. The peaking load is supplied mainly by hydro resources in addition to the NG power plants and imported electricity in case of low water levels . The total electricity generation for years 2004 to 2006 in Manitoba, as well as the types and amounts of fuel used for electricity generation are given in Table 7.

Table 7. Electricity generation in Manitoba and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated**  **(MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** |
| Imported subbitum. | 266,029 | 0.96 | 180,400Mg | 421,103 | 1.14 | 278,021Mg | 322,994 | 0.94 | 193,244 |
| Light fuel oil | 3,107 | 0.01 | 1,140kL | 3,622 | 0.01 | 1,360kL | 7,513 | 0.02 | 2,376 |
| Diesel | 11,348 | 0.04 | 3,622kL | 11,496 | 0.03 | 3,381kL | 12,696 | 0.04 | 3,785 |
| Natural gas | 85,656 | 0.31 | 31,768k.m3 | 10,577 | 0.03 | 4,392k.m3 | 51,436 | 0.15 | 19,958 |
| Hydro | 27,219,340 | 98.67 | N/A | 36,439,655 | 98.65 | N/A | 33,650,538 | 97.91 | N/A |
| Wind and tidal | 0 | 0 | 0 | 53,420 | 0.14 | N/A | 325,115 | 0.95 | N/A |
| Total | 27,585,480 | 100 | - | 36,939,873 | 100 | - | 34,370,292 | 100 | - |

## 3.8 Saskatchewan

SaskPower is the main provider of the electricity in the province. It relies mostly on fossil fuel for electricity generation; the remainder comes from hydroelectric and wind. SaskPower has 16 generating plants throughout the province with a total generating capacity as 2006 was 3660 MW, including 3211 MW from SaskPower’s facilities and 449 MW through purchase agreements with independent power producers. The current supply mix as of January 2009 is 45.2% coal, 14.7% NG, 23.3% hydroelectric, and 4.4% wind power. Purchased power provides the remaining 12.3% .

Saskatchewan’s base load is normally supplied by coal fired power plants, where the intermediate load is supplied by hydro and imported power. The highest demand in the province normally occurs in winter months with the colder temperatures and early darkness, and during the hottest days of summer. The province’s peak load is supplied by NG-fired power plants, hydro, and imported power . The total electricity generation for years 2004 to 2006 in Saskatchewan, as well as the types and amounts of fuel used for electricity generation are given in Table 8.

Table 8. Electricity generation in Saskatchewan and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated**  **(MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity**  **Generated**  **(MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity**  **Generated**  **(MWh)** | **% of**  **Total Generation** | **Fuel Input** |
| Lignite | 13,108,671 | 69.60 | 9,945,941Mg | 12,170,798 | 62.54 | 9,340,616Mg | 11,782,144 | 60.86 | 9,013,345Mg |
| Light fuel oil | 0 | 0 | 0 | 0 | 0 | 0 | 17,470 | 0.09 | 4,744kL |
| Heavy fuel oil | 10,136 | 0.05 | 2,859kL | 11,488 | 0.06 | 3,238kL | 0 | 0 | 0 |
| Diesel | 402 | 0 | 119kL | 538 | 0 | 118kL | 518 | 0 | 112kL |
| Natural gas | 2,893,767 | 15.37 | 850,142k.m3 | 2,612,793 | 13.43 | 765,158k.m3 | 2,956,455 | 15.27 | 845,583 k.m3 |
| Hydro | 2,746,393 | 14.58 | N/A | 4,572,910 | 23.50 | N/A | 4,031,938 | 20.83 | N/A |
| Wind and tidal | 73,634 | 0.39 | N/A | 91,916 | 0.47 | N/A | 572,202 | 2.96 | N/A |
| Total | 18,833,003 | 100 | - | 19,460,443 | 100 | - | 19,360,727 | 100 | - |

## 3.9 Alberta

The electricity system in Alberta is owned and operated by several companies, not by the Alberta government. The majority of Alberta's installed generating capacity comes from thermal sources. In early 2008 about 48.8% of the electricity in the province is generated from coal-fired power plants. The NG accounts for 38.4% of total generation, hydro 7.1%, and the remainder 5.6% from wind and biomass .

In general, Alberta has winter peaking load due to lower temperatures and shorter daylight hours. The electricity demand becomes lower in summer than in fall and spring. In 2005, the summer peak load was about 90% of the winter peak load for that year . Alberta peaking load is supplied mainly by NG and coal power plants where the remaining is supplied by hydro resources . The total electricity generation for years 2004 to 2006 in Alberta, as well as the types and amounts of fuel used for electricity generation are given in Table 9.

Table 9. Electricity generation in Alberta and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated**  **(MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** |
| Canadian bitum. | 9,069,920 | 16.37 | 5,274,798Mg | 5,178,512 | 9.06 | 3,174,054Mg | 874,377 | 1.50 | 504,575Mg |
| Canadian subbitum. | 33,331,826 | 60.15 | 20,138,584Mg | 37,003,716 | 64.71 | 21,669,912Mg | 39,108,456 | 70.00 | 25,064,926Mg |
| Light fuel oil | 40 | 0 | 10kL | 40 | 0 | 10kL | 40 | 0 | 10kL |
| Heavy fuel oil | 8,874 | 0.02 | 4,224kL | 0 | 0 | 0 | 0 | 0 | 0 |
| Diesel | 14,079 | 0.03 | 4,142kL | 13,729 | 0.02 | 4,039kL | 10,067 | 0.02 | 3,643kL |
| Natural gas | 10,207,864 | 18.42 | 3,142,429k.m3 | 11,599,542 | 20.28 | 3,301,348k.m3 | 12,545,425 | 22.55 | 3,695,187 k.m3 |
| Wood | 282,097 | 0.51 | 363,069Mg | 313,531 | 0.55 | 396,895Mg | 390,361 | 0.70 | 475,051Mg |
| Hydro | 1,876,384 | 3.39 | N/A | 2,241,937 | 3.92 | N/A | 1,868,916 | 3.36 | N/A |
| Wind and tidal | 620,700 | 1.12 | N/A | 836,986 | 1.46 | N/A | 839,582 | 1.51 | N/A |
| Total | 55,411,784 | 100 | - | 57,187,993 | 100 | - | 55,637,224 | 100 | - |

## 3.10 British Columbia

BC Hydro is one of the largest electric utilities in Canada; it is responsible for electricity generation and distribution in the province of British Columbia. It supplies electricity to more than 94% of the British Columbia’s population. BC Hydro electricity generation system includes 30 integrated hydroelectric generating plants; one gas-fired thermal power plant and two combustion turbine plants with a total installed capacity of more than 11,000 MW . The hydroelectric power plants produce most of the electricity in the province. Over 90% of the total system load is served by hydro facilities. The remaining 10% is served by a combination of NG fired power plants, and energy imports from Alberta and the US Pacific Northwest. The BC Hydro system is predominately hydro based, with some instances of natural gas which supports the hydro system in low water years, and provides transmission support in case of transmission interruptions or outages .

British Columbia has a winter peaking load. The peak load is primarily provided by hydro resources, NG thermal power plants, and import . The total electricity generation for years 2004 to 2006 in British Columbia, as well as the types and amounts of fuel used for electricity generation are given in Table 10.

Table 10. Electricity generation British Columbia and fuels used [8-10]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | | **2005** | | | **2006** | | |
| **Energy Source** | **Electricity Generated**  **(MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** | **Electricity Generated (MWh)** | **% of**  **Total Generation** | **Fuel**  **Input** |
| Diesel | 58,798 | 0.12 | 12,051kL | 62,174 | 0.12 | 12,725kL | 10,879 | 0.02 | 2,232kL |
| Natural gas | 2,380,966 | 4.96 | 564,907k.m3 | 2,436,996 | 4.57 | 554,648k.m3 | 2,165,673 | 4.59 | 502,300 k.m3 |
| Wood | 554,559 | 1.15 | 685,728Mg | 545,907 | 1.02 | 311,058Mg | 546,358 | 1.16 | 716,641Mg |
| Hydro | 45,023,675 | 93.76 | N/A | 50,305,334 | 94.29 | N/A | 44,463,830 | 94.23 | N/A |
| Total | 48,017,998 | 100 | - | 53,350,411 | 100 | - | 47,186,740 | 100 | - |

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# 4. PREVIOUS METHODS TO CALCULATE GHG EMISSION REDUCTION FROM ELECTRICITY GENERATION

The primary greenhouse gases emitted during the combustion of fossil fuels are carbon dioxide (CO2), water (H2O), methane (CH4), and nitrous oxide (N2O). Among these gases 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[[3]](#footnote-4) (GWP). The GWP is referenced to the strength of CO2 (i.e. equivalent CO2, or CO2eq) as it is the dominant gas emitted during combustion. Considering the GWP of CO2 to be unity, CH4 and N2O have 100 year GWPs of 25 and 298 by mass, respectively [37]. Thus, CO2eq can be determined as follows:

[1]

In the rest of this work, all GHG emissions and emission intensity factors are expressed in terms of CO2eq emissions. The GHG emission intensity factor, i.e. the total CO2eq GHG emissions generated per unit of electricity generation (g CO2eq/kWh) is a function of the properties of the fuel used to generate electricity and to a lesser extent, on the combustion technology [1]. The GHG emissions factors as a result of combusting fuels used in the electric utility sector are given in Table 11. The GHG emissions factor for any given fuel is the amount of CO2, CH4 and NO2 in grams emitted as result of burning one unit of that fuel. 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.

Two previous methods have been used to predict the GHG emission reductions associated with reductions in electricity consumption due to energy efficiency and renewable energy measures [38, 39] These are summarized as follows.

Table 11. GHG emissions due to the conversion of fuels to generate electricity [1]

|  |  |  |  |
| --- | --- | --- | --- |
| **Fuel Used** | **CO2 (g)\*** | **CH4 (g)** | **N2O (g)** |
| Natural gas (m3) | 1891 | 0.49 | 0.049 |
| Heavy Fuel Oil (L) | 3080 | 0.034 | 0.064 |
| Light Fuel Oil (L) | 2830 | 0.18 | 0.013 |
| Diesel (L) | 2730 | 0.133 | 0.4 |
| Canadian Bituminous (kg) | 1852-2254 | 0.022 | 0.032 |
| US Bituminous (kg) | 2288-2432 | 0.022 | 0.032 |
| Sub- Bituminous (kg)\*\* | 1733-1765 | 0.022 | 0.032 |
| Lignite (kg) | 1424-1476 | 0.022 | 0.032 |
| Wood & Wood Waste (kg) | 0 | 0.05 | 0.02 |
| Spent Liquor (kg) | 0 | 0.05 | 0.02 |
| Landfill Gas (L) | 0 | N/A | N/A |
| Orimulsion (kg)\*\*\* | 2219 | N/A | N/A |

\* CO2 emissions from biogenic materials are considered as complement of the natural carbon cycle. CO2 emissions is emitted by the combustion of biogenic materials will return to the atmosphere where it was originally removed by photosynthesis.

\*\* Represents both domestic and imported sub-bituminous.

\*\*\* CO2 emission for Orimulsion is calculated in Appendix D.

## 4.1 Average GHG Intensity Factor (GHGIFA)

The Average GHG Intensty Factor “GHGIFA” can be defined as the average amount of GHG emissions produced as a result of generating one kWh of electricity:

[2]

where,

TGHG = total GHG emissions from electricity generation in one year (grams/year)

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

GHGIFA method neglects the transmission and distribution losses. GHGIFA 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 GHGIFA is substantially different from one province 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.

## 4.2 GHG Intensities Factor from Fossil Fuel Fired Power Plants (GHGIFM)

The GHG Intensity Factor for fossil fuel “GHGIFM” 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:

[3]

where,

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

FFNEG = net electricity generation from only fossil fuel fired power plants in one year (kWh/year)

The net electricity generation from only fossil fuel fired power plants in one year can be calculated for each provine by subtracting the transmission and distribution losses from the total electricity generated from fossil fuel power plants. The overall transmission and distribution losses for each province in Canada are given in Table 12.

Table 12. Overall transmission and distribution losses for each province in Canada [40]

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Province** | NF | PE | NS | NB | QC | ON | MB | SK | AB | BC |
| **% losses** | 9 | 6 | 4 | 6 | 4 | 6 | 12 | 6 | 4 | 3 |

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 GHGIFA represent the lower limit of the GHG emissions reduction, whereas the emission reductions predicted using the GHGIFM 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 GHGIFA and GHGIFM values for each province over the years 2004 to 2006 and the average values over this period, are presented in Table 13. These values were calculated using the latest available Statistics Canada data on electricity generation and fuels used [8-10]. The detailed data used to calculate GHGIFA and GHGIFM values for each province over 2004 to 2006 are given in Tables A1-A10 of Appendix A.

Table 13. GHGIFA and GHGIFM values (g CO2eq/kWh) over 2004-2006 and the average values over these years for each province

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2004** | | **2005** | | **2006** | | **Average over**  **2004-2006** | |
| **GHGIFA** | **GHGIFM** | **GHGIFA** | **GHGIFM** | **GHGIFA** | **GHGIFM** | **GHGIFA** | **GHGIFM** |
| **NF** | 34 | 872 | 27 | 886 | 16 | 784 | 26 | 847 |
| **PE** | 303 | 1,647 | 168 | 2,395 | 101 | 1,506 | 191 | 1,849 |
| **NS** | 740 | 865 | 740 | 890 | 719 | 762 | 733 | 839 |
| **NB** | 463 | 804 | 452 | 839 | 384 | 788 | 433 | 810 |
| **QC** | 10 | 817 | 4 | 831 | 5 | 522 | 6 | 723 |
| **ON** | 195 | 878 | 215 | 843 | 186 | 864 | 199 | 862 |
| **MB** | 14 | 1,207 | 14 | 1,288 | 11 | 1,131 | 13 | 1,209 |
| **SK** | 846 | 1,059 | 766 | 1,071 | 754 | 1,052 | 789 | 1,061 |
| **AB** | 932 | 1,022 | 887 | 982 | 944 | 1,041 | 921 | 1,015 |
| **BC** | 23 | 472 | 21 | 454 | 21 | 459 | 22 | 462 |

As it can be seen in Table 13, the values of GHGIFA and GHGIFM are highly variable from one province to another. The lowest value of GHGIFA is for Quebec where electricity generation is primarily from hydro power plants, while other provinces such as Alberta and Saskatchewan have higher values of GHGIFA due to their dependency on fossil fuel power plants

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# 5. 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:

* Weighted Annual Marginal GHG Intensity Factors
* Monthly GHG Intensity Factors based on ICF[[4]](#footnote-5) Estimates
* Monthly or Seasonal GHG Intensity Factors Estimated Based on Reported Data

In the weighted annual marginal GHG intensity factors method, the mix of the fuel sources used for marginal generation were identified for each province. The annual marginal GHG intensity factors were calculated for years 2004-2006, assuming that the fuel mix used for marginal generation has the same ratio as the mix of these fuels in the annual generation. Based on the predicted marginal fuels mix for years 2004-2006, the weighted averaging approch was used to calculate the weighted annual marginal GHG intensity factors. This method is described in detail in section 5.2.

For the monthly GHG intensity factors based on ICF estimates, the International Consulting Firm used its modelling tool Inegrated Planing Model (IPM) to identify the magnitude of and the fuels mix used for marginal electricity generation over the period of 2004-2007 on monthly basis for each province in Canada except for Prince Edward Island and Newfoundland. Based on these estimates, the predicted marginal fuel mix and the associated GHG intensity factors on a monthly basis were developed using the weighted averaging approch. This method is described in detail in section 5.3.

Finally, the monthly or seasonal GHG intensity factors were estimated based on reported data, where such data were available. This approch requires more detailed data on electricity generation and fuels used as a function of time to predict the marginal GHG intensity factors. The required data are reported by electric utilities in Alberta, Ontario, and Qubece. However, the level of data particularization varies significantly among these provinces. Therefore, different methods were used to estimate the monthly or seasonly GHG intensity factors in each province. This method is described in detail in section 5.4.

The three methods presented here and the marginal GHG intensity factors calculated using these three methods reflect the current mix of fuels used in the electricity sectors of the Canadian provinces. As such, considering the rate at which new power plants are brought on line, the GHG intensity factors reported in this work are likely accurate in a time frame of two to five years. It is recommended that the GHG intensity factors should be recalculated and updated as new data become available.

## 5.1 GHG Intensity Factors of Fuel Sources

The values of the GHG intensity factors (g CO2eq/kWhfuel) for the fuel sources used for marginal generation in a given province are considerably different from one year to the next, due to changes in the efficiencies of the power plants that operate on margin. There are many factors that affect power plant efficiecncy, such as fuel type, load factor (i.e. full load, part load), and the technology used. Therefore, in the rest of this work, the average GHG emission intensity factors for marginal fuel sources (g CO2eq/kWhfuel) over the years of 2004 to 2006 as shown in Table 14 will be used.

Table 14. Average GHG intensity factors for the marginal fuel sources over 2004-2006

[1, 8-10]

|  |  |  |
| --- | --- | --- |
| **Province** | **Marginal Fuel Source** | **GHG Intensity Factor (g CO2eq/kWhfuel)** |
| **NF** | Oil | 817 |
| **PE** | Oil | 1,722 |
| **NS** | Heavy oil | 660 |
| Natural gas | 522 |
| US bituminous | 873 |
| **NB** | Coal | 873 |
| Oil | 814 |
| Natural gas | 474 |
| Orimulsion\* | 699 |
| **QC** | Oil | 926 |
| Natural gas | 599 |
| Wood | 4 |
| Spent liquor\* | 5 |
| Landfill gas\* | 0 |
| SK lignite | 1,098 |
| **ON** | Natural gas | 476 |
| Coal | 941 |
| Oil | 737 |
| SK lignite | 1,098 |
| US bituminous | 918 |
| **MB** | Natural gas | 751 |
| Montana sub- bituminous\*\* | 1,125 |
| **SK** | Natural gas | 558 |
| SK lignite | 1,098 |
| **AB** | Natural gas | 567 |
| Coal | 1,088 |
| Landfill gas | 0 |
| AB bituminous | 1,100 |
| **BC** | Natural gas | 445 |
| Wood | 7 |

\* All GHG intensity factors are based on the average values over 2004-2006 except for orimulsion and spent liquor. The detailed data used to calculate the emission factors for these fuels, are given in Table D1 of Appendix D. For the landfill gas, the CO2 emissions is considered as complement of the natural carbon cycle.

\*\* Montana sub-bituminous is considered as imported sub-bituminous.

## 5.2 Weighted Annual Marginal GHG Intensity Factors

Through the information that is made publicly available or has been obtained through personal communication with electric utility officers 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 15.

Table 15. Fuels used for marginal electricity generation

|  |  |  |
| --- | --- | --- |
| **Province** | **Fuels Used for Marginal Electricity Generation** | **Reference** |
| **NF** | Oil, hydro | [7] |
| **PE** | Oil, imports | [14] |
| **NS** | Natural gas, hydro, oil | [19] |
| **NB** | Coal, oil | [22] |
| **QC** | Natural gas, hydro, oil | [25] |
| **ON** | Natural gas, hydro, coal, oil | [27] |
| **MB** | Natural gas, hydro, imports | [29] |
| **SK** | Natural gas, hydro, imports | [30] |
| **AB** | Natural gas, hydro, coal | [33] |
| **BC** | Natural gas, hydro, imports | [35] |

The range of GHG emission intensity factors from marginal electricity generation based on the fuels identified in Table 15 are given in Table 16. 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 [1].

In the absence of detailed data on the amounts of marginal electricity generated from each fuel, it 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.

[4]

where,

MEGMFi = marginal electricity generation using marginal fuel i (MWh)

TEGMFi = total electricity generation using marginal fuel i (MWh)

n = number of fuels used for marginal electricity generation

Table 16. Range and annual marginal GHG intensity factors over 2004-2006, and the weighted annual marginal GHG intensity factors (g CO2eq /kWh)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Year** | **Range GHG Intensity Factor** | **Annual Marginal GHG Intensity Factor** | **Weighted Annual Marginal GHG Intensity Factor** |
| **NF** | 2004 | 0 ~ 792 | 33 | 22 |
| 2005 | 0 ~ 801 | 26 |
| 2006 | 0 ~ 857 | 15 |
| **PE** | 2004 | 0 ~ 1,475 | 11 | 6 |
| 2005 | 0 ~ 2,277 | 7 |
| 2006 | 0 ~ 1,416 | 3 |
| **NS** | 2004 | 0 ~ 763 | 501 | 360 |
| 2005 | 0 ~ 763 | 459 |
| 2006 | 0 ~ 453 | 212 |
| **NB** | 2004 | 795 ~ 870 | 820 | 837 |
| 2005 | 809 ~ 887 | 835 |
| 2006 | 838 ~ 863 | 850 |
| **QC** | 2004 | 0 ~ 796 | 10 | 7 |
| 2005 | 0 ~ 843 | 4 |
| 2006 | 0 ~ 1,141 | 5 |
| **ON** | 2004 | 0 ~ 943 | 397 | 407 |
| 2005 | 0 ~ 927 | 435 |
| 2006 | 0 ~ 953 | 408 |
| **MB** | 2004 | 0 ~ 711 | 2 | 1 |
| 2005 | 0 ~ 796 | 0 |
| 2006 | 0 ~ 744 | 1 |
| **SK** | 2004 | 0 ~ 563 | 243 | 225 |
| 2005 | 0 ~ 562 | 254 |
| 2006 | 0 ~ 549 | 199 |
| **AB** | 2004 | 0 ~ 1,075 | 947 | 937 |
| 2005 | 0 ~ 1,052 | 905 |
| 2006 | 0 ~ 1,136 | 965 |
| **BC** | 2004 | 0 ~ 455 | 20 | 18 |
| 2005 | 0 ~ 436 | 19 |
| 2006 | 0 ~ 445 | 16 |

The annual marginal GHG intensity factors are calculated based on the fuel percentages and the GHG emission intensity factors for each fuel as shown in Equation 5:

[5]

where:

[6]

Using the latest available Statistics Canada data on electricity generation and fuels used [8-10], and the GHG intensity factors for each fuel (g CO2eq/kWhfuel) used for marginal generation in each province, the range of and the annual marginal GHG intensity factors for the years 2004 to 2006 were calculated. These are presented in Tables B1-B10 of Appendix B.

Since the marginal fuel mix was estimated for the years of 2004 to 2006, and since the electricity supply mix changes from year to year with the new power plants added to the grid whether due to the retirement of the old power plants or the increase in electricity demand, to predict the fuel mix used for marginal generation, a weighted averaging approach, as described in Equation 7, is used here.

[7]

The weighted averaging approach described by Equation 7 assumes that the recent years have a higher contribution to predict the future fuel mix than that of the earlier years. The predicted marginal fuel mix according to Equation 7 is given in Table B11 of Appendix B. Using the predicted marginal fuel mix according to Equation 7, and the GHG intensity factors in Table 14, the weighted annual marginal GHG intensity factors were calculated using Equation 5. The annual marginal GHG intensity factors over the years of 2004 to 2006, as well as the weighted annual marginal GHG intensity factors are presented in Table 16.

The range of the GHG intensity factors given in Table 16 provides the lower and upper limits of the GHG intensity factors over the year based on the marginal fuel mix for each province. Therefore, for British Columbia, Saskatchewan, and Manitoba, the lower limit of the marginal GHG intensity factor (0 g CO2eq/kWh) reflects the emission factor for imported electricity or hydroelectric generation, whereas the lower limit (0 g CO2eq/kWh) for Alberta, Ontario, Quebec, Nova Scotia and Newfoundland reflect the emission factor for hydroelectric generation. The lower limit (0 g CO2eq/kWh) for Prince Edwerd Island reflects the emission factor for imported electricity. On the other hand, the upper limit of the marginal GHG intensity factor is obtained when 100% of the marginal generation comes from the fuel that has the highest GHG intensity factor. For example, the upper limits for British Columbia, Saskatchewan and Manitoba in 2005 (436, 562, 796 g CO2eq /kWh, respectively) are due to 100% nutaral gas on margin, whereas for Quebec, Nova Scotia, Prince Edward Island and Newfoundland, the upper limits reflect 100% oil on the margin. For Alberta, Ontario and New Brunswick, the upper limit reflects 100% coal on the margin.

## 5.3 Monthly GHG Intensity Factors based on ICF Estimates

In 2003, Environment Canada contracted International Consulting Firm (ICF) to conduct an analysis of electricity dispatch in Canada [41]. The objectives of this study were as follows:

- Project generation source dispatch order over 2004, 2005, 2006, and 2007.

- Calculate the marginal GHG intensities factors for each province on a monthly basis which can be used to quantify displaced GHG emissions.

Using its modelling tool "Integrated Planning Model (IPM)", ICF prepared monthly estimates of the magnitude of the marginal electricity generation (MWh) and the fuel mix used for the marginal generation over the period of 2004-2007 for each province except Prince Edward Island and Newfoundland[[5]](#footnote-6).

Based on IPM assessments of the total monthly generation on margin and the percentages of fuel sources setting those capacities, the monthly marginal emissions intensities (g CO2eq/kWh) for each province were calculated. The emission intensity for each fuel (g CO2eq /kWh fuel) was calculated based on the heat rate of the capacity on margin and the energy content of the fuel used as shown in Equation 8.

[8]

The marginal GHG intensity factor for each month can be obtained by multiplying the GHG emission intensity factor for each fuel on margin by the percent generation on margin for the capacity type as shown in Equation 9.

[9]

where:

n = the number of the fuel sources on the margin

The estimates obtained in the ICF study are summarized in Figures C1-C16 of Appendix C. The conclusions of the ICF study can be summarized as follows:

* In British Columbia, biomass is the main fuel used on the margin with some instances of NG and imports used in the highest demand period in the winter months.
* Alberta has a winter peaking load that is supplied by coal fired power plants. In the summer months, NG and coal are used on the margin.
* In Saskatchewan, coal supplies the marginal capacity with the assistance of U.S imports and NG.
* Manitoba’s marginal capacity is provided by coal, except in the peak months of December and January when the demand becomes high enough to require U.S imports.
* Ontario has a diverse fuel mix on the margin with coal and U.S imports providing the largest contribution on the margin.
* Quebec relies mainly on biomass and landfill gas on the margin, with US imports during high demand periods.
* New Brunswick depends mostly on Orimulsion and US imports on the margin.
* Nova Scotia is predominantly powered by coal on the margin with some instances of natural gas.

The mix of fuel sources used for the marginal generation in each province based on ICF estimates are given in Table 17.

Table 17. Fuels used for marginal electricity generation based on ICF estimates [41]

|  |  |
| --- | --- |
| **Province** | **Fuel used for Marginal Generation** |
| **NS** | Natural gas, coal |
| **NB** | Orimulsion, natural gas, imports |
| **QC** | Wood & wood waste, spent liquor, imports, landfill gas, coal |
| **ON** | Coal, oil, natural gas, imports |
| **MB** | Coal, imports |
| **SK** | Natural gas, coal, imports |
| **AB** | Natural gas, landfill gas, coal |
| **BC** | Natural gas, wood & wood waste, imports |

Since the estimates developed by ICF cover a period of four years (2004-2007), and to develop representative estimates of the fuel mix used for marginal generation and the GHG intensity factor in each province for each month, a weighted averaging approach, as described in Equation 10, is used here.

[10]

As in the case of Equation 7, Equation 10 assumes that the recent years have a higher contribution to predict the fuel mix than that of earlier years.

Based on the predicted monthly fuel mix according to Equation 10, and the GHG emission factors given in Table 14, the monthly GHG intensity factors based on ICF estimates were calculated using Equation 9. The weighted ICF estimates are presented in Table D2-D9 in Appendix D. The predicted fuel percentages as well the fuel percentages over the years of 2004 to 2007 are plotted in Figures E1-E26 in Appendix E.

The monthly GHG intensity factors (g CO2eq/ kWh) for each province based on these representative estimates calculated using Equation 9, are given in Table 18.

Table 18. The monthly GHG intensity factors (g CO2eq/ kWh) for each province based on ICF estimates

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Month** | **NS** | **NB** | **QC** | **ON** | **MB** | **SK** | **AB** | **BC** |
| **Jan.** | 670 | 638 | 2 | 16 | 675 | 851 | 567 | 445 |
| **Feb.** | 693 | 697 | 4 | 518 | 1,125 | 882 | 567 | 445 |
| **Mar.** | 557 | 699 | 2 | 764 | 1,125 | 762 | 567 | 445 |
| **Apr.** | 575 | 699 | 4 | 905 | 1,125 | 329 | 567 | 124 |
| **May** | 867 | 699 | 4 | 701 | 1,125 | 110 | 567 | 167 |
| **Jun.** | 811 | 699 | 4 | 992 | 1,125 | 882 | 617 | 7 |
| **Jul.** | 745 | 699 | 4 | 995 | 1,125 | 882 | 855 | 9 |
| **Aug.** | 758 | 699 | 4 | 795 | 1,125 | 882 | 867 | 7 |
| **Sep.** | 673 | 699 | 5 | 15 | 1,125 | 746 | 640 | 46 |
| **Oct.** | 677 | 699 | 4 | 545 | 1,125 | 880 | 567 | 12 |
| **Nov.** | 659 | 699 | 4 | 0 | 675 | 558 | 567 | 126 |
| **Dec.** | 589 | 655 | 126 | 8 | 0 | 568 | 567 | 317 |

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## 5.4 Monthly or Seasonal GHG Intensity Factors Estimated Based on Reported Data

To predict monthly or seasonal GHG intensity factors, detailed data are needed from utilities on electricity generation and fuels used as a function of time. However, in Canada data on electricity generation and fuels used are reported by utilities only in Alberta, Ontario, and Quebec, and the level of particularization of data varies amongst these provinces. In the following sections, first a review of the data available for each one of these provinces is presented. This is followed by the presentation of the methods developed based on the reported data to estimate the monthly or seasonal marginal GHG intensity factors for those provinces over the next few years.

### 5.4.1 Data Available on Marginal Electricity Generation and Fuels Used

#### 5.4.1.1 Alberta

As of February 2008, the installed capacity in Alberta as reported by Alberta Electric System Operator (AESO) [31] is as follows:

* Coal: 5,893 MW
* Natural gas: 4,635 MW
* Hydroelectric: 869 MW
* Wind: 497 MW
* Other renewable: 178 MW
* Total: 12,072 MW

The deregulated electric utility sector in Alberta provides detailed data on generation and fuels used through the AESO. AESO has on its website a report that identifies the mix of the fuel sources used for marginal generation [33]. Based on this report, the marginal generation in Alberta comes mainly from three fuel sources: coal, gas and hydro-power. The seasonal percentages of each fuel source on margin for the period 2004 to 2006 are given in Table 19.

Table 19. Seasonal percentages of the fuel mix used on margin over 2004-2006 in Alberta [33]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **2004** | **Summer (%)** | | **Winter (%)** | | **Shoulder (%)** | |
| Peak\* | Off Peak\* | Peak\* | Off Peak\* | Peak\* | Off Peak\* |
| Coal | 20.1 | 54.0 | 34.8 | 64.3 | 23.9 | 54.1 |
| Gas | 78.2 | 44.5 | 64.7 | 34.8 | 75.8 | 45.6 |
| Hydro | 1.7 | 1.5 | 0.6 | 1.0 | 0.3 | 0.3 |
| **2005** | **Summer (%)** | | **Winter (%)** | | **Shoulder (%)** | |
| Peak | Off Peak | Peak | Off Peak | Peak | Off Peak |
| Coal | 42.8 | 71.4 | 32.0 | 62.4 | 39.9 | 71.6 |
| Gas | 51.5 | 25.6 | 66.4 | 36.9 | 59.6 | 27.9 |
| Hydro | 5.7 | 3.0 | 1.6 | 0.7 | 0.5 | 0.4 |
| **2006** | **Summer (%)** | | **Winter (%)** | | **Shoulder (%)** | |
| Peak | Off Peak | Peak | Off Peak | Peak | Off Peak |
| Coal | 37.0 | 65.6 | 51.8 | 73.6 | 36.9 | 68.8 |
| Gas | 59.7 | 33.4 | 47.7 | 26.2 | 61.7 | 30.6 |
| Hydro | 3.2 | 1.0 | 0.6 | 0.2 | 1.4 | 0.6 |

\*Peak times are considered as business days except Alberta statutory holidays, and off peak times are considered as all other times

Summer months include June, July, August and September, whereas winter months include November, December, January and February. The rest of the year, which is March, April, May and October, comprises the shoulder months. Peak periods occur on business days, whereas off peak periods include all other times. Based on this information, it can be seen that coal and gas play a significant role in supplying the marginal generation, whereas hydro resources correspond to a small portion of the marginal generation over the period 2004-2006.

AESO forecasts that the Alberta peak load will be substantially increasing over the next ten years . Alberta peaking load will increase by 3,280 MW from 9,580 MW in 2005 to reach 12,860 MW by 2016, as a result of an annual average growth rate of 2.6%. Based on this forecasting and due to the retirement of some power plants, about 2,300 MW of additional generating capacity is expected to be added to the grid by 2011 and 4,100 MW by 2016.

Alberta’s electricity generation comes mainly from coal, natural gas, hydro, and wind, and in small quantity from small generators. The capacity addition projections provided by AESO [42] for each one of the major fuels can be summarized as follows:

Coal: There are currently seven coal power plants operating in Alberta with a total capacity of 5,893 MW. It is projected that about 80 MW of coal capacity will be added by 2011 and further 80 MW between 2012 and 2016 as result of upgrading the existing coal power plants.

Natural Gas: Over the past ten years, about 3,500 MW of new generation capacity was added to the Alberta system. Of this total, about 2,500 MW was in the form of natural gas fired power plants consisting of gas turbine, combined cycle and cogeneration power plants. It is projected that 245 MW of peaking gas turbine capacity will be installed over the period of 2007 to 2010, an additional 300 MW new peaking capacity by 2011, and 100 MW by 2016.

Hydro: In addition to the existing 869 MW in hydro resources, about 100 MW of hydro capacity is projected to be added by 2012. This addition is projected to contribute 50 MW at peak time.

Wind: In addition to the existing 497 MW wind capacity; there is about 3,000 MW new generation under the development. An additional 600 MW of wind capacity will be installed by 2011, and another 600 MW by 2016, bringing the total installed wind capacity to 1,500 MW by 2016.

Others: Of the 3,500 MW of new capacity that has been added to the system since 1996, approximately 20% was from small generators (smaller than 50 MW), most of which are natural gas fired, and a small number of biomass fired power plants. It is projected that new small-scale capacity additions will add 50 MW to the system by 2011 and another 50 MW between 2011 and 2016.

Oil sands cogeneration: these cogenerations will contribute by 50 MW in 2011 and further 100 MW by 2016; however most of the cogenerations will be converted to use natural gas rather than oil sands and coke.

Based on this review of existing and forecasting electricity generation resources, the new generation capacity that will be added to the system in Alberta over the next ten years is summarized in Table 20.

Table 20. Current and the new projected generation capacity in Alberta by 2016

|  |  |  |  |
| --- | --- | --- | --- |
| Source | Installed capacity in 2008  (MW) | Projected additional capacity (MW) | Year |
| Coal | 5,893 | 80 | 2011 |
| 80 | 2016 |
| Gas | 4,635 | 300 | 2011 |
| 100 | 2016 |
| Hydro | 869 | 100 | 2012 |
| Wind | 497 | 600 | 2011 |
| 600 | 2016 |
| Other | - | 50 | 2011 |
| 50 | 2016 |
| Oil sands | - | 50 | 2011 |
| 100 | 2016 |

#### 5.4.1.2 Ontario

In Ontario, the Independent Electricity System Operator (IESO) forecasts the provincial electricity demand to ensure that the existing and the proposed generation are sufficient to meet Ontario’s electricity needs. As of September 2008, the installed capacity in Ontario as reported on the IESO website [43] is as follows:

* Nuclear: 11,426 MW
* Hydroelectric: 7,730 MW
* Coal: 6,434 MW
* Oil and natural gas: 5,499 MW
* Wind: 504 MW
* Biomass: 75 MW
* Total: 31,668 MW

Ontario base load is generated mainly from nuclear and hydro resources, while the intermediate and peak loads are supplied by coal, natural gas, oil, and hydroelectric generators with storage. However, Ontario’s government is committed to replace the existing coal capacity in the province starting in 2007 and ending in 2014 [44, 45]. In 2008, IESO forecasted that more than 5,000 MW of new and upgraded supply is scheduled to be added to the grid over the next one and a half years to meet the provincial demand. It is projected that the additional capacity will be distributed as follows:

* Natural gas: 2,800 MW
* Refurbished nuclear: 1,500 MW
* Hydro: 100 MW
* Wind: 600 MW

In addition to the 5,000 MW projected additional capacity, the Ontario’s imported electricity is expected to increase up to 750 MW over the same period [43].

Based on this review of existing and forecasting electricity generation resources, the new generation capacity that will be added to the system in Ontario by 2010 is summarized in Table 21.

Table 21. Ontario’s current and the new projected generation capacity (MW) by 2010

|  |  |  |
| --- | --- | --- |
| **Source** | **Installed capacity in 2008** | **Projected additional capacity by 2010** |
| Nuclear | 11,426 | 1,500 |
| Hydro | 7,730 | 100 |
| Coal | 6,434 | - |
| Oil & natural gas | 5,499 | 2,800 \* |
| Wind | 504 | 600 |
| Biomass | 75 | - |
| Import | - | 750 |

\*The additional 2,800 MW will be generated from only natural gas power plants

In addition to forecasting electricity demand of the province, the IESO publishes on its website the hourly data on electricity generation and fuels used [46]. The hourly data has been obtained over the period of 2007 to 2008 through a personal communication with IESO [47]. To visualize the hourly data on electricity generation and fuels used, the data for the period of April 1-8, 2008 obtained from Ontario’s IESO are plotted in Figure 7.

As it can be seen in Figure 7, during the period April 1-8, 2008, nuclear power plants operated close to their full capacities continuously (i.e. they were operated as base load plants), while the generation output of hydro, coal and others (oil and gas) fluctuated with time, indicating that these power plants were used to supply the marginal load for the province. The data over the period of 2007 to 2008 were analyzed to determine the fuel sources used for marginal generation and the percentages of these fuels in order to develop monthly GHG intensity factor. The results are presented in section 5.4.2.2.

Figure 7. Electrical generation energy source components for Ontario for April 1-8, 2008 [47]

#### 5.4.1.3 Quebec

In Quebec, most of the electricity generation is from hydro resources. For example, in 2007, hydroelectricity supplied about 97.2% of the total electricity generation, up from 95.6% in 2005. The installed capacity for 2007 as reported by Hydro Quebec [48] is as follows:

* Hydroelectric: 33,305 MW
* Nuclear: 675 MW
* Thermal: 1,665 MW
* Wind: 2 MW
* Total: 35,647 MW

The development of hydro resources is continuing at a steady pace, with new hydro projects constructed in the last a few years and some still under construction or under study. About 2,015 MW of additional hydro capacity is projected to be added by 2010 when the electricity demand is expected to exceed the available generating capacity. A further 3,173 MW will be added by 2019. About 4,000 MW of wind capacity is expected to be added to the grid between 2006 and 2015 to represent about 10% of the installed capacity [49]. The nuclear power station in the province is expected to be upgraded by 2011 to continue its operation for the next 40 years [50].

Based on this review of existing and forecasting electricity generation resources, the new generation capacity that will be added to the system in Quebec by 2019 is summarized in Table 22.

Table 22. Current and the new projected generation capacity in Quebec by 2019

|  |  |  |  |
| --- | --- | --- | --- |
| **Source** | **Installed capacity in 2008 (MW)** | **Projected additional capacity (MW)** | **Year** |
| Hydro | 5,893 | 2,015 | 2010 |
| 3,173 | 2019 |
| Nuclear | 4,635 | - | - |
| Thermal | 869 | - | - |
| Wind | 497 | 4,000 | 2015 |

As stated by Hydro Quebec officers [25], the marginal generation in the province comes from hydro resources except during the coldest days, which normally occur in January. During the coldest days, thermal generating stations are used to meet the extra demand. During these days, the Tracy oil fired thermal power plant, which has a generating capacity of 600 MW, is operated for two weeks per year on average, whereas the natural gas power plant Becancour, which has a 428 MW capacity, is used approximately for 200 hours per year, and other thermal power plants work approximately 20 hours per year.

### 

### 5.4.2 Methods Developed to Estimate Monthly or Seasonal GHG Intensity Factors

#### 5.4.2.1 Alberta

Based on the reported data on the fuel sources used for marginal generation over the period of 2004-2006 (coal, gas, and hydro), the marginal generation in Alberta in the near future is assumed to be generated from coal, gas, and hydro. The fuel mix on the margin is estimated using seasonal marginal fuel mix over 2004-2006 and the weighted averaging approach described in Equation 11, which assigns a higher contribution to recent years to predict the fuel mix ( as in Equation 7 and 10).

[11]

The seasonal percentages of each fuel source on margin based on Equation 11 are given in Table 23. As it can be seen, natural gas provides most of the marginal capacity during peak period where the coal provides most of the marginal capacity during off peak period.

Table 23. Predicted seasonal percentages of the fuel mix used on margin in Alberta

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Summer (%)** | | **Winter (%)** | | **Shoulder (%)** | |
| Peak\* | Off Peak\* | Peak\* | Off Peak\* | Peak\* | Off Peak\* |
| Coal | 35.4 | 65.0 | 42.5 | 68.4 | 35.2 | 66.7 |
| Gas | 60.9 | 33.3 | 56.7 | 31.1 | 63.9 | 32.8 |
| Hydro | 3.7 | 1.7 | 0.9 | 0.5 | 0.9 | 0.5 |

\*Peak times are considered as business days except Alberta statutory holidays, and off peak times are considered as all other times

Peak times are business days, which are approximately 21 days per month and off peak times, include all other times, which are approximately 9 days per month . Therefore, the prediction of marginal GHG intensity factors (g CO2eq/kWh) for each season can be calculated as shown in Equation 12 using the fuel percentages given in Table 23 and the emission intensity factors for each fuel on margin.

[12]

where:

21 = number of peak days per month

9 = number of off peak days per month

30 = number of days per month (peak days plus off peak days)

The marginal GHG intensity factors for each season based on Equation 12 are given in Table 24.

Table 24. Predicted seasonal marginal GHG intensity factors (g CO2eq/kWh) for Alberta

|  |  |  |  |
| --- | --- | --- | --- |
| **Season** | **Summer** | **Winter** | **Shoulder** |
| Marginal GHG intensity factor | 769 | 591 | 785 |

#### 5.4.2.2 Ontario

Hourly data on the electricity generation and fuels used in Ontario were obtained for the period of 2007 to 2008. A technique was developed to identify the energy sources that are on the margin 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 from one hour to the next was set to 250 MW for consideration of marginal sources. If the change is less than 250 MW, the change is ignored. The choice of 250 MW is to eliminate the wind generation from the margin where its output can be variable from 0 MW up to 250 MW from hour to hour depending on the availability of the wind.
* A marginal energy source must contribute at least 20% of the change in total generation to be considered of significance and to eliminate possible noise.
* 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.

Based on these assumptions, the hourly marginal energy sources were averaged over individual days for the period of April 1-8, 2008 to identify the significant components. These daily average marginal generation energy source components are shown in Figure 8.

Figure 8. Energy sources for the marginal electricity generation in Ontario for April 1-7, 2008

As it can be seen, 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 7. As expected, at no point during the period of April 1-8, 2008 is nuclear or wind on the margin.

The same technique was applied to the data over 2007-2008 to identify the energy sources that are on the margin. The results obtained from this analysis were analogous to the result obtained for April 1-7, 2008 with coal and hydro providing a significant portion of the marginal generation, and the remainder coming from natural gas. The hourly marginal generation for each energy source was averaged over individual months to identify the monthly fuel mix on the margin. The monthly average marginal generation energy source components, as well as the marginal GHG intensity factors (g CO2eq/kWh) calculated using Equation 9 over the period of 2007 to 2008, are given in Table 25.

Table 25. Monthly average marginal generation energy source components and marginal GHG intensity factors for Ontario (g CO2eq/kWh) over 2007-2008

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2007** | | | | | **2008** | | | | |
| **Month** | **Hydro**  **%** | **Nuclear**  **%** | **Other**  **%** | **Coal**  **%** | **Marginal GHG intensity factor** | **Hydro**  **%** | **Nuclear**  **%** | **Other**  **%** | **Coal**  **%** | **Marginal GHG intensity factor** |
| **Jan.** | 54 | 1 | 14 | 32 | 366 | 51 | 0 | 10 | 39 | 415 |
| **Feb.** | 57 | 0 | 24 | 19 | 293 | 52 | 1 | 11 | 36 | 391 |
| **Mar.** | 57 | 2 | 20 | 21 | 293 | 55 | 1 | 13 | 31 | 354 |
| **Apr.** | 52 | 2 | 8 | 38 | 396 | 42 | 0 | 8 | 50 | 509 |
| **May** | 50 | 1 | 9 | 40 | 419 | 39 | 0 | 4 | 57 | 555 |
| **Jun.** | 38 | 1 | 16 | 45 | 500 | 35 | 0 | 19 | 46 | 523 |
| **Jul.** | 45 | 1 | 12 | 42 | 452 | 37 | 0 | 17 | 46 | 514 |
| **Aug.** | 35 | 0 | 27 | 38 | 486 | 44 | 0 | 7 | 49 | 494 |
| **Sep.** | 40 | 0 | 18 | 42 | 481 | 47 | 0 | 13 | 40 | 438 |
| **Oct.** | 39 | 1 | 21 | 39 | 467 | 46 | 0 | 12 | 42 | 452 |
| **Nov.** | 47 | 1 | 17 | 35 | 410 | 52 | 0 | 20 | 28 | 359 |
| **Dec.** | 49 | 1 | 19 | 31 | 382 | 52 | 0 | 19 | 29 | 363 |

The monthly average marginal generation energy source components are shown in Figure 9. As it can be seen in Figure 9 and Table 25, nuclear appears as a part of the marginal generation, however its contribution is very small (about ≤ 2%) and can be neglected. Therefore, coal, hydro and natural gas (other) are considered to be on the margin

Figure 9. Energy sources for the marginal electricity generation in Ontario over 2007- 2008

On numerous occasions during the past two years, the Government of Ontario has indicated that Ontario is committed to replacing the existing coal fired generating stations by natural gas, hydro and renewable. The time frame for the replacement is reported to be the end of 2014. Based on that, two scenarios are used here to predict the marginal monthly GHG intensities for Ontario:

**Scenario 1**: The fuel mix on the margin is estimated using the monthly average marginal fuels mix over 2007-2008 and the weighted averaging approach described in Equation 13.

[13]

Using the predicted fuel mix according to Equation 13 and the GHG intensity factors for marginal fuel sources in Table 14, the monthly marginal GHG intensity factors (g CO2eq/kWh)were calculated using Equation 9. The predicted marginal fuel sources, as well as the marginal GHG intensity factors (g CO2eq/kWh) are given in Table 26.

Table 26. Predicted marginal fuel sources and the marginal GHG intensity factors for Ontario, Scenario #1

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Month** | **Hydro %** | **Nuclear %** | **Other %** | **Coal %** | **Marginal GHG intensity factor** |
| **Jan.** | 52 | 0 | 11 | 36 | 395 |
| **Feb.** | 54 | 1 | 16 | 29 | 352 |
| **Mar.** | 56 | 1 | 16 | 27 | 329 |
| **Apr.** | 46 | 1 | 8 | 45 | 463 |
| **May** | 43 | 0 | 6 | 50 | 501 |
| **Jun.** | 36 | 0 | 18 | 46 | 514 |
| **Jul.** | 40 | 0 | 15 | 44 | 489 |
| **Aug.** | 40 | 0 | 15 | 45 | 491 |
| **Sep.** | 44 | 0 | 15 | 41 | 455 |
| **Oct.** | 43 | 0 | 16 | 41 | 458 |
| **Nov.** | 50 | 0 | 19 | 31 | 379 |
| **Dec.** | 51 | 0 | 19 | 30 | 371 |

**Scenario 2**: The Government of Ontario has announced to replace the existing coal capacity starting from 2007 and to end by 2014, and to add about 5,000 MW of new generating capacity to the grid by 2010 with 2,800 MW from natural gas and 100 MW from hydro resources.

Based on this information, the marginal coal capacity will be assumed to be replaced by natural gas and hydro resources by the end of 2014. The contribution of natural gas and hydro in replacing the coal capacity on margin will be based on their additional capacity as shown in Table 27.

Table 27. New additional capacity in Ontario from hydro and natural gas

|  |  |  |
| --- | --- | --- |
| **Fuel Source** | **(MW)** | **NG: Hydro** |
| Hydro | 100 | 0.034 |
| Natural gas | 2,800 | 0.966 |
| Total | 2,900 | 1 |

Therefore, 3.4% of the predicted marginal coal capacity in Table 26 will be replaced by hydro resources and 96.6% will be replaced by natural gas by the end of 2014. Based on these assumptions, the marginal fuel mix and the marginal GHG intensity factors (g CO2eq/kWh) calculated using Equation 9, are given in Table 28.

Table 28. Predicted marginal fuel sources and the marginal GHG intensity factors for Ontario, Scenario #2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Month** | **Hydro %** | **Nuclear %** | **Other %** | **Marginal GHG intensity factor** |
| **Jan.** | 53 | 0 | 46 | 221 |
| **Feb.** | 55 | 1 | 44 | 211 |
| **Mar.** | 57 | 1 | 42 | 199 |
| **Apr.** | 48 | 1 | 52 | 246 |
| **May** | 45 | 0 | 54 | 259 |
| **Jun.** | 38 | 0 | 62 | 294 |
| **Jul.** | 42 | 0 | 58 | 276 |
| **Aug.** | 42 | 0 | 58 | 276 |
| **Sep.** | 46 | 0 | 54 | 259 |
| **Oct.** | 45 | 0 | 55 | 262 |
| **Nov.** | 51 | 0 | 49 | 231 |
| **Dec.** | 52 | 0 | 48 | 227 |

#### 

#### 5.4.2.3 Quebec

Based on the reported data on marginal electricity generation and fuels used that have been obtained from Hydro Quebec presented in section 5.4.1.3, the marginal generation comes primarily from hydro resources for most of the year except during the coldest days on the year which is in January, when oil and natural gas fired thermal generating stations are used with hydro to meet the peak demand. The latest available Statistics Canada data on electric power statistics [51] for January 2008 shows the components of the electricity generation (MWh) during this month which is mainly hydro, nuclear, and thermal generation. The electricity generation in (MWh) and the percentages generated from each source are shown in Table 29.

Table 29. Electricity generation (MWh) for January 2008 in Quebec [51]

|  |  |  |
| --- | --- | --- |
| **Source** | **MWh** | **% Generation** |
| Hydro | 16,877,926 | 96.8 |
| Steam-nuclear | 425,985 | 2.4 |
| Total thermal | 127,701 | 0.7 |
| Total | 17,431,612 | 100 |

Based on this information, the contribution of the thermal generation (oil and natural gas) on January’s marginal capacity was liberally assumed to be five times of the thermal generation contribution during this month. Since the rest of the marginal capacity comes from hydro resources the marginal generation capacity for January is assumed to be as follows:

Thermal generation = 5 \* 0.7% = 3.7 %

Hydro generation = 100 – 3.7% = 96.3%

The contribution of oil and natural gas to the thermal marginal generation in January will be based on their contribution to annual electricity generation. Using the latest available Statistics Canada data on electricity generation and fuels used for 2006 [10], the ratio of oil generation to natural gas generation can be calculated as shown in Table 30.

Table 30. MWh generated from oil and natural gas in Quebec in 2006 [10]

|  |  |  |
| --- | --- | --- |
| **Fuel Source** | **(MWh)** | **Oil:NG** |
| Oil | 135,020 | 0.08 |
| Natural gas | 1,471,377 | 0.92 |
| Total | 1,606,397 | 1 |

Based on this, the mix of oil and natural gas in the marginal generation for January can be predicted as follows:

The contribution of oil and natural gas to marginal electricity generation in January:

Oil on margin = 3.7 \* 0.08 = 0.30%

Natural gas on margin = 3.7 \* 0.92 = 3.40%

The marginal GHG intensity factor for January can be calculated based on the predicted marginal fuel mix and their GHG intensity factors, using Equation 9. For the rest of the year, the marginal generation is 100% from hydro resources with zero GHG emissions. The predicted marginal fuel mix and the associated marginal GHG intensity factors for Quebec are given in Table 31.

Table 31. Predicted marginal fuel mix and the associated marginal GHG intensity factors for Quebec

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Month** | **Oil %** | **Natural gas %** | **Hydro %** | **Marginal GHG intensity factor** |
| **Jan.** | 0.3 | 3.4 | 96.3 | 23 |
| **Feb. ~ Dec.** | - | - | 100 | 0 |

# 6. RESULTS AND DISCUSSION

In this work, five different methods to predict the GHG emissions reductions due to electricity savings in the residential sector of each province of Canada were presented and discussed. These methods are:

* Average GHG intensity factor (GHGIFA)
* GHG intensity factor from fossil fuel power plants (GHGIFM)
* Weighted annual marginal GHG intensity factors
* Monthly GHG intensity factors based on ICF estimates
* Monthly or seasonal GHG intensity factors estimated based on reported data

The first two methods are based on a previous work that utilized the GHGIFA and the GHGIFM to calculate the GHG emission from electricity generation [38, 39]. The other three methods proposed and developed in this work are based on the limited available data on fuel sources used for marginal electricity generation in each province on an annual, seasonal, and monthly basis. A qualitative comparison of all five methods is presented Table 32.

As it was discussed in the previous chapter, and as shown in Table 32, there is no data available on the magnitude of the marginal electricity generation except the predictions presented by ICF [41].

To demonstrate the magnitude of the differences between these methods, the values of the GHG intensity factors calculated based on each method are presented in Table 33 and plotted in Figures 10-19. (Note: In all figures of this section, data points are connected with lines to make the graphs, and the trends, easier to read. The lines have no other purpose as there are no data in between discrete data points).

Table 32. Comparison of the five methods that can be used to predict the GHG emission reductions due to electricity savings in the residential sector

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | | **Methods proposed in this work** | | | **Previously available methods** | |
| **weightedAnnual Marginal GHGIF** | **Monthly GHGIF based on ICF Estimates** | **Monthly or Seasonal GHGIF Estimated Based on Reported Data** | **GHGIFA** | **GHGIFM** |
| Provinces included | | All provinces | All provinces except PE & NF | AB, ON, QC | All provinces | All provinces |
| Fuel type on margin | NF | Oil, hydro | Not modelled | - | Fossil fuels, wood, uranium, hydro | Fossil fuels |
| PE | Oil, imports | Not modelled | - |
| NS | Natural gas, hydro, oil | Natural gas, coal | - |
| NB | Coal, oil | Natural gas, Orimulsion, imports | - |
| QC | Natural gas, hydro, oil | wood & wood waste, spent liquor, imports, landfill gas, coal | Natural gas, hydro, oil |
| ON | Natural gas, hydro, coal, oil | Coal, oil, natural gas, imports | Natural gas, hydro, coal, oil |
| MB | Natural gas, hydro, imports | Coal, imports | - |
| SK | Natural gas, hydro, import | Natural gas, coal, imports | - |
| AB | Natural gas, hydro, coal | Natural gas, landfill gas, coal | Natural gas, hydro, coal |
| BC | Natural gas, hydro, imports | Natural gas, wood & wood waste, imports | - |
| The magnitude of marginal generation (MWh) | | N/A | Estimated by using (IPM) | N/A | N/A | N/A |

Table 33. GHG intensity factors (g CO2eq/kWh) using the five different methods

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Method** | | **Weighted Annual Marginal GHGIF** | | | | **GHGIFA** | | | | **GHGIFM** | | | |
| **NF** | | 22 | | | | 26 | | | | 847 | | | |
| **PE** | | 6 | | | | 191 | | | | 1,849 | | | |
| **NS** | | 360 | | | | 689 | | | | 786 | | | |
| **NB** | | 837 | | | | 433 | | | | 810 | | | |
| **QC** | | 7 | | | | 6 | | | | 723 | | | |
| **ON** | | 407 | | | | 199 | | | | 862 | | | |
| **MB** | | 1 | | | | 13 | | | | 1,209 | | | |
| **SK** | | 225 | | | | 789 | | | | 1,061 | | | |
| **AB** | | 937 | | | | 921 | | | | 1,015 | | | |
| **BC** | | 18 | | | | 22 | | | | 462 | | | |
| **Method** | | **Monthly GHGIF based on ICF Estimates** | | | | | | | | | | | |
| **Month** | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
| **NS** | | 670 | 693 | 557 | 575 | 867 | 811 | 745 | 758 | 673 | 677 | 659 | 589 |
| **NB** | | 638 | 697 | 699 | 699 | 699 | 699 | 699 | 699 | 699 | 699 | 699 | 655 |
| **QC** | | 2 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 126 |
| **ON** | | 16 | 518 | 764 | 905 | 701 | 992 | 995 | 795 | 15 | 545 | 0 | 8 |
| **MB** | | 675 | 1,125 | 1,125 | 1,125 | 1,125 | 1,125 | 1,125 | 1,125 | 1,125 | 1,125 | 675 | 0 |
| **SK** | | 851 | 882 | 762 | 329 | 110 | 882 | 882 | 882 | 746 | 880 | 558 | 568 |
| **AB** | | 567 | 567 | 567 | 567 | 567 | 617 | 855 | 867 | 640 | 567 | 567 | 567 |
| **BC** | | 445 | 445 | 445 | 124 | 167 | 7 | 9 | 7 | 46 | 12 | 126 | 317 |
| **Method** | | **Monthly or Seasonal GHGIF Estimated Based on Reported Data** | | | | | | | | | | | |
| **Month** | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
| **AB** | | 591 | 591 | 785 | 785 | 785 | 769 | 769 | 769 | 769 | 785 | 591 | 591 |
| **ON** | **#1** | 395 | 352 | 329 | 463 | 501 | 514 | 489 | 491 | 455 | 458 | 379 | 371 |
| **#2** | 221 | 211 | 199 | 246 | 259 | 294 | 276 | 276 | 259 | 262 | 231 | 227 |
| **QC** | | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 10. The GHG intensity factors for Newfoundland based on GHGIFA, GHGIFM, and weighted annual marginal approach

Figure 11. The GHG intensity factors for Prince Edward Island based on GHGIFA, GHGIFM, and weighted annual marginal approach

Figure 12. The GHG intensity factors for Nova Scotia based on GHGIFA, GHGIFM, weighted annual marginal approach, and ICF estimates

Figure 13. The GHG intensity factors for New Brunswick based on GHGIFA, GHGIFM, weighted annual marginal approach, and ICF estimates

Figure 14. The GHG intensity factors for Quebec based on GHGIFA, GHGIFM, weighted annual marginal approach, ICF estimates, and the reported data

Figure 15. The GHG intensity factors for Ontario based on GHGIFA, GHGIFM, weighted annual marginal approach, ICF estimates, and the reported data

Figure 16. The GHG intensity factors for Manitoba based on GHGIFA, GHGIFM, weighted annual marginal approach, and ICF estimates

Figure 17. The GHG intensity factors for Saskatchewan based on GHGIFA, GHGIFM, weighted annual marginal approach, and ICF estimates

Figure 18. The GHG intensity factors for Alberta based on GHGIFA, GHGIFM, weighted annual marginal approach, ICF estimates, and the reported data

Figure 19. The GHG intensity factors for British Columbia based on GHGIFA, GHGIFM, weighted annual marginal approach, and ICF estimates

Based on this comparison, the following can be concluded:

* **General Conclusions**:

1. As seen in Table 32, the fuel sources predicted to be on the margin by ICF are substantially different than those identified in the open literature and reported by electric utilities. Therefore, the use of monthly GHG intensity factors values calculated based on the ICF estimates are not recommended to predict the GHG emission reductions due to electricity savings in the residential sector.
2. In the absence of any other data to verify the accuracy of the ICF estimates of the magnitude of marginal electricity generation, and based on conclusion #1 above, it is recommended that the ICF estimates not be used to predict the magnitude of marginal electricty generation.

* **Conclusions Specific to Each Province**

1. Newfoundland:

* In Newfoundland, the marginal electricity generation, like the total electricity generation comes mainly from hydro resources which has zero GHG emissions, and a small proportion from oil. Therefore, the magnitudes of both the GHGIFA or the GHG intensity factor predicted using the weighted annual marginal method are close to each other as seen in Figure 10.
* While the GHG intensity factor predicted using the weighted annual marginal method and the GHGIFA are very close to each other (22 and 26 g CO2eq/kWh, respectively), the GHGIFM provides a substantially higher estimate. The large difference between the predictions of the two methods and the GHGIFM is due to the fact that a very small proportion of electricity generation in Newfoundland is by fossil fuels. Consequently, the use of GHGIFM would not be realistic for Newfoundland.
* Therefore, for Newfoundland, the use of the GHG intensity factor predicted using the weighted annual marginal method is recommended here because it is based on the latest available information.

1. Prince Edward Island:

* More than 70% of the total electricity generation in Prince Edward Island comes from renewable resources, whereas more than 99% of the marginal generation comes from imported electricity with zero GHG emissions, and the remainder (less than 1%) of the marginal generation is from oil. Consequently, there is a substantial difference between GHGIFM and GHGIFA as seen in Figure 11, and GHGIFM is not applicable for marginal generation.
* Since imported electricity constitutes more than 99% of marginal generation, the weighted annual marginal GHG intensity factor which is 6 g CO2eq/kWh produces a realistic estimate.
* Therefore, it is recommended here that the weighted annual marginal GHG intensity factor is used for Prince Edward Island.

1. Nova Scotia:

* Nova Scotia relies heavily on fossil fuels for its electricity generation, therefore, the GHGIFA and GHGIFM are close to each other (689 and 786 g CO2eq/kWh, respectively) as seen in Figure 12. The GHG intensity factor predicted using the weighted annual marginal method is about 360 (g CO2eq/kWh) because about 45% of the marginal generation comes from hydro resource, and the rest from heavy oil and natural gas.
* Since the weighted annual marginal GHG intensity factor takes into consideration the mix of fuels used for marginal generation, it provides a more accurate estimate than both GHGIFA and GHGIFM.
* Therefore, it is recommended here that the weighted annual marginal GHG intensity factor is used for Nova Scotia.

1. New Brunswick:

* Although more than 40% of the total electricity generation in New Brunswick is from nuclear and hydro resoures with zero GHG emissions, the marginal generation comes mainly from coal and oil generation which have the highest GHG emission factors among the fossil fuels. Therefore, the magnitudes of both the GHGIFM and the GHG intensity factor predicted using the weighted annual marginal method are close to each other as seen in Figure 13.
* While the GHG intensity factor predicted using the weighted annual marginal method and the GHGIFM are very close to each other (837and 810 g CO2eq/kWh, respectively), the GHGIFA provides a substantially lower estimate. Consequently, the use of GHGIFA is not realistic for New Brunswick.
* Based on the information reported by New Brunswick Power officer [52], the New Brunswick Power considers 800 (g CO2eq/kWh) as a reasonable estimate for the marginal GHG intensity factor for all periods. Therefore, 800 g CO2eq/kWh is recommended for New Brunswick.

1. Quebec:

* In Quebec, the marginal electricity generation, like the total electricity generation comes mainly from hydro resources with zero GHG emissions, and a small proportion from natural gas and oil. Therefore, the magnitudes of both the GHGIFA and the GHG intensity factor predicted using the weighted annual marginal method are very close to each other as seen in Figure 14.
* While the GHG intensity factor predicted using the weighted annual marginal method and the GHGIFA are very close to each other, the GHGIFM provides a substantially higher estimate. The large difference between the predictions of the two methods and the GHGIFM is due to the fact that a very small proportion of electricity generation in Quebec is by fossil fuels. Consequently, the use of GHGIFM would not be realistic for Quebec.
* The GHG intensity factors determined based on latest available information on marginal fuels used have a value of 23 (g CO2eq/kWh) for January, and 0 (g CO2eq/kWh) for the rest of the year. The marginal generation in January comes primarily from hydro (about 96%) and the rest from natural gas and oil (4%). During the rest of the year, the marginal generation comes only from hydro resource with zero GHG emission.
* Therefore, for Quebec, the use of the GHG intensity factor predicted based on reported information is recommended here because it is based on the latest available information.

1. Ontario:

* About 75% of the electricty generation on Ontario comes from nuclear generation and hydro resources which have zero GHG emissions, the rest comes from fossil fuels. Therefore, the GHG intensity factors predicted using the GHGIFA and GHGIFM methods are a substantially different (199 and 862 g CO2eq/kWh, respectively) as seen in Figure 15. The weighted annual marginal GHG intensity factor is also within this range (407 g CO2eq/kWh) since the marginal generation comes from about 50% fossil fuels and 50% hydro resources.
* The monthly marginal GHG intensity factors determined using the houly data on electricity generation and fuels used are in the 329-514 (g CO2eq/kWh) range for Scenario #1 and 199-276 (g CO2eq/kWh) for Scenario #2[[6]](#footnote-7). The low GHG intensity factors predicted for Scenario #2 is due to the planned replacement of the existing marginal coal capacity with natural gas and hydro resources.
* Considering the higher level of accuracy of the houly data, it is recommended here that the monthly marginal GHG intensity factors determined using the houly data is used for Ontario. Since it is not known whether the Ontario government will retire coal fired power plants as it was announced, the user should decide which one of the two scenarios to use in the prediction.

1. Manitoba:

* More than 90% of the total electricity generation in Manitoba comes from hydro resources, while more than 99% of the marginal generation comes from hydro resources and imported electricity with zero GHG emissions. The remainder (less than 1%) of the marginal generation comes from natural gas. Consequently, there is a substantial difference between GHGIFM and GHGIFA as seen in Figure 16, and GHGIFM is not applicable for marginal generation.
* The GHGIFA and the weighted annual marginal GHG intensity factor are close to each other (13 and 1 g CO2eq/kWh, respectively). However, since hydro electricty and imports constitute more than 99% of marginal generation, the weighted annual marginal GHG intensity factor produces a more realistic value.
* Therefore, it is recommended here that the weighted annual marginal GHG intensity factor is used for Manitoba.

1. Saskatchewan:

* Although a substantial part of the total electricity generation in Saskatchewan is from fossil fuels, marginal generation comes mainly from hydro resources and imported electricity with zero GHG emissions, and a small amount from natural gas which has lower GHG emissions compared to coal. Therefore, both the GHGIFA and GHGIFM values shown in Figure 17 are unrealistically high and should not be used.
* The weighted annual marginal GHG intensity factor takes into consideration the mix of fuels used for marginal generation and provides a more accurate estimate than both GHGIFA and GHGIFM.

Therefore, it is recommended here that the weighted annual marginal GHG intensity factor is used for Saskatchewan.

1. Alberta:

* Alberta relies heavly on fossil fuels for its electricity generation, therefore, the GHGIFA and GHGIFM are close to each other (921 and 1,015 g CO2eq/kWh, respectively). The weighted annual marginal GHG intensity factor is also within this range (937 g CO2eq/kWh) as seen in Figure 18.
* The GHG intensity factors determined using the seasonal data on marginal fuels used are in the 769-785 (g CO2eq/kWh) range from March to October, and about 590 (g CO2eq/kWh) from November to February.
* Considering the higher level of accuracy of the seasonal data, it is recommended here that the GHG intensity factors determined using the seasonal data on marginal fuels is used for Alberta.

1. British Columbia:

* In British Columbia, the marginal electricity generation, like the total electricity generation, comes mainly from hydro resources and imported electricity which have zero GHG emissions, and a small proportion from natural gas. Therefore, the magnitudes of both the GHGIFA and the GHG intensity factor predicted using the weighted annual marginal method are close to each other as seen in Figure 19.
* While the GHG intensity factor predicted using the weighted annual marginal method and the GHGIFA are very close to each other, the GHGIFM provides a substantially higher estimate. The large difference between the predictions of the two methods and the GHGIFM is due to the fact that a very small proportion of electricity generation in British Columbia is by fossil fuels. Consequently, the use of GHGIFM would not be realistic for British Columbia.
* Therefore, for British Columdia, the use of the GHG intensity factor predicted using the weighted annual marginal method (18 g CO2eq/kWh) is recommended here because it is based on the latest available information.

Based on this discussion, the recommended GHG intensity factors for each province are given in Table 34.

Table 34. Recommended GHG intensity factors (g CO2eq/kWh) for each province

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **NF** | **PE** | **NS** | **NB** | **QC** | **ON** | | **MB** | **SK** | **AB** | **BC** |
| **Scenario #1** | **Scenario #2** |
| **Jan.** | 22 | 6 | 360 | 800 | 23 | 395 | 221 | 1 | 225 | 591 | 18 |
| **Feb.** | 0 | 352 | 211 | 591 |
| **Mar.** | 0 | 329 | 199 | 785 |
| **Apr.** | 0 | 463 | 246 | 785 |
| **May** | 0 | 501 | 259 | 785 |
| **Jun.** | 0 | 514 | 294 | 769 |
| **Jul.** | 0 | 489 | 276 | 769 |
| **Aug.** | 0 | 491 | 276 | 769 |
| **Sep.** | 0 | 455 | 259 | 769 |
| **Oct.** | 0 | 458 | 262 | 785 |
| **Nov.** | 0 | 379 | 231 | 591 |
| **Dec.** | 0 | 371 | 227 | 591 |
| **%losses** | 9 | 6 | 4 | 6 | 4 | 6 | | 12 | 6 | 4 | 3 |

The last row in Table 34 gives the overall transmission and distribution losses for each province in Canada. These values should be used to determine the GHG reductions from electricity generation in each province using Equation 14:

[14]

# 7. CASE STUDY

To show the magnitude of the differences in the GHG emission reductions predicted using the five methods discussed in this work, a case study is presented. The case study is based on the work by Guler [38, 39, 53] which assessed the energy savings due to a variety of energy efficiency improvements in the Canadian residenatial sector.

The ceiling insulation upgrade scenario is selected as the case study. In this scenario, the energy savings possible by adding ceiling insulation to the houses in the residential sector to obtain an overall thermal resistance of RSI 8.8 is predicted using the Canadian Residential Energy End-use Model - CREEM [54].

The annual electricity savings associated with ceiling insulation upgrade scenario for each province in Canada are presented in Table 35.

The annual reductions in electricity generation associated with the ceiling insulation upgrade scenario can be calculated by taking into consideration the transmission and distribution losses presented in Table 12. Thus, the annual reduction in electricity generation for each province can be calculated using Equation 15. The annual reductions in electricity generation are given in Table 35.

[15]

The monthly reductions in electricity generation associated with ceiling insulation upgrade scenario can be predicted based on the annual reductions in electricity generation in Table 35 and the monthly heating degree-days [55]. The monthly and the yearly average degree days values for each province in Canada are given in Table 36 [56].

Table 35. Annual electricity savings and annual reductions in electricity generation (MWh/year) associated with ceiling insulation upgrade scenario [38, 39, 51]

|  |  |  |  |
| --- | --- | --- | --- |
| **Province** | **Annual electricity savings** | **Transmission and distribution losses %** | **Annual reduction in electricity generation** |
| **NF** | 90,909 | 9 | 99,900 |
| **PE** | 2,433 | 6 | 2,588 |
| **NS** | 59,946 | 4 | 62,443 |
| **NB** | 134,969 | 6 | 143,584 |
| **QC** | 1,000,000 | 4 | 1,041,667 |
| **ON** | 492,647 | 6 | 524,093 |
| **MB** | 90,909 | 12 | 103,306 |
| **SK** | 35,176 | 6 | 37,421 |
| **AB** | 26,059 | 4 | 27,144 |
| **BC** | 135,135 | 3 | 139,315 |

Table 36. Monthly average degree days (18 ºC base) and yearly total for each province in Canada [54]

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Jan.** | **Feb.** | **Mar.** | **Apr.** | **May** | **Jun.\*** | **Jul.\*** | **Aug.\*** | **Sep.** | **Oct.** | **Nov.** | **Dec.** | **Yearly total** |
| **NF** | 821 | 765 | 706 | 511 | 348 | 0 | 0 | 0 | 199 | 387 | 532 | 724 | 4993 |
| **PE** | 767 | 713 | 651 | 478 | 308 | 0 | 0 | 0 | 130 | 305 | 448 | 645 | 4446 |
| **NS** | 743 | 668 | 604 | 421 | 256 | 0 | 0 | 0 | 124 | 301 | 449 | 645 | 4231 |
| **NB** | 865 | 741 | 634 | 411 | 217 | 0 | 0 | 0 | 154 | 340 | 507 | 752 | 4620 |
| **QC** | 958 | 812 | 703 | 442 | 218 | 0 | 0 | 0 | 173 | 368 | 564 | 828 | 5065 |
| **ON** | 1297 | 1088 | 975 | 632 | 377 | 0 | 0 | 0 | 304 | 518 | 813 | 1188 | 7191 |
| **MB** | 1107 | 886 | 770 | 440 | 226 | 0 | 0 | 0 | 214 | 426 | 740 | 1008 | 5816 |
| **SK** | 1065 | 881 | 732 | 431 | 221 | 0 | 0 | 0 | 223 | 423 | 711 | 993 | 5681 |
| **AB** | 835 | 680 | 618 | 401 | 252 | 0 | 0 | 0 | 218 | 392 | 631 | 787 | 4814 |
| **BC** | 847 | 701 | 617 | 444 | 309 | 0 | 0 | 0 | 237 | 418 | 600 | 758 | 4931 |

\* The monthly average degree day for the summer months ( June, July, August) are asummed to be zero since no space heating is being used in these months.

Based on the annual reductions in electricity generation given in Table 35 and monthly average and yearly degree day values in Table 36, the monthly reductions in electricity generation associated with ceiling insulation upgrade scenario can be predicted using Equation 16. The predicted monthly reductions in electricity generation are given in Table 37.

[16]

where:

AREG = annual reduction in electricity generation (MWh/year)

DDm = monthly degree days

DDy = yearly total degree days

Table 37. The predicted monthly reductions in electricity generation (MWh) associated with ceiling insulation upgrade scenario

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **NF** | **PE** | **NS** | **NB** | **QC** | **ON** | **MB** | **SK** | **AB** | **BC** |
| **Jan.** | 16,418 | 447 | 10,964 | 26,879 | 197,018 | 94,524 | 19,665 | 7,018 | 4,706 | 23,917 |
| **Feb.** | 15,311 | 415 | 10,154 | 23,019 | 166,972 | 79,263 | 15,742 | 5,806 | 3,832 | 19,809 |
| **Mar.** | 14,131 | 379 | 8,914 | 19,694 | 144,658 | 71,028 | 13,678 | 4,824 | 3,485 | 17,436 |
| **Apr.** | 10,225 | 278 | 6,215 | 12,767 | 90,838 | 46,088 | 7,815 | 2,842 | 2,262 | 12,539 |
| **May** | 6,961 | 179 | 3,778 | 6,731 | 44,751 | 27,453 | 4,009 | 1,458 | 1,419 | 8,733 |
| **Jun.** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Jul.** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Aug.** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Sep.** | 3,984 | 76 | 1,831 | 4,777 | 35,620 | 22,170 | 3,792 | 1,466 | 1,230 | 6,702 |
| **Oct.** | 7,750 | 178 | 4,442 | 10,569 | 75,702 | 37,773 | 7,563 | 2,789 | 2,209 | 11,799 |
| **Nov.** | 10,639 | 261 | 6,622 | 15,766 | 115,928 | 59,243 | 13,143 | 4,681 | 3,561 | 16,956 |
| **Dec.** | 14,481 | 375 | 9,523 | 23,383 | 170,180 | 86,551 | 17,898 | 6,539 | 4,439 | 21,423 |

The monthly reductions in GHG emission with ceiling insulation upgrade to RSI 8.8 can be calculated based on the predicted monthly reductions in electricity generationin Table 37 and the GHG intensity factors estimated using the five different methods presented in Table 33.

The monthly reductions in GHG emission (Tonne CO2eq/month) for each province using the five different methods are given in Tables F1-F10 of Appendix F and are plotted in

Figures 20- 29.

Note 1: In all figures of this section, data points are connected with lines to make the graphs, and the trends, easier to read. The lines have no other purpose as there are no data in between discrete data points.

Note 2: The GHG emission reduction predicted using the method recommended in Table 34 is marked in black colour.

Figure 20. Monthly GHG emission reductions as result of ceiling insulation upgrade for Newfoundland

Figure 21. Monthly GHG emission reductions as result of ceiling insulation upgrade for Prince Edward Island

Figure 22. Monthly GHG emission reductions as result of ceiling insulation upgrade for Nova Scotia

Figure 23. Monthly GHG emission reductions as result of ceiling insulation upgrade for New Brunswick

Figure 24. Monthly GHG emission reductions as result of ceiling insulation upgrade for Quebec

Figure 25. Monthly GHG emission reductions as result of ceiling insulation upgrade for Ontario

Figure 26. Monthly GHG emission reductions as result of ceiling insulation upgrade for Manitoba

Figure 27. Monthly GHG emission reductions as result of ceiling insulation upgrade for Saskatchewan

Figure 28. Monthly GHG emission reductions as result of ceiling insulation upgrade for Alberta

Figure 29. Monthly GHG emission reductions as result of ceiling insulation upgrade for British Columbia

These results indicate that the five methods produce substantially different predictions of GHG reductions for the same magnitude of electricity generation reductions. Therefore, it is important to use the method that produces the most realistic predictions.

This work has identified the most appropriate GHG intensity factors for each province, which are presented in Table 34.

# 8. CONCLUSION AND RECOMMENDATIONS

## 8.1. Conclusion

In this work the following objectives were accomplished:

1. Gathering information on marginal electricity generation and fuel used for each province from the open literature as well as electric utilities through personal contacts and utility websites.
2. Determination of the magnitude of the marginal electricity generation using IPM modelling tools for each province included in ICF estimates; however, in the absence of any other data to verify the accuracy of these estimates, it is recommended that ICF estimates for the magnitude of the marginal generation not be used to predict the magnitude of marginal generation.
3. Based on the information obtained in (1), the fuels used for marginal electricity generation in each province were determined.
4. Development of three new methods to predict the GHG emissions due to marginal electricity generation based on (1) and (3).
5. Comparison of the GHG emission reductions predicted by the methods developed in (4) with the estimates obtained from previous studies that utilize average GHG intensity factors and GHG intensity factors for only fossil fuel fired power plants.
6. Demonstration of the capabilities of the new and the previous methods by applying them to the ceiling insulation upgrade scenario as an example of energy efficiency improvements in the Canadian residential sector.

Based on the findings of this work, it is recommended that the GHG emission intensity factors given in Table 34 be used to estimate the reduction in GHG emissions due to electricity generation in Canada.

The last row in Table 34 gives the overall transmission and distribution losses for each province in Canada. These values should be used to determine the GHG reductions from electricity generation in each province using Equation 14:

[14]

Table 34. Recommended GHG intensity factors (g CO2eq/kWh) for each province

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **NF** | **PE** | **NS** | **NB** | **QC** | **ON** | | **MB** | **SK** | **AB** | **BC** |
| **Scenario #1** | **Scenario #2** |
| **Jan.** | 22 | 6 | 360 | 800 | 23 | 395 | 221 | 1 | 225 | 591 | 18 |
| **Feb.** | 0 | 352 | 211 | 591 |
| **Mar.** | 0 | 329 | 199 | 785 |
| **Apr.** | 0 | 463 | 246 | 785 |
| **May** | 0 | 501 | 259 | 785 |
| **Jun.** | 0 | 514 | 294 | 769 |
| **Jul.** | 0 | 489 | 276 | 769 |
| **Aug.** | 0 | 491 | 276 | 769 |
| **Sep.** | 0 | 455 | 259 | 769 |
| **Oct.** | 0 | 458 | 262 | 785 |
| **Nov.** | 0 | 379 | 231 | 591 |
| **Dec.** | 0 | 371 | 227 | 591 |
| **%losses** | 9 | 6 | 4 | 6 | 4 | 6 | | 12 | 6 | 4 | 3 |

## 8.2. Recommendations

* It is recommended that the GHG emission intensity factors presented in this work to be updated periodically as new data on electricity generation and fuels used become available.
* It is recommended that electric utilities in all provinces provide more detailed data on marginal generation and fuels used similar to the data available for Ontario in order to provide more realistic estimates of marginal GHG intensity factors and the associated GHG emission reduction.

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# APPENDICES

## APPENDIX A

**The Detailed Data Used to Calculate the GHGIFA and GHGIFM Values for each Province for the Period 2004 to 2006**

Table A.1. GHG emissions in Newfoundland from electricity generation, 2004-2006 [1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Light fuel oil | -4,629\* | 681kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 1,936,586 |
| Heavy fuel oil | 1,647,586 | 419,385kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 1,300,060,788 |
| Diesel | 53,204 | 15,579kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 44,439,487 |
| Hydro | 38,101,914 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 39,798,075 |  | | | | | 1,346,436,861 |
| **Year** | **2005** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Light fuel oil | -6,331\* | 1,217kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 3,460,829 |
| Heavy fuel oil | 1,326,672 | 339,876kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 1,053,589,090 |
| Diesel | 44,257 | 15,017kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 42,836,368 |
| Hydro | 38,949,551 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | -6,331\* |  | | | | | 1,099,886,287 |
| **Year** | **2006** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Light fuel oil | -9,480\* | 1,679kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 4,774,636 |
| Heavy fuel oil | 738,835 | 200,098kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 620,288,192 |
| Diesel | 43,991 | 14,395kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 41,062,097 |
| Hydro | 40,056,901 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 40,830,247 |  | | | | | 666,124,926 |

\* Source: [8-10]

\*\* Source: [1]

Table A.2. GHG emissions in Prince Edward Island from electricity generation, 2004-2006

[1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Light fuel oil | 853 | 181kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 514,717 |
| Heavy fuel oil | 7,718 | 3,911kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 12,123,795 |
| Diesel | 508 | 498kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 1,420,557 |
| Wood | 2,583 | 1,096Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 7,902 |
| Wind and tidal | 34,703 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 46,365 |  | | | | | 14,066,971 |
| **Year** | **2005** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Light fuel oil | 243 | 278kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 790,559 |
| Heavy fuel oil | 3,075 | 2,182kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 6,764,030 |
| Diesel | 68 | 24kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 68,461 |
| Wood | 1,977 | 1,037Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 7,477 |
| Wind and tidal | 40,104 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 45,467 |  | | | | | 7,630,526 |
| **Year** | **2006** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Light fuel oil | 2,633 | 252kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 716,622 |
| Heavy fuel oil | 372 | 1,141kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 3,537,011 |
| Wood | 2,927 | 1,012Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 7,297 |
| Wind and tidal | 36,249 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 42,181 |  | | | | | 4,260,929 |

\* Source: [8-10]

\*\* Source: [1]

Table A.3. GHG emissions in Nova Scotia from electricity generation, 2004-2006 [1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Canadian bit. | 1,001,570 | 437,577Mg | 2,249g/kg | 0.022g/kg | 0.032g/kg | 2,259g/kg | 988,524,075 |
| Imported bit. | 4,995,331 | 1,850,817Mg | 2,288g/kg | 0.022g/kg | 0.032g/kg | 2,298g/kg | 4,253,336,636 |
| Imported sub-bit.\*\*\* | 932,057 | 346,858 Mg | 1,733g/kg | 0.022g/kg | 0.032g/kg | 1,743g/kg | 604,603,324 |
| Light fuel oil | 15,888 | 4,564kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 12,978,820 |
| Heavy fuel oil | 1,650,432 | 406,063kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 1,258,763,627 |
| Diesel | 128,443 | 44,920kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 128,135,423 |
| Natural gas | 13,795 | 3,760k.m3 | 1,891g/L | 0.49g/L | 0.049g/L | 1,918g/L | 7,211,124 |
| Wood | 178,346 | 133,088Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 959,564 |
| Hydro | 864,526 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 28,961 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 9,809,349 |  | | | | | 7,254,512,593 |
| **Year** | **2005** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Canadian bit. | 826,513 | 359,452Mg | 2,249g/kg | 0.022g/kg | 0.032g/kg | 2,259g/kg | 812,032,981 |
| Imported bit. | 4,908,846 | 1,907,420Mg | 2,288g/kg | 0.022g/kg | 0.032g/kg | 2,298g/kg | 4,383,415,198 |
| Imported sub-bit.\*\*\* | 1,032,824 | 403,420 Mg | 1,733g/kg | 0.022g/kg | 0.032g/kg | 1,743g/kg | 703,195,754 |
| Light fuel oil | 15,440 | 4,400kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 12,512,447 |
| Heavy fuel oil | 1,558,644 | 383,875kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 1,189,982,558 |
| Diesel | 198,955 | 70,157kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 200,124,596 |
| Natural gas | 12,767 | 3,476k.m3 | 1,891g/L | 0.49g/L | 0.049g/L | 1,918g/L | 6,666,454 |
| Wood | 167,960 | 134,625Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 970,646 |
| Hydro | 1,036,471 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 113,088 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 9,871,508 |  | | | | | 7,308,900,634 |
| **Year** | **2006** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Canadian bit. | 886,333 | 386,505Mg | 2,249g/kg | 0.022g/kg | 0.032g/kg | 2,259g/kg | 873,148,034 |
| Imported bit. | 5,671,452 | 2,155,488Mg | 2,288g/kg | 0.022g/kg | 0.032g/kg | 2,298g/kg | 4,953,496,796 |
| Light fuel oil | 16,952 | 4,519kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 12,850,852 |
| Heavy fuel oil | 860,920 | 125,718kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 389,715,994 |
| Diesel | 105,840 | 35,279kL | 1,891g/L | 0.49g/L | 0.049g/L | 1,918g/L | 100,634,229 |
| Wood | 156,491 | 122,225Mg | 0.05g/kg | 0.02g/kg | 7g/kg | 0.05g/kg | 881,242 |
| Hydro | 978,661 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 128,679 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 8,805,328 |  | | | | | 6,330,727,148 |

\* Source: [8-10]

\*\* Source: [1]

\*\*\* Assumed same source of sub-bituminous for Ontario, Manitoba and Nova Scotia

Table A.4. GHG emissions in New Brunswick from electricity generation, 2004-2006 [1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Canadian bit. | 322,446 | 152,045 Mg | 1,996g/kg | 0.022g/kg | 0.032g/kg | 2,006g/kg | 305,015,346 |
| Imported bit. | 2,858,731 | 1,061,015 Mg | 2,311g/kg | 0.022g/kg | 0.032g/kg | 2,321g/kg | 2,462,707,062 |
| Light fuel oil | 64,368 | 27,862kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 79,232,228 |
| Heavy fuel oil | 6,480,139 | 1,653,394kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 5,125,392,435 |
| Diesel | 1,604 | 706kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 2,013,883 |
| Natural gas | 1,777,371 | 374,474k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 718,185,710 |
| Hydro | 2,954,100 | N/A | 0 | 0 | 0 | 0 | 0 |
| Nuclear | 4,298,814 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 18,757,573 |  | | | | | 8,692,546,664 |
| **Year** | **2005** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Canadian bit. | 299,438 | 139,317 Mg | 1,996g/kg | 0.022g/kg | 0.032g/kg | 2,006g/kg | 279,481,883 |
| Imported bit. | 261,953 | 995,840 Mg | 2,311g/kg | 0.022g/kg | 0.032g/kg | 2,321g/kg | 2,311,430,282 |
| Light fuel oil | 20,154 | 10,010kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 28,465,817 |
| Heavy fuel oil | 6,084,657 | 1,584,966kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 4,913,270,973 |
| Diesel | 4,661 | 1,562kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 4,455,644 |
| Natural gas | 1,966,849 | 592,041k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 1,135,447,016 |
| Hydro | 3,817,074 | N/A | 0 | 0 | 0 | 0 | 0 |
| Nuclear | 4,377,987 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 19,192,773 |  | | | | | 8,672,551,616 |
| **Year** | **2006** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Canadian bit. | 230,436 | 109,194Mg | 1,996g/kg | 0.022g/kg | 0.032g/kg | 2,006g/kg | 219,052,555 |
| Imported bit. | 2,697,997 | 994,420Mg | 2,311g/kg | 0.022g/kg | 0.032g/kg | 2,321g/kg | 2,308,134,340 |
| Light fuel oil | 11,457 | 5,228kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 14,867,062 |
| Heavy fuel oil | 3,414,998 | 921,960kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 2,858,004,087 |
| Diesel | 4,028 | 1,302kl | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 3,713,988 |
| Natural gas | 2,319,797 | 533,857 k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 1,023,858,715 |
| Hydro | 3,714,228 | N/A | 0 | 0 | 0 | 0 | 0 |
| Nuclear | 4,366,463 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 16,759,404 |  | | | | | 6,427,630,747 |

\* Source: [8-10]

\*\* Source: [1]

Table A.5. GHG emissions in Quebec from electricity generation, 2004-2006 [1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | |
| Energy Source\* | Electricity\*  Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Light fuel oil | 11,654 | 6,697kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 19,044,513 |
| Heavy fuel oil | 1,718,554 | 438,211kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 1,358,419,920 |
| Diesel | 99,261 | 27,140kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 77,417,529 |
| Natural gas | 209,820 | 75,310k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 144,433,434 |
| Wood | 350,271 | 171,798Mg | 0 | 0.05 | 0.02 | 7 | 1,238,664 |
| Hydro | 146,157,421 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 186,783 | N/A | 0 | 0 | 0 | 0 | 0 |
| Nuclear | 4,877,718 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 153,611,482 |  | | | | | 1,600,554,059 |
| **Year** | **2005** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Light fuel oil | 1,685 | 3,620kL | 2,830g/L | 0.18g/L | 0.031g/L | 2844g/L | 10,294,332 |
| Heavy fuel oil | 567,336 | 151,345kL | 3,080g/L | 0.034g/L | 0.064g/L | 3100g/L | 469,157,695 |
| Diesel | 98,703 | 27,051kL | 2,730g/L | 0.133g/L | 0.4g/L | 2853g/L | 77,163,654 |
| Natural gas | 212,073 | 75,774k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1918g/m3 | 145,323,317 |
| Wood | 319,861 | 159,331Mg | 0 | 0.05 | 0.02 | 7 | 1,148,777 |
| Hydro | 154,677,596 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 416,241 | N/A | 0 | 0 | 0 | 0 | 0 |
| Nuclear | 4,483,055 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 160,776,550 |  | | | | | 703,087,774 |
| **Year** | **2006** | | | | | | |
| Energy Source\* | Electricity\*  Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Light fuel oil | 3,973 | 2,059kl | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 5,855,257 |
| Heavy fuel oil | 131,047 | 47,799kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 148,173,172 |
| Diesel | 98,523 | 27,071kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 77,220,704 |
| Natural gas | 141,377 | 325,013 k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 623,326,832 |
| Wood | 327,881 | 192,584Mg | 0 | 0.05 | 0.02 | 7 | 1,388,531 |
| Hydro | 151,792,208 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 418,791 | N/A | 0 | 0 | 0 | 0 | 0 |
| Nuclear | 4,595,198 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 157,508,998 |  | | | | | 855,964,495 |

\* Source: [8-10]

\* Source: [1]

Table A.6. GHG emissions in Ontario from electricity generation, 2004-2006 [1, 8-10]

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | | N2O |
| Canadian bit. | 234,489 | 87,111Mg | 2,254g/kg | 0.022g/kg | | 0.032g/kg | 2,264g/kg | 197,226,796 |
| Imported bit. | 15,630,797 | 5,796,892Mg | 2,432g/kg | 0.022g/kg | | 0.032g/kg | 2,442g/kg | 14,156,508,797 |
| Imported sub-bit. | 8,456,845 | 4,785,959Mg | 1,733g/kg | 0.022g/kg | | 0.032g/kg | 1,743g/kg | 8,342,338,129 |
| Lignite | 1,757,382 | 1,276,426Mg | 1,476g/kg | 0.022g/kg | | 0.032g/kg | 1,486g/kg | 1,896,878,809 |
| Light fuel oil | 43,801 | 14,077kL | 2,830g/L | 0.18g/L | | 0.031g/L | 2,844g/L | 40,031,300 |
| Heavy fuel oil | 617,814 | 1kL | 3,080g/L | 0.034g/L | | 0.064g/L | 3,100g/L | 569,105,380 |
| Diesel | 2 | 2,088,723k.m3 | 2,730g/L | 0.133g/L | | 0.4g/L | 2,853g/L | 2,853 |
| Natural gas | 8,665,151 | 595,472Mg | 1,891g/m3 | 0.49g/m3 | | 0.049g/m3 | 1,918g/m3 | 4,005,861,583 |
| Wood | 532,576 | N/A | 0 | 0.05g/kg | | 0.02g/kg | 7g/kg | 4,293,353 |
| Hydro | 38,083,122 | N/A | 0 | 0 | | 0 | 0 | 0 |
| Wind and tidal | 25,110 | N/A | 0 | 0 | | 0 | 0 | 0 |
| Nuclear | 76,063,313 | N/A | 0 | 0 | | 0 | 0 | 0 |
| Total | 150,110,402 |  | | | | | | 29,212,246,999 |
| **Year** | **2005** | | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | | CH4 | N2O |
| Imported bit. | 16,183,127 | 5,896,334Mg | 2,432g/kg | | 0.022g/kg | 0.032g/kg | 2,442g/kg | 14,399,354,713 |
| Imported sub-bit. | 11,511,735 | 6,303,708Mg | 1,733g/kg | | 0.022g/kg | 0.032g/kg | 1,743g/kg | 10,987,905,163 |
| Lignite | 1,733,513 | 1,267,687Mg | 1,476g/kg | | 0.022g/kg | 0.032g/kg | 1,486g/kg | 1,883,891,903 |
| Light fuel oil | 56,751 | 16,620kL | 2,830g/L | | 0.18g/L | 0.031g/L | 2,844g/L | 47,262,926 |
| Heavy oil | 677,790 | 188,332kL | 3,080g/L | | 0.034g/L | 0.064g/L | 3100g/L | 583,814,510 |
| Natural gas | 11,901,579 | 2,832,214k.m3 | 1,891g/m3 | | 0.49g/m3 | 0.049g/m3 | 1918g/m3 | 5,431,767,284 |
| Wood | 431,975 | 505,578Mg | 0 | | 0.05g/kg | 0.02g/kg | 7g/kg | 3,645,217 |
| Hydro | 34,550,848 | N/A | 0 | | 0 | 0 | 0 | 0 |
| Wind and tidal | 155,596 | N/A | 0 | | 0 | 0 | 0 | 0 |
| Nuclear | 77,968,854 | N/A | 0 | | 0 | 0 | 0 | 0 |
| Total | 155,171,768 |  | | | | | | 33,337,641,716 |
| **Year** | **2006** | | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | | N2O |
| Imported bit. | 10,621,771 | 4,018,681Mg | 2,432g/kg | 0.022g/kg | | 0.032g/kg | 2,442g/kg | 9,813,964,609 |
| Imported sub-bit. | 12,022,456 | 6,607,856Mg | 1,733g/kg | 0.022g/kg | | 0.032g/kg | 1,743g/kg | 11,518,061,284 |
| Lignite | 1,593,196 | 1,180,889Mg | 1,476g/kg | 0.022g/kg | | 0.032g/kg | 1,486g/kg | 1,754,902,610 |
| Light fuel oil | 308,160 | 15,355kL | 2,830g/L | 0.18g/L | | 0.031g/L | 2,844g/L | 43,665,597 |
| Heavy fuel oil | 121,950 | 45,756kL | 3,080g/L | 0.034g/L | | 0.064g/L | 3,100g/L | 141,840,031 |
| Natural gas | 10,693,529 | 2,833,982 k.m3 | 1,891g/m3 | 0.49g/m3 | | 0.049g/m3 | 1,918g/m3 | 5,435,158,047 |
| Wood | 438,310 | 476,992Mg | 0 | 0.05g/kg | | 0.02g/kg | 7g/kg | 3,439,112 |
| Hydro | 35,004,137 | N/A | 0 | 0 | | 0 | 0 | 0 |
| Wind and tidal | 144,467 | N/A | 0 | 0 | | 0 | 0 | 0 |
| Nuclear | 83,456,853 | N/A | 0 | 0 | | 0 | 0 | 0 |
| Total | 154,404,829 |  | | | | | | 28,711,031,290 |

\* Source: [8-10]

\*\* Source: [1]

Table A.7. GHG emissions in Manitoba from electricity generation, 2004-2006 [1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Imported sub-bit. | 266,029 | 180,400Mg | 1,733g/kg | 0.022g/kg | 0.032g/kg | 1,743g/kg | 314,452,714 |
| Light fuel oil | 3,107 | 1,140kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 3,241,861 |
| Diesel | 11,348 | 3,622kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 10,331,846 |
| Natural gas | 85,656 | 31,768k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 60,926,322 |
| Hydro | 27,219,340 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 27,585,480 |  | | | | | 388,952,744 |
| **Year** | **2005** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Imported sub-bit. | 421,103 | 278,021Mg | 1,733g/kg | 0.022g/kg | 0.032g/kg | 1,743g/kg | 484,614,513 |
| Light fuel oil | 3,622 | 1,360kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 3,867,484 |
| Diesel | 11,496 | 3,381kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 9,644,387 |
| Natural gas | 10,577 | 4,392k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 8,423,206 |
| Hydro | 36,439,655 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 53,420 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 36,939,873 |  | | | | | 506,549,589 |
| **Year** | **2006** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Imported sub-bit. | 322,994 | 193,244 | 1,733g/kg | 0.022g/kg | 0.032g/kg | 1,743g/kg | 336,840,911 |
| Light fuel oil | 7,513 | 2,376 | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 6,756,721 |
| Diesel | 12,696 | 3,785 | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 10,796,807 |
| Natural gas | 51,436 | 19,958 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 38,276,490 |
| Hydro | 33,650,538 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 325,115 | N/A |  |  |  |  | 0 |
| Total | 34,370,292 |  | | | | | 392,670,930 |

\* Source: [8-10]

\* Source: [1]

Table A.8. GHG emissions in Saskatchewan from electricity generation, 2004-2006 [1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Lignite | 13,108,671 | 9,945,941Mg | 1,427g/kg | 0.022g/kg | 0.032g/kg | 1,437g/kg | 14,293,172,568 |
| Heavy fuel oil | 10,136 | 2,859kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 8,862,677 |
| Diesel | 402 | 119kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 339,450 |
| Natural gas | 2,893,767 | 850,142k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 1,630,446,535 |
| Hydro | 2,746,393 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 73,634 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 18,833,003 |  | | | | | 15,932,821,230 |
| **Year** | **2005** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Lignite | 12,170,798 | 9,340,616Mg | 1,427g/kg | 0.022g/kg | 0.032g/kg | 1,437g/kg | 13,423,268,485 |
| Heavy fuel oil | 11,488 | 3,238kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 10,037,547 |
| Diesel | 538 | 118kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 336,598 |
| Natural gas | 2,612,793 | 765,158k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 1,467,459,801 |
| Hydro | 4,572,910 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 91,916 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 19,460,443 |  | | | | | 14,901,102,431 |
| **Year** | **2006** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Lignite | 11,782,144 | 9,013,345Mg | 1,427g/kg | 0.022g/kg | 0.032g/kg | 1,437g/kg | 12,952,951,913 |
| Light fuel oil | 17,470 | 4,744kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 13,490,693 |
| Diesel | 518 | 112kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 319,483 |
| Natural gas | 2,956,455 | 845,583 k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 1,621,703,048 |
| Hydro | 4,031,938 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 572,202 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 19,360,727 | N/A | | | | | 14,588,465,136 |

\* Source: [8-10]

\* Source: [1]

Table A.9. GHG emissions in Alberta from electricity generation, 2004-2006 [1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | |
| Energy Source\* | Electricity\*  Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Canadian bit. | 9,069,920 | 5,274,798Mg | 1,852g/kg | 0.022g/kg | 0.032g/kg | 1,862g/kg | 9,822,127,509 |
| Canadian sub-bit. | 33,331,826 | 20,138,584Mg | 1,765g/kg | 0.022g/kg | 0.032g/kg | 1,775g/kg | 35,747,718,518 |
| Light fuel oil | 40 | 10kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 28,437 |
| Heavy fuel oil | 8,874 | 4,224kL | 3,080g/L | 0.034g/L | 0.064g/L | 3,100g/L | 13,094,071 |
| Diesel | 14,079 | 4,142kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 11,815,159 |
| Natural gas | 10,207,864 | 36,3069k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 6,026,713,743 |
| Wood | 282,097 | 36,3069Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 2,617,727 |
| Hydro | 18,763,84 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 620,700 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 55,411,784 |  | | | | | 51,624,115,163 |
| **Year** | **2005** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Canadian bit. | 5,178,512 | 3,174,054Mg | 1,852g/kg | 0.022g/kg | 0.032g/kg | 1,862g/kg | 5,910,361,517 |
| Canadian sub-bit. | 37,003,716 | 21,669,912Mg | 1,765g/kg | 0.022g/kg | 0.032g/kg | 1,775g/kg | 38,465,957,412 |
| Light fuel oil | 40 | 10kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 28,437 |
| Diesel | 13,729 | 4,039kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 11,521,348 |
| Natural gas | 11,599,542 | 396,895k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 6,331,496,864 |
| Wood | 313,531 | 396,895Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 2,861,613 |
| Hydro | 2,241,937 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 836,986 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 57,187,993 |  | | | | | 50,722,227,192 |
| **Year** | **2006** | | | | | | |
| Energy Source\* | Electricity\*  Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Canadian bit. | 874,377 | 504,575Mg | 1,852g/kg | 0.022g/kg | 0.032g/kg | 1,862g/kg | 939,562,043 |
| Canadian sub-bit. | 39,108,456 | 25,064,926Mg | 1,765g/kg | 0.022g/kg | 0.032g/kg | 1,775g/kg | 44,492,399,234 |
| Light fuel oil | 40 | 10kL | 2,830g/L | 0.18g/L | 0.031g/L | 2,844g/L | 28,437 |
| Diesel | 10,067 | 3,643kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 10,391,749 |
| Natural gas | 12,545,425 | 3,695,187 k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 7,086,821,778 |
| Wood | 390,361 | 475,051Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 3,425,118 |
| Hydro | 1,868,916 | N/A | 0 | 0 | 0 | 0 | 0 |
| Wind and tidal | 839,582 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 55,637,224 |  | | | | | 52,532,628,359 |

\* Source: [8-10]

\*\* Source: [1]

Table A.10. GHG emissions in British Columbia from electricity generation, 2004-2006

[1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2004** | | | | | | |
| Energy Source\* | Electricity\*  Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Diesel | 58,798 | 12,051kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 34,375,779 |
| Natural gas | 2,380,966 | 564,907k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 1,083,408,020 |
| Wood | 554,559 | 685,728Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 4,944,099 |
| Hydro | 45,023,675 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 48,017,998 |  | | | | | 1,122,727,897 |
| **Year** | **2005** | | | | | | |
| Energy Source\* | Electricity\* Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Diesel | 62,174 | 12,725kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 36,298,381 |
| Natural gas | 2,436,996 | 554,648k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 1,063,732,776 |
| Wood | 545,907 | 311,058Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 2,242,728 |
| Hydro | 50,305,334 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 53,350,411 |  | | | | | 1,102,273,885 |
| **Year** | **2006** | | | | | | |
| Energy Source\* | Electricity\*  Generated (MWh) | Fuel Input\* | Emission factor\*\* | | | CO2eq/  quaintly fuel | Total GHG emission in  kg CO2eq |
| CO2 | CH4 | N2O |
| Diesel | 10,879 | 2,232kL | 2,730g/L | 0.133g/L | 0.4g/L | 2,853g/L | 6,366,836 |
| Natural gas | 2,165,673 | 502,300 k.m3 | 1,891g/m3 | 0.49g/m3 | 0.049g/m3 | 1,918g/m3 | 963,337,060 |
| Wood | 546,358 | 716,641Mg | 0 | 0.05g/kg | 0.02g/kg | 7g/kg | 5,166,982 |
| Hydro | 44,463,830 | N/A | 0 | 0 | 0 | 0 | 0 |
| Total | 47,186,740 |  |  |  |  |  | 974,870,877 |

\* Source: [8-10]

\*\* Source: [1]

## APPENDIX B

**Annual Marginal GHG Intensity Factors based on the Latest Available Statistics Canada Data on Electricity Generation and Fuels Used for the Period 2004 to 2006**

Table B.1. Annual marginal GHG intensity factor for Newfoundland, 2004-2006

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\* Generated (MWh) | Fuel Input\*\* | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g /kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Oil | 1,642,957 | |  | | --- | | 420,066kL | | 1,301,997,374 | 792 | 4.13 | 33 |
| Hydro | 38,101,914 | N/A | 0 | 0 | 95.87 |
| Total | 39,744,871 |
| 2005 | Oil | 1,320,341 | |  | | --- | | 341,093kL | | 1,057,049,919 | 801 | 3.28 | 26 |
| Hydro | 38,949,551 | N/A | 0 | 0 | 96.72 |
| Total | 40,269,892 |
| 2006 | Oil | 729,355 | |  | | --- | | 201,777kL | | 625,062,828 | 857 | 1.79 | 15 |
| Hydro | 40,056,901 | N/A | 0 | 0 | 98.21 |
| Total | 40,786,256 |

\*Source: [8-10]

\*\*Source: [1]

Table B.2. Annual marginal GHG intensity factor for Prince Edward Island, 2004-2006

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\* Generated (MWh) | Fuel Input\*\* | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g/kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Oil | 8,571 | 4,092kL | 12,638,512 | 1,475 | 0.75 | 11 |
| Import | 1,151,689 | N/A | 0 | 0 | 99.25 |
| Total | 1,160,260 |
| 2005 | Oil | 3,318 | 3,318kL | 7,554,589 | 2,277 | 0.29 | 7 |
| Import | 11,151,689 | N/A | 0 | 0 | 99.71 |
| Total | 11,155,007 |
| 2006 | Oil | 3,005 | 1,393kL | 4,253,633 | 1,416 | 0.24 | 3 |
| Import | 1,262,821 | N/A | 0 | 0 | 99.76 |
| Total | 1,265,826 |

\*Source: [8-10]

\*\*Source: [1]

Table B.3. Annual marginal GHG intensity factor for Nova Scotia, 2004-2006

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\* Generated (MWh) | Fuel Input\*\* | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g/kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Heavy Oil | 1,650,432 | 406,063kL | 1,258,763,627 | 763 | 65.27 | 501 |
| Natural gas | 13,795 | 3,760km3 | 7,211,124 | 523 | 0.55 |
| Hydro | 864,526 | N/A | 0 | 0 | 34.19 |
| Total | 2,528,753 |
| 2005 | Heavy Oil | 1,558,644 | 383,875kL | 1,189,982,558 | 763 | 59.77 | 459 |
| Natural gas | 12,767 | 3,476km3 | 6,666,454 | 522 | 0.49 |
| Hydro | 1,036,471 | N/A | 0 | 0 | 39.74 |
| Total | 2,607,882 |
| 2006 | Heavy Oil | 860,920 | 125,718kL | 389,715,994 | 453 | 46.80 | 212 |
| Natural gas | 0 | 0 | 0 | 0 | 0 |
| Hydro | 978,661 | N/A | 0 | 0 | 53.20 |
| Total | 1,839,581 |

\*Source: [8-10]

\*\*Source: [1]

Table B.4. Annual marginal GHG intensity factor for New Brunswick, 2004-2006 [1, 8-10]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\* Generated (MWh) | Fuel Input\*\* | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g/kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Coal | 3,181,177 | 1,213,060Mg | 2,767,722,408 | 870 | 32.71 | 820 |
| Oil | 6,544,507 | 6,544,507kL | 5,204,624,663 | 795 | 67.29 |
| Total | 9,725,684 |
| 2005 | Coal | 2,921,391 | 1,135,15Mg | 2,590,912,166 | 887 | 32.37 | 835 |
| Oil | 6,104,811 | 1,594,976kL | 4,941,736,790 | 809 | 67.63 |
| Total | 9,026,202 |
| 2006 | Coal | 2,928,433 | 1,103,614Mg | 2,527,186,895 | 863 | 46.08 | 850 |
| Oil | 3,426,455 | 927,188kL | 2,872,871,149 | 838 | 53.92 |
| Total | 6,354,888 |

\*Source: [8-10]

\*\*Source: [1]

Table B.5. Annual marginal GHG intensity factor for Quebec, 2004-2006

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\* Generated (MWh) | Fuel Input\*\* | | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g/kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Natural gas | 209,820 | 75,310km3 | | 144,433,434 | 688 | 0.14 | 10 |
| Oil | 1,730,208 | 438,211kL | | 1,377,464,433 | 796 | 1.17 |
| Hydro | 146,157,421 | N/A | | 0 | 0 | 98.69 |
| Total | 148,097,449 |
| 2005 | Natural  gas | 212,073 | 75,774km3 | | 145,323,317 | 685 | 0.14 | 4 |
| Oil | 569,021 | 151,345kL | | 479,452,027 | 843 | 0.37 |
| Hydro | 154,677,596 | N/A | | 0 | 0 | 99.50 |
| Total | 155,458,690 |
| 2006 | Natural  gas | 1,471,377 | 325,013km3 | | 623,326,832 | 424 | 0.96 | 5 |
| Oil | 135,020 | 49,858kL | | 154,028,428 | 1,141 | 0.09 |
| Hydro | 151,792,208 | N/A | | 0 | 0 | 98.95 |
|  | Total | 153,398,605 | |

\*Source: [8-10]

\*\*Source: [1]

Table B.6. Annual marginal GHG intensity factor for Ontario, 2004-2006

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\* Generated (MWh) | Fuel Input\*\* | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g/kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Hydro | 38,083,122 | N/A | 0 | 0 | 51.82 | 401 |
| Natural gas | 8,665,151 | 2,088,723km3 | 4,005,861,583 | 462 | 12.6 |
| Coal | 26,079,513 | 87,111Mg | 24,592,952,530 | 943 | 35.49 |
| Oil | 661,615 | 197,664kL | 609,136,680 | 921 | 0.90 |
| Total | 73,489,401 |
| 2005 | Hydro | 34,550,848 | N/A | 0 | 0 | 45.10 | 435 |
| Natural  gas | 11,901,579 | 2,832,214km3 | 5,431,767,284 | 456 | 15.53 |
| Coal | 29,428,375 | 13,467,729Mg | 27,271,151,779 | 927 | 38.41 |
| Oil | 734,541 | 204,952kL | 631,077,436 | 859 | 0.96 |
| Total | 76,615,343 |
| 2006 | Hydro | 35,004,137 | N/A | 0 | 0 | 49.75 | 408 |
| Natural gas | 10,693,529 | 2,833,982km3 | 5,435,158,047 | 508 | 15.20 |
| Coal | 24,237,423 | 11,807,426Mg | 23,086,928,503 | 953 | 34.45 |
| Oil | 430,110 | 61,111kL | 185,505,628 | 431 | 0.61 |
| Total | 70,365,199 |

\*Source: [8-10]

\*\*Source: [1]

Table B.7. Annual marginal GHG intensity factor for Manitoba, 2004-2006

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\* Generated (MWh) | Fuel Input\*\* | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g/kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Natural gas | 85,656 | 31,768km3 | 60,926,322 | 711 | 0.29 | 2 |
| Hydro | 27,219,340 | N/A | 0 | 0 | 91.11 |
| Import | 2,569,716 | N/A | 0 | 0 | 8.60 |
| Total | 29,874,712 |
| 2005 | Natural  gas | 10,577 | 4,392km3 | 8,423,206 | 796 | 0.03 | 0 |
| Hydro | 36,439,655 | N/A | 0 | 0 | 99.3 |
| Import | 244,347 | N/A | 0 | 0 | 0.67 |
| Total | 36,694,579 |
| 2006 | Natural  gas | 51,436 | 19,958km3 | 38,276,490 | 744 | 0.15 | 1 |
| Hydro | 33,650,538 | N/A | 0 | 0 | 97.45 |
| Import | 828,572 | N/A | 0 | 0 | 2.40 |
| Total | 36,694,579 |

\*Source: [8-10]

\*\*Source: [1]

Table B.8. Annual marginal GHG intensity factor for Saskatchewan, 2004-2006

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\* Generated (MWh) | Fuel Input\*\* | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g/kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Natural gas | 2,893,767 | 850,142km3 | 1,630,446,535 | 563 | 43.04 | 243 |
| Hydro | 2,746,393 | N/A | 0 | 0 | 40.85 |
| Import | 1,082,597 | N/A | 0 | 0 | 16.11 |
| Total | 6,722,757 |
| 2005 | Natural  gas | 2,612,793 | 765,158km3 | 1,467,459,801 | 562 | 45.16 | 254 |
| Hydro | 2,746,393 | N/A | 0 | 0 | 47.47 |
| Import | 426,913 | N/A | 0 | 0 | 7.37 |
| Total | 5,786,099 |
| 2006 | Natural  gas | 2,956,455 | 845,583km3 | 1,621,703,048 | 549 | 36.34 | 199 |
| Hydro | 4,031,938 | N/A | 0 | 0 | 49.56 |
| Import | 1,147,079 | N/A | 0 | 0 | 14.10 |
| Total | 8,135,472 |

\*Source: [8-10]

\*\*Source: [1]

Table B.9. Annual marginal GHG intensity factor for Alberta, 2004-2006

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\* Generated (MWh) | Fuel Input\*\* | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g/kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Natural gas | 10,207,864 | 3,142,429 km3 | 6,026,713,743 | 590 | 18.73 | 947 |
| Coal | 42,401,746 | 25,413,382Mg | 45,569,846,027 | 1,075 | 77.83 |
| Hydro | 1,876,384 | N/A | 0 | 0 | 3.44 |
| Total | 54,852,605 |
| 2005 | Natural  gas | 11,599,542 | 3,301,348 km3 | 6,331,496,864 | 546 | 20.70 | 905 |
| Coal | 42,182,228 | 24,843,966Mg | 44,376,318,929 | 1,052 | 75.30 |
| Hydro | 2,241,937 | N/A | 0 | 0 | 4.00 |
| Total | 56,023,707 |
| 2006 | Natural  gas | 12,545,425 | 3,695,187km3 | 7,086,821,778 | 565 | 23.06 | 965 |
| Coal | 39,982,833 | 25,569,501Mg | 45,431,961,277 | 1,136 | 73.50 |
| Hydro | 1,868,916 | N/A | 0 | 0 | 3.44 |
| Total | 54,397,174 |

\*Source: [8-10]

\*\*Source: [1]

Table B.10. Annual marginal GHG intensity factor for British Columbia, 2004-2006

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Marginal fuel source | Electricity\*  Generated (MWh) | Fuel Input\*\* | Total GHG Emission in  kg CO2eq | GHG Intensity Factor  (g/kWh fuel) | % On  Margin | Annual Marginal GHG Intensity Factor (g/kWh) |
| 2004 | Natural gas | 2,380,966 | 564,907km3 | 1,083,408,020 | 455 | 4.35 | 20 |
| Import | 7,310,108 | N/A | 0 | 0 | 13.36 |
| Hydro | 45,023,675 | N/A | 0 | 0 | 82.29 |
| Total | 54,714,749 |
| 2005 | Natural gas | 2,436,996 | 554,648km3 | 1,063,732,776 | 436 | 4.13 | 19 |
| Import | 6,253,114 | N/A | 0 | 0 | 10.60 |
| Hydro | 50,305,334 | N/A | 0 | 0 | 85.27 |
| Total | 58,995,444 |
| 2006 | Natural gas | 2,165,673 | 554,648 km3 | 963,337,060 | 455 | 3.68 | 16 |
| Import | 12,265,719 | N/A | 0 | 0 | 20.82 |
| Hydro | 44,463,830 | N/A | 0 | 0 | 75.50 |
| Total | 58,895,222 |

\*Source: [8-10]

\*\*Source: [1]

**The Predicted Marginal Fuel Mix Used to Calculate the Weighted Annual Marginal GHG Intensity Factors Based on the Weighted Average Approach**

Table B.11. Predicted marginal fuel mix used to calculate the weighted annual marginal GHG intensity factors

|  |  |  |
| --- | --- | --- |
| **Province** | **Marginal Fuel Source** | **% On Margin** |
| **NF** | Oil | 2.71 |
| Hydro | 97.30 |
| **PE** | Oil | 0.36 |
| Import | 99.64 |
| **NS** | Heavy oil | 54.39 |
| Natural gas | 0.26 |
| Hydro | 45.36 |
| **NB** | Coal | 39.29 |
| Oil | 60.71 |
| **QC** | Oil | 0.39 |
| Natural gas | 0.55 |
| Hydro | 99.06 |
| **ON** | Hydro | 48.77 |
| Natural gas | 14.78 |
| Coal | 35.85 |
| Oil | 0.61 |
| **MB** | Natural gas | 0.14 |
| Hydro | 3.12 |
| Import | 96.74 |
| **SK** | Natural gas | 40.33 |
| Hydro | 47.19 |
| Import | 12.48 |
| **AB** | Natural gas | 21.49 |
| Coal | 74.91 |
| Hydro | 3.61 |
| **BC** | Natural gas | 4.02 |
| Hydro | 78.90 |
| Import | 17.09 |

## APPENDIX C

**ICF Estimates of Monthly Marginal Generation (MWh) and the Marginal Fuel Mix Setting the Marginal Capacities over the period of 2004 to 2007**

**Figure C.1.** Total marginal generation (MWh) for Nova Scotia over 2004-2007 estimated by ICF

**Figure C.2.** Monthly Fuel mix used for marginal electricity generation in Nova Scotia

over 2004 to 2007 estimated by ICF

**Figure C.3.** Total marginal generation (MWh) for New Brunswick over 2004-2007 estimated by ICF

**Figure C.4.** Monthly Fuel mix used for marginal electricity generation in New Brunswick

over 2004 to 2007 estimated by ICF

**Figure C.5.** Total marginal generation (MWh) for Quebec over 2004-2007 estimated by ICF

**Figure C.6.** Monthly Fuel mix used for marginal electricity generation in Quebec

over 2004 to 2007 estimated by ICF

**Figure C.7.** Total marginal generation (MWh) for Ontario over 2004-2007 estimated by ICF

**Figure C.8.** Monthly Fuel mix used for marginal electricity generation in Ontario

over 2004 to 2007 estimated by ICF

**Figure C.9.** Total marginal generation (MWh) for Manitoba over 2004-2007 estimated by ICF

**Figure C.10.** Monthly Fuel mix used for marginal electricity generation in Manitoba

over 2004 to 2007 estimated by ICF

**Figure C.11.** Total marginal generation (MWh) for Saskatchewan over 2004-2007 estimated by ICF

**Figure C.12.** Monthly Fuel mix used for marginal electricity generation in Saskatchewan

over 2004 to 2007 estimated by ICF

**Figure C.13.** Total marginal generation (MWh) for Alberta over 2004-2007 estimated by ICF

**Figure C.14.** Monthly Fuel mix used for marginal electricity generation in Alberta

over 2004 to 2007 estimated by ICF

**Figure C.15.** Total marginal generation (MWh) for British Columbia over 2004-2007 estimated by ICF

**Figure C.16.** Monthly Fuel mix used for marginal electricity generation in British Colombia

over 2004 to 2007 estimated by ICF

## APPENDIX D

**The Detailed Data Used to Calculate the GHG Emission Intensity Factors for Orimulsion and Spent Liquor**

Table D.1. Detailed data used to calculate the GHG emission intensity factor for Orimulsion and spent liquor

|  |  |  |  |
| --- | --- | --- | --- |
| Fuel Source | Emission Factor | Heat Rate | Energy Content |
| Orimulsion\* | 80.7 kg CO2eq/GJ | 8,200 Btu/kWh | 27.5 MJ/ kg Orimulsion |
| Spent liquor\*\* | 7 g CO2eq/kg Spent liquor | 9,000 Btu/kWh | 6250 Btu/Ib |

\*Source: Orimulsion emission factor and energy content are from: The Netherland List of Fuels and Standard CO2 Emission Factors, 2004. The heat rate source: Comparative Advantages of Orimulsion, LNG, and Petcoke, 2002

\*\*Source: spent liquor emission factor is by calculating CO2equsing Equation 1 and data in Table 11. The heat rate value for liquid spent liquor is approximation between the heat rate values for solid and gaseous biomass” for solid biomass (wood &wood waste = 9,145 Btu/kWh) and for gaseous biomass (landfill gas = 11,000 Btu/kWh), ICF, 2003. Analysis of Electricity Dispatch in Canada, Final Report, Submitted to Environment Canada”. Energy content source: CIPEC, Energy Cost Reduction in Pulp and Paper Industrial, National Resource Canada.

The GHG emission intensity factors for Orimulsion and spent liquor are shown below:

**The GHG Intensity Factors Predicted Using the Weighted Average Approach and the Monthly GHG Intensity Factors based on ICF Estimates**

Table D.2. The predicted marginal fuel mix and the monthly GHG intensity factors based on ICF estimates for Nova Scotia

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | Gas % | US coal bituminous % | US import % | Marginal GHG intensity factor  (g CO2eq/kWh) |
| Jan. | 58 | 42 | 0 | 670 |
| Feb. | 51 | 49 | 0 | 693 |
| Mar. | 90 | 10 | 0 | 557 |
| Apr. | 85 | 15 | 0 | 575 |
| May | 2 | 98 | 0 | 867 |
| Jun. | 18 | 82 | 0 | 811 |
| Jul. | 37 | 63 | 0 | 745 |
| Aug. | 33 | 67 | 0 | 758 |
| Sep. | 57 | 43 | 0 | 673 |
| Oct. | 56 | 44 | 0 | 677 |
| Nov. | 61 | 39 | 0 | 659 |
| Dec. | 81 | 19 | 0 | 589 |

Table D.3. The predicted marginal fuel mix and the monthly GHG intensity factors based on ICF estimates for New Brunswick

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | Gas % | Orimulsion % | US import % | Marginal GHG intensity factor  (g CO2eq/kWh) |
| Jan. | 2 | 90 | 8 | 638 |
| Feb. | 1 | 99 | 0 | 697 |
| Mar. | 0 | 100 | 0 | 699 |
| Apr. | 0 | 100 | 0 | 699 |
| May | 0 | 100 | 0 | 699 |
| Jun. | 0 | 100 | 0 | 699 |
| Jul. | 0 | 100 | 0 | 699 |
| Aug. | 0 | 100 | 0 | 699 |
| Sep. | 0 | 100 | 0 | 699 |
| Oct. | 0 | 100 | 0 | 699 |
| Nov. | 0 | 100 | 0 | 699 |
| Dec. | 0 | 94 | 6 | 655 |

Table D.4. The predicted marginal fuel mix and the monthly GHG intensity factors based on ICF estimates for Quebec

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Month | Wood &  wood waste% | Spent liquor % | US import % | Landfill  gas % | SK coal lignite % | Marginal GHG intensity factor (g CO2eq/kWh) |
| Jan. | 37 | 13 | 51 | 0 | 0 | 2 |
| Feb. | 100 | 0 | 0 | 0 | 0 | 4 |
| Mar. | 35 | 2 | 0 | 63 | 0 | 2 |
| Apr. | 100 | 0 | 0 | 0 | 0 | 4 |
| May | 51 | 49 | 0 | 0 | 0 | 4 |
| Jun. | 100 | 0 | 0 | 0 | 0 | 4 |
| Jul. | 100 | 0 | 0 | 0 | 0 | 4 |
| Aug. | 100 | 0 | 0 | 0 | 0 | 4 |
| Sep. | 0 | 100 | 0 | 0 | 0 | 5 |
| Oct. | 100 | 0 | 0 | 0 | 0 | 4 |
| Nov. | 100 | 0 | 0 | 0 | 0 | 4 |
| Dec. | 42 | 17 | 30 | 0 | 11 | 126 |

Table D.5. The predicted marginal fuel mix and the monthly GHG intensity factors based on ICF estimates for Ontario

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Month | Gas % | Oil % | SK coal  lignite % | US coal  bituminous % | US import % | Marginal GHG intensity factor (g CO2eq/kWh) |
| Jan. | 0 | 2 | 0 | 0 | 98 | 16 |
| Feb. | 0 | 0 | 47 | 0 | 52 | 518 |
| Mar. | 0 | 0 | 41 | 34 | 25 | 764 |
| Apr. | 0 | 0 | 50 | 39 | 11 | 905 |
| May | 0 | 0 | 40 | 28 | 32 | 701 |
| Jun. | 0 | 0 | 49 | 50 | 2 | 992 |
| Jul. | 0 | 2 | 44 | 54 | 0 | 995 |
| Aug. | 2 | 0 | 39 | 40 | 20 | 795 |
| Sep. | 0 | 0 | 1 | 0 | 99 | 15 |
| Oct. | 0 | 0 | 40 | 11 | 49 | 545 |
| Nov. | 0 | 0 | 0 | 0 | 100 | 0 |
| Dec. | 1 | 0 | 0 | 0 | 99 | 8 |

Table D.6. The predicted marginal fuel mix and the monthly GHG intensity factors based on ICF estimates for Manitoba

|  |  |  |  |
| --- | --- | --- | --- |
| Month | Montana coal sub-bituminous % | US import % | Marginal GHG intensity factor (g CO2eq/kWh) |
| Jan. | 60 | 40 | 675 |
| Feb. | 100 | 0 | 1,125 |
| Mar. | 100 | 0 | 1,125 |
| Apr. | 100 | 0 | 1,125 |
| May | 100 | 0 | 1,125 |
| Jun. | 100 | 0 | 1,125 |
| Jul. | 100 | 0 | 1,125 |
| Aug. | 100 | 0 | 1,125 |
| Sep. | 100 | 0 | 1,125 |
| Oct. | 100 | 0 | 1,125 |
| Nov. | 60 | 40 | 675 |
| Dec. | 0 | 100 | 0 |

Table D.7. The predicted marginal fuel mix and the monthly GHG intensity factors based on ICF estimates for Saskatchewan

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | Gas % | Saskatchewan coal lignite % | US import % | Marginal GHG intensity factor (g CO2eq/kWh) |
| Jan. | 46 | 54 | 0 | 851 |
| Feb. | 40 | 60 | 0 | 882 |
| Mar. | 62 | 38 | 0 | 762 |
| Apr. | 0 | 30 | 70 | 329 |
| May | 0 | 10 | 90 | 110 |
| Jun. | 40 | 60 | 0 | 882 |
| Jul. | 40 | 60 | 0 | 882 |
| Aug. | 40 | 60 | 0 | 882 |
| Sep. | 0 | 68 | 32 | 746 |
| Oct. | 40 | 60 | 0 | 880 |
| Nov. | 100 | 0 | 0 | 558 |
| Dec. | 98 | 2 | 0 | 568 |

Table D.8. The predicted marginal fuel mix and the monthly GHG intensity factors based on ICF estimates for Alberta

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | Gas % | Landfill gas % | AB coal bituminous % | Marginal GHG intensity factor (g CO2eq/kWh) |
| Jan. | 100 | 0 | 0 | 567 |
| Feb. | 100 | 0 | 0 | 567 |
| Mar. | 100 | 0 | 0 | 567 |
| Apr. | 100 | 0 | 0 | 567 |
| May | 100 | 0 | 0 | 567 |
| Jun. | 91 | 0 | 9 | 617 |
| Jul. | 44 | 1 | 55 | 855 |
| Aug. | 44 | 0 | 56 | 867 |
| Sep. | 86 | 0 | 14 | 640 |
| Oct. | 100 | 0 | 0 | 567 |
| Nov. | 100 | 0 | 0 | 567 |
| Dec. | 100 | 0 | 0 | 567 |

Table D.9. The predicted marginal fuel mix and the monthly GHG intensity factors based on ICF estimates for British Columbia

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | Gas % | Wood & wood waste % | US import % | Marginal GHG intensity factor (g CO2eq/kWh) |
| Jan. | 100 | 0 | 0 | 445 |
| Feb. | 100 | 0 | 0 | 445 |
| Mar. | 100 | 0 | 0 | 445 |
| Apr. | 27 | 73 | 0 | 124 |
| May | 37 | 53 | 10 | 167 |
| Jun. | 0 | 100 | 0 | 7 |
| Jul. | 0 | 100 | 0 | 9 |
| Aug. | 0 | 100 | 0 | 7 |
| Sep. | 9 | 84 | 7 | 46 |
| Oct. | 1 | 99 | 0 | 12 |
| Nov. | 28 | 18 | 54 | 126 |
| Dec. | 71 | 0 | 29 | 317 |

## APPENDIX E

**Fuel Usage for Marginal Generation: ICF Estimates and Predicted Values based on ICF Estimates**

Note 1: In all graphs of this appendix, data points are connected with lines to make the graphs, and the trends, easier to read. The lines have no other purpose as there are no data in between discrete data points.

Note 2: 2004, 2005, 2006 and 2007 data are those reported by ICF . The “predicted” values are those calculated in this work based on ICF estimates.

**Figure E.1.** Natural gas usage for marginal electricity generation in Nova Scotia over the period 2004-2007 , and predicted values

**Figure E.2.** US coal bituminous usage for marginal electricity generation in Nova Scotia over the period 2004-2007 , and predicted values

**Figure E.3.** Natural gas usage for marginal electricity generation in New Brunswick over the period 2004-2007 , and predicted values

**Figure E.4.** Orimulsion usage for marginal electricity generation in New Brunswick over the period 2004-2007 , and predicted values

**Figure E.5.** US import usage for marginal electricity generation in New Brunswick over the period 2004-2007 , and predicted values

**Figure E.6.** Wood & wood waste usage for marginal electricity generation in Quebec over the period 2004-2007 , and predicted values

**Figure E.7.** Spent liquor usage for marginal electricity generation in Quebec over the period 2004-2007 , and predicted values

**Figure E.8.** US import usage for marginal electricity generation in Quebec over the period 2004-2007 , and predicted values

**Figure E.9.** Landfill gas usage for marginal electricity generation in Quebec over the period 2004-2007 , and predicted values

**Figure E.10.** Saskatchewan Coal Lignite usage for marginal electricity generation in Quebec over the period 2004-2007 , and predicted values

**Figure E.11.** Natural gas usage for marginal electricity generation in Ontario over the period 2004-2007 , and predicted values

**Figure E.12.** Oil usage for marginal electricity generation in Ontario over the period 2004-2007 , and predicted values

**Figure E.13.** Saskatchewan coal lignite usage for marginal electricity generation in Ontario over the period 2004-2007 , and predicted values

**Figure E.14.** US coal bituminous usage for marginal electricity generation in Ontario over the period 2004-2007 , and predicted values

**Figure E.15.** US Imports usage for marginal electricity generation in Ontario over the period 2004-2007 , and predicted values

**Figure E.16.** Montana coal sub-bituminous usage for marginal electricity generation in Manitoba over the period 2004-2007 , and predicted values

**Figure E.17.** US import usage for marginal electricity generation in Manitoba over the period 2004-2007 , and predicted values

**Figure E.18.** Natural gas usage for marginal electricity generation in Saskatchewan over the period 2004-2007 , and predicted values

**Figure E.19.** Saskatchewan coal lignite usage for marginal electricity generation in Saskatchewan over the period 2004-2007 , and predicted values

**Figure E.20.** US import usage for marginal electricity generation in Saskatchewan over the period 2004-2007 , and predicted values

**Figure E.21.** Natural gas usage for marginal electricity generation in Alberta over the period 2004-2007 , and predicted values

**Figure E.22.** Landfill gas usage for marginal electricity generation in Alberta over the period 2004-2007 , and predicted values

**Figure E.23.** Alberta coal bituminous usage for marginal electricity generation in Alberta over the period 2004-2007 , and predicted values

**Figure E.24.** Natural gas usage for marginal electricity generation in British Colombia over the period 2004-2007 , and predicted values

**Figure E.25.** Wood & wood waste Natural gas usage for marginal electricity generation in British Colombia over the period 2004-2007 , and predicted values

**Figure E.26.** US import usage for marginal electricity generation in British Colombia over the period 2004-2007 , and predicted values

## APPENDIX F

**Monthly GHG Emission Reduction (Tonne CO2eq/month) as Result of Ceiling Insulation Upgrade Using the Five Different Methods**

Table F.1. Monthly GHG emission reductions as a result of ceiling insulation upgrade for Newfoundland (Tonne CO2eq/month)

|  |  |  |  |
| --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | **Weighted Annual Marginal GHGIF** |
| Jan. | 427 | 13,906 | 361 |
| Feb. | 398 | 12,969 | 337 |
| Mar. | 367 | 11,969 | 311 |
| Apr. | 266 | 8,661 | 225 |
| May | 181 | 5,896 | 153 |
| Jun. | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 |
| Sep. | 104 | 3,374 | 88 |
| Oct. | 201 | 6,564 | 170 |
| Nov. | 277 | 9,011 | 234 |
| Dec. | 377 | 12,265 | 319 |
| Total | 2,597 | 84,615 | 2,198 |

Table F.2. Monthly GHG emission reductions as a result of ceiling insulation upgrade for Prince Edward Island (Tonne CO2eq/month)

|  |  |  |  |
| --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | **Weighted Annual Marginal GHGIF** |
| Jan. | 85 | 826 | 3 |
| Feb. | 79 | 767 | 2 |
| Mar. | 72 | 701 | 2 |
| Apr. | 53 | 515 | 2 |
| May | 34 | 332 | 1 |
| Jun. | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 |
| Sep. | 14 | 140 | 0 |
| Oct. | 34 | 329 | 1 |
| Nov. | 50 | 483 | 2 |
| Dec. | 72 | 694 | 2 |
| Total | 494 | 4,786 | 16 |

Table F.3. Monthly GHG emission reductions as a result of ceiling insulation upgrade for Nova Scotia (Tonne CO2eq/month)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | **Weighted Annual Marginal GHGIF** | Monthly GHGIF based on ICF Estimates |
| Jan. | 7,554 | 8,618 | 3,947 | 7,346 |
| Feb. | 6,996 | 7,981 | 3,655 | 7,036 |
| Mar. | 6,142 | 7,006 | 3,209 | 4,965 |
| Apr. | 4,282 | 4,885 | 2,237 | 3,573 |
| May | 2,603 | 2,970 | 1,360 | 3,276 |
| Jun. | 0 | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 | 0 |
| Sep. | 1,262 | 1,440 | 659 | 1,233 |
| Oct. | 3,061 | 3,492 | 1,599 | 3,007 |
| Nov. | 4,563 | 5,205 | 2,384 | 4,364 |
| Dec. | 6,562 | 7,485 | 3,428 | 5,609 |
| Total | 43,023 | 49,080 | 22,480 | 40,409 |

Table F.4. Monthly GHG emission reductions as a result of ceiling insulation upgrade for New Brunswick (Tonne CO2eq/month)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | Weighted Annual Marginal GHGIF | Monthly GHGIF based on ICF Estimates | **based on Reported marginal GHGIF** |
| Jan. | 11,639 | 21,772 | 22,498 | 17,149 | 21,503 |
| Feb. | 9,967 | 18,645 | 19,267 | 16,044 | 18,415 |
| Mar. | 8,527 | 15,952 | 16,484 | 13,766 | 15,755 |
| Apr. | 5,528 | 10,341 | 10,686 | 8,924 | 10,213 |
| May | 2,915 | 5,452 | 5,634 | 4,705 | 5,385 |
| Jun. | 0 | 0 | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 | 0 | 0 |
| Sep. | 2,068 | 3,869 | 3,998 | 3,339 | 3,821 |
| Oct. | 4,577 | 8,561 | 8,847 | 7,388 | 8,456 |
| Nov. | 6,827 | 12,770 | 13,196 | 11,020 | 12,613 |
| Dec. | 10,125 | 18,940 | 19,571 | 15,316 | 18,706 |
| Total | 62,172 | 116,303 | 120,180 | 97,651 | 114,868 |

Table F.5. Monthly GHG emission reductions as a result of ceiling insulation upgrade for Quebec (Tonne CO2eq/month)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | Weighted Annual Marginal GHGIF | Monthly GHGIF based on ICF Estimates | **Monthly GHGIF based Reported data** |
| Jan. | 1,182 | 142,444 | 1,379 | 394 | 4,531 |
| Feb. | 1,002 | 120,721 | 1,169 | 668 | 0 |
| Mar. | 868 | 104,588 | 1,013 | 289 | 0 |
| Apr. | 545 | 65,676 | 636 | 363 | 0 |
| May | 269 | 32,355 | 313 | 179 | 0 |
| Jun. | 0 | 0 | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 | 0 | 0 |
| Sep. | 214 | 25,753 | 249 | 178 | 0 |
| Oct. | 454 | 54,732 | 530 | 303 | 0 |
| Nov. | 696 | 83,816 | 811 | 464 | 0 |
| Dec. | 1,021 | 123,040 | 1,191 | 21,443 | 0 |
| Total | 6,250 | 753,125 | 7,292 | 24,281 | 4,531 |

Table F.6. Monthly GHG emission reductions as a result of ceiling insulation upgrade for Ontario (Tonne CO2eq/month)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | Weighted Annual Marginal GHGIF | Monthly GHGIF based on ICF Estimates | **GHGIF based Reported data**  **Scenario#1** | **GHGIF based Reported data**  **Scenario#2** |
| Jan. | 18,810 | 81,479 | 38,471 | 1,512 | 37,357 | 20,892 |
| Feb. | 15,773 | 68,325 | 32,260 | 41,058 | 27,891 | 16,754 |
| Mar. | 14,134 | 61,226 | 28,908 | 54,265 | 23,388 | 14,160 |
| Apr. | 9,172 | 39,728 | 18,758 | 41,710 | 21,358 | 11,334 |
| May | 5,463 | 23,665 | 11,174 | 19,245 | 13,753 | 7,121 |
| Jun. | 0 | 0 | 0 | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 | 0 | 0 | 0 |
| Sep. | 4,412 | 19,110 | 9,023 | 333 | 10,094 | 5,742 |
| Oct. | 7,517 | 32,560 | 15,374 | 20,586 | 17,307 | 9,891 |
| Nov. | 11,789 | 51,068 | 24,112 | 0 | 22,472 | 13,692 |
| Dec. | 17,224 | 74,607 | 35,226 | 692 | 32,098 | 19,687 |
| Total | 104,294 | 451,768 | 213,306 | 179,402 | 205,718 | 119,274 |

Table F.7. Monthly GHG emission reductions as a result of ceiling insulation upgrade for Manitoba (Tonne CO2eq/month)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | **Weighted Annual Marginal GHGIF** | Monthly GHGIF based on ICF Estimates |
| Jan. | 256 | 23,776 | 20 | 13,274 |
| Feb. | 205 | 19,032 | 16 | 17,710 |
| Mar. | 178 | 16,537 | 14 | 15,388 |
| Apr. | 102 | 9,448 | 8 | 8,792 |
| May | 52 | 4,847 | 4 | 4,510 |
| Jun. | 0 | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 | 0 |
| Sep. | 49 | 4,585 | 4 | 4,266 |
| Oct. | 98 | 9,143 | 8 | 8,508 |
| Nov. | 171 | 15,890 | 13 | 8,872 |
| Dec. | 233 | 21,639 | 18 | 0 |
| Total | 1,343 | 124,897 | 103 | 81,320 |

Table F.8. Monthly GHG emission reductions as a result of ceiling insulation upgrade for Saskatchewan (Tonne CO2eq/month)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | **Weighted Annual Marginal GHGIF** | Monthly GHGIF based on ICF Estimates |
| Jan. | 5,537 | 7,446 | 1,579 | 5,972 |
| Feb. | 4,581 | 6,160 | 1,306 | 5,121 |
| Mar. | 3,806 | 5,118 | 1,085 | 3,676 |
| Apr. | 2,242 | 3,015 | 639 | 935 |
| May | 1,151 | 1,547 | 328 | 160 |
| Jun. | 0 | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 | 0 |
| Sep. | 1,156 | 1,555 | 330 | 1,093 |
| Oct. | 2,200 | 2,959 | 627 | 2,454 |
| Nov. | 3,694 | 4,967 | 1,053 | 2,612 |
| Dec. | 5,159 | 6,938 | 1,471 | 3,714 |
| Total | 29,525 | 39,704 | 8,420 | 25,737 |

Table F.9. Monthly GHG emission reductions as a result of ceiling insulation upgrade for Alberta (Tonne CO2eq/month)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | Weighted Annual Marginal GHGIF | Monthly GHGIF based on ICF Estimates | **Seasonal GHGIF based Reported data** |
| Jan. | 4,335 | 4,777 | 4,410 | 2,669 | 2,781 |
| Feb. | 3,530 | 3,890 | 3,591 | 2,173 | 2,265 |
| Mar. | 3,210 | 3,537 | 3,265 | 1,976 | 2,736 |
| Apr. | 2,084 | 2,296 | 2,120 | 1,283 | 1,776 |
| May | 1,307 | 1,441 | 1,330 | 805 | 1,114 |
| Jun. | 0 | 0 | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 | 0 | 0 |
| Sep. | 1,133 | 1,249 | 1,153 | 787 | 946 |
| Oct. | 2,035 | 2,243 | 2,070 | 1,253 | 1,734 |
| Nov. | 3,279 | 3,614 | 3,336 | 2,019 | 2,104 |
| Dec. | 4,088 | 4,505 | 4,159 | 2,517 | 2,623 |
| Total | 25,000 | 27,552 | 25,434 | 15,481 | 18,080 |

Table F.10. Monthly GHG emission reductions as a result of ceiling insulation upgrade for British Columbia (Tonne CO2eq/month)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | GHGIFA | GHGIFM | **Weighted Annual Marginal GHGIF** | Monthly GHGIF based on ICF Estimates |
| Jan. | 526 | 11,050 | 431 | 10,643 |
| Feb. | 436 | 9,152 | 357 | 8,815 |
| Mar. | 384 | 8,055 | 314 | 7,759 |
| Apr. | 276 | 5,793 | 226 | 1,555 |
| May | 192 | 4,035 | 157 | 1,458 |
| Jun. | 0 | 0 | 0 | 0 |
| Jul. | 0 | 0 | 0 | 0 |
| Aug. | 0 | 0 | 0 | 0 |
| Sep. | 147 | 3,096 | 121 | 308 |
| Oct. | 260 | 5,451 | 212 | 142 |
| Nov. | 373 | 7,833 | 305 | 2,136 |
| Dec. | 471 | 9,897 | 386 | 6,791 |
| Total | 3,065 | 64,363 | 2,508 | 39,608 |

1. Anthropogenic: refers to greenhouse gas emissions that are produced as result of human activities or as a result of natural processes that have been affected by human activities. [↑](#footnote-ref-2)
2. 2006 is the latest year for which electricity generation data is available for all provinces in Canada at present. [↑](#footnote-ref-3)
3. GWP: is a measure of how much a given mass of GHG is estimated to contribute to global warming over a period of 100 years. [↑](#footnote-ref-4)
4. ICF: International Consulting Firm [↑](#footnote-ref-5)
5. PEI was not included because most of its electricity is imported [41] . NF was not included because its transmission system is not connected to any other province [40]. [↑](#footnote-ref-6)
6. Scenarios #1 and #2 were described in Section 5.4.2.2 [↑](#footnote-ref-7)