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

by

Amal Ahmed Mohmed Farhat

Submitted
in partial fulfillment of the requirements
for the degree of

MASTER OF APPLED SCIENCE

Major Subject: Department of Mechanical Engineering

at

DALHOUSIE UNIVERSITY

Halifax, Nova Scotia March, 2009

Dalhousie University

Faculty of Engineering

Department of Mechanical Engineering

The undersigned hereby certify that they have examined, and recommend to the Faculty of Graduate Studies for acceptance, the thesis entitled "A New Methodology to Predict the GHG Emission Reductions Due to Electricity Savings in the Residential Sector" by Amal Ahmed Mohmed Farhat in partial fulfillment of the requirements for the degree of Master of Applied Since.

Dated: ______________________________

Supervisor: ______________________________

Dr. V.I. Ugursal

Internal Examiner: ______________________________

Dr. J. Militzar

External Examiner: ______________________________

Dr. T.A. Little

Dalhousie University

Faculty of Engineering

DATED: ______________________________

AUTHOR:	Amal Ahmed Mohmed Farhat
TITLE:	A New Methodology to Predict the GHG Emission Reductions due to Electricity Savings in the Residential Sector
MAJOR SUBJECT:	Department of Mechanical Engineering
DEGREE:	Master of Applied Science
CONVOCATION:	May, 2009

____
Signature of Author

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

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AESO	Alberta Electric System Operator
AREG	Annual reduction in electricity generation (MWh/year)
DD_m	Monthly degree days
DD_y	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
$GHGIF_A$	Average GHG intensity factor (g CO_{2eq}/kWh)
$GHGIF_M$	GHG Intensity Factor for fossil fuel (g CO_{2eq}/kWh)
GWP	Global warming potential
HO	Heavy oil
ICF	International Consulting Firm
IESO	Independent Electricity System Operator
IPM	Integrated Planning Model
$MEGMF_i$	Marginal electricity generation using marginal fuel i (MWh)
NG	Natural gas
NSP	Nova Scotia power
RSI	Thermal resistance (m^2 ºC /W)
SaskPower	Saskatchewan power
TEG	Total electricity generation in one year (kWh/year)
$TEGMF_i$	Total electricity generation using marginal fuel i (MWh)
TGHG	Total GHG emissions from electricity generation in one year (grams/year)

ACKNOWLEDGEMENT

I would like to express my deep appreciation to my supervisor Dr. V. Ismet Ugursal for his patience, guidance, and encouragement from the early stage of this work. It is the most rewarding learning experience to work under his supervision.

I would like also to extend my thanks to Dr. J. Militzar and Dr. T.A. Little for participating on the examining committee and their effort in reading this thesis and providing me with valuable comments.

I would like to thank Dr. Ian Beausoleil-Morrison for his help and support throughout this work, and for his valuable comments on the final draft of this thesis

I also would like to thank Lukas Swan for the development of the methodology used to analyse monthly Ontario data, and his willingness to help during the course of this work.

I gratefully acknowledge the Libyan Ministry of Education for the financial support. I am also grateful for the financial support provided to this project through the NSERC funded Solar Buildings Research Network.

I am deeply thankful to my brother in-law Dr. Mohmed Alsagheer for his valuable efforts to enrol me in this program and for his moral support.

My sincere gratitude to my beloved husband for his continuous support, encouragement and assistance, I always feel happy for having him in my life.

I would like to thank my entire family for their love and motivation during my study, particularly my devoted parents. I have always been surrounded by their love, care, and support; the challenges always vanish with their prayers.

Above all, I would like to express my deep gratitude to Allah who has given me the power to carry out this work.

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 CO_{2eq}/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 on published 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] 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 [2]. However, the levels of GHG emissions vary

[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.

considerably from province to province due to the variance of the availability of energy resources which is reflected on the electricity generation system.

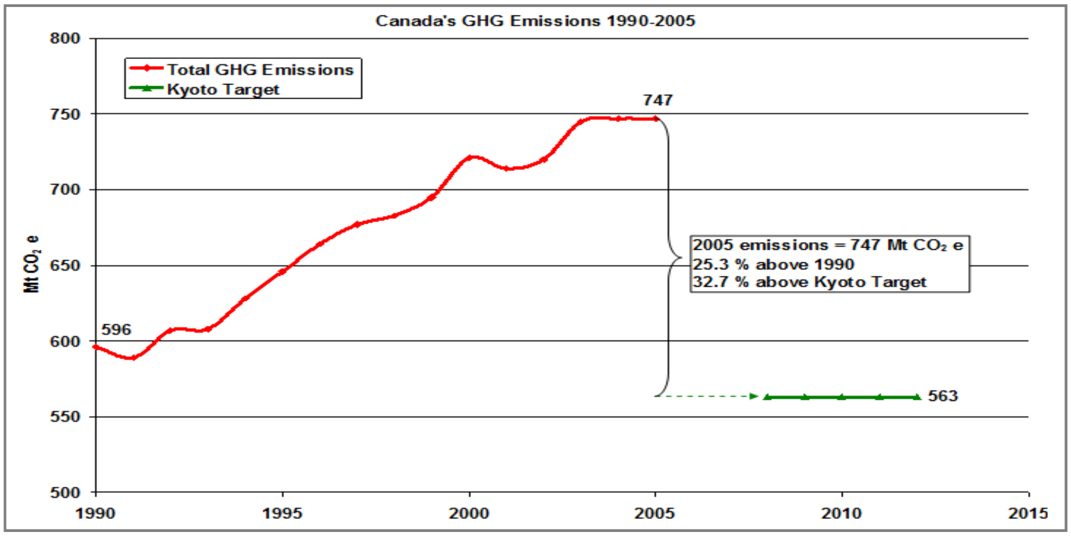

Figure 1. Canada's GHG Emissions and the Kyoto Target [1]

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.

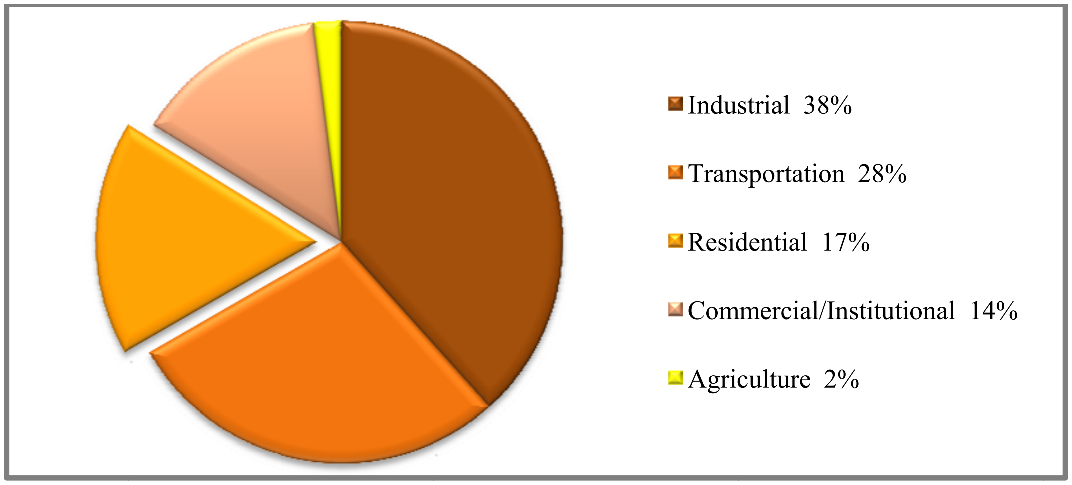

Figure 2. Annual Energy Consumption by Sector [3]

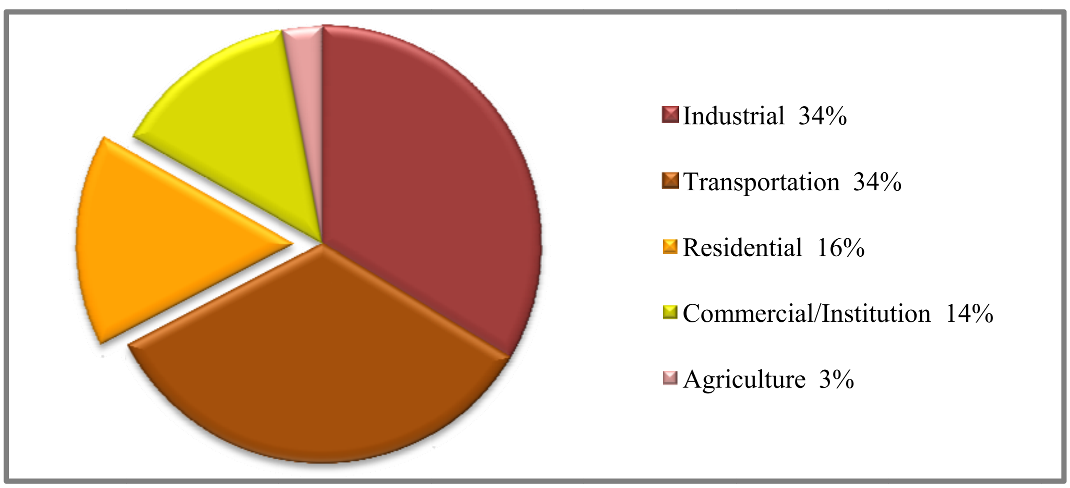

Figure 3. Annual GHG Emission by Sector [3]

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.

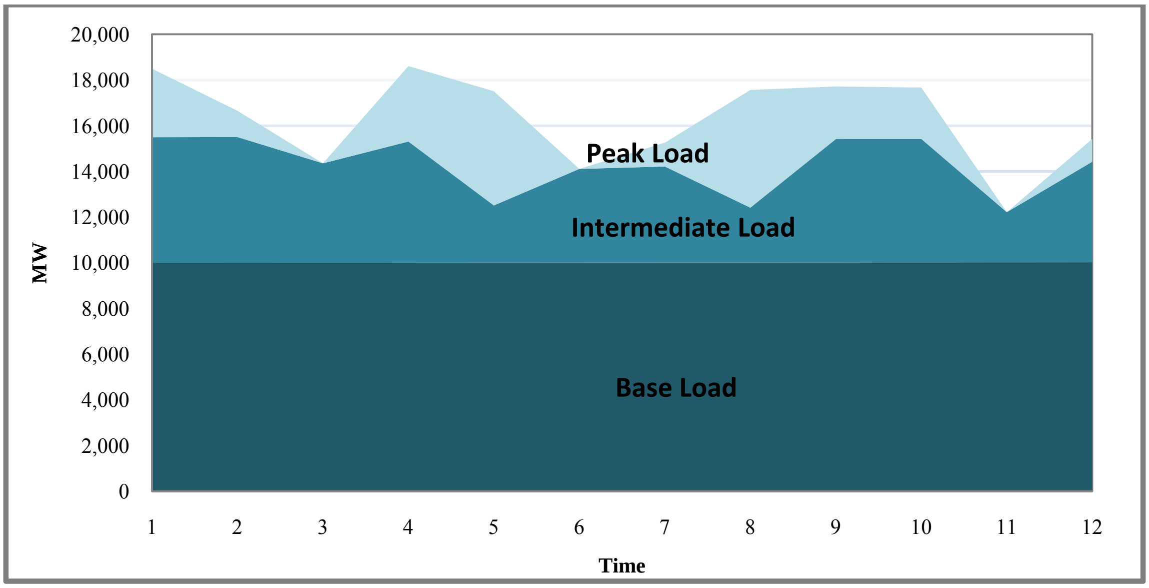

Figure 4. Electricity supply mix in terms of base load, intermediate load and peaking load power

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 [1].

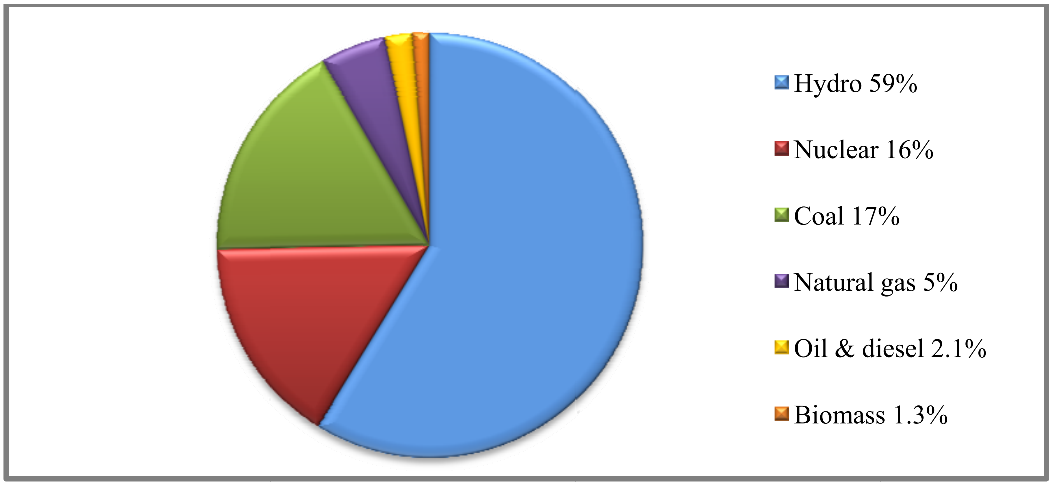

Figure 5. Electricity Generation in Canada by Fuel Source 2005 [1]

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 [1].

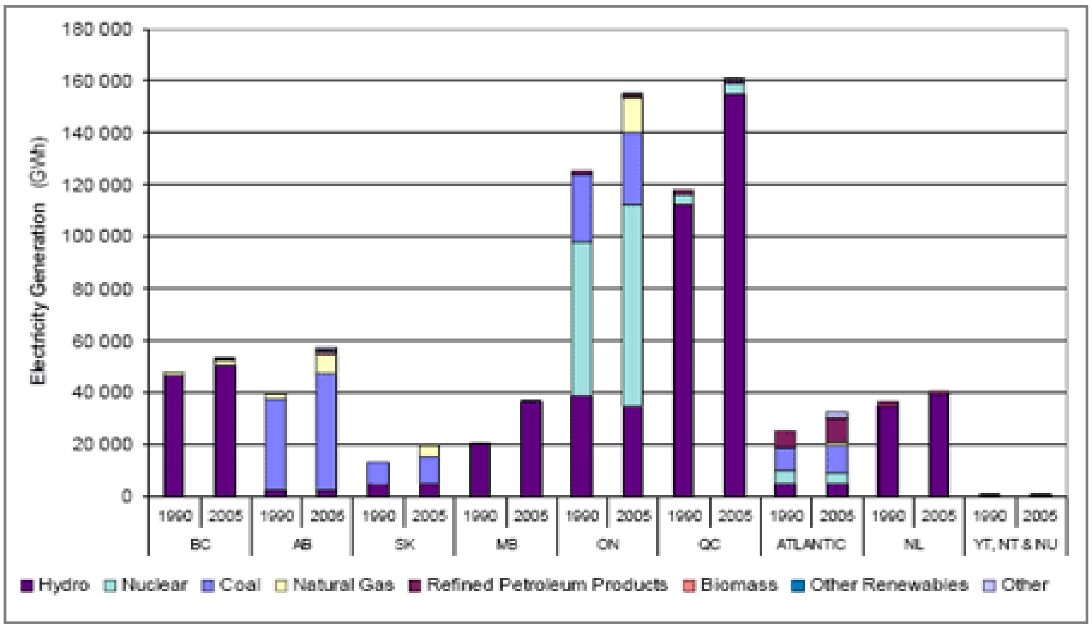

Figure 6. Electricity Generation by Region and Source for 1990 and 2005 [1]

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 [5]:

(i) Gather information on marginal electricity generation and fuel used from the open literature as well as electric utilities through personal contacts and utility websites.

(ii) Based on the information obtained in (i), determine the magnitude of the marginal electricity generation in each province as a function of time.

(iii) Based on the information obtained in (i), determine the fuels used for marginal electricity generation in each province as a function of time.

(iv) Develop a methodology to predict the GHG emissions due to marginal electricity generation based on (ii) and (iii).

(v) 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.

(vi) 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 [6].

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 [7]. The total electricity generation for years 2004 to 2006[2] 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].

[2] 2006 is the latest year for which electricity generation data is available for all provinces in Canada at present.

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 [12]. 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 [13]. 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 [14]. 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) [15]. 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 [16].

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 [17].

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 [18]. 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 [16].

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 [19]. 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.m^3	12,767	0.13	3,476k.m^3	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 [20].

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 [21]. The peak load in the province is primarily generated from a mix of coal and oil [22], 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.m^3	1,966,849	10.25	592,041k.m^3	2,319,797	13.84	533,857 k.m^3
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 [24]. 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.m^3	212,073	0.13	75,774k.m^3	141,377	0.09	325,013 k.m^3
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 [26]. 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.m^3	11,901,579	7.67	2,832,214k.m^3	10,693,529	6.93	2,833,982 k.m^3
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 [28]. 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 [29]. 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 [29]. 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.m^3	10,577	0.03	4,392k.m^3	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% [30] .

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 [30]. 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.m^3	2,612,793	13.43	765,158k.m^3	2,956,455	15.27	845,583 k.m^3
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 [31].

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 [32]. Alberta peaking load is supplied mainly by NG and coal power plants where the remaining is supplied by hydro resources [33]. 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.m^3	11,599,542	20.28	3,301,348k.m^3	12,545,425	22.55	3,695,187 k.m^3
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 [34]. 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 [35].

British Columbia has a winter peaking load. The peak load is primarily provided by hydro resources, NG thermal power plants, and import [36]. 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.m^3	2,436,996	4.57	554,648k.m^3	2,165,673	4.59	502,300 k.m^3
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	-

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 (CO_2), water (H_2O), methane (CH_4), and nitrous oxide (N_2O). 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] (GWP). The GWP is referenced to the strength of CO_2 (i.e. equivalent CO_2, or CO_{2eq}) as it is the dominant gas emitted during combustion. Considering the GWP of CO_2 to be unity, CH_4 and N_2O have 100 year GWPs of 25 and 298 by mass, respectively [37]. Thus, CO_{2eq} can be determined as follows:

$$\mathrm{CO_{2eq}} = \mathrm{CO_2} + 25\,\mathrm{CH_4} + 298\,\mathrm{N_2O} \qquad [1]$$

In the rest of this work, all GHG emissions and emission intensity factors are expressed in terms of CO_{2eq} emissions. The GHG emission intensity factor, i.e. the total CO_{2eq} GHG emissions generated per unit of electricity generation (g CO_{2eq}/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 CO_2, CH_4 and NO_2 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.

[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.

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

Fuel Used	CO_2 (g)*	CH_4 (g)	N_2O (g)
Natural gas (m^3)	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

* CO_2 emissions from biogenic materials are considered as complement of the natural carbon cycle. CO_2 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.
*** CO_2 emission for Orimulsion is calculated in Appendix D.

4.1 Average GHG Intensity Factor ($GHGIF_A$)

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

$$GHGIF_A = \frac{TGHG}{TEG} \qquad [2]$$

where,

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

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

$GHGIF_A$ method neglects the transmission and distribution losses. $GHGIF_A$ can be calculated for the whole country, or for each individual province. Since each province uses a substantially different fuel mix for electricity generation, the $GHGIF_A$ is substantially different from one 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 ($GHGIF_M$)

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

$$\mathrm{GHGIF_M} = \frac{\mathrm{FFGHG}}{\mathrm{FFNEG}} \qquad [3]$$

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

To demonstrate the magnitude of the differences between the two methods, the $GHGIF_A$ and $GHGIF_M$ values for each province 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 $GHGIF_A$ and $GHGIF_M$ values for each province over 2004 to 2006 are given in Tables A1-A10 of Appendix A.

Table 13. $GHGIF_A$ and $GHGIF_M$ values (g CO_{2eq}/kWh) over 2004-2006 and the average values over these years for each province

	2004		**2005**		**2006**		**Average over 2004-2006**	
	$GHGIF_A$	**$GHGIF_M$**	**$GHGIF_A$**	**$GHGIF_M$**	**$GHGIF_A$**	**$GHGIF_M$**	**$GHGIF_A$**	**$GHGIF_M$**
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 $GHGIF_A$ and $GHGIF_M$ are highly variable from one province to another. The lowest value of $GHGIF_A$ is for Quebec where electricity generation is primarily from hydro power plants, while other provinces such as Alberta and Saskatchewan have higher values of $GHGIF_A$ due to their dependency on fossil fuel power plants

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] 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

[4] ICF: International Consulting Firm

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 CO_{2eq}/kWh_{fuel}) 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 CO_{2eq}/kWh_{fuel}) 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 CO_{2eq}/kWh_{fuel})
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 CO_2 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.

$$\frac{\mathrm{MEGMF_i}}{\sum_{i=1}^{n}\mathrm{MEGMF_i}} = \frac{\mathrm{TEGMF_i}}{\sum_{i}^{n}\mathrm{TEGMF_i}} \qquad [4]$$

where,

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

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

n = number of fuels used for marginal electricity generation

Table 16. Range and annual marginal GHG intensity factors over 2004-2006, and the weighted annual marginal GHG intensity factors (g CO_{2eq} /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:

$$\text{The Annual Marginal GHG Intensity Factor}\left(\frac{\text{g CO}_{2\text{eq}}}{\text{kWh}}\right) = \sum_{i}^{n} \%\ \text{fuel}_{\text{i}} * \text{GHG intensity factor for fuel}_{\text{i}}\left(\frac{\text{g CO}_{2\text{eq}}}{\text{kWh}_{\text{fuel i}}}\right) \qquad [5]$$

where:

$$\text{The GHG intensity factor for fuel}_{\text{i}} = \frac{\text{emission factor for fuel}_{\text{i}}(\text{g CO}_{2\text{eq}}/\text{quantity}_{\text{fuel}}) * \text{quantity of fuel}_{\text{i}}\text{ consumed}}{\text{electricity generated by fuel}_{\text{i}}\text{ (kWh)}} \qquad [6]$$

Using the latest available Statistics Canada data on electricity generation and fuels used [8-10], and the GHG intensity factors for each fuel (g CO_{2eq}/kWh_{fuel}) 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.

$$\%\ \text{fuel mix on margin} = \%\text{fuel mix in 2004} * 20\% + \%\text{fuel mix in 2005} * 30\% + \%\text{fuel mix in 2006} * 50\% \qquad [7]$$

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 CO_{2eq}/kWh) reflects the emission factor for imported electricity or hydroelectric generation, whereas the lower limit (0 g CO_{2eq}/kWh) for Alberta, Ontario, Quebec, Nova Scotia and Newfoundland reflect the emission factor for hydroelectric generation. The lower limit (0 g CO_{2eq}/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 CO_{2eq} /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].

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 CO_{2eq}/kWh) for each province were calculated. The emission intensity for each fuel (g CO_{2eq} /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.

$$\text{The emission intensity for each fuel } \left(\mathrm{g\ CO_{2eq}/kWh_{fuel}}\right) = \frac{\text{Emission Factor } \left(\mathrm{g\ CO_{2eq}/quantity_{fuel}}\right) * \text{Heat Rate(Btu/kWh)}}{\text{Energy Content } \left(\mathrm{Btu/quantity_{fuel}}\right)} \quad [8]$$

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.

$$\text{The marginal intensity factor } \left(\frac{\mathrm{g\ CO_{2eq}}}{\mathrm{kWh}}\right) = \sum_{i=1}^{n} \%\mathrm{fuel_i} * \text{emission intensity factor for } \mathrm{fuel_i} \ \left(\frac{\mathrm{g\ CO_{2eq}}}{\mathrm{kWh_{fueli}}}\right) \quad [9]$$

---

[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].

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.

$$\begin{aligned}\%\ \text{monthly fuel mix on margin} \\ &= \%\text{fuel mix in 2004} * 10\% + \%\text{fuel mix in 2005} * 20\% \\ &+ \%\text{fuel mix in 2006} * 30\% + \%\text{fuel mix in 2007} * 40\%\end{aligned} \qquad [10]$$

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 CO_{2eq}/ 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 CO_{2eq}/ 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

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]

	Summer (%)		**Winter (%)**		**Shoulder (%)**	
2004	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
	Summer (%)		**Winter (%)**		**Shoulder (%)**	
2005	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
	Summer (%)		**Winter (%)**		**Shoulder (%)**	
2006	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 [42]. 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.

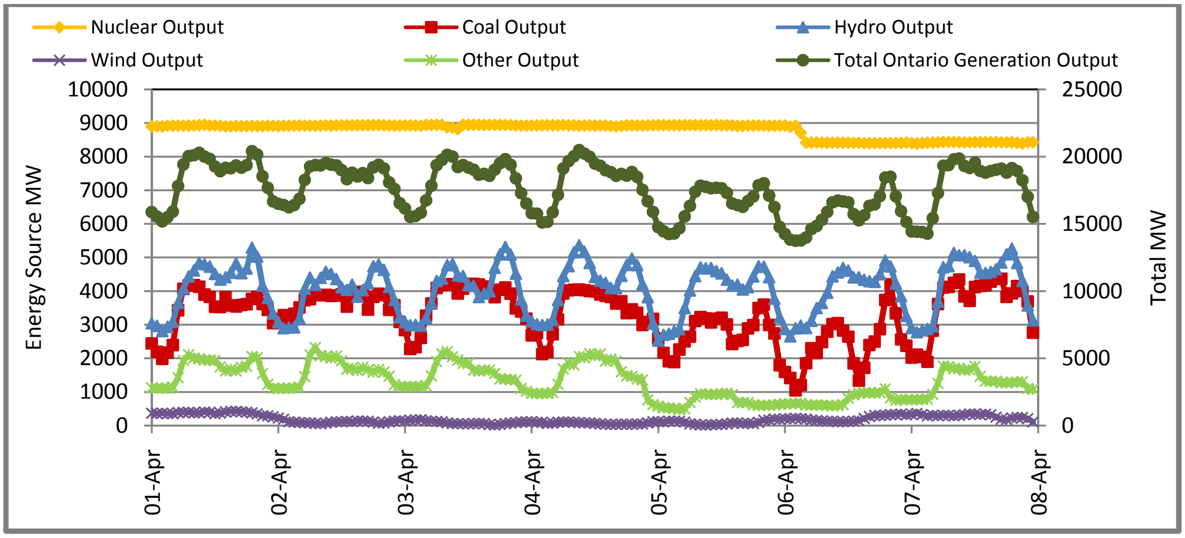

Figure 7. Electrical generation energy source components for Ontario for April 1-8, 2008 [47]

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).

$$\%\,\text{monthly fuel mix on margin} = \%\text{fuel mix in 2004} * 20\% + \%\text{fuel mix in 2005} * 30\% + \%\text{fuel mix in 2006} * 50\% \quad [11]$$

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 [33]. Therefore, the prediction of marginal GHG intensity factors (g CO_{2eq}/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.

$$\text{The marginal intensity factor}\left(\frac{\text{g CO}_{2\text{eq}}}{\text{kWh}}\right) = \Big[21 * [\textstyle\sum_{i=1}^{n} \%\,\text{fuel}_i \text{ on peak} * \text{emission intensity factor for fuel}_i \left(\frac{\text{g CO}_{2\text{eq}}}{\text{kWh}_{\text{fueli}}}\right)] + 9 * [\sum_{i=1}^{n} \%\ \text{of fuel}_i \text{ off peak} * \text{emission intensity factor for fuel}_i \left(\frac{\text{g CO}_{2\text{eq}}}{\text{kWh}_{\text{fueli}}}\right)]\Big] / 30 \quad [12]$$

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 CO_{2eq}/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.

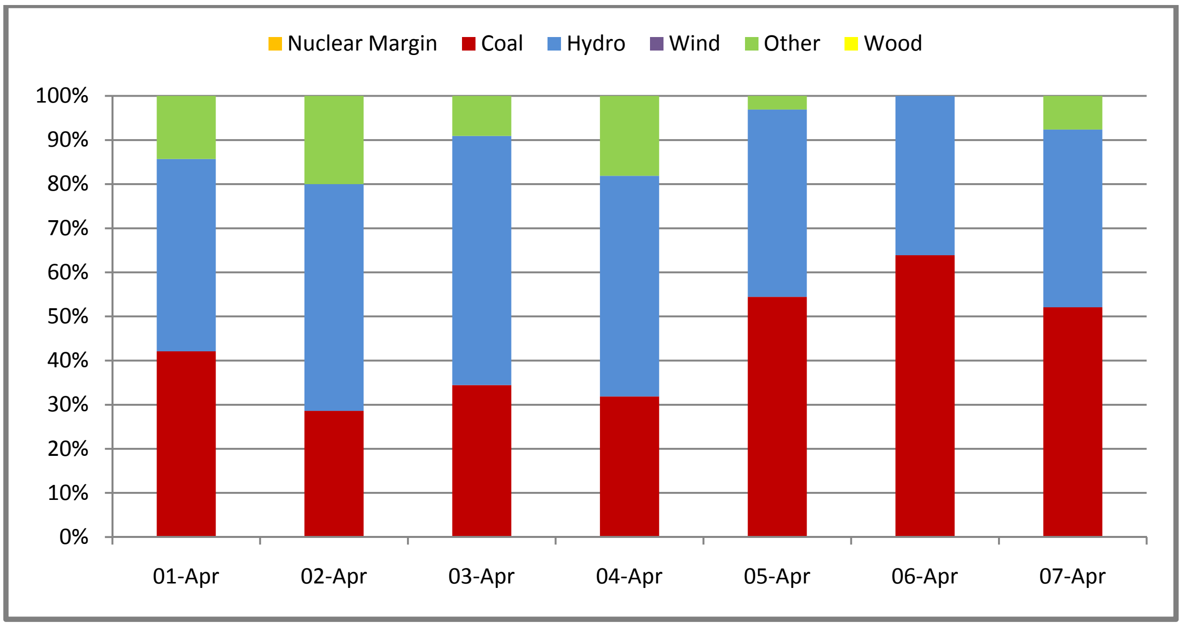

Figure 8. Energy sources for the marginal electricity generation in Ontario for April 1-7, 2008

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 CO_{2eq}/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 CO_{2eq}/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 $\leq$ 2%) and can be neglected. Therefore, coal, hydro and natural gas (other) are considered to be on the margin

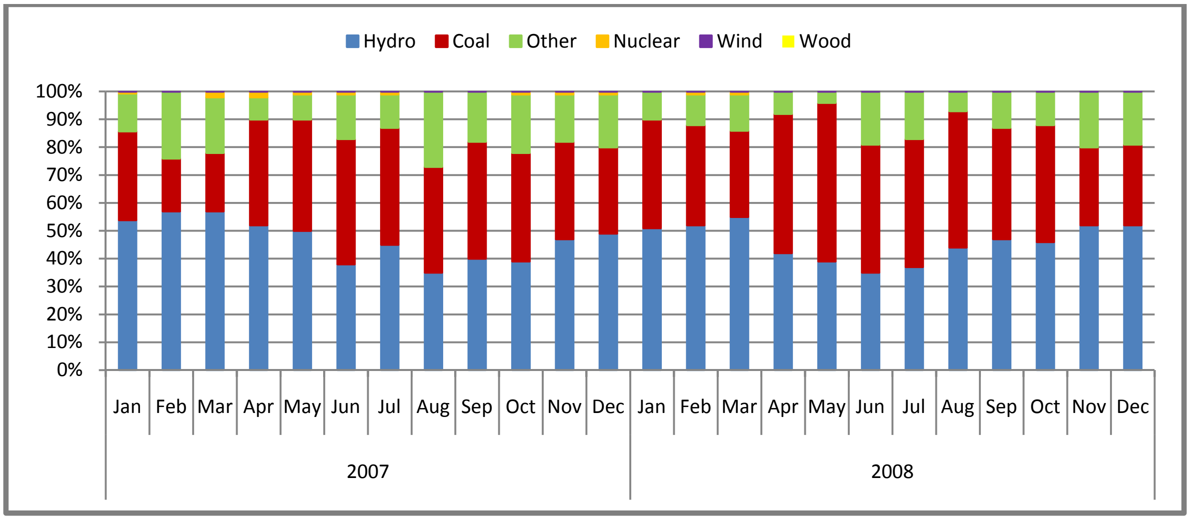

Figure 9. Energy sources for the marginal electricity generation in Ontario over 2007-2008

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.

$$\%\text{ monthly fuel mix on margin} = \%\text{fuel mix in 2007} * 40\% + \%\text{fuel mix in 2008} * 60\% \qquad [13]$$

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 CO_{2eq}/kWh) were calculated using Equation 9. The predicted marginal fuel sources, as well as the marginal GHG intensity factors (g CO_{2eq}/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 CO_{2eq}/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 ($GHGIF_A$)
- GHG intensity factor from fossil fuel power plants ($GHGIF_M$)
- 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 $GHGIF_A$ and the $GHGIF_M$ 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**	**$GHGIF_A$**	**$GHGIF_M$**
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 CO_{2eq}/kWh) using the five different methods

Method	**Weighted Annual Marginal GHGIF**				**$GHGIF_A$**				**$GHGIF_M$**			
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
ON #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

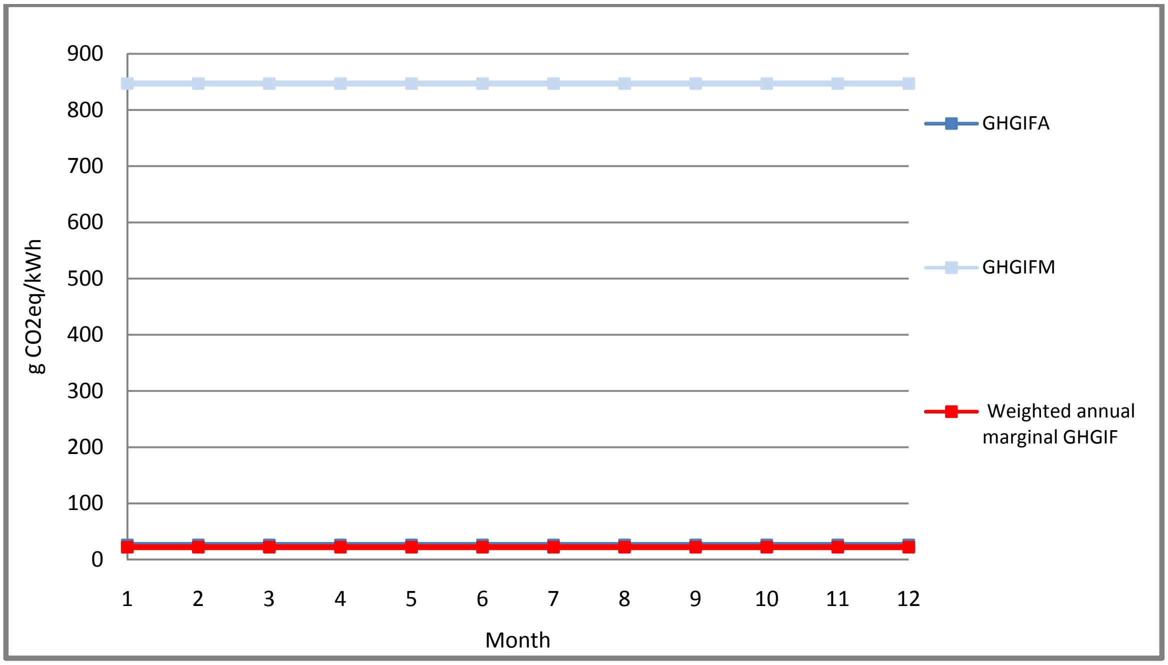

Figure 10. The GHG intensity factors for Newfoundland based on $GHGIF_A$, $GHGIF_M$, and weighted annual marginal approach

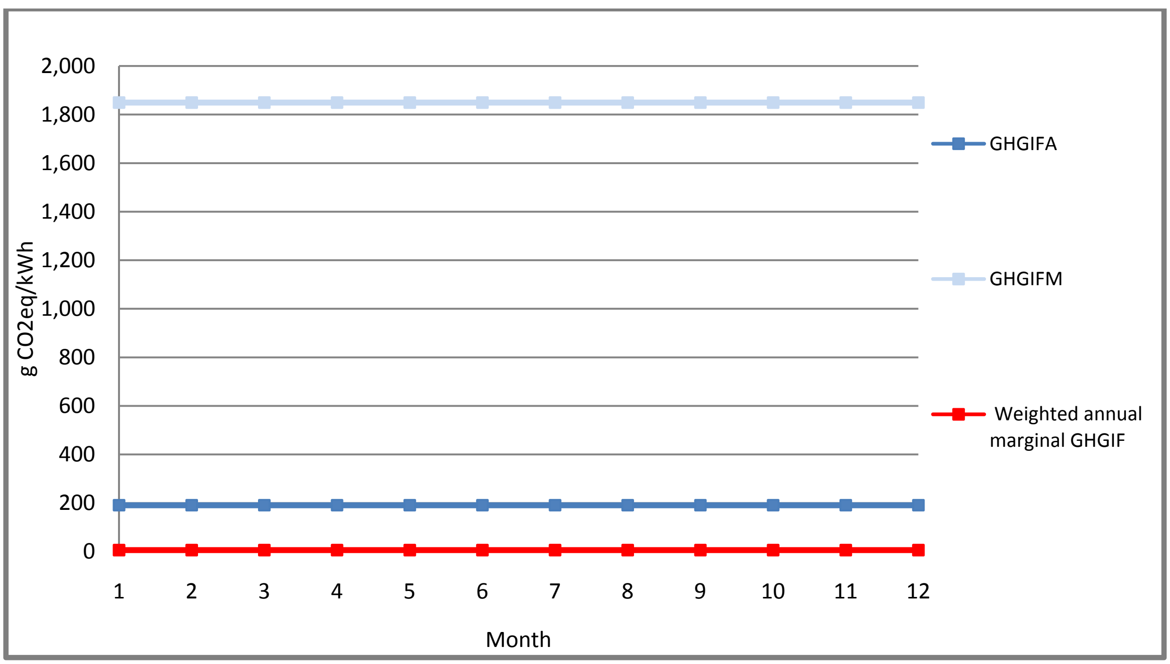

Figure 11. The GHG intensity factors for Prince Edward Island based on $GHGIF_A$, $GHGIF_M$, and weighted annual marginal approach

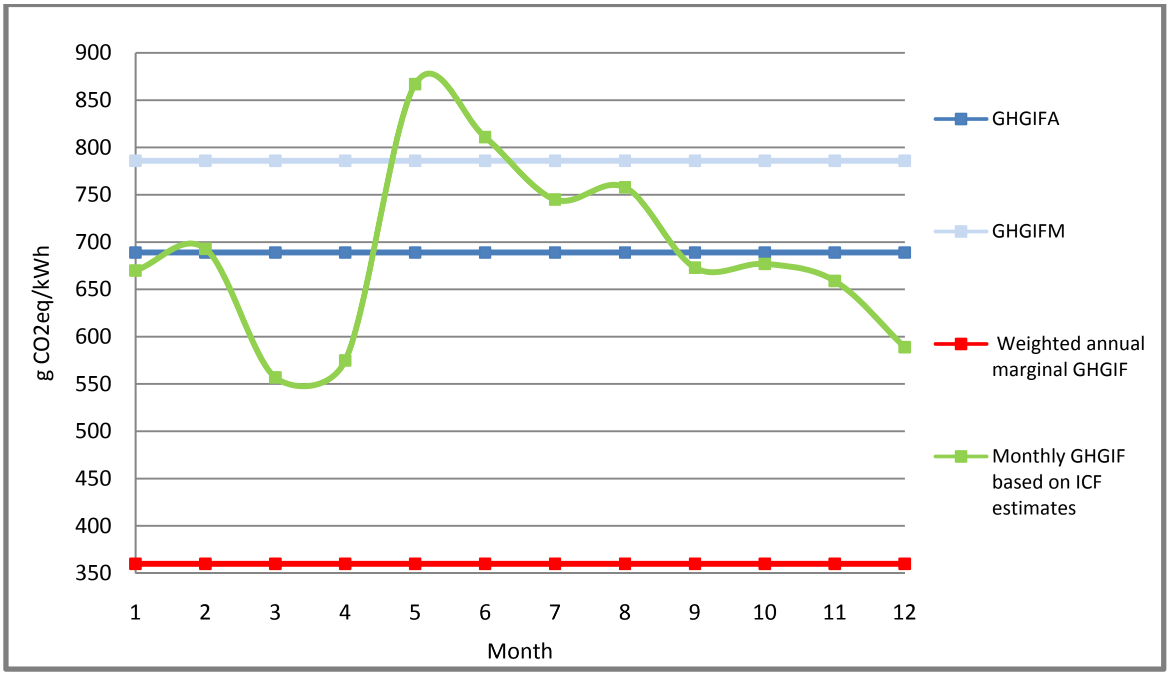

Figure 12. The GHG intensity factors for Nova Scotia based on $GHGIF_A$, $GHGIF_M$, weighted annual marginal approach, and ICF estimates

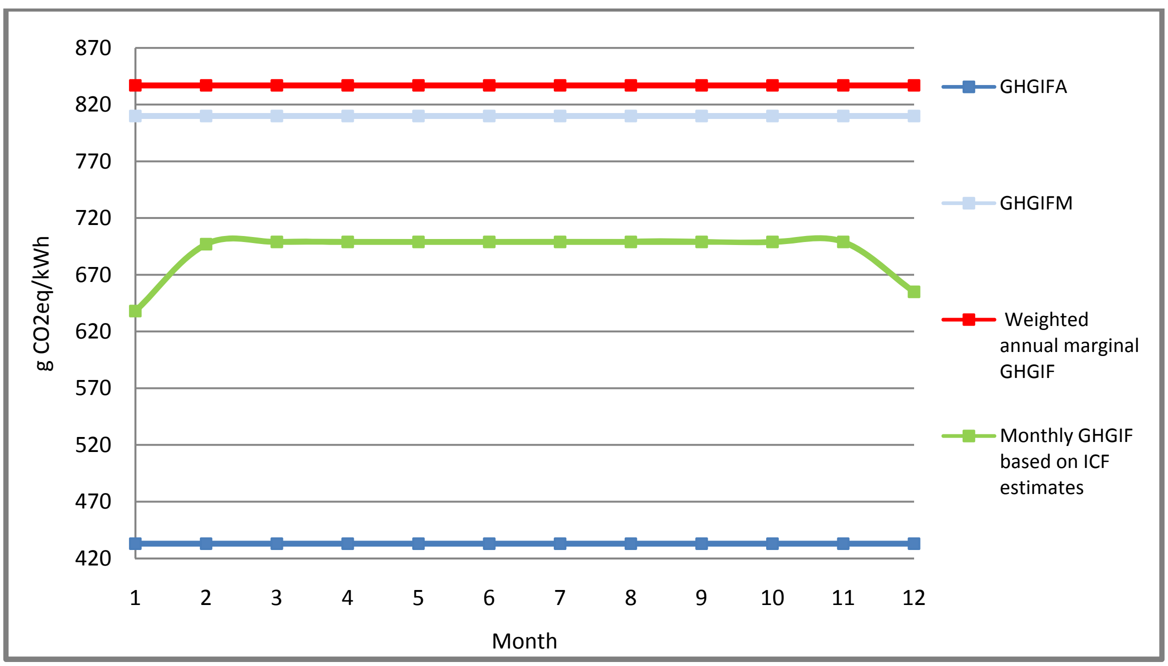

Figure 13. The GHG intensity factors for New Brunswick based on $GHGIF_A$, $GHGIF_M$, weighted annual marginal approach, and ICF estimates

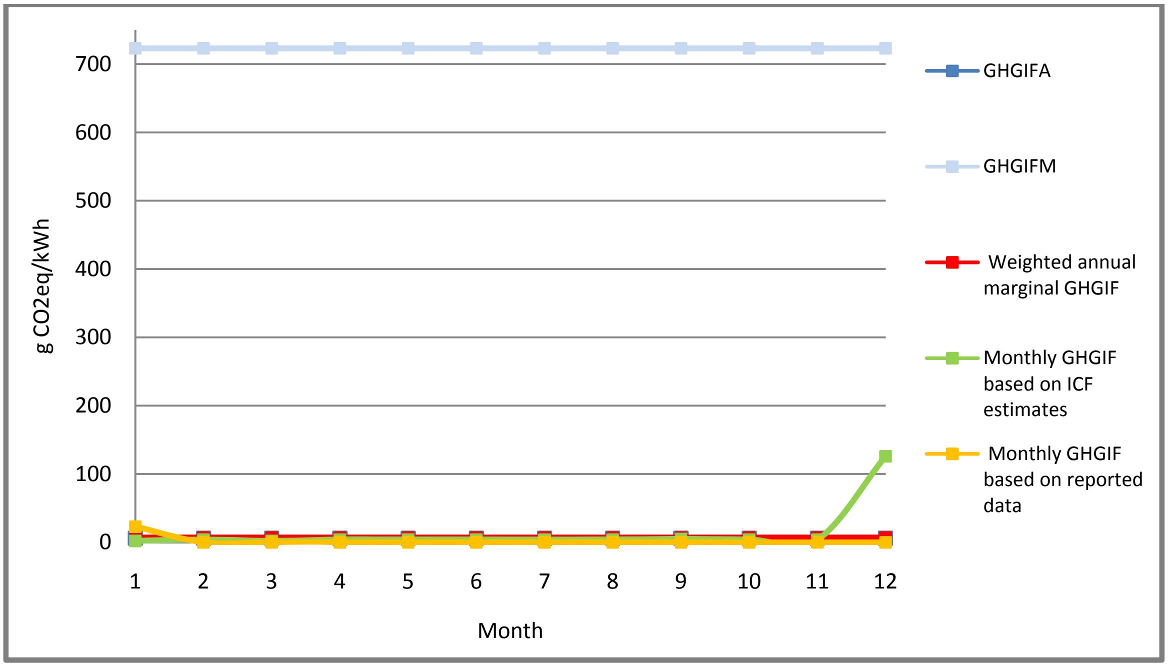

Figure 14. The GHG intensity factors for Quebec based on $GHGIF_A$, $GHGIF_M$, weighted annual marginal approach, ICF estimates, and the reported data

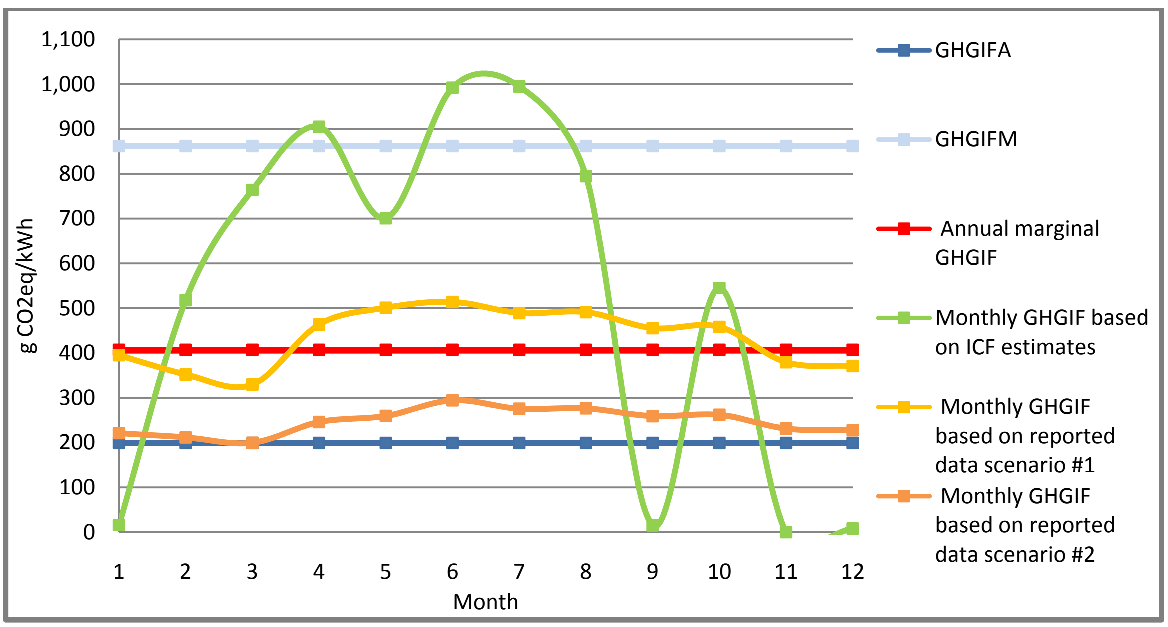

Figure 15. The GHG intensity factors for Ontario based on $GHGIF_A$, $GHGIF_M$, weighted annual marginal approach, ICF estimates, and the reported data

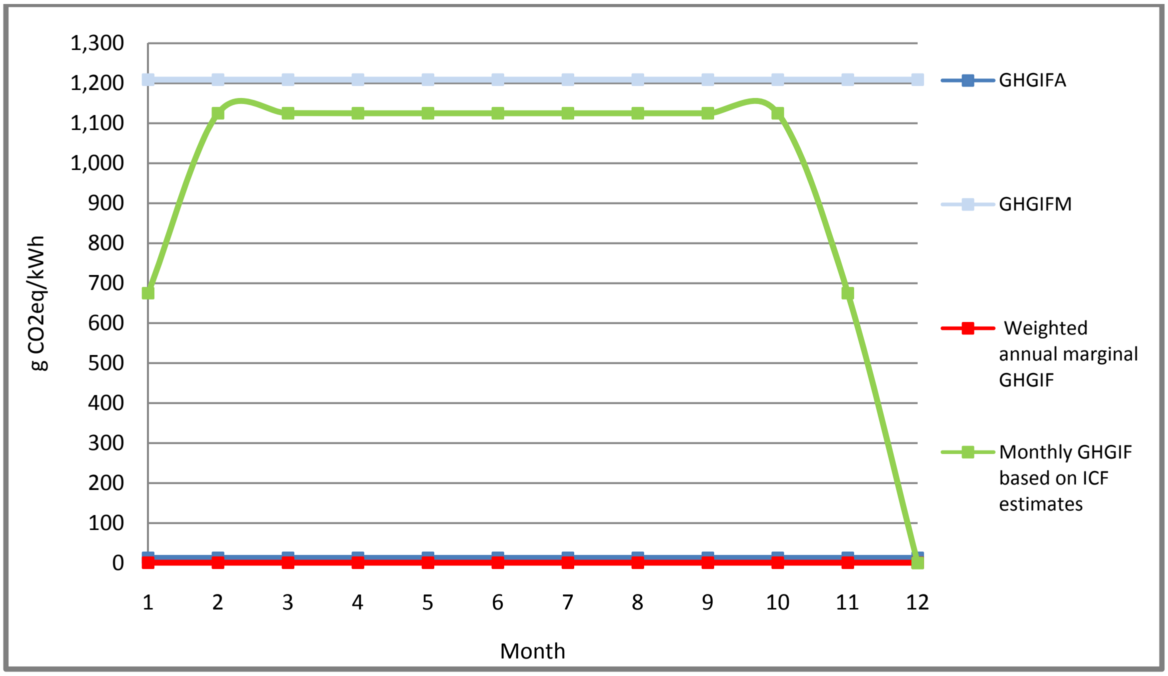

Figure 16. The GHG intensity factors for Manitoba based on $GHGIF_A$, $GHGIF_M$, weighted annual marginal approach, and ICF estimates

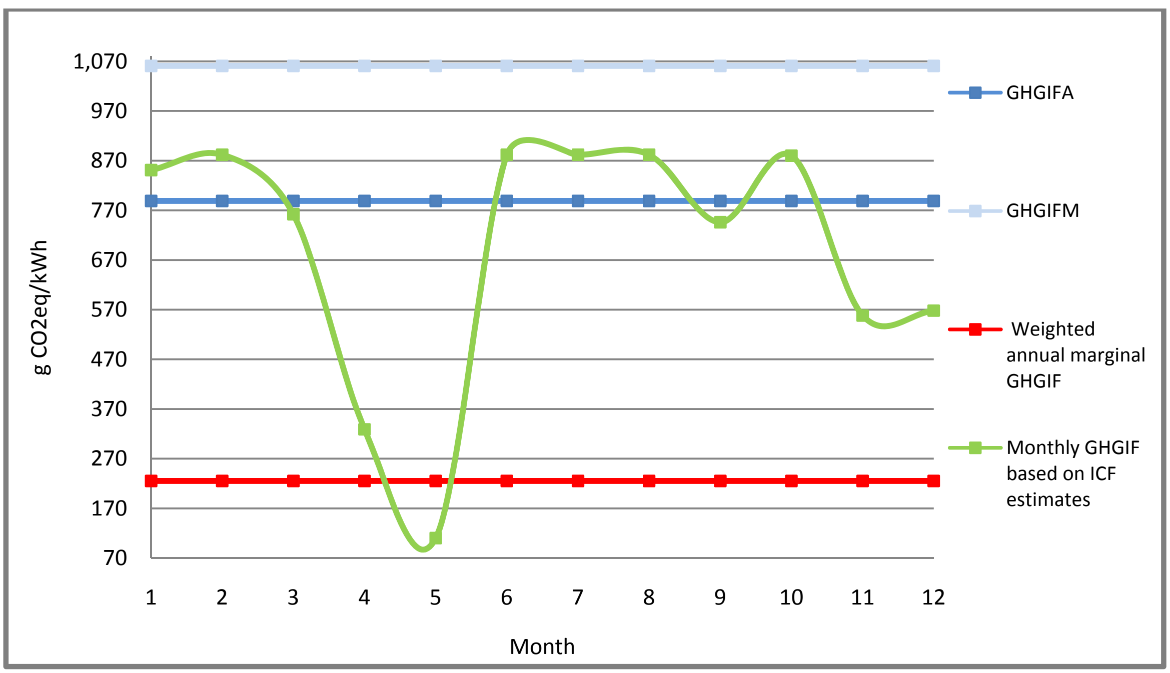

Figure 17. The GHG intensity factors for Saskatchewan based on $GHGIF_A$, $GHGIF_M$, weighted annual marginal approach, and ICF estimates

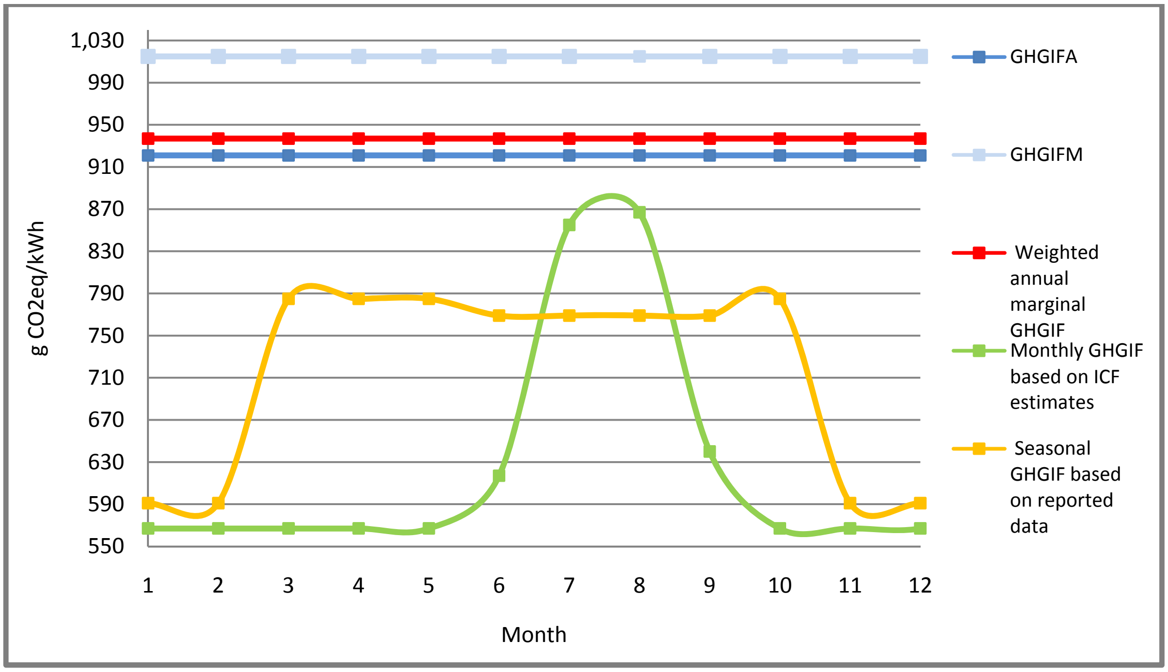

Figure 18. The GHG intensity factors for Alberta based on $GHGIF_A$, $GHGIF_M$, weighted annual marginal approach, ICF estimates, and the reported data

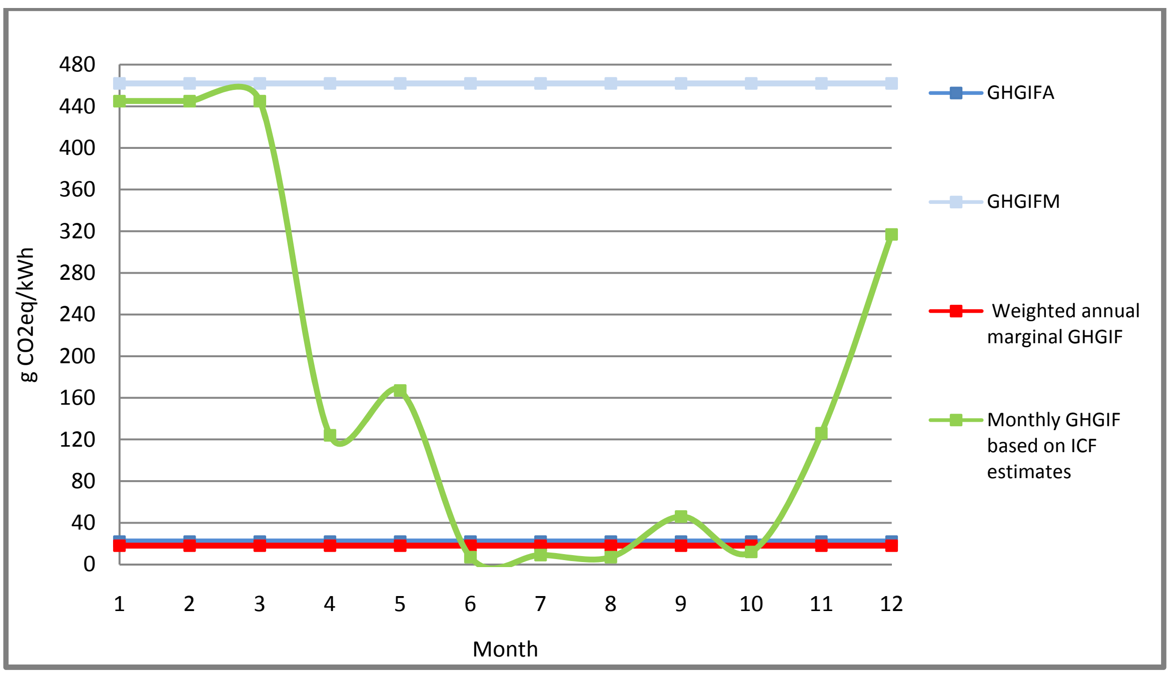

Figure 19. The GHG intensity factors for British Columbia based on $GHGIF_A$, $GHGIF_M$, weighted annual marginal approach, and ICF estimates

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 $GHGIF_A$ 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 $GHGIF_A$ are very close to each other (22 and 26 g CO_{2eq}/kWh, respectively), the $GHGIF_M$ provides a substantially higher estimate. The large difference between the predictions of the two methods and the $GHGIF_M$ is due to the fact that a very small proportion of electricity generation in Newfoundland is by fossil fuels. Consequently, the use of $GHGIF_M$ 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.

2) 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 $GHGIF_M$ and $GHGIF_A$ as seen in Figure 11, and $GHGIF_M$ 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 CO_{2eq}/kWh produces a realistic estimate.
- Therefore, it is recommended here that the weighted annual marginal GHG intensity factor is used for Prince Edward Island.

3) Nova Scotia:

- Nova Scotia relies heavily on fossil fuels for its electricity generation, therefore, the $GHGIF_A$ and $GHGIF_M$ are close to each other (689 and 786 g CO_{2eq}/kWh, respectively) as seen in Figure 12. The GHG intensity factor predicted using the weighted annual marginal method is about 360 (g CO_{2eq}/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 $GHGIF_A$ and $GHGIF_M$.
- Therefore, it is recommended here that the weighted annual marginal GHG intensity factor is used for Nova Scotia.

4) 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 $GHGIF_M$ 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 $GHGIF_M$ are very close to each other (837and 810 g CO_{2eq}/kWh, respectively), the $GHGIF_A$ provides a substantially lower estimate. Consequently, the use of $GHGIF_A$ is not realistic for New Brunswick.
- Based on the information reported by New Brunswick Power officer [52], the New Brunswick Power considers 800 (g CO_{2eq}/kWh) as a reasonable estimate for the marginal GHG intensity factor for all periods. Therefore, 800 g CO_{2eq}/kWh is recommended for New Brunswick.

5) 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 $GHGIF_A$ 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 $GHGIF_A$ are very close to each other, the $GHGIF_M$ provides a substantially higher estimate. The large difference between the predictions of the two methods and the $GHGIF_M$ is due to the fact that a very small proportion of electricity generation in Quebec is by fossil fuels. Consequently, the use of $GHGIF_M$ 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 CO_{2eq}/kWh) for January, and 0 (g CO_{2eq}/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.

6) 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 $GHGIF_A$ and $GHGIF_M$ methods are a substantially different (199 and 862 g CO_{2eq}/kWh, respectively) as seen in Figure 15. The weighted annual marginal GHG intensity factor is also within this range (407 g CO_{2eq}/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 CO_{2eq}/kWh) range for Scenario #1 and 199-276 (g CO_{2eq}/kWh) for Scenario #2[6]. 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.

[6] Scenarios #1 and #2 were described in Section 5.4.2.2

7) 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 $GHGIF_M$ and $GHGIF_A$ as seen in Figure 16, and $GHGIF_M$ is not applicable for marginal generation.
- The $GHGIF_A$ and the weighted annual marginal GHG intensity factor are close to each other (13 and 1 g CO_{2eq}/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.

8) 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 $GHGIF_A$ and $GHGIF_M$ 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 $GHGIF_A$ and $GHGIF_M$.

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

9) Alberta:

- Alberta relies heavly on fossil fuels for its electricity generation, therefore, the $GHGIF_A$ and $GHGIF_M$ are close to each other (921 and 1,015 g CO_{2eq}/kWh, respectively). The weighted annual marginal GHG intensity factor is also within this range (937 g CO_{2eq}/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 CO_{2eq}/kWh) range from March to October, and about 590 (g CO_{2eq}/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.

10) 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 $GHGIF_A$ 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 $GHGIF_A$ are very close to each other, the $GHGIF_M$ provides a substantially higher estimate. The large difference between the predictions of the two methods and the $GHGIF_M$ is due to the fact that a very small proportion of electricity generation in British Columbia is by fossil fuels. Consequently, the use of $GHGIF_M$ 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 CO_{2eq}/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 CO_{2eq}/kWh) for each province

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

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:

$$\text{GHG emission reduction} \;=\; \left[\frac{\text{reduction in electricity consumption (KWh)}}{1-\frac{\%\ \text{losses}}{100}}\right] * \text{GHGIF}$$

[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.

$$\text{Annual reduction in electricity generation} = \frac{\text{annual reduction in electricity consumption (KWh)}}{1-\frac{\%\,\text{losses}}{100}} \qquad [15]$$

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.

$$\text{Monthy reductions in electricity generation (MWh/month)} = \text{AREG} * \frac{\text{DD}_\text{m}}{\text{DD}_\text{y}} \qquad [16]$$

where:

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

DD_m = monthly degree days

DD_y = 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 generation in Table 37 and the GHG intensity factors estimated using the five different methods presented in Table 33.

The monthly reductions in GHG emission (Tonne CO_{2eq}/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.

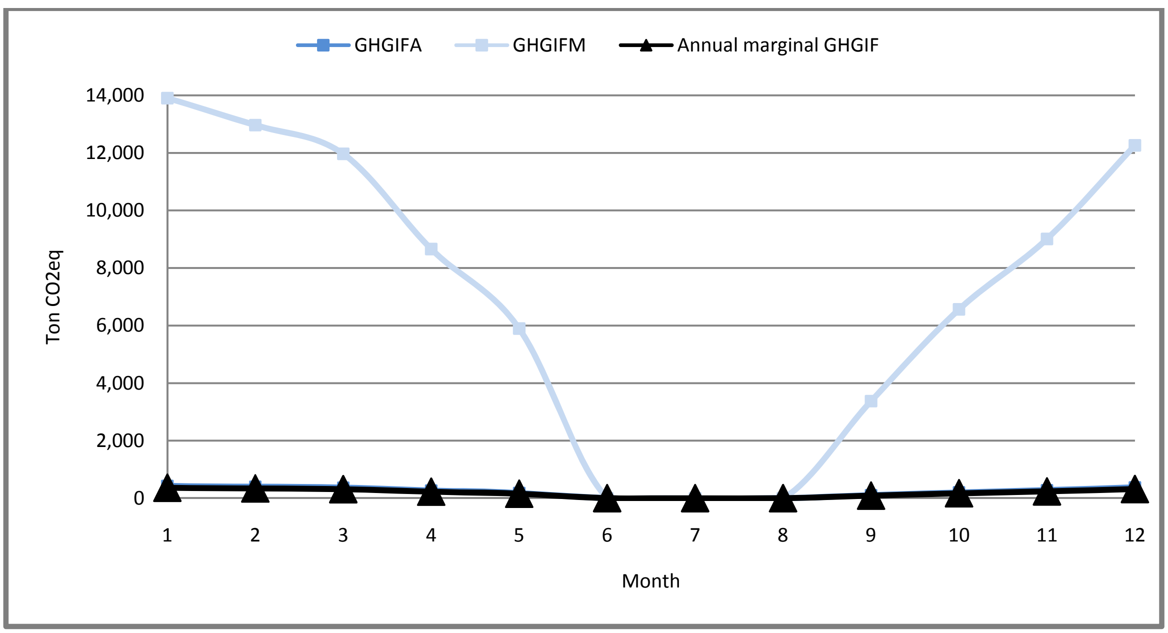

Figure 20. Monthly GHG emission reductions as result of ceiling insulation upgrade for Newfoundland

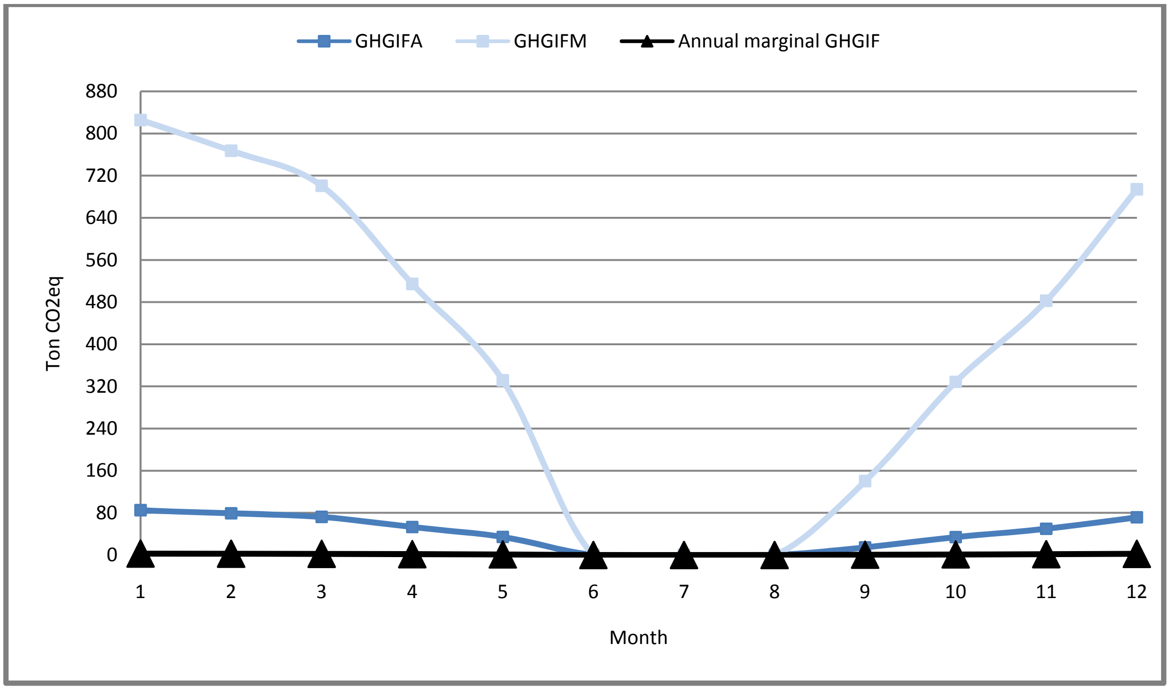

Figure 21. Monthly GHG emission reductions as result of ceiling insulation upgrade for Prince Edward Island

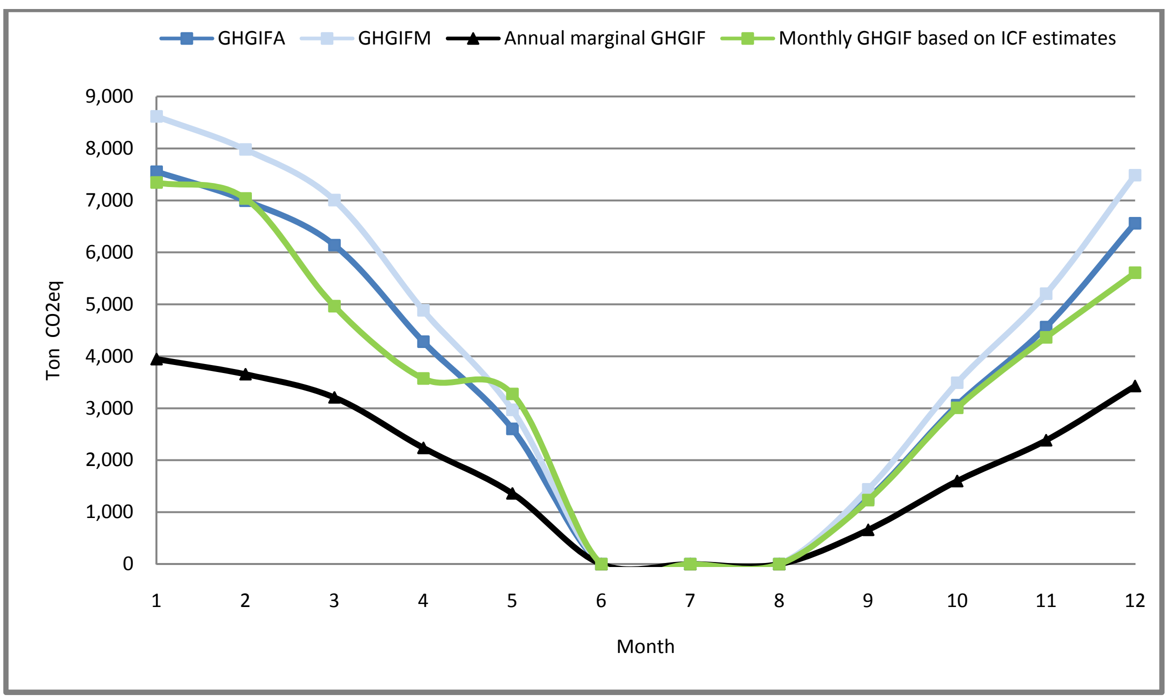

Figure 22. Monthly GHG emission reductions as result of ceiling insulation upgrade for Nova Scotia

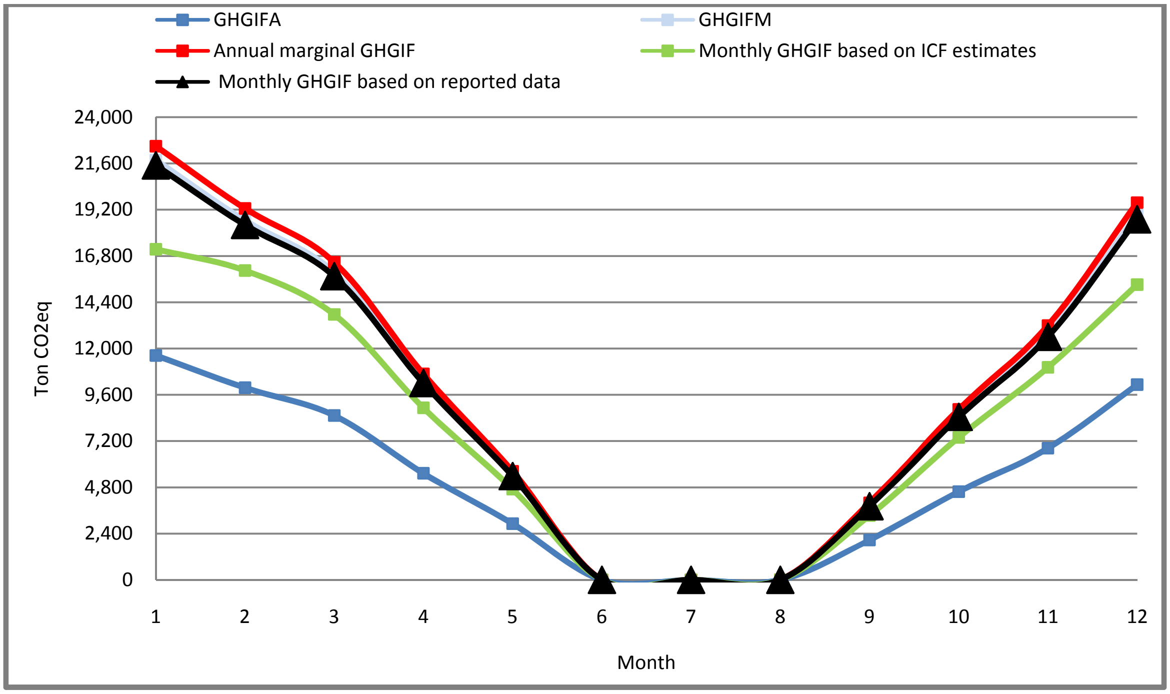

Figure 23. Monthly GHG emission reductions as result of ceiling insulation upgrade for New Brunswick

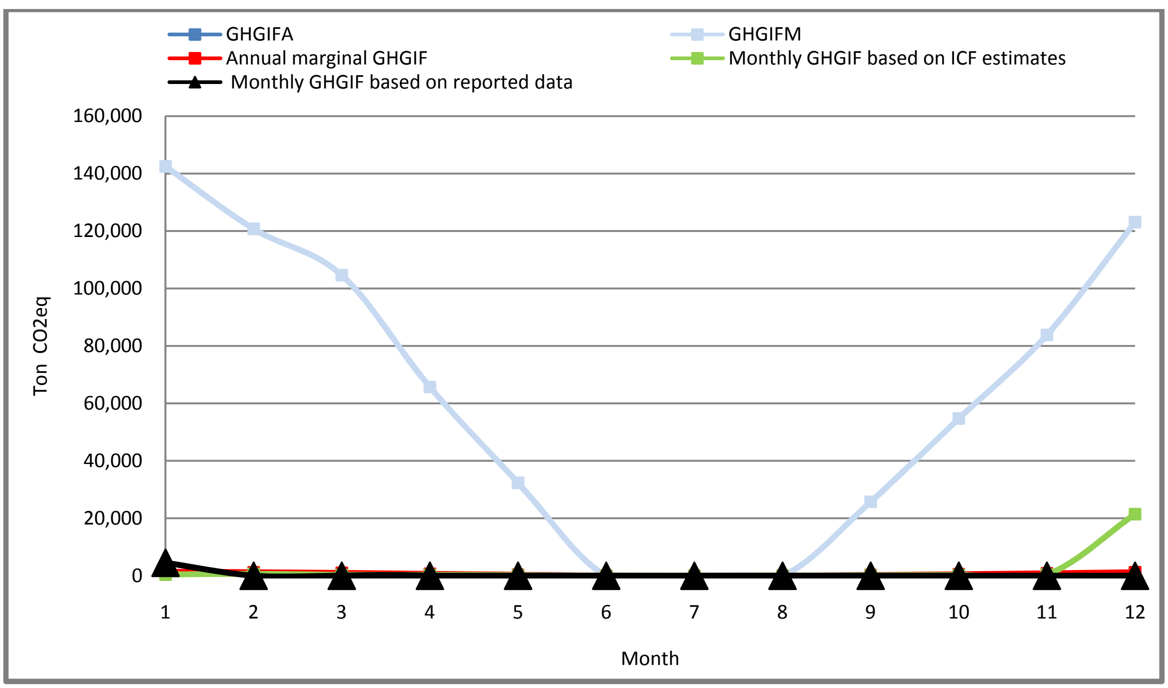

Figure 24. Monthly GHG emission reductions as result of ceiling insulation upgrade for Quebec

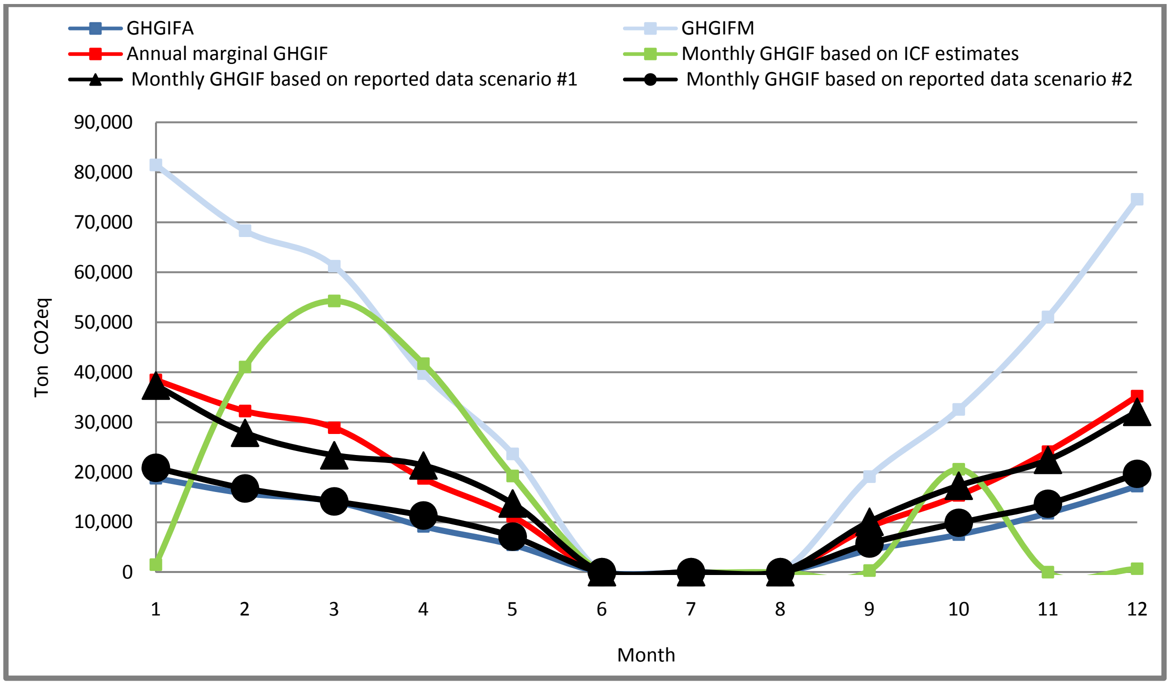

Figure 25. Monthly GHG emission reductions as result of ceiling insulation upgrade for Ontario

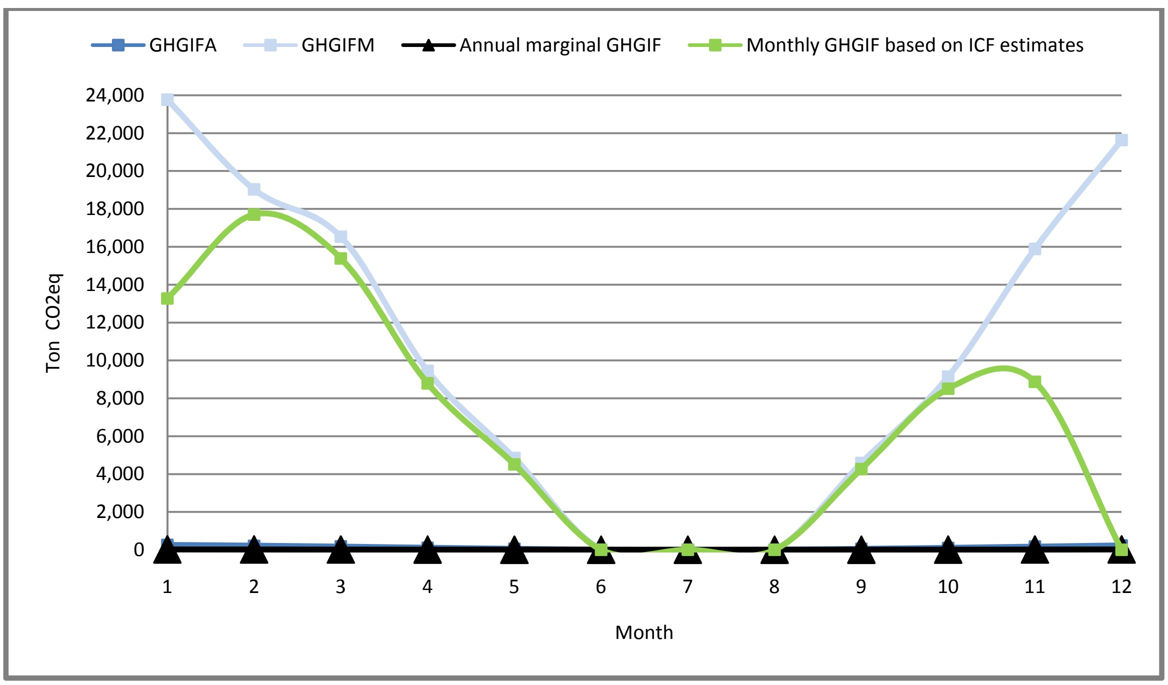

Figure 26. Monthly GHG emission reductions as result of ceiling insulation upgrade for Manitoba

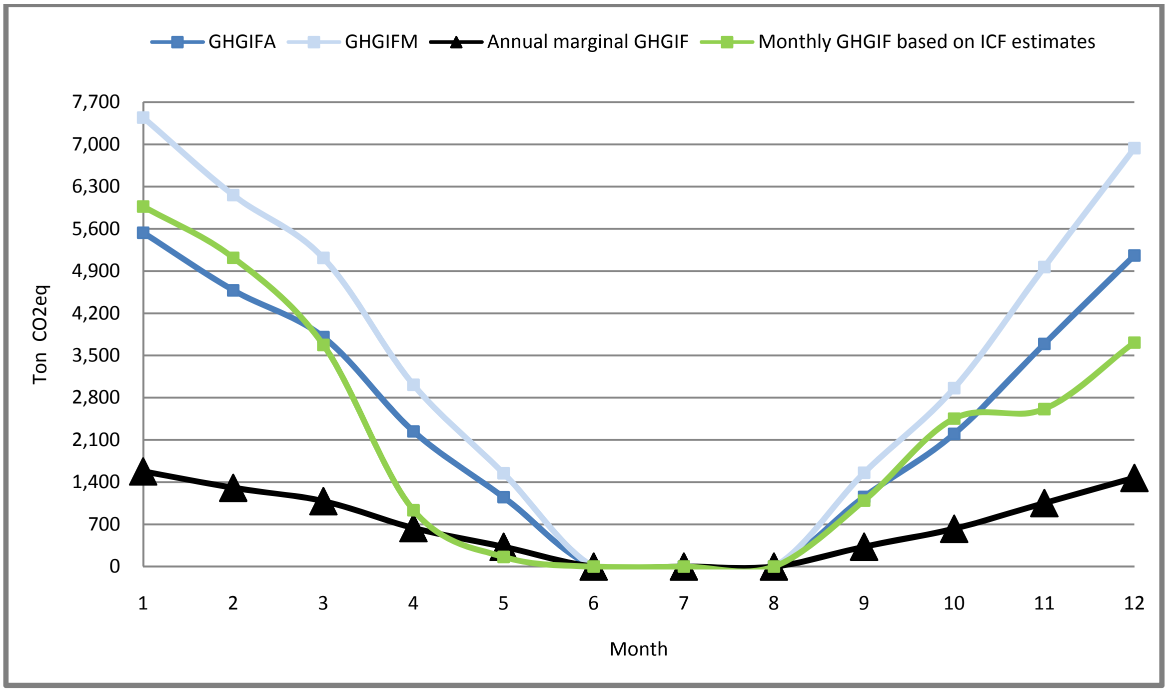

Figure 27. Monthly GHG emission reductions as result of ceiling insulation upgrade for Saskatchewan

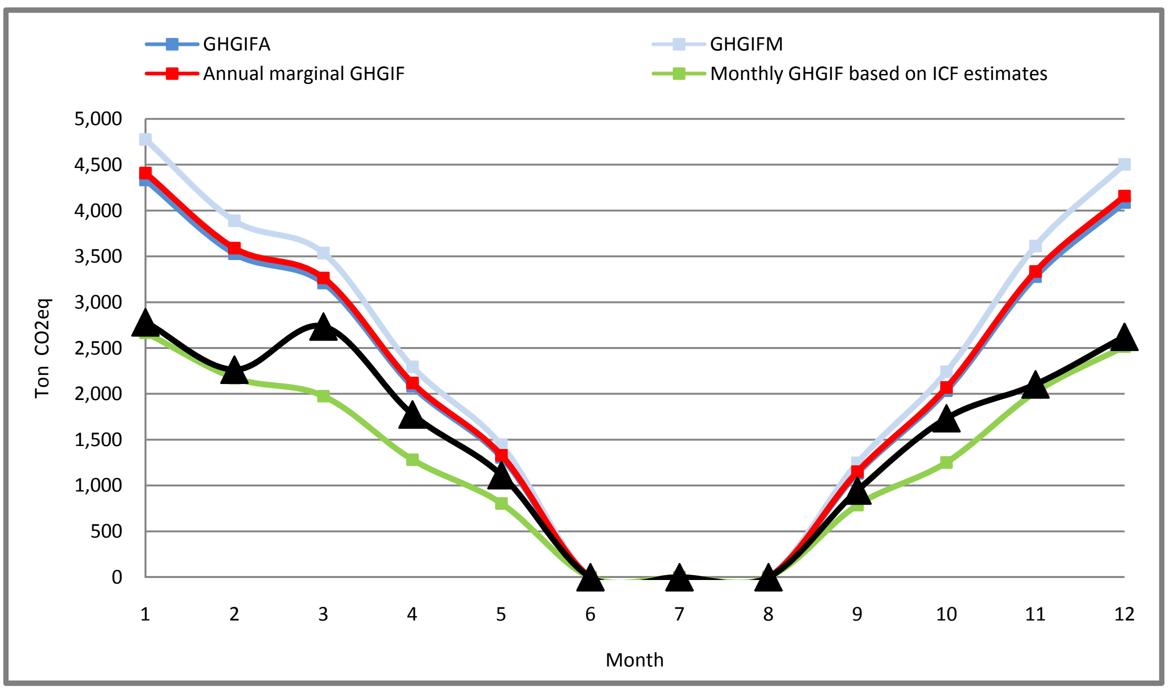

Figure 28. Monthly GHG emission reductions as result of ceiling insulation upgrade for Alberta

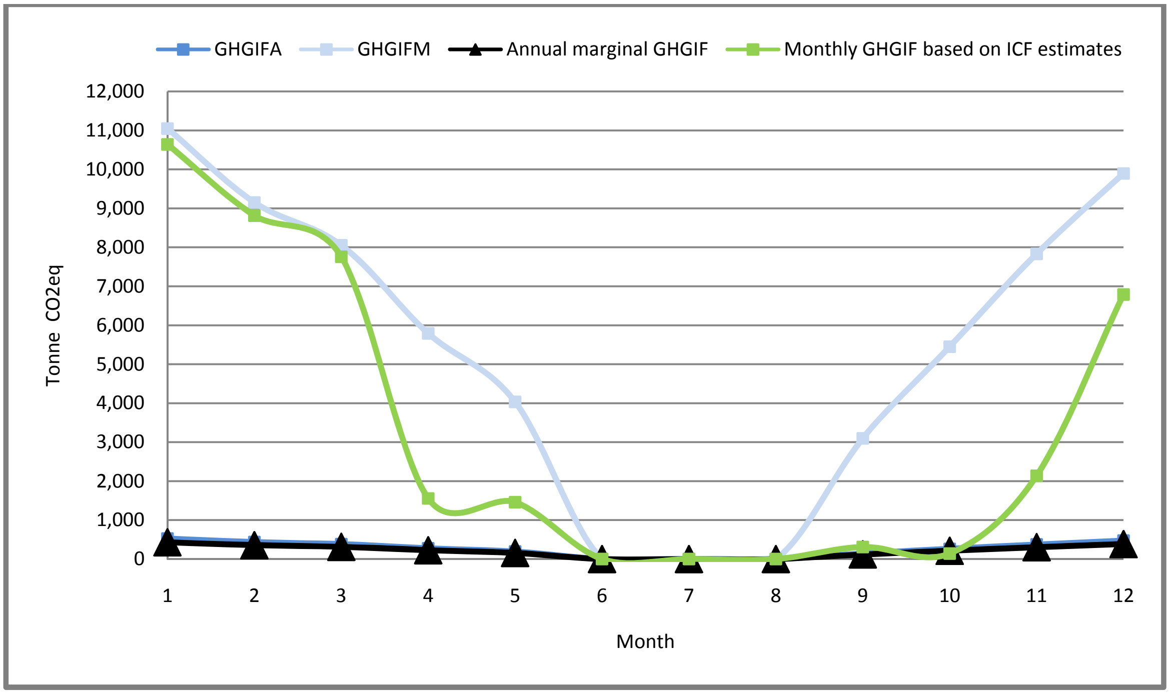

Figure 29. Monthly GHG emission reductions as result of ceiling insulation upgrade for British Columbia

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:

$$\text{GHG emission reduction} \;=\; \left[\frac{\text{reduction in electricity consumption (KWh)}}{1-\frac{\%\ \text{losses}}{100}}\right] * \text{GHGIF} \qquad [14]$$

Table 34. Recommended GHG intensity factors (g CO_{2eq}/kWh) for each province

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

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.

9. BIBLIOGRAPHY

[1] Environment Canada, 2007. National Inventory Report, 1990-2005: Greenhouse Gas Sources and Sinks in Canada. Ottawa. Available from: http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/tdm-toc_eng.cfm

[2] Government of Canada, 2007. Canadian Environmental Sustainability Indicators 2007. Available from: http://www.ec.gc.ca/environmentandresources/CESIFeature2007/Feature2007_e.cfm [2008, 11 December]

[3] OEE, 2006. Energy use data handbook - 1990 and 1998 to 2004. Office of Energy Efficiency, Natural Resources Canada, Ottawa.

[4] Canadian Electricity Association, 2006. Power Generation in Canada**:** A Guide. Available from: http://www.canelect.ca/en/aboutcea/aboutcea_news_release_2006.html

[5] Mohmed, A., Ugursal, V.I., 2008.A New Methodology to Predict the GHG Emission Reductions due to Electricity Savings in the Residential Sector, 2008 Solar Buildings Conf., Fredericton.

[6] Newfoundland and Labrador Hydro. Hydro Generation. Available from: http://www.nlh.nl.ca/Hydroweb/hydroweb.nsf/GeneralDocs/00C75006AAC842DDA3256FD6007D16F8?OpenDocument&menucat=About%20Hydro&submenucat=&linkname=About%20Hydro%20Generation [2008, 16 July]

[7] T. Blackler, M.T. Iqbal. Pre-feasibility study of wind power generation in Holyrood, Newfoundland. Renewable Energy, Volume 31, Issue 4, April 2006, pp. 489-502

[8] Statistics Canada, 2006. Electric Power Generation, Transmission and Distribution 2004. Catalogue no. 57-202-XIE, Ottawa.

[9] Statistics Canada, 2007. Electric Power Generation, Transmission and Distribution 2005. Catalogue no. 57-202-XIE, Ottawa.

[10] Statistics Canada, 2008. Electric Power Generation, Transmission and Distribution 2006. Catalogue no. 57-202-X, Ottawa.

[11] Personal Communication: Deslauriers, Stephane, April 2, 2008. Statistics Canada. E-mail:MCED@statcan.ca

[12] Environment Canada, 2005. Backgrounder: PEI Electricity Transmission System. Available from:

http://atlantic-web1.ns.ec.gc.ca/newsreleases/default.asp?lang=En&n=78079B82- [2008, 12 November]

[13] Piedmont Biofuels, 2007. PEI Leads the Way. Available from: http://www.biofuels.coop/windblog/?p=147 [2008, 12 November]

[14] Committee on Knowledge Assessment, National Research Council. Background, Lighting the Way: Knowledge Assessment in Prince Edward Island. The National Academies Press, 1999. Available from: http://books.nap.edu/openbook.php?record_id=6413&page=92

[15] Nova Scotia Power. Quick Facts. Available from: http://www.nspower.ca/about_nspi/quick.shtml [2008, 12 November]

[16] Nova Scotia Power. Generation. Available from: http://www.nspower.ca/about_nspi/generation/ [2008, 12 November]

[17] Nova Scotia Power. Coal. Available from: http://www.nspower.ca/about_nspi/generation/coal/index.shtml [2008, 12 November]

[18] Nova Scotia Power. Natural Gas. Available from: http://www.nspower.ca/about_nspi/generation/gas.shtml [2008, 12 November]

[19] Nova Scotia Power. Dispatching Generating Plants. Available from: http://www.nspower.ca/about_nspi/generation/dispatching.shtml [2008, 14 November]

[20] NB Power. NB Power Group. Available from: http://www.nbpower.com/html/en/about/operating/operating_companies.html [2008, 12 November]

[21] Efficiency NB. Moving Away from Electricity Space Heating. Available from: http://www.efficiencynb.ca/enb/1625/Moving-away-from-electric-space-heating [2008, 12 November]

[22] Personal Communication: Trenholm, Arden, March 25, 2008. NB Power. E-mail: ATrenholm@nbpower.cam

[23] Legislative Assembly of New Brunswick. NB power. Available from: http://www.gnb.ca/legis/business/committees/previous/reports-e/nbpowerbp/bus_unit-e.asp#generation [2008, 12 November]

[24] Hydro Quebec. Power Generation. Available from: http://www.hydroquebec.com/learning/production/pourquoi/index.html

[2008, 12 November]

[25] Personal Communication: Lebrun-Pare, Felix, March 5, 2008. Hydro Quebec. E-mail:Accueil2.Siege.Social@hydro.qc.ca

[26] Ontario Ministry of Energy and Infrastructure. Electricity. Available from: http://www.mei.gov.on.ca/english/energy/electricity/?page=nuclear-electricity-supply [2008, 16 July]

[27] IESO, 10- Year Outlook Highlights (January 2006 to December 2015). The Independent Electricity System Operator, Ontario. Available from: http://www.ieso.ca/imoweb/siteShared/pubs_library.asp?sid=bi

[28] Manitoba Hydro. Role of the Selkirk Generation Station. Available from: http://www.hydro.mb.ca/regulatory_affairs/selkirk/role.shtml [2008, 14 November]

[29] Manitoba Hydro, 2003. Need for and Alternatives to the Wuskwatim Project. Availabel from: http://www.hydro.mb.ca/regulatory_affairs/wuskwatim/submissions_nfatt.shtml

[30] SaskPower. Electricity Basics. Available from: http://www.saskpower.com/poweringyourfuture/today/electricitybasics.shtml [2008, 14 November]

[31] AESO, 2008. Powering Albertans. Alberta Electricity System Operator. Available from: http://www.aeso.ca/ourcompany/39.html

[32] Serletis, Apostolos; Bianchi, Mattia. Informational efficiency and interchange transactions in Alberta's electricity market. Energy Journal. July 2007. Available from: http://goliath.ecnext.com/coms2/summary_0199-6625408_ITM

[33] AESO. Percentage of Time Each Fuel Type is ‘On the Margin’. Alberta Electricity System Operator. Available from: http://www.aeso.ca/downloads/Percent_of_Time_Each_Fuel_Type_is_on_the_Margin.pdf [2008, 14 November]

[34] BC Hydro. Our Facilities. Available from: http://www.bchydro.com/about/our_system/generation/our_facilities.html [2008, 14 November]

[35] Personal Communication: Gaspard, Jim, March 10, 2008. BC Hydro. E-mail: Jim.Gaspard@bchydro.com

[36] Personal Communication: Gaspard, Jim, September 15, 2008. BC Hydro. E-mail: Jim.Gaspard@bchydro.com

[37] Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in atmospheric constituents and in radiative forcing. in: Climate change 2007:The physical science basis. contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. chen, M. marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[38] Guler, B. 2000. Impact of Energy Efficiency Retrofits on Residential Energy Consumption and Associated GHG Emissions, MASc Thesis, Dalhousie University, Halifax.

[39] Guler, B., Fung, A.S., Aydinalp, M., Ugursal, V.I., 2001. Impact of energy efficiency upgrade retrofits on the residential energy consumption in Canada, Int. J. of Energy Research, Vol 25, pp. 785-792, 2001.

[40] Environment Canada, 2005. Report of the Development of a Canadian Electricity Sector Module for the Integrated Planning Model. Available from: http://www.ec.gc.ca/cleanair-airpur/caol/canus/IPM_TECHNICAL/ipm_technical_report/c3_e.cfm [2008, 14 November]

[41] ICF, 2003. Analysis of Electricity Dispatch in Canada, Final Report, Submitted to Environment Canada. Available from: http://www.ec.gc.ca/pdb/ghg/guidance/protocols/Electric2003/p1_e.cfm

[42] AMEC Americas Limited, 2006. Alberta 10 Years Generation Outlook. Prepared for Alberta Electricity System Operator. Available from: http://www.aeso.ca/files/FINALAESOGeneration.pdf

[43] IESO, 2008. 18-Month Outlook:An Assessment of the Reliability of the Ontario Electricity System From October 2008 to March 2010. Independent Electricity System Operator, Ontario. Available from: http://www.ieso.ca/imoweb/monthsYears/monthsAhead.asp

[44] Cleantech Group, 2007. Ontario Aim to Kick out Coal by 2014. Available from: http://cleantech.com/news/1683/ontario-aims-to-kick-out-coal-by-2014 [2008, 10 March]

[45] OPA, 2008. Integrated Power System Plan EB-2007-0707 ont. Ontario Power Authority. Available from: http://www.powerauthority.on.ca/IPSP/Page.asp?PageID=924&SiteNodeID=320 [2009, 10 March]

[46] IESO. Hourly generator output & capability report. Independent Electricity System Operator, Ontario. Available from: http://www.theimo.com/imoweb/marketdata/GenDisReports.asp [2008, 14 November]

[47] Personal Communication: Lafoyiannis, Peter, January 2, 2009. IESO. E-mail: peter.lafoyiannis@ieso.ca

[48] Hydro Quebec, 2007. Sustainability Report 2007. Available from: http://www.hydroquebec.com/publications/en/enviro_performance/2007/index.html

[49] Hydro Quebec, 2006. Sustainability Report 2006. Available from: http://www.hydroquebec.com/publications/en/enviro_performance/2006/index.html

[50] Natural Resources Canada, 1997. Canada's Energy Outlook: 1996-2020. Ottawa, Ontario. Available from: http://www.nrcan.gc.ca/es/ceo/toc-96E.html

[51] Statistic Canada. Table 127-0001 Electric Power Statistics, Monthly (MWh) (table), CANSIM (database) Using E-SEAT (distributor). Available from: http://estat.statcan.ca/cgiwin/cnsmcgi.exe?Lang=E&ESTATFile=EStat\English\CII_1_E.htm&RootDir=ESTAT/ [2008, 4 December]

[52] Personal Communication: Trenholm, Arden, September 16, 2008. NB Power. E-mail:ATrenholm@nbpower.cam

[53] Guler, B., Ugursal, V.I., Fung, A.S., Aydinalp-Koksal, M., 2008. Impact of energy efficiency upgrade retrofits on the residential energy consumption and greenhouse gas emissions, Int. J. Environmental Technology and Management, V. 9, No. 4, pp. 434-444, 2008.

[54] Farahbakhsh, H., V.I. Ugursal, A.S. Fung, 1998. A residential end-use energy consumption model for Canada, Int. J. of Energy Research, V. 22, pp.1133-1143, 1998.

[55] Faye C. McQuiston, Jerald D. Parker. Energy Calculations, Heating, Ventilating, and Air Conditioning: Analysis and Design. 4th ed, 1994.

[56] Environment Canada, Climate Normals and averages 1971-2000. Available from: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [2009, 28 January]

APPENDICES

APPENDIX A

The Detailed Data Used to Calculate the $GHGIF_A$ and $GHGIF_M$ 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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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**			CO_{2eq}/ quaintly fuel	Total GHG emission in kg CO_{2eq}
			CO_2	CH_4	N_2O		
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.m^3	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 [1, 8-10]

Year	Marginal fuel source	Electricity* Generated (MWh)	Fuel Input**	Total GHG Emission in kg CO_{2eq}	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 [1, 8-10]

Year	Marginal fuel source	Electricity* Generated (MWh)	Fuel Input**	Total GHG Emission in kg CO_{2eq}	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 [1, 8-10]

Year	Marginal fuel source	Electricity* Generated (MWh)	Fuel Input**	Total GHG Emission in kg CO_{2eq}	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	3,760km^3	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	3,476km^3	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 CO_{2eq}	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 [1, 8-10]

Year	Marginal fuel source	Electricity* Generated (MWh)	Fuel Input**	Total GHG Emission in kg CO_{2eq}	GHG Intensity Factor (g/kWh $_{fuel}$)	% On Margin	Annual Marginal GHG Intensity Factor (g/kWh)
2004	Natural gas	209,820	75,310km^3	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	75,774km^3	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	325,013km^3	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 [1, 8-10]

Year	Marginal fuel source	Electricity* Generated (MWh)	Fuel Input**	Total GHG Emission in kg CO_{2eq}	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	2,088,723km^3	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	2,832,214km^3	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	2,833,982km^3	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 [1, 8-10]

Year	Marginal fuel source	Electricity* Generated (MWh)	Fuel Input**	Total GHG Emission in kg CO_{2eq}	GHG Intensity Factor (g/kWh $_{fuel}$)	% On Margin	Annual Marginal GHG Intensity Factor (g/kWh)
2004	Natural gas	85,656	31,768km^3	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	4,392km^3	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	19,958km^3	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 [1, 8-10]

Year	Marginal fuel source	Electricity* Generated (MWh)	Fuel Input**	Total GHG Emission in kg CO_{2eq}	GHG Intensity Factor (g/kWh $_{fuel}$)	% On Margin	Annual Marginal GHG Intensity Factor (g/kWh)
2004	Natural gas	2,893,767	850,142km^3	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	765,158km^3	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	845,583km^3	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 [1, 8-10]

Year	Marginal fuel source	Electricity* Generated (MWh)	Fuel Input**	Total GHG Emission in kg CO_{2eq}	GHG Intensity Factor (g/kWh $_{fuel}$)	% On Margin	Annual Marginal GHG Intensity Factor (g/kWh)
2004	Natural gas	10,207,864	3,142,429 km^3	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 km^3	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	3,695,187km^3	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 [1, 8-10]

Year	Marginal fuel source	Electricity* Generated (MWh)	Fuel Input**	Total GHG Emission in kg CO_{2eq}	GHG Intensity Factor (g/kWh $_{fuel}$)	% On Margin	Annual Marginal GHG Intensity Factor (g/kWh)
2004	Natural gas	2,380,966	564,907km^3	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	554,648km^3	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 km^3	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

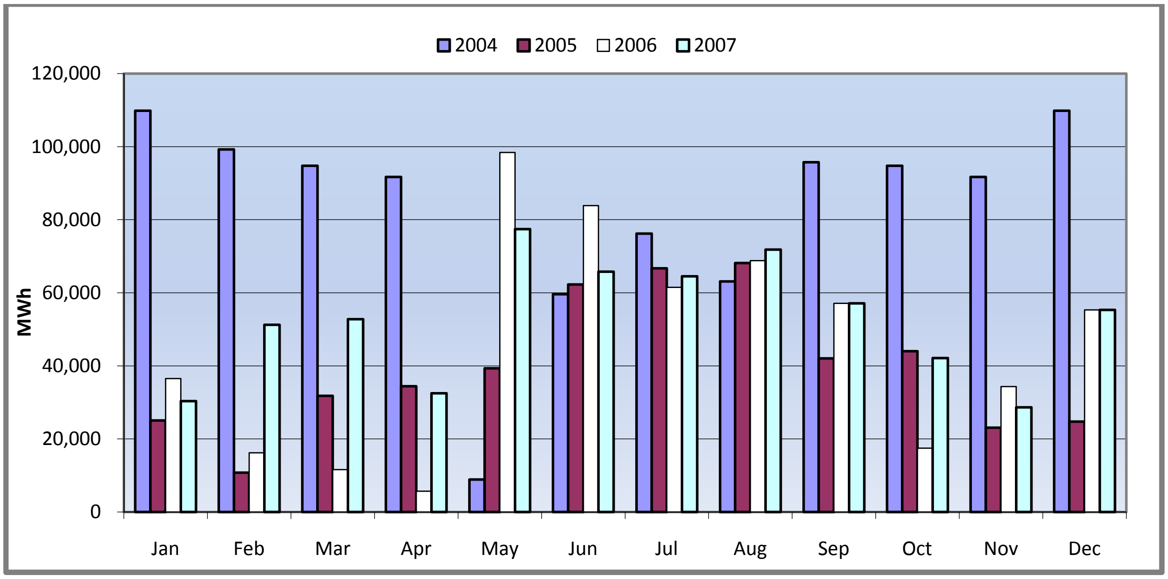

Figure C.1. Total marginal generation (MWh) for Nova Scotia over 2004-2007 estimated by ICF [41]

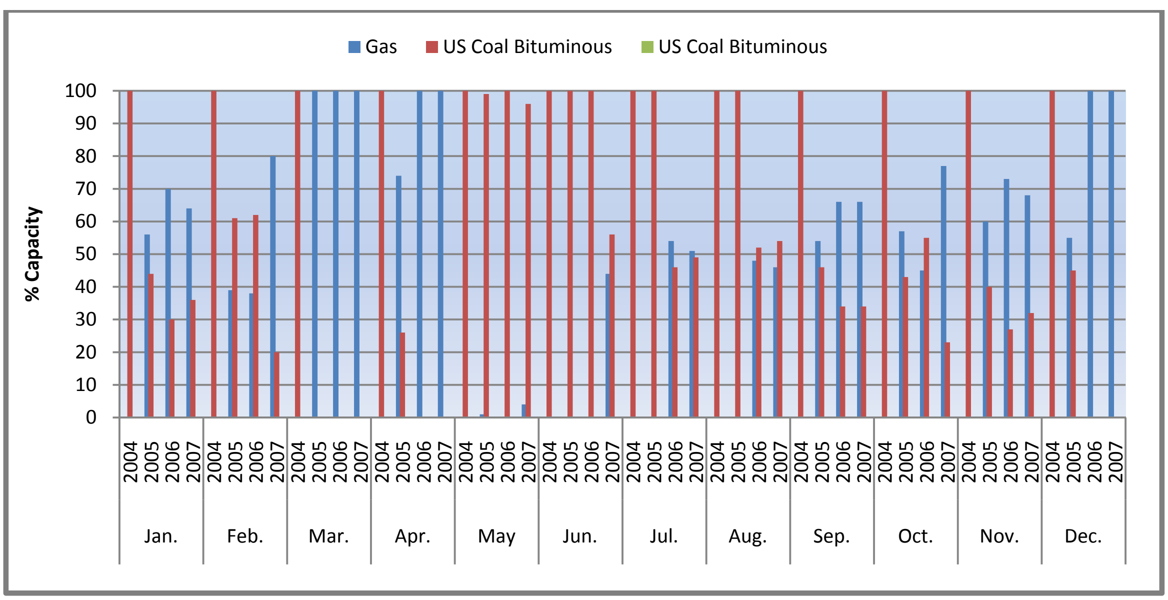

Figure C.2. Monthly Fuel mix used for marginal electricity generation in Nova Scotia over 2004 to 2007 estimated by ICF [41]

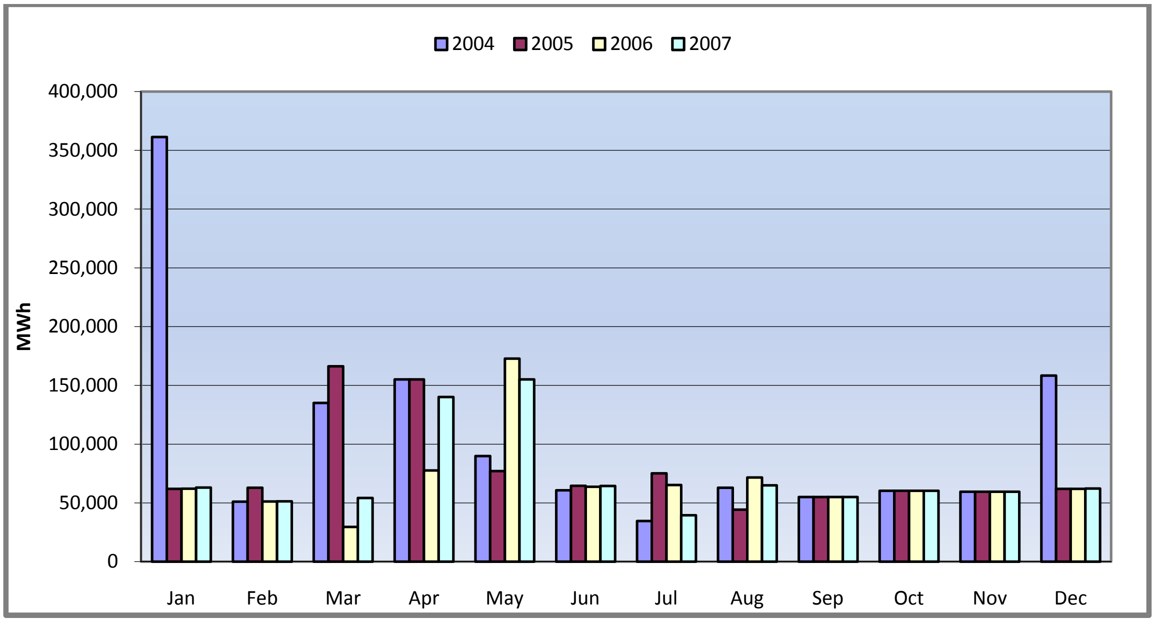

Figure C.3. Total marginal generation (MWh) for New Brunswick over 2004-2007 estimated by ICF [41]

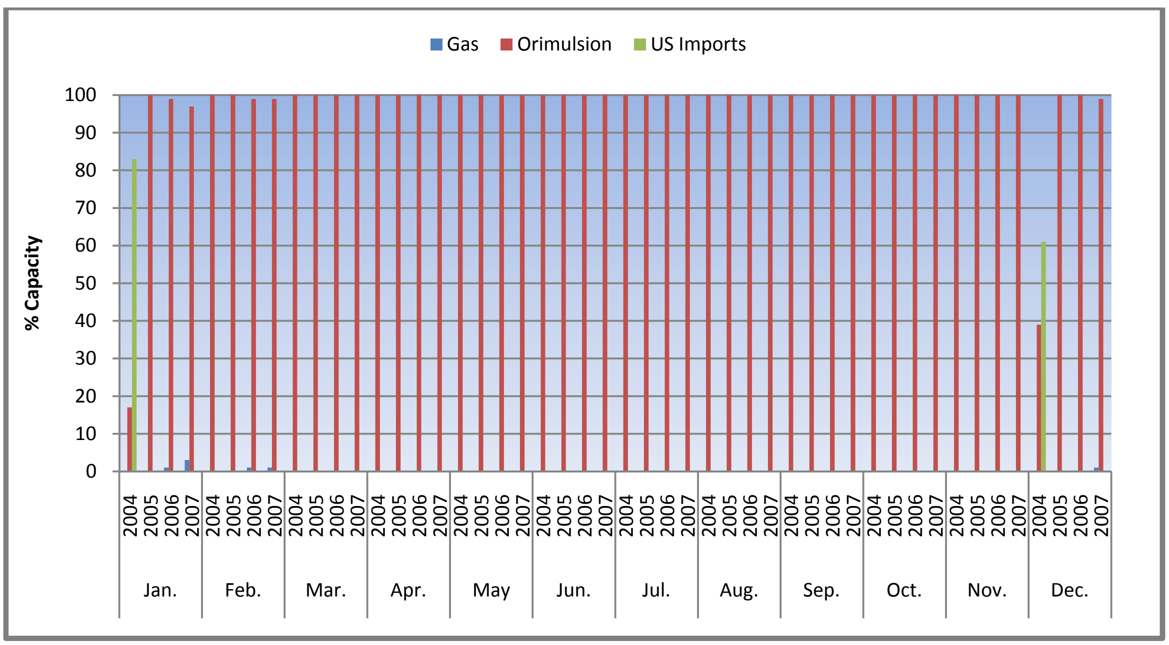

Figure C.4. Monthly Fuel mix used for marginal electricity generation in New Brunswick over 2004 to 2007 estimated by ICF [41]

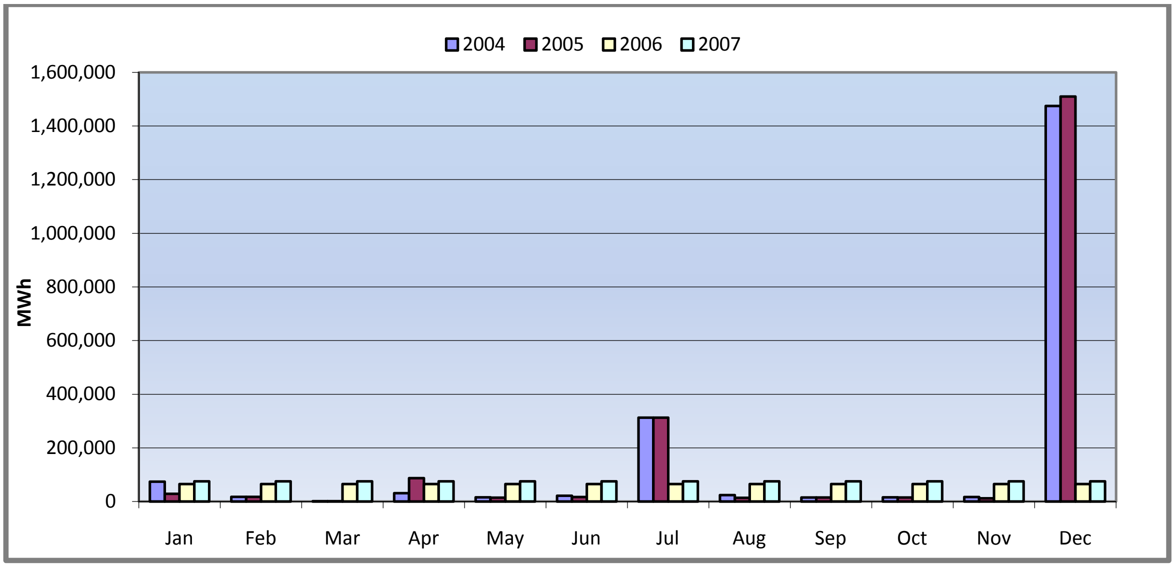

Figure C.5. Total marginal generation (MWh) for Quebec over 2004-2007 estimated by ICF [41]

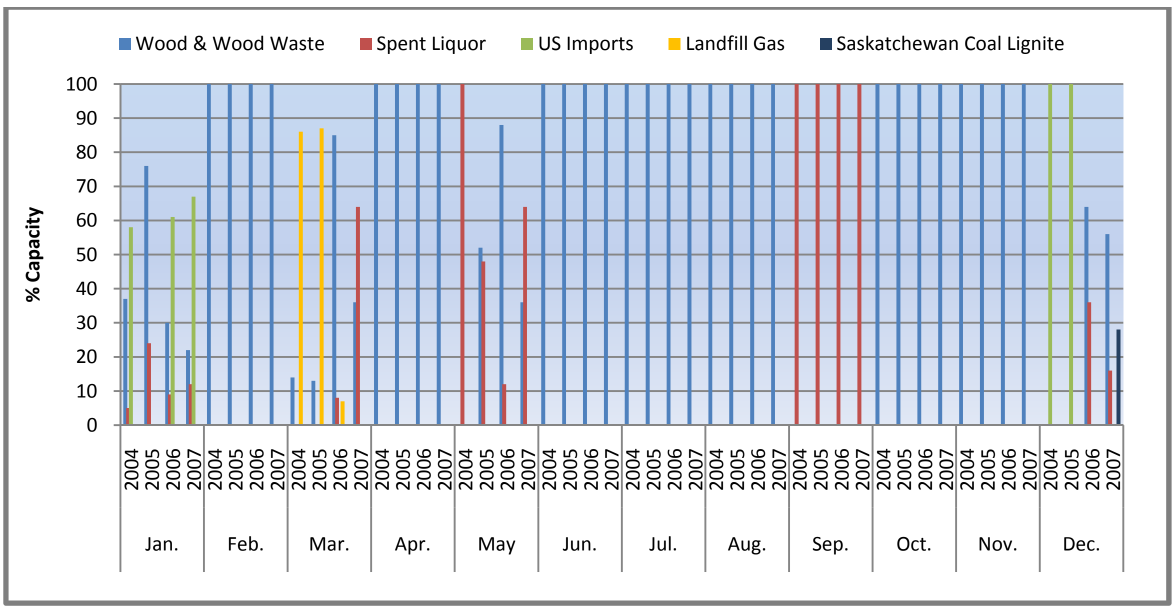

Figure C.6. Monthly Fuel mix used for marginal electricity generation in Quebec over 2004 to 2007 estimated by ICF [41]

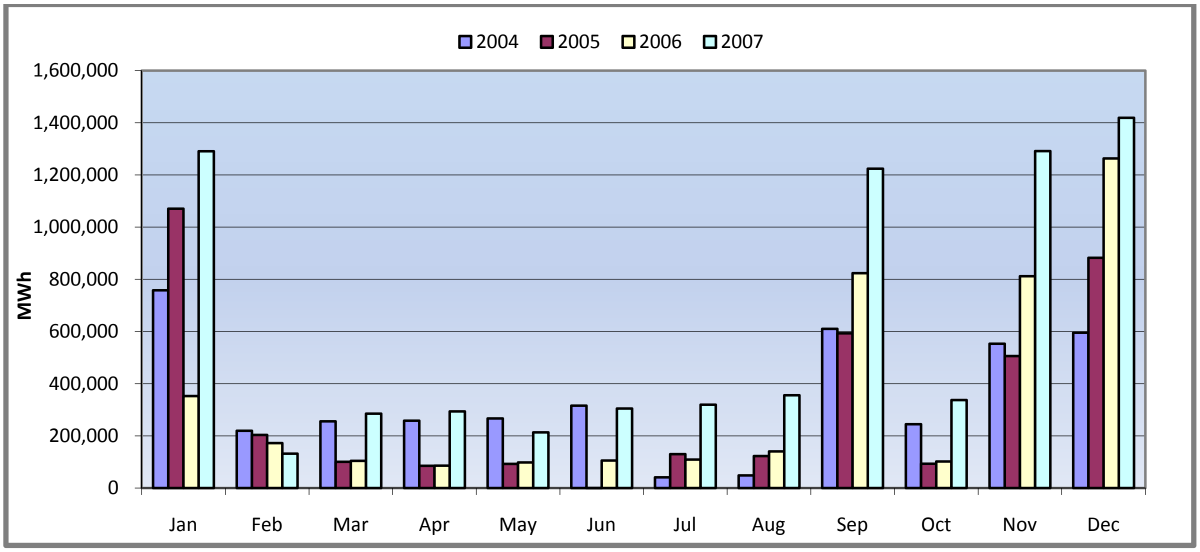

Figure C.7. Total marginal generation (MWh) for Ontario over 2004-2007 estimated by ICF [41]

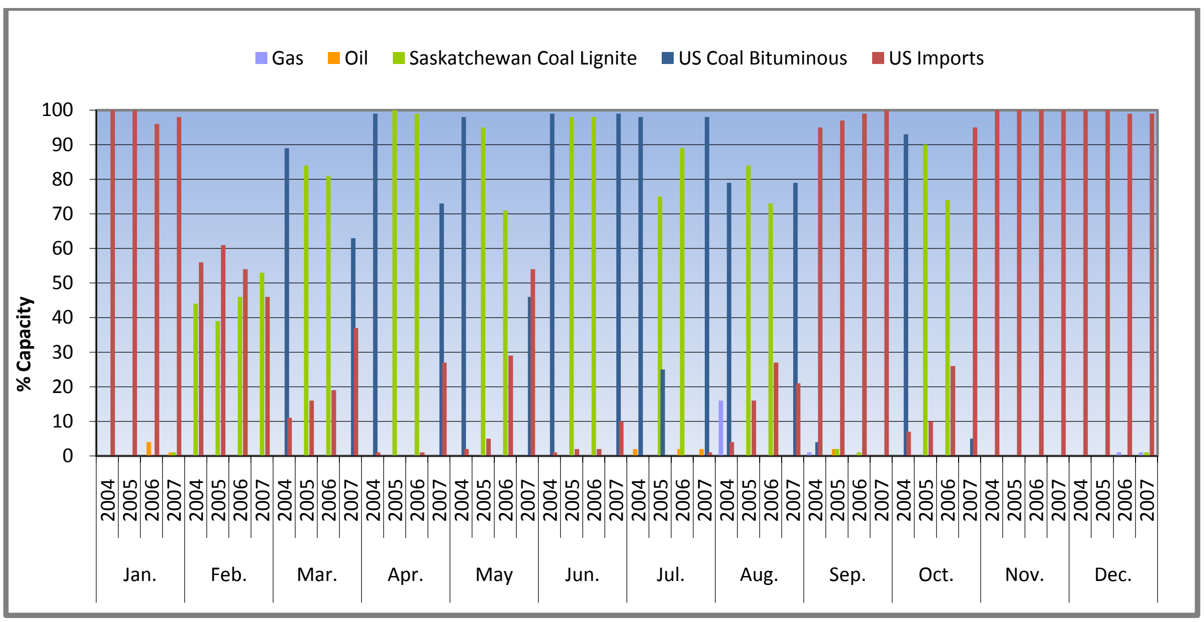

Figure C.8. Monthly Fuel mix used for marginal electricity generation in Ontario over 2004 to 2007 estimated by ICF [41]

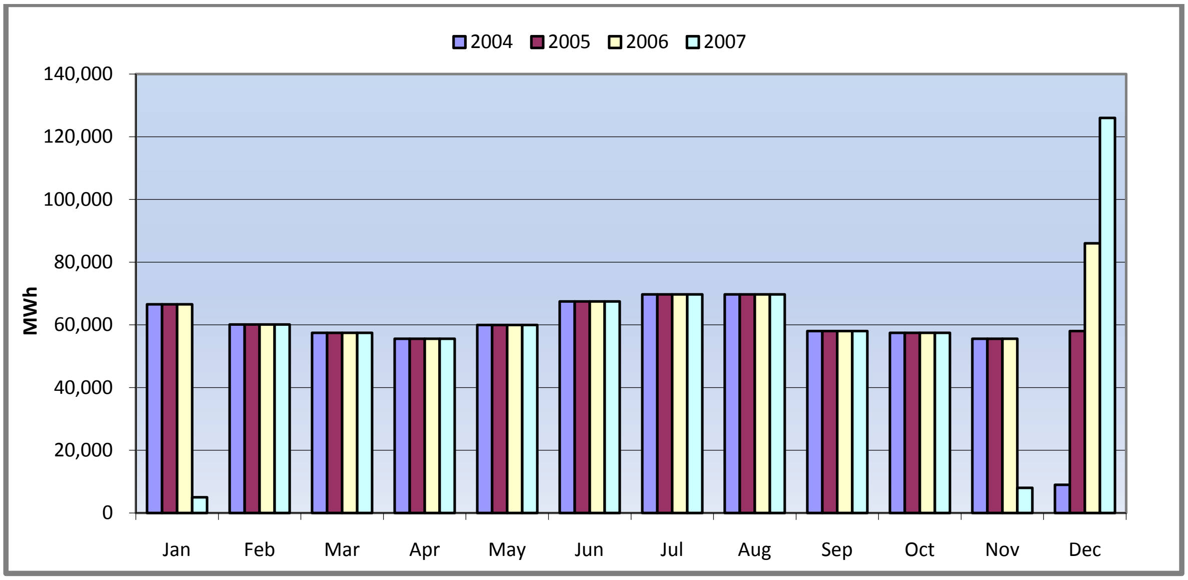

Figure C.9. Total marginal generation (MWh) for Manitoba over 2004-2007 estimated by ICF [41]

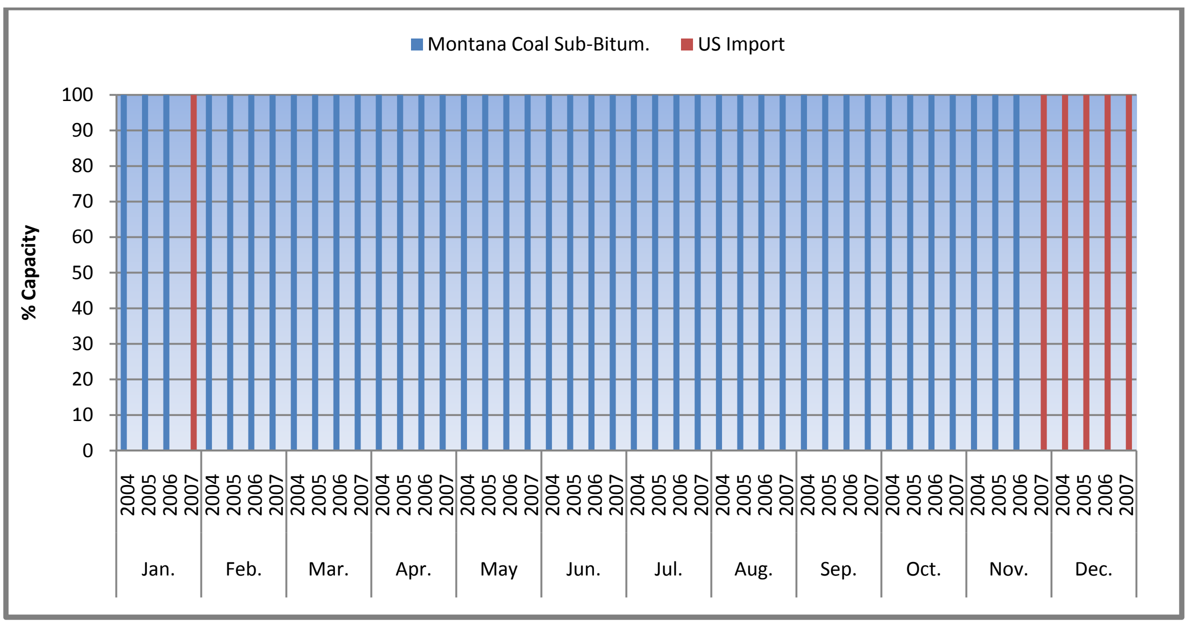

Figure C.10. Monthly Fuel mix used for marginal electricity generation in Manitoba over 2004 to 2007 estimated by ICF [41]

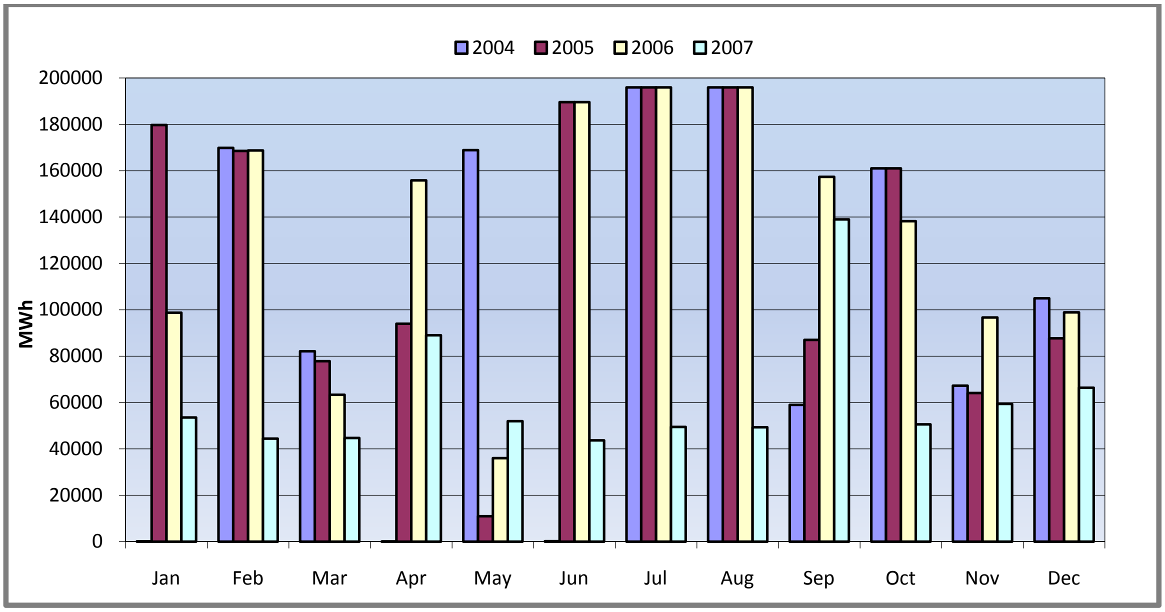

Figure C.11. Total marginal generation (MWh) for Saskatchewan over 2004-2007 estimated by ICF [41]

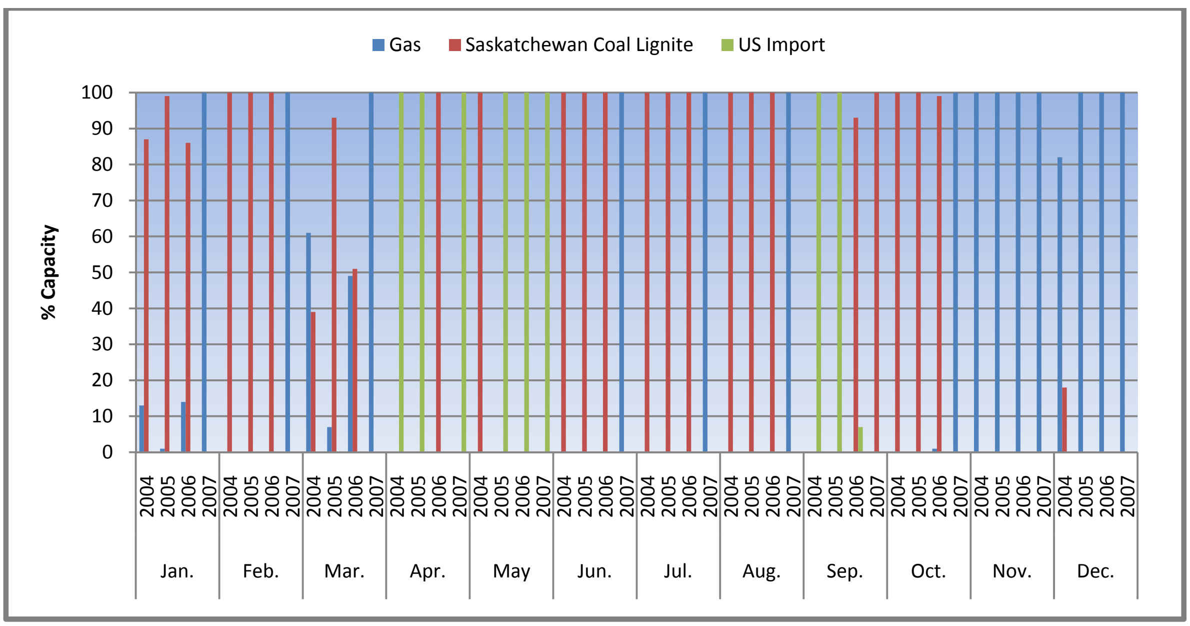

Figure C.12. Monthly Fuel mix used for marginal electricity generation in Saskatchewan over 2004 to 2007 estimated by ICF [41]

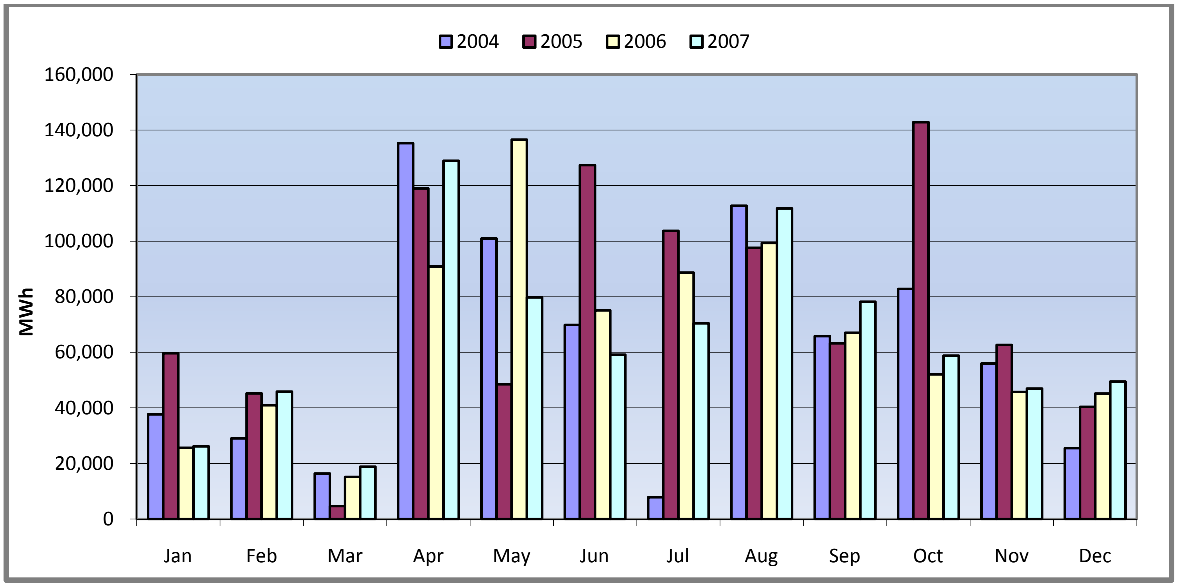

Figure C.13. Total marginal generation (MWh) for Alberta over 2004-2007 estimated by ICF [41]

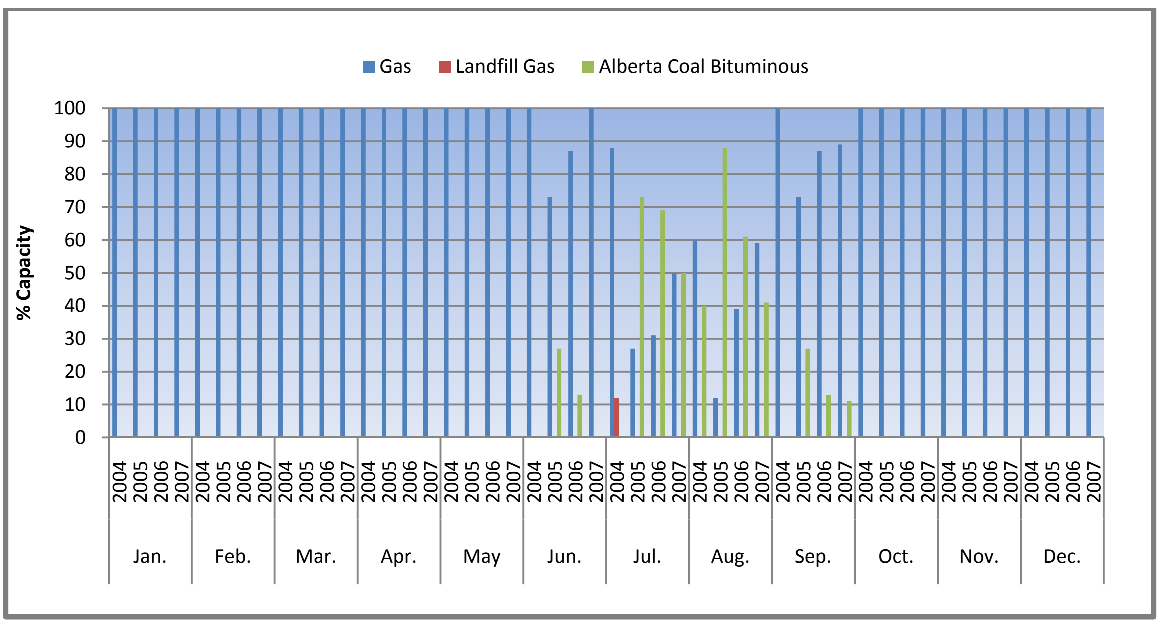

Figure C.14. Monthly Fuel mix used for marginal electricity generation in Alberta over 2004 to 2007 estimated by ICF [41]

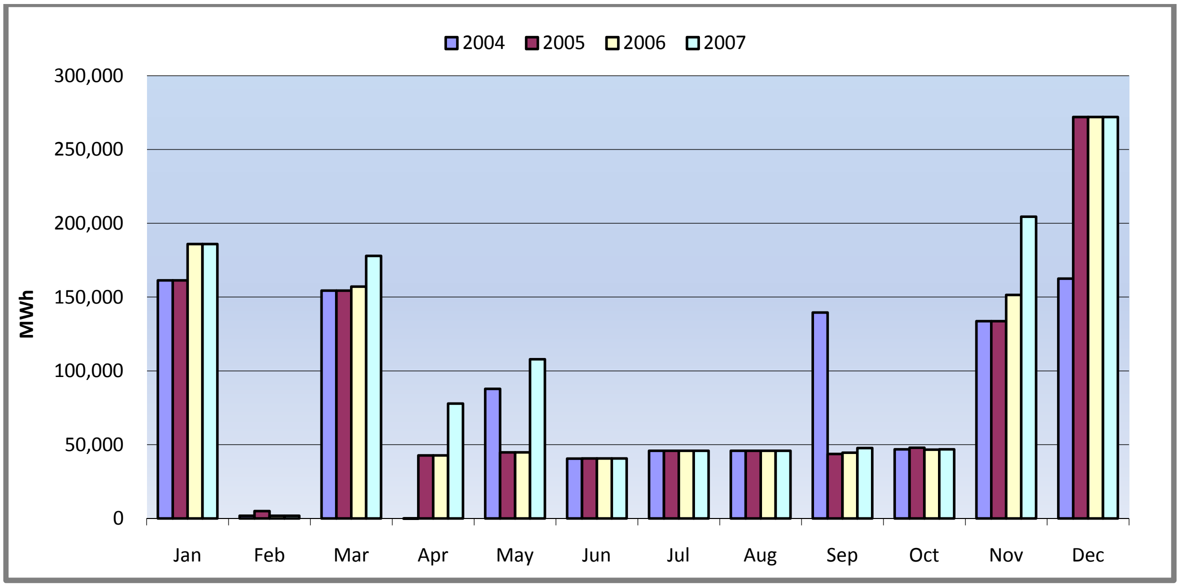

Figure C.15. Total marginal generation (MWh) for British Columbia over 2004-2007 estimated by ICF [41]

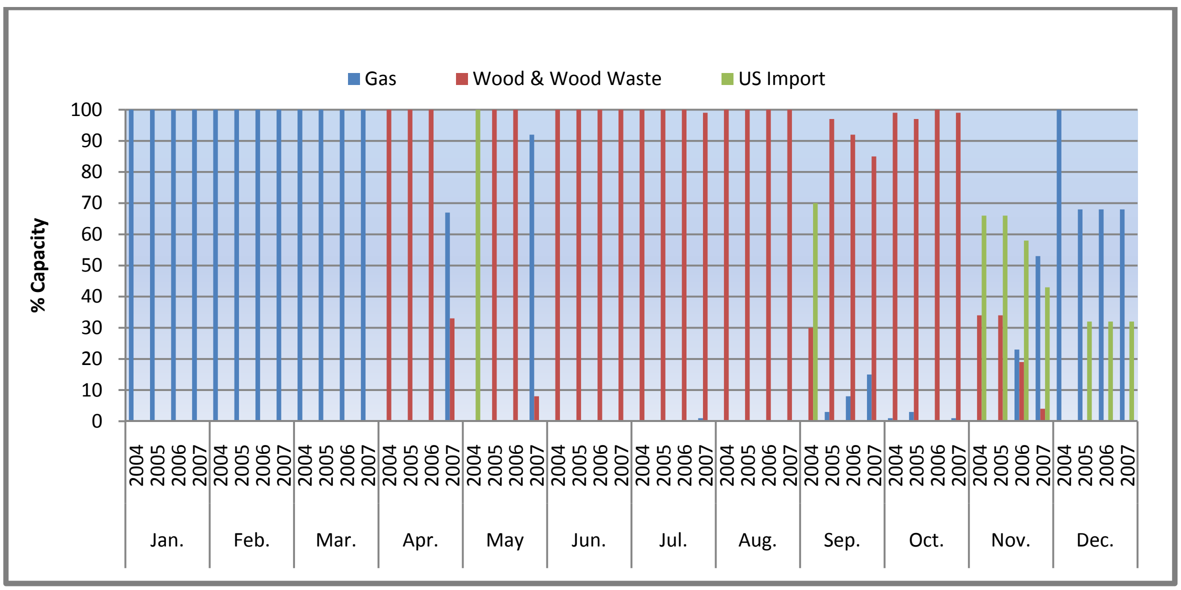

Figure C.16. Monthly Fuel mix used for marginal electricity generation in British Colombia over 2004 to 2007 estimated by ICF [41]

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 CO_{2eq}/GJ	8,200 Btu/kWh	27.5 MJ/ kg $_{Orimulsion}$
Spent liquor**	7 g CO_{2eq}/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 CO_{2eq}using 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:

$$\text{Orimulsion emission factor } \left(\text{g CO}_{2\text{eq}}/\text{kg}_{\text{orimulsion}}\right) = 80.7\left(\text{g CO}_{2\text{eq}}/\text{MJ}\right) * 27.5\left(\text{MJ}/\text{kg}_{\text{orimulsion}}\right) = 2{,}219$$

$$\text{Orimulsion GHG intensity factor } \left(\text{g CO}_{2\text{eq}}/\text{kWh}_{\text{orimulsion}}\right) = 80.7 * 10^{-6}\left(\text{g CO}_{2\text{eq}}/\text{J}\right) * 8{,}200 * 1{,}056(\text{J}/\text{kWh}) = 699$$

$$\text{Spent liquor GHG intensity factor } \left(\text{g CO}_{2\text{eq}}/\text{kWh}_{\text{spent liquor}}\right) = \frac{7\left(\text{g CO}_{2\text{eq}}/\text{kg}_{\text{spent liquor}}\right) * 9{,}000(\text{Btu}/\text{kWh})}{6{,}250 * 2.2\left(\text{Btu}/\text{kg}_{\text{spent liquor}}\right)} = 5$$

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 ($g\ CO_{2eq}/kWh$)
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 ($g\ CO_{2eq}/kWh$)
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 CO_{2eq}/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 CO_{2eq}/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 CO_{2eq}/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 CO_{2eq}/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 CO_{2eq}/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 CO_{2eq}/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 [41]. The “predicted” values are those calculated in this work based on ICF estimates.

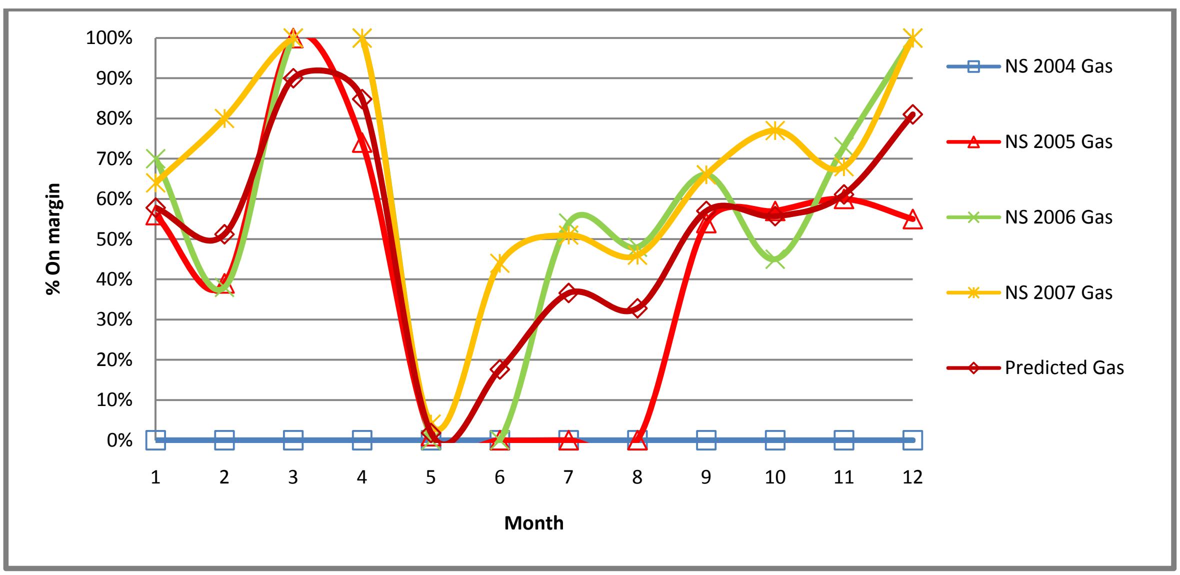

Figure E.1. Natural gas usage for marginal electricity generation in Nova Scotia over the period 2004-2007 [41], and predicted values

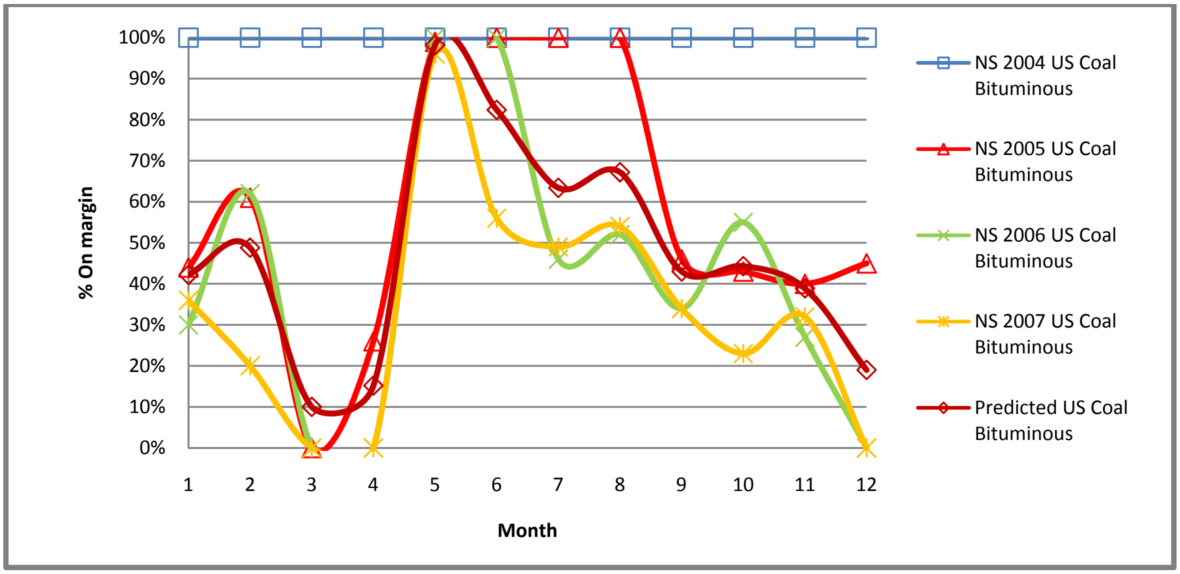

Figure E.2. US coal bituminous usage for marginal electricity generation in Nova Scotia over the period 2004-2007 [41], and predicted values

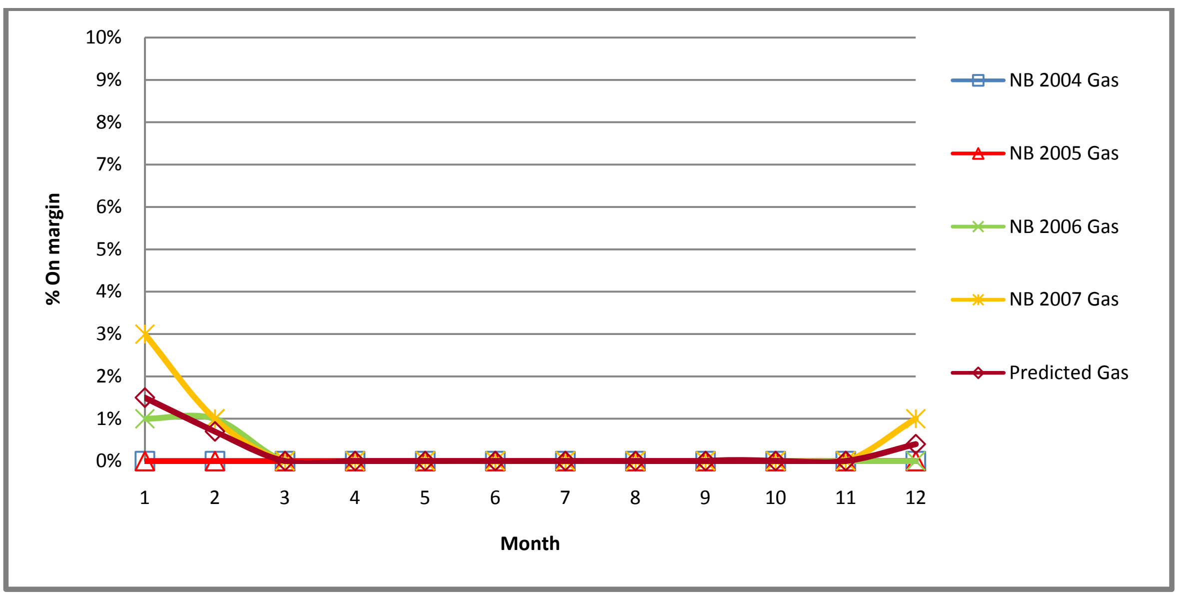

Figure E.3. Natural gas usage for marginal electricity generation in New Brunswick over the period 2004-2007 [41], and predicted values

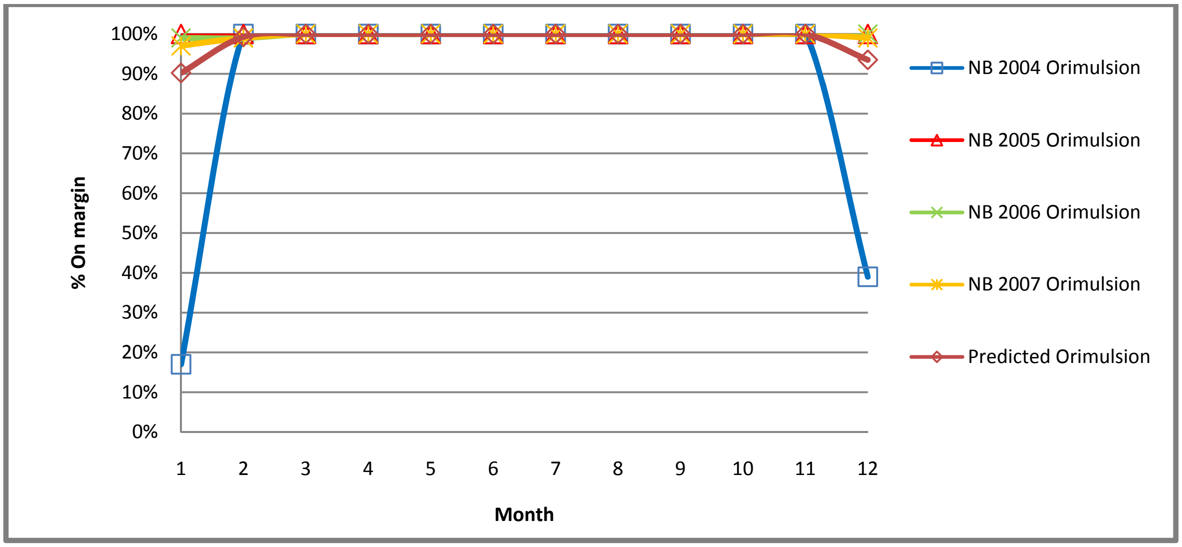

Figure E.4. Orimulsion usage for marginal electricity generation in New Brunswick over the period 2004-2007 [41], and predicted values

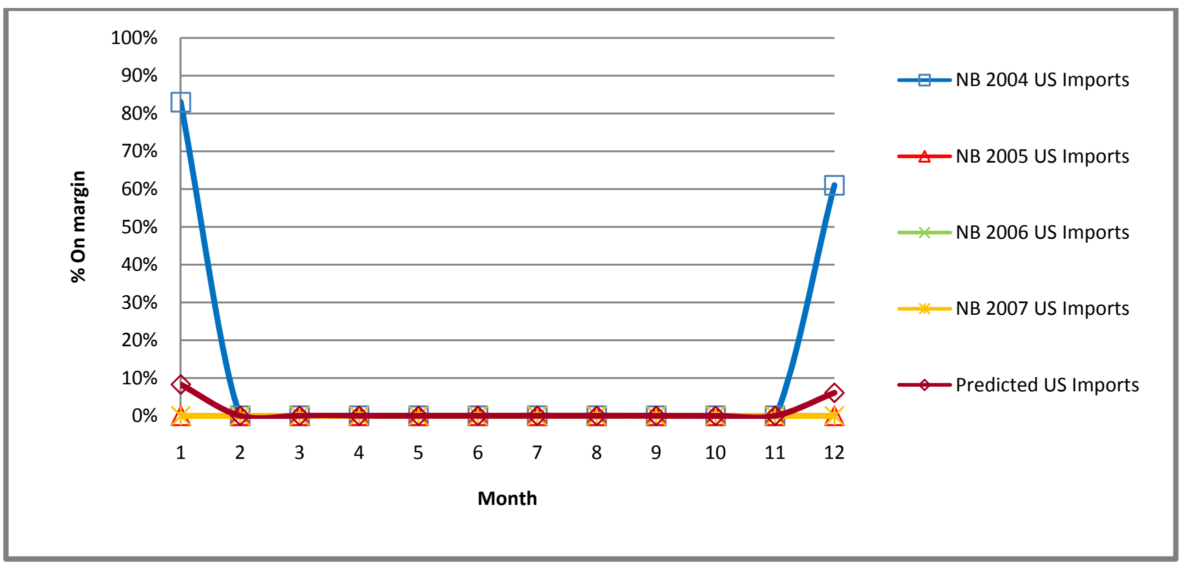

Figure E.5. US import usage for marginal electricity generation in New Brunswick over the period 2004-2007 [41], and predicted values

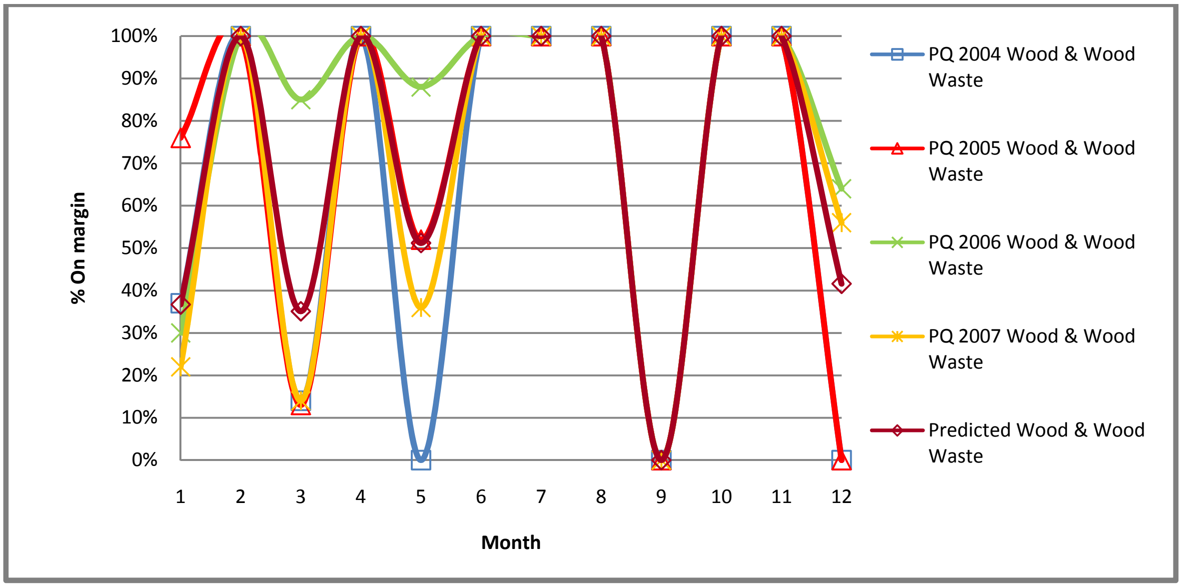

Figure E.6. Wood & wood waste usage for marginal electricity generation in Quebec over the period 2004-2007 [41], and predicted values

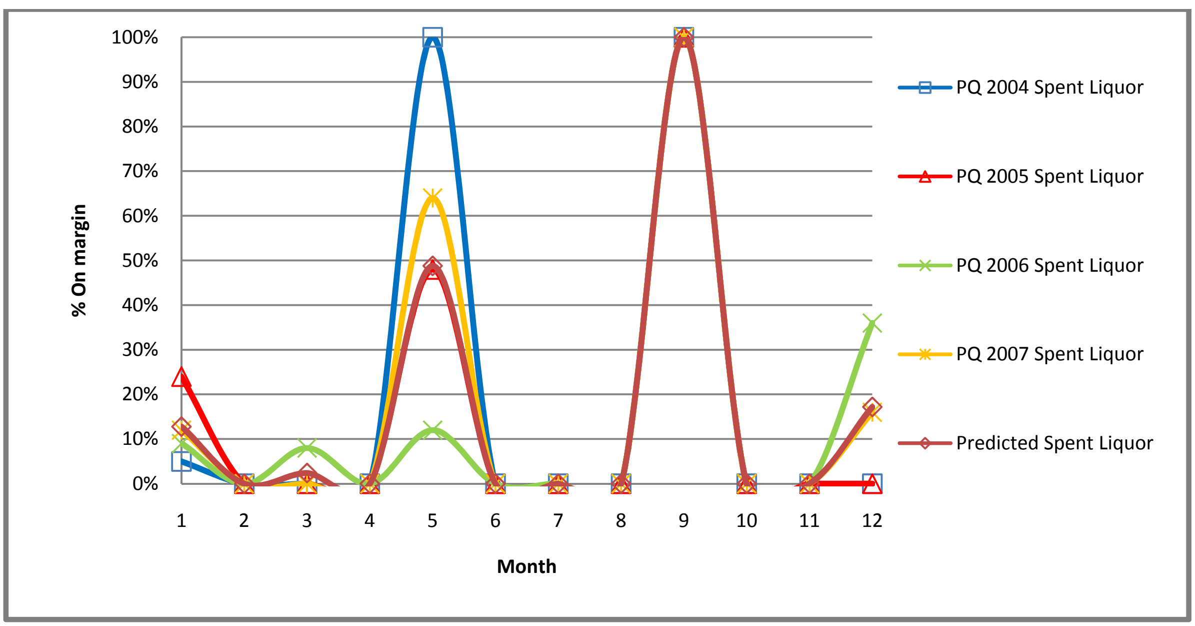

Figure E.7. Spent liquor usage for marginal electricity generation in Quebec over the period 2004-2007 [41], and predicted values

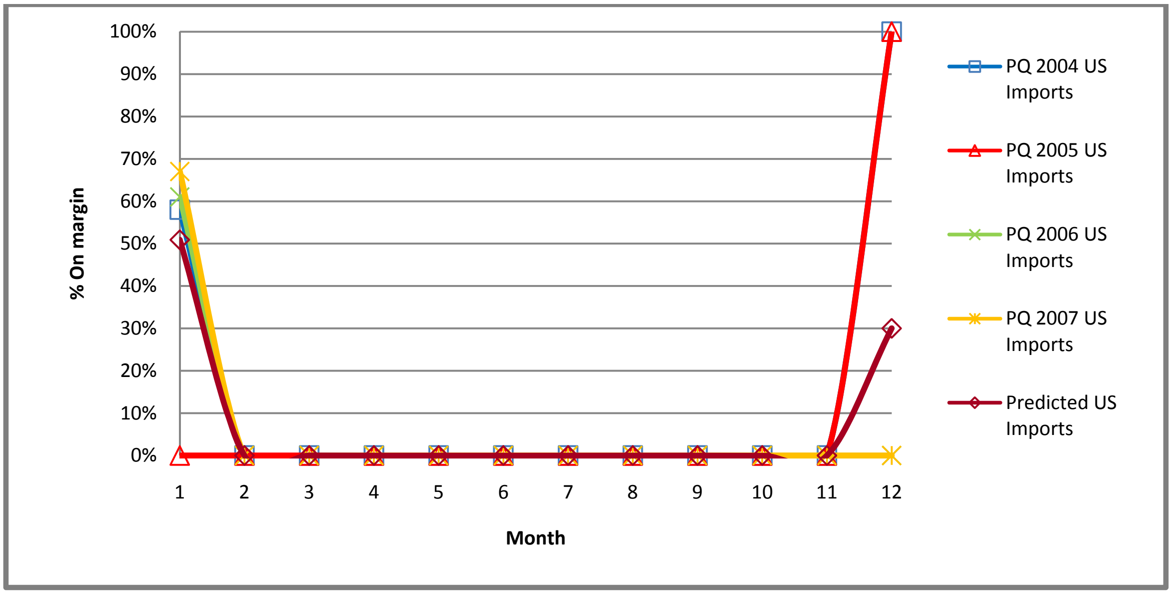

Figure E.8. US import usage for marginal electricity generation in Quebec over the period 2004-2007 [41], and predicted values

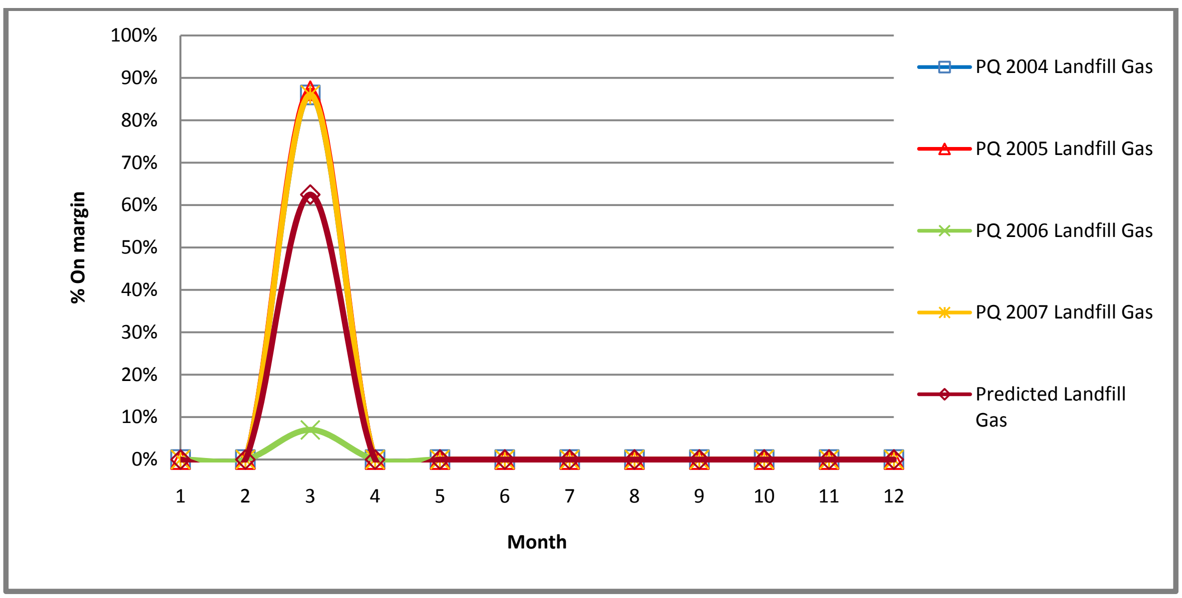

Figure E.9. Landfill gas usage for marginal electricity generation in Quebec over the period 2004-2007 [41], and predicted values

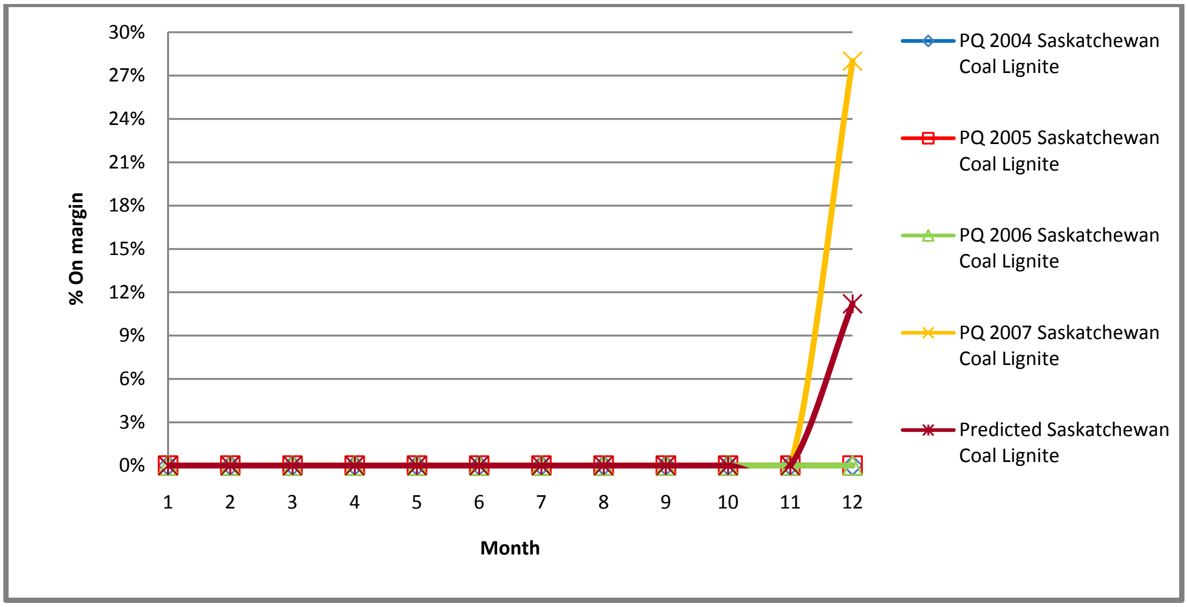

Figure E.10. Saskatchewan Coal Lignite usage for marginal electricity generation in Quebec over the period 2004-2007 [41], and predicted values

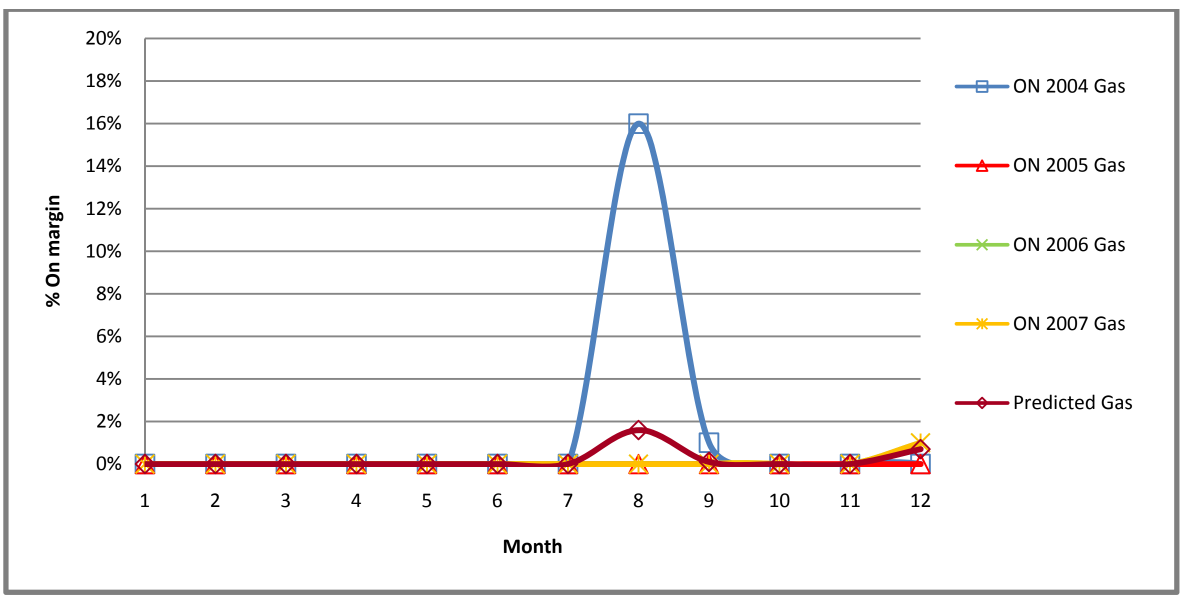

Figure E.11. Natural gas usage for marginal electricity generation in Ontario over the period 2004-2007 [41], and predicted values

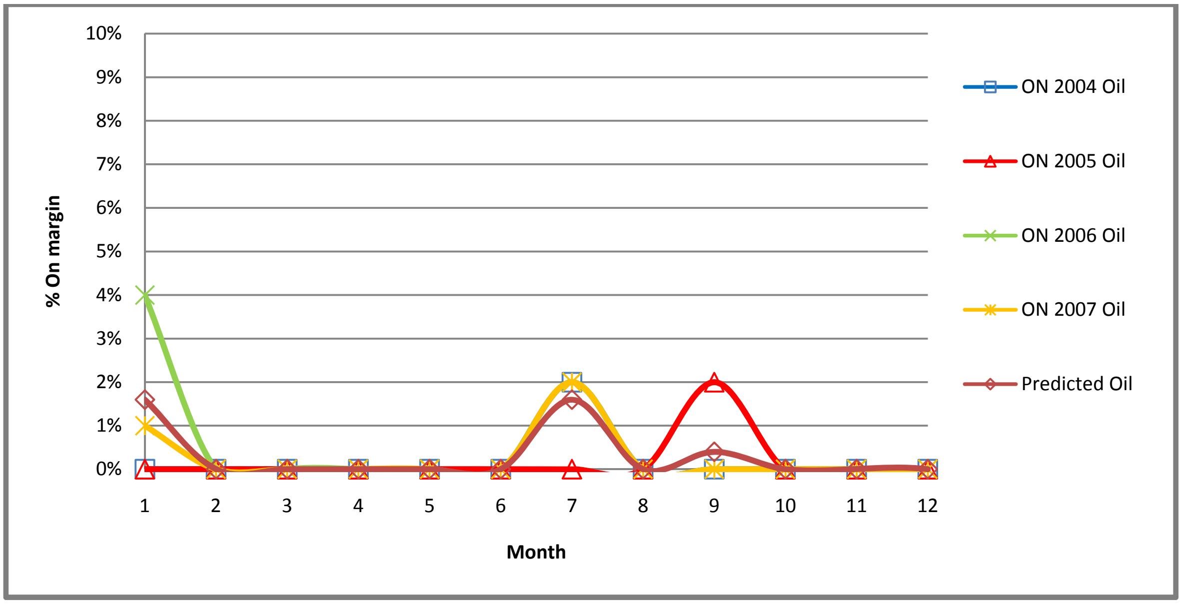

Figure E.12. Oil usage for marginal electricity generation in Ontario over the period 2004-2007 [41], and predicted values

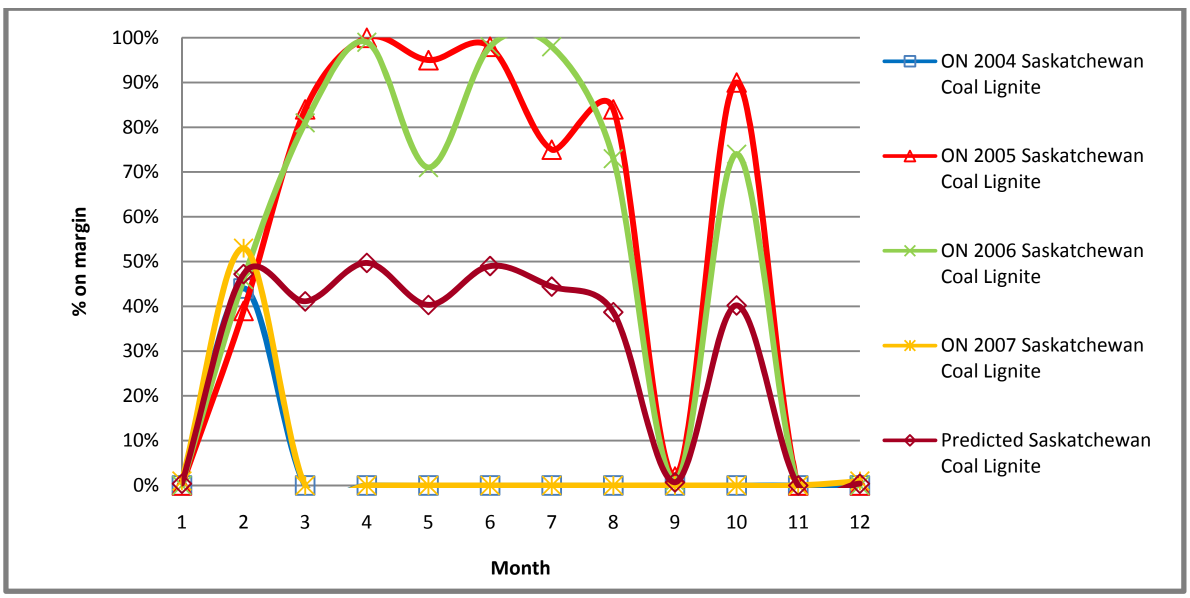

Figure E.13. Saskatchewan coal lignite usage for marginal electricity generation in Ontario over the period 2004-2007 [41], and predicted values

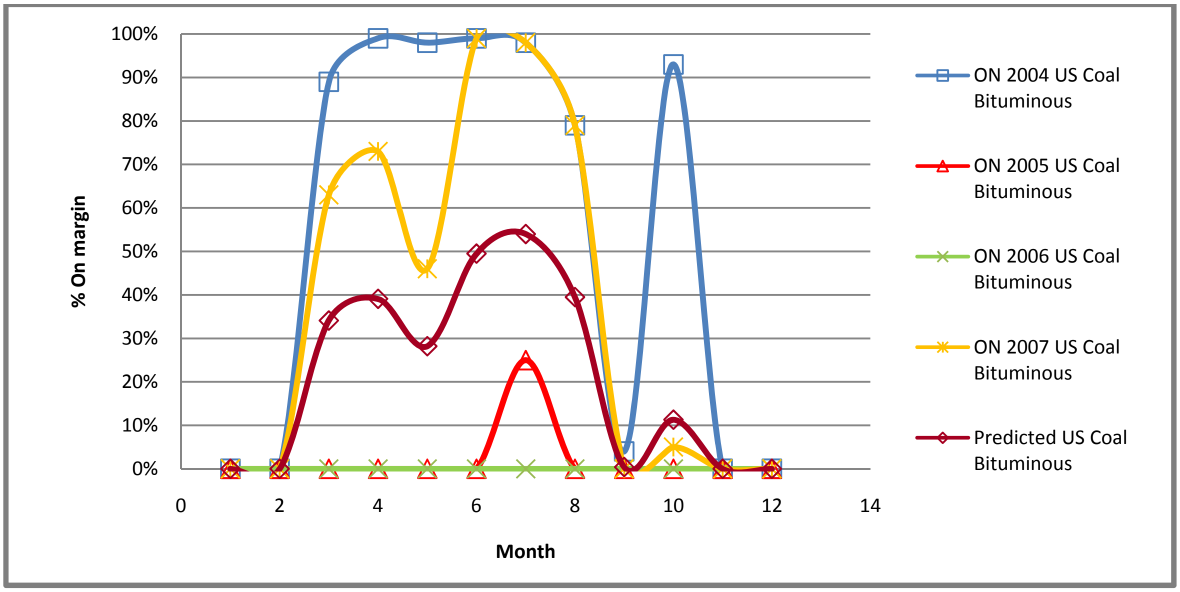

Figure E.14. US coal bituminous usage for marginal electricity generation in Ontario over the period 2004-2007 [41], and predicted values

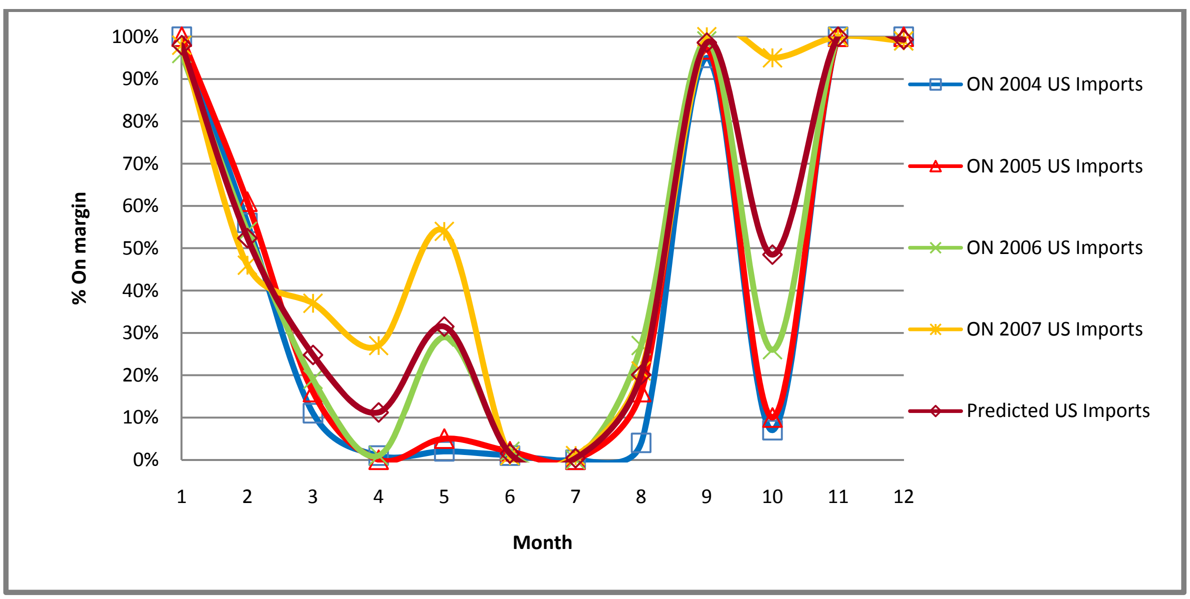

Figure E.15. US Imports usage for marginal electricity generation in Ontario over the period 2004-2007 [41], and predicted values

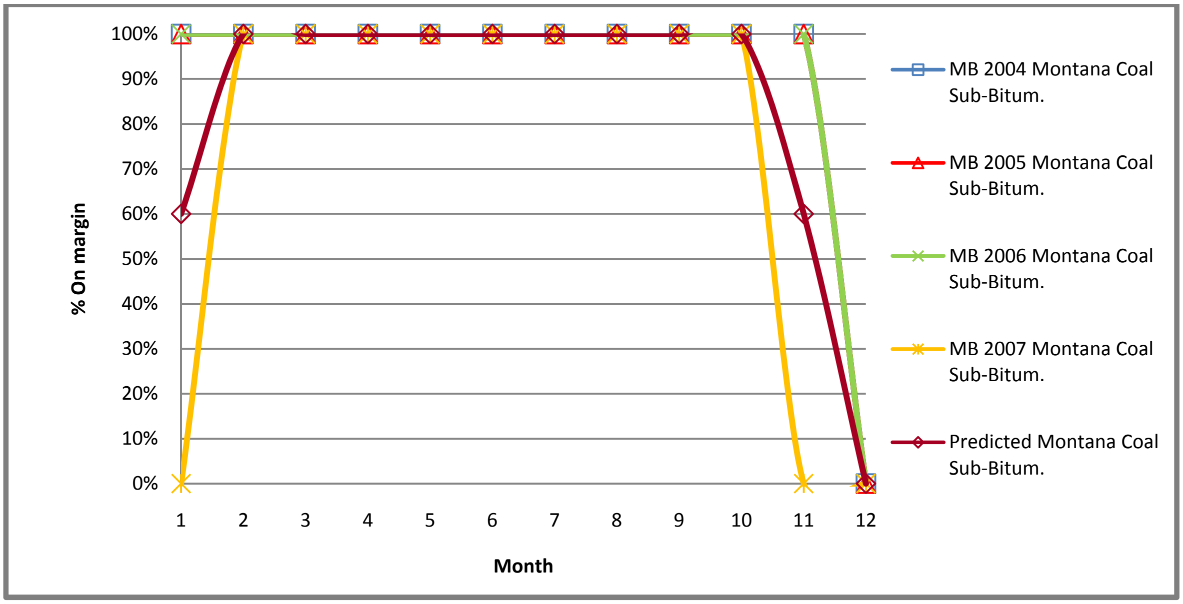

Figure E.16. Montana coal sub-bituminous usage for marginal electricity generation in Manitoba over the period 2004-2007 [41], and predicted values

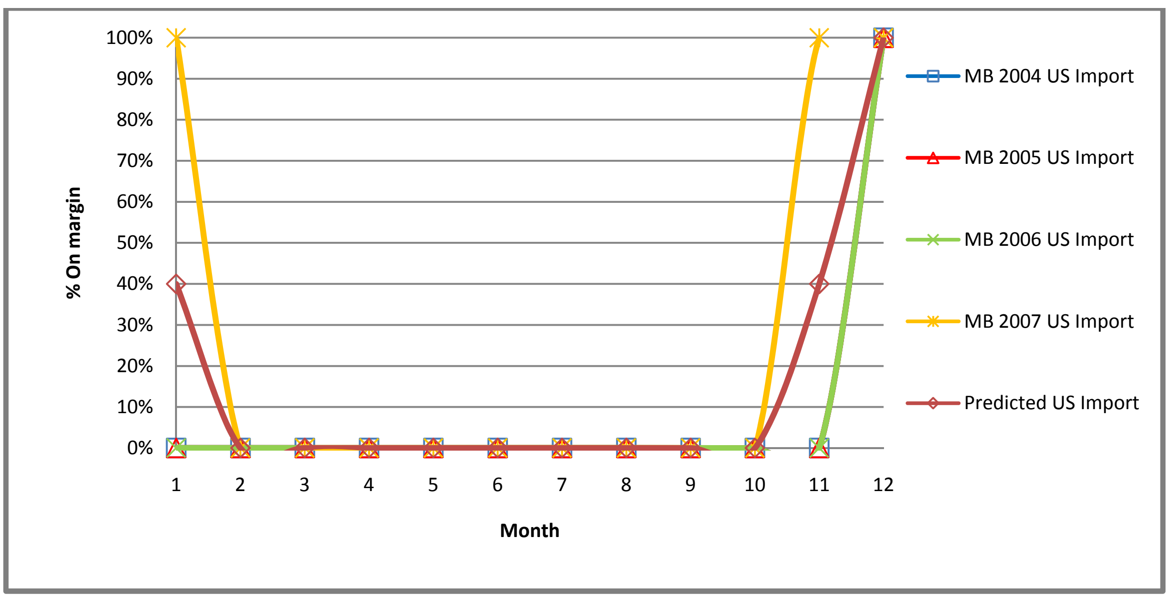

Figure E.17. US import usage for marginal electricity generation in Manitoba over the period 2004-2007 [41], and predicted values

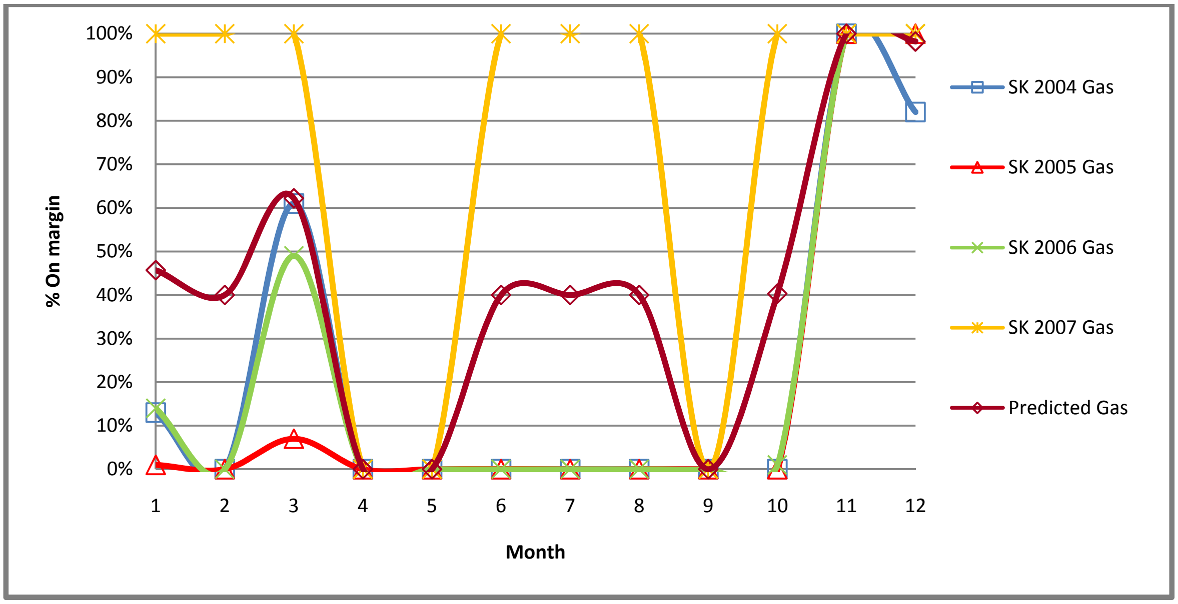

Figure E.18. Natural gas usage for marginal electricity generation in Saskatchewan over the period 2004-2007 [41], and predicted values

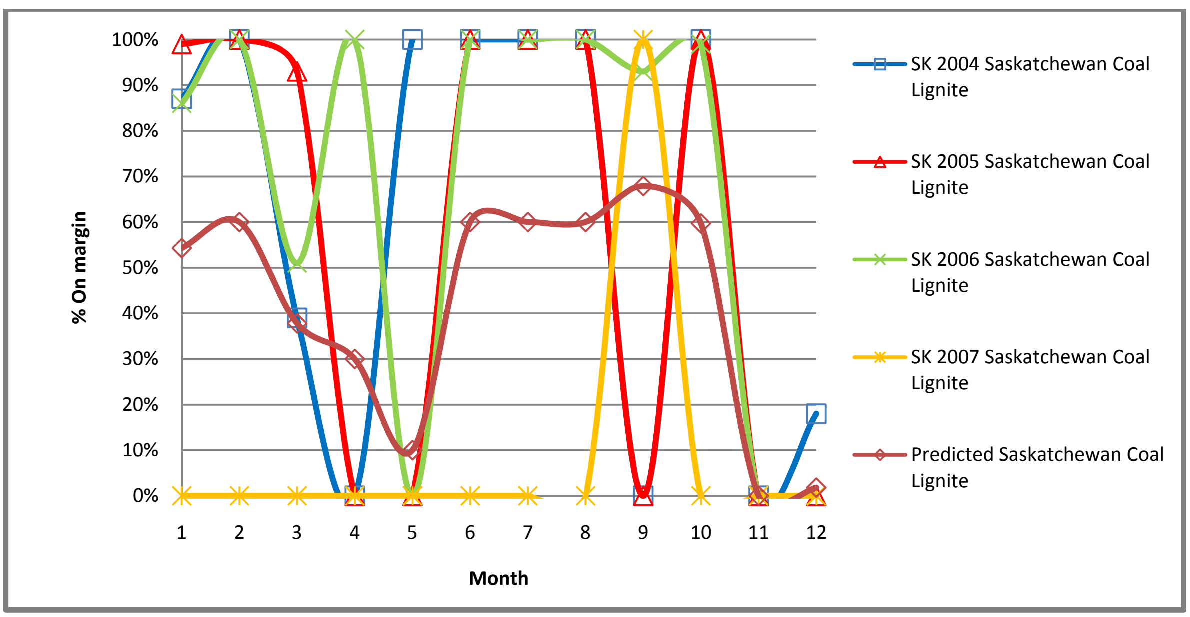

Figure E.19. Saskatchewan coal lignite usage for marginal electricity generation in Saskatchewan over the period 2004-2007 [41], and predicted values

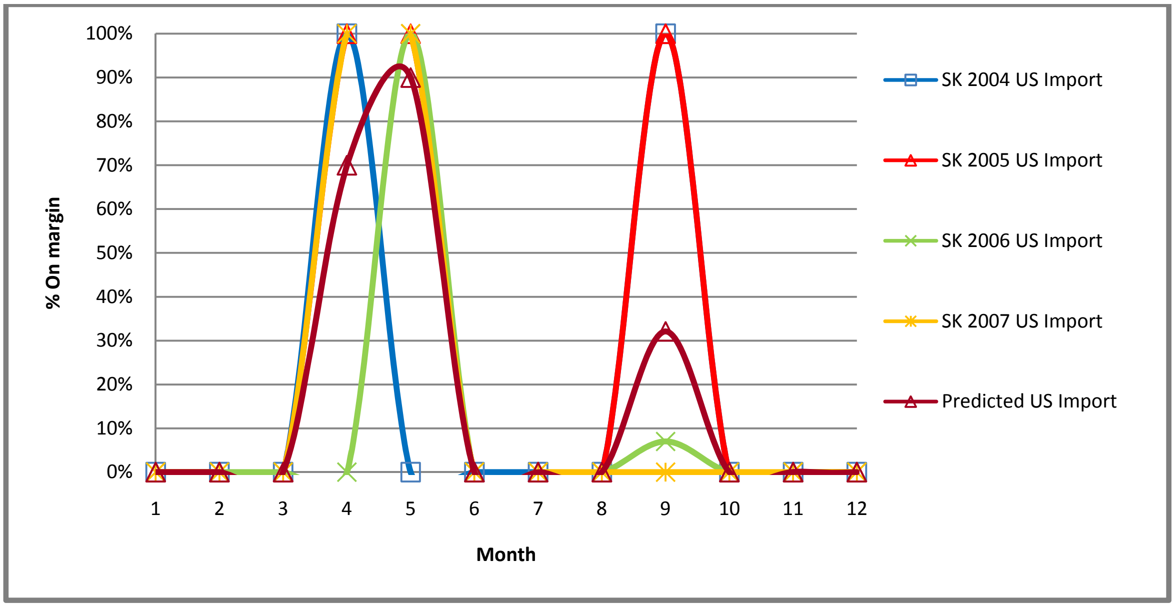

Figure E.20. US import usage for marginal electricity generation in Saskatchewan over the period 2004-2007 [41], and predicted values

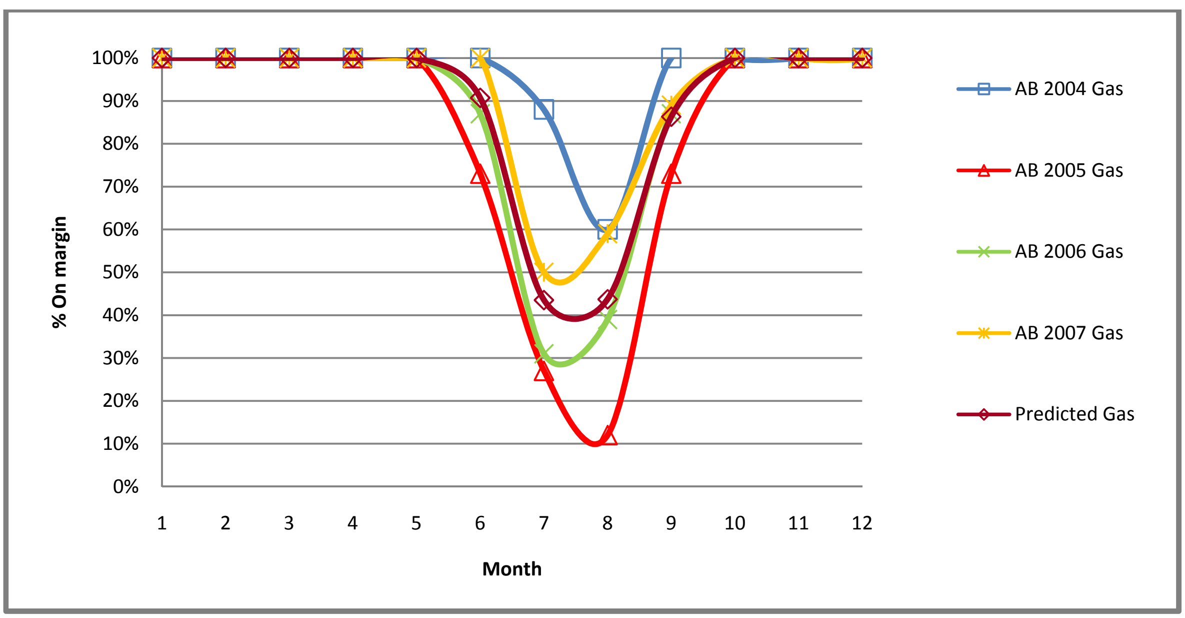

Figure E.21. Natural gas usage for marginal electricity generation in Alberta over the period 2004-2007 [41], and predicted values

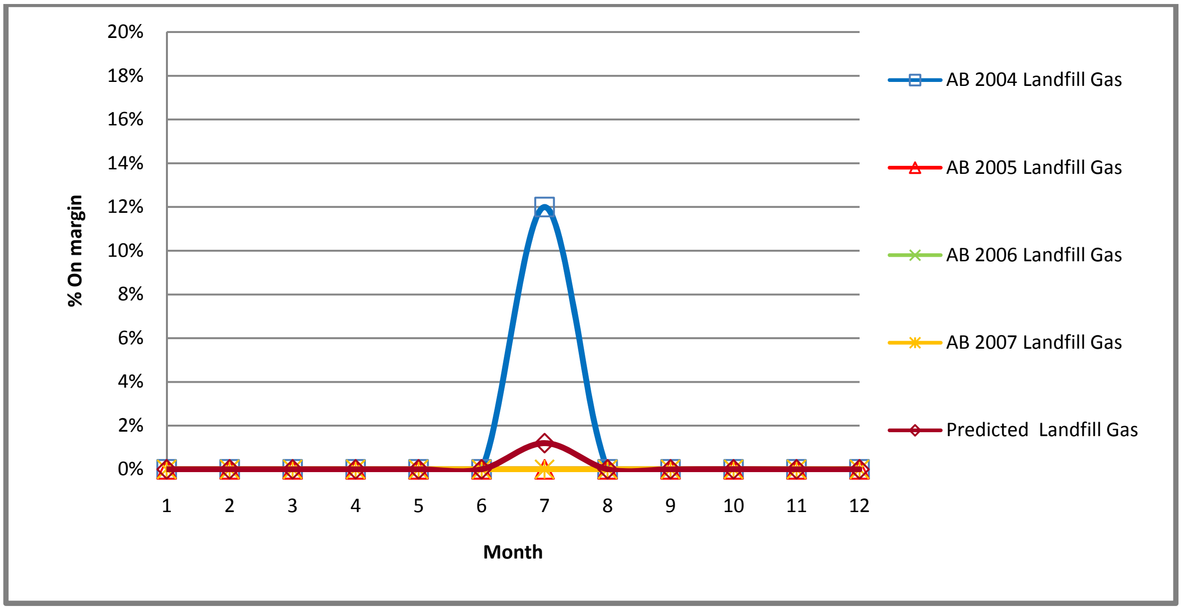

Figure E.22. Landfill gas usage for marginal electricity generation in Alberta over the period 2004-2007 [41], and predicted values

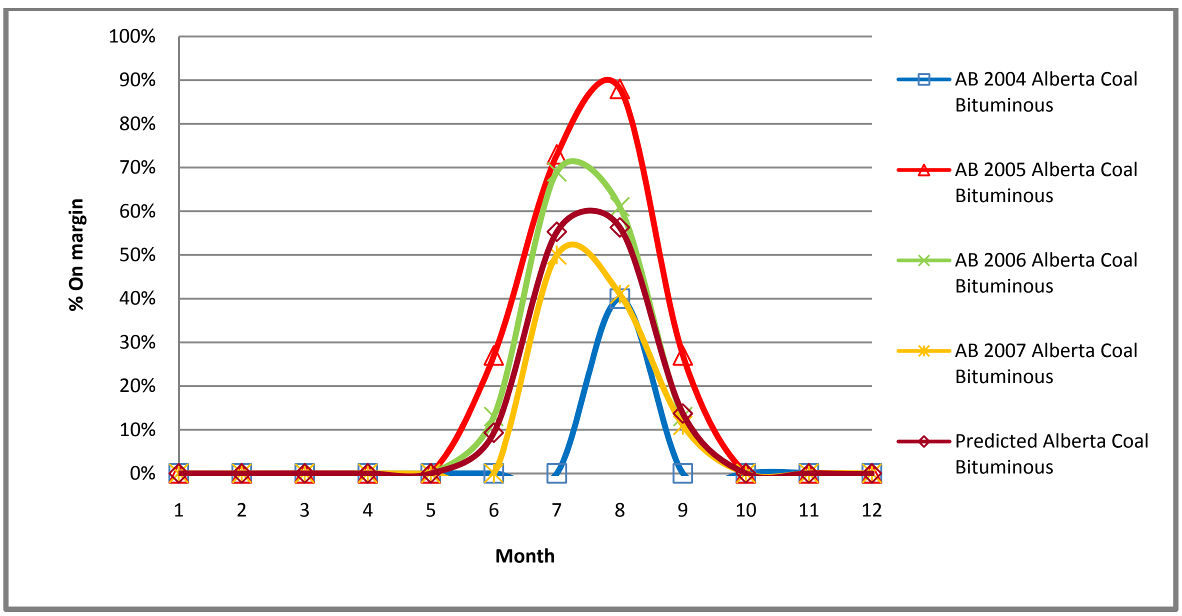

Figure E.23. Alberta coal bituminous usage for marginal electricity generation in Alberta over the period 2004-2007 [41], and predicted values

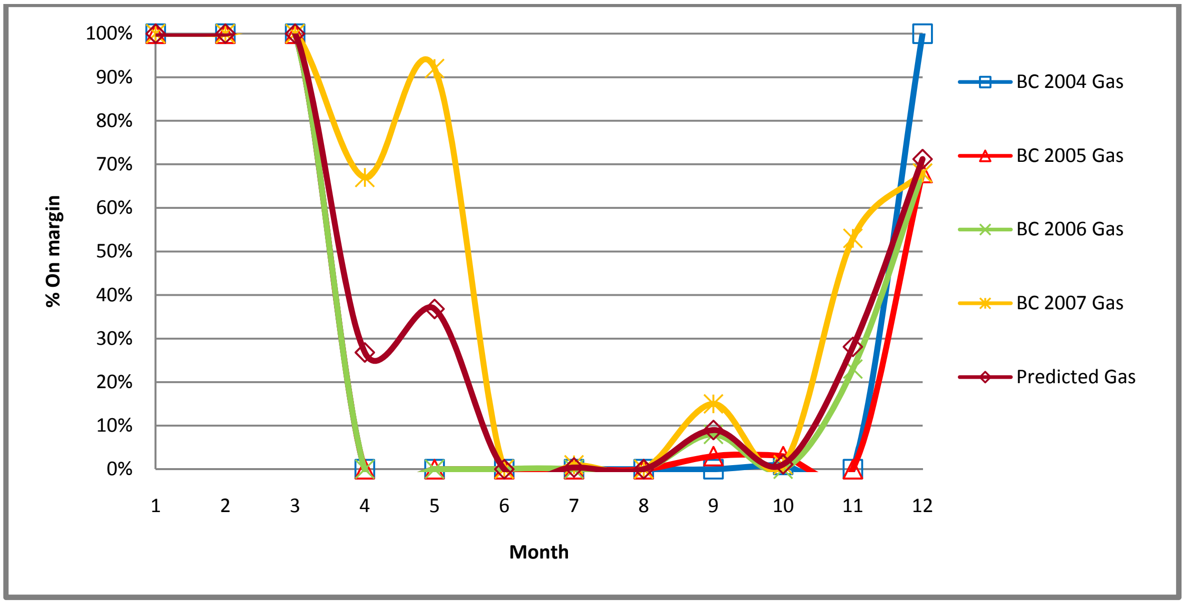

Figure E.24. Natural gas usage for marginal electricity generation in British Colombia over the period 2004-2007 [41], and predicted values

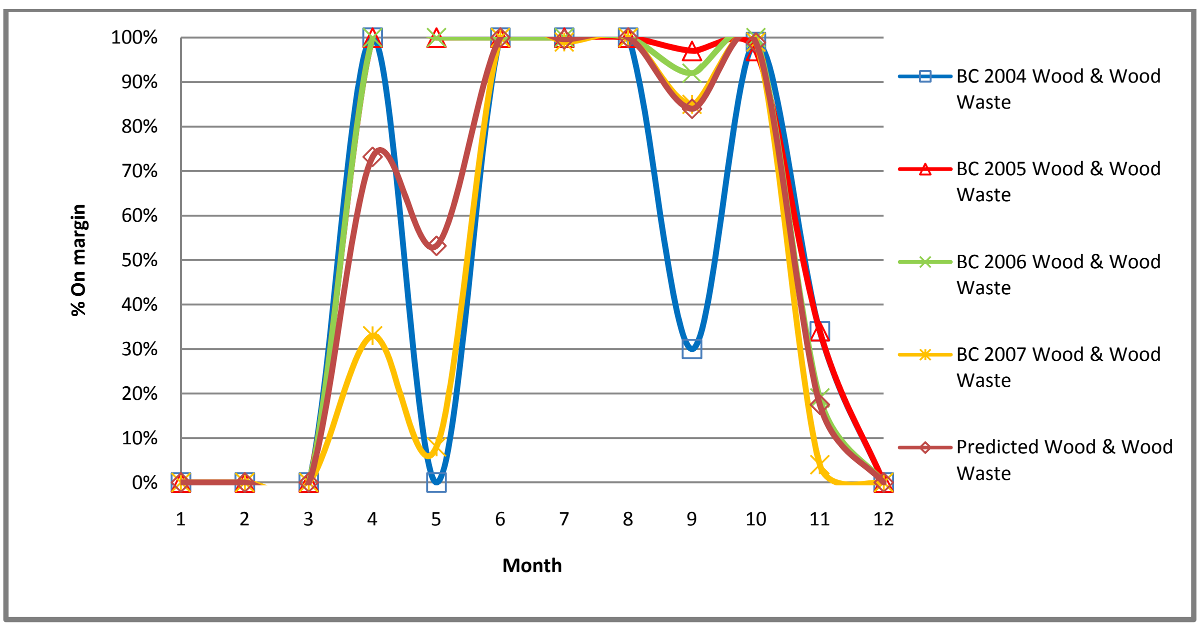

Figure E.25. Wood & wood waste Natural gas usage for marginal electricity generation in British Colombia over the period 2004-2007 [41], and predicted values

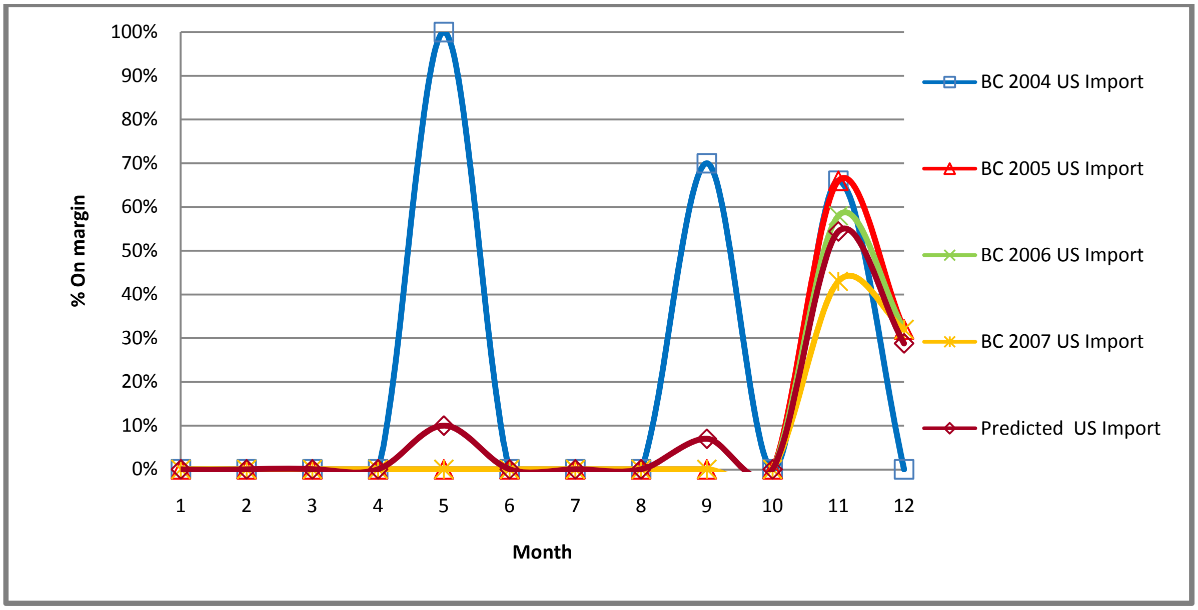

Figure E.26. US import usage for marginal electricity generation in British Colombia over the period 2004-2007 [41], and predicted values

APPENDIX F

Monthly GHG Emission Reduction (Tonne CO_{2eq}/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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	**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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	**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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	**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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	**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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	**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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	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 CO_{2eq}/month)

Month	$GHGIF_A$	$GHGIF_M$	**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