The Determinants of Greenhouse Gas Emissions: Empirical Evidence From Canadian Provinces

by

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Submitted in partial fulfilment of the requirements
for the degree of Master of Development Economics

at

Dalhousie University
Halifax, Nova Scotia
December 2021

Dalhousie University is located in Mi'kma'ki,
the ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

Dedication

I dedicate this piece of work to my kids, Farrukh Hayat Haider and Umaiza Haider.

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Abstract

The main objective of the present study is to examine the determinants of greenhouse gas emissions in Canada using panel data of 10 provinces from 1990 to 2019. The pooled ordinary least squares method is used to estimate the models. The main findings of the basic model show that provinces with greater populations, younger ages, and more income produce higher levels of greenhouse gas emissions. The results of the extended model (per capita greenhouse gas emissions as dependent variable) show that only five factors: oil production per capita, gas production per capita, motor vehicles registered per capita, electricity generation intensity, and heating degree days—are significant determinants of per capita greenhouse gas emissions. The results also reveal that the provinces with older populations have lower per capita greenhouse gas emissions in Canada. However, both trend variables have played an important role in explaining greenhouse gas emissions per capita in Canada.

Keywords: greenhouses gas emissions, Canada, gas production, oil production, electricity generation intensity

Acknowledgments

“In the name of Allah, the most gracious, the most merciful”, praises and thanks are first and foremost due to the Almighty Allah, who gave me the strength, patience, and the ability to complete this piece of work.

It is difficult to overstate my gratitude to my supervisor, Prof. Peter Burton. With his enthusiasm and expertise in explaining the economics concepts clearly and simply, he helped to make the discipline of economics fun for me. Throughout my thesis-writing period, he provided encouragement, sound advice, good teaching, good company, support, and many good ideas. Also, my special gratitude to my other committee members Professor Wimal Rankaduwa and Professor Teresa Cyrus who have shown immense interest in my work and provided valuable observations and productive feedback that improve this piece of research work.

My appreciations are also due to Prof. Casey Warman whose classes strengthened my interest in applied economics and inspired me to conduct applied research. A special thanks and gratitude to all the faculty members and administrative staff (especially Monique Comeau) of the Economics Department.

Words are inadequate to express my full and sincere gratitude to my mother and family. Special thought is devoted to my wife for never-ending support - for her understanding, endless patience, and encouragement when it was most required.

CHAPTER 1: Introduction

The world is facing a climate crisis due to the high emission of greenhouse gases. Such emissions do not respect the national borders of any country, and Canada is no exception. The global temperature has increased by approximately 0.7℃ from the baseline period of 1961-1990 due to human activities that produce greenhouse gases (Intergovernmental Panel on Climate Change, 2014). This rising temperature may affect various aspects of the economy, such as agriculture and forest productivity, marine life, recreational activities, and human health (Ochuodho & Lantz 2014). It is quite difficult to achieve a sustainable future if we do not overcome this crisis.

These climatic changes are hard-hitting around the globe, and Canada is one of the most affected countries. One recent example is from Lytton, a small town in the province of British Columbia:

> *The summer of 2021 began with alarming weather that quickly turned into a tragedy for Lytton, temperatures hit 46.6 C one day and 47.9 C the next, before finally peaking at 49.6 C on June 29, breaking the Canadian record for hottest temperature recorded for three straight days and as nearly five degrees hotter than anything recorded anywhere in Canada before. The very next day, a wildfire devoured most of the village within a matter of minutes. (Lindsay, 2021)*

A heat dome emerged in western Canada, and the death toll suddenly rose as the blistering heatwave continued. Christopher Harley, a marine biologist from the University of British Columbia, calculated that *"more than a billion marine animals may have been killed by the unusual heat"* (Cecco, 2021).

Climatic changes and greenhouse gas emissions due to human activity led to Western Canadian glaciers melting at a faster pace. According to Garry Clarke of the University of British Columbia, "*Canadian glaciers are expected to be completely melted by the end of this century"* (Pearce, 2015). It is also projected by Derksen et al. (2019) that "*glaciers across the Western Cordillera will lose 74% to 96% of their volume and most small ice caps and ice shelves in the Canadian Arctic will disappear by 2100"*.

Most countries around the world are committed to overcoming the global warming issue irrespective of their development level. Many advanced countries in the world have agreed to reduce greenhouse gas emissions to zero by the end of 2050 as part of the Paris Agreement (United Nations Framework Convention on Climate Change, 2015).

Canada is one of the most emissions-intensive economies in per capita terms in the developed world, and it is ranked among the top 10 global emitters of greenhouse gases (Boothe & Boudreault, 2016). Canada contains only 0.5% of the world's population, but it emits 1.6% of the world's total greenhouse gas emissions (World Resources Institute, 2021). So, in this context, the big challenge for Canada is to determine how much and how to reduce greenhouse gas emissions.

The solution to the first part of the question is a simple one: Canada agreed to reduce its greenhouse gas emissions by 30% below its 2005 base level by 2030 under the Paris Agreement (United Nations Framework Convention on Climate Change, 2015). However, according to the Copenhagen Accord (United Nations Framework Convention on Climate Change, 2010), Canada had committed to reducing its greenhouse gas emissions by 17% of its 2005 base by 2020. Rogelj et al. (2016) pointed out that greenhouse gas emissions continue to increase, and if the aim is to limit global warming to "well below 2°C" as set in the Paris agreement (United Nations Framework Convention on Climate Change, 2015), most countries, including Canada, are far below this target emission reduction set for 2030.[1]

A recent National Inventory Report also projected that Canada is well below its emissions reduction targets. The greenhouse gas emissions will decrease only 43 Mt (716 Mt to 673 Mt), 6% below the 2017 level by 2030. But the per capita greenhouse gas emissions will decrease by only 3.57 Mt (19.59 Mt to 16.02 Mt) in the same period. The main reason is that Canada's population will be increasing at a faster pace (15%) between 2017 and 2030 as compared to greenhouse gas emissions (Government of Canada, 2021b). To achieve the desired target set in the Paris agreement (United Nations Framework Convention on Climate Change, 2015), Canada should reduce its greenhouse gas emissions by over 30%. Recently, the Prime Minister of Canada announced a new target to cut emissions by 40-45% of its 2005 base level. He also said that "*if you don't have a plan to tackle climate change, then you don't have a plan to create jobs and economic growth*." The Minister of Environment and Climate Change said that *"with time running out and with the global shift to a low-carbon economy turning into a sprint, Canadians have been calling for increased climate ambition"* (Government of Canada, 2021a). The climate change issue faced by Canadians highlights the importance of reducing greenhouse gas emissions for a better future.

The problem of how to reduce greenhouse gas emissions is a complex one. There is no one magic bullet to get the solution to this problem. We need to identify the factors that boost or impede greenhouse gas emissions. Furthermore, for policy purposes, the determinants of greenhouse gas emissions must be analyzed to achieve the target set in

1 Paris Agreement Article 2 (a): "Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change."

the Paris agreement. In this context, the geographic and climatic factors—inflexible national characteristics—might have a significant effect on the country's greenhouse gas emissions. Policymakers have a limited ability to alter these factors, which include demographic factors like population, average age, etc. (Dietz & Roza, 1997; York et al., 2003; Cole & Neumayer, 2004; Fan et al., 2006; O'Neill et al., 2012; Jones & Kammen, 2014; Jones & Kammen, 2015; Feng et al., 2015; Tavakoli, 2018; Gonzalez-Sanchez & Martin-Ortega, 2020). Climatic variables include maximum temperature, minimum temperature, heating degree days, cooling degree days, precipitation, etc. (Calbick & Gunton, 2014; European Environment Agency, 2019; Gonzalez-Sanchez & Martin-Ortega, 2020). The cost of heating (or cooling) varies quite a bit between the provinces in Canada as well. Gonzalez-Sanchez and Martin-Ortega (2020) identified that heating degree days and cooling degree days are among the main determinants of greenhouse gas emissions in European countries.

On the other hand, many flexible national and regional characteristics (such as economic factors, energy sources, industrial and agricultural variables, transport sector, and provincial government policies) might have effects on regional greenhouse gas emissions (Liobikiene & Butkus, 2017; Gonzalez-Sanchez & Martin-Ortega, 2020; Ritchie & Roser, 2020). Policymakers have a substantial role in controlling these factors.

Based on the flexible national and regional characteristics, global energy use is the main emissions driver, producing almost 70% of the global greenhouse gas emissions (International Energy Agency [IEA], 2017). The energy sector produces over 80% of the total greenhouse gas emissions in Canada. The energy sources include stationary combustion, transport, fugitive sources, and CO_2 transport and storage (Government of Canada, 2021b).

Canada is a decentralized federation, and climate change is a shared jurisdiction, so all the provincial governments have their greenhouse gas emission policies. It is quite possible that the variables identified do not capture the province's greenhouse gas emissions differences in the most populous or more energy-rich provinces. This will raise a little concern about how co-linear some of the variables must appear given the relative sizes of the provinces. So, in this context, it is imperative to understand how effectively and efficiently the environmental control policies are implemented at the provincial and national levels to identify those factors that are responsible for high greenhouse gas emissions in Canada.

The main research question is as follows:

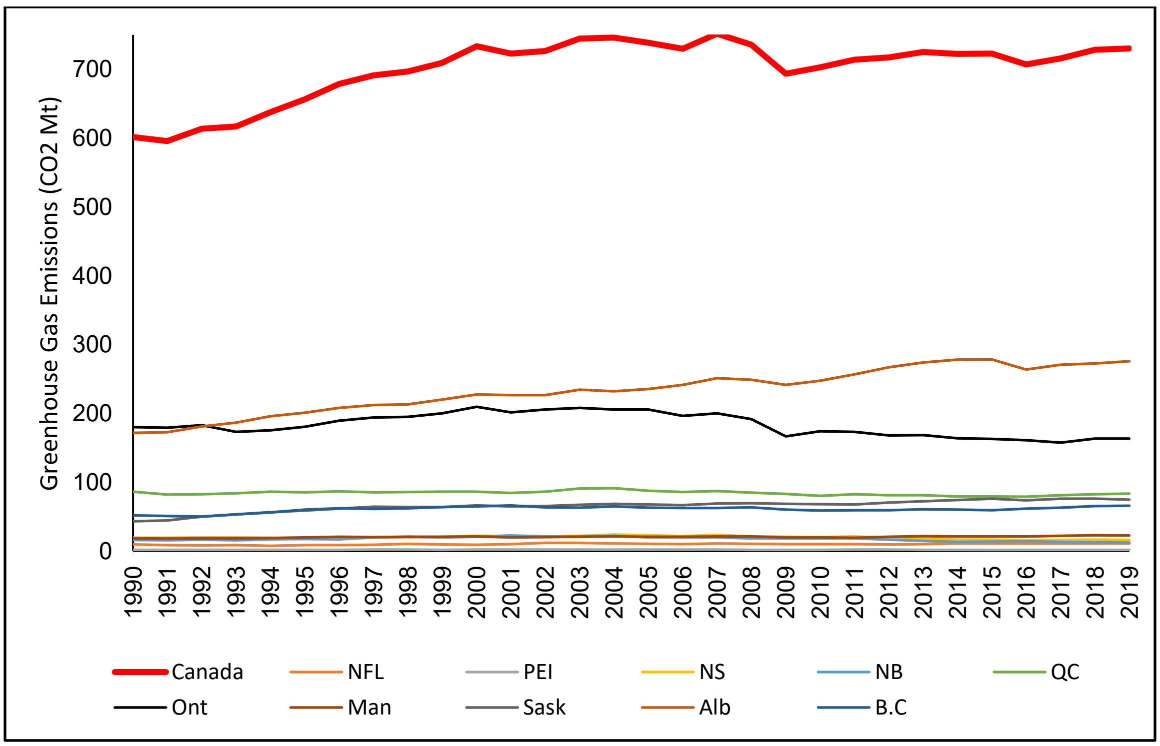
What are the main determinants of per-capita greenhouse gas emissions in Canada?

The rest of the thesis is as follows: Chapter 2 briefly discusses the past trends in greenhouse gas emissions in Canada and its provinces; a literature review is presented in Chapter 3. The model, data, and econometric model are presented in Chapter 4, and estimation results and their discussion are presented in Chapter 5; the key findings are discussed in the last Chapter.

CHAPTER 2: Past Trends in Greenhouse Gas Emissions in Canada and its Provinces

In light of the discussion above in Chapter 1, it is very important to analyze past trends in greenhouse gas emissions in Canada and its provinces. These trends will further highlight the importance of the issue under discussion. Figure 1 presents the level of greenhouse gas emissions in Canada and its provinces, which shows that over time, the trend in greenhouse gas emissions is increasing in Canada.

Figure 1: Greenhouse Gas Emissions (CO_2 Mt)



Source: National Inventory Report, Government of Canada (2021b); NFL = Newfoundland and Labrador, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, QC = Quebec, Ont = Ontario, Man = Manitoba, Sask = Saskatchewan, Alb = Alberta, B.C = British Columbia.

The level of greenhouse gas emissions has increased by 129 Mega tonnes (Mt) from 1990 to 2019 in Canada. The sharp increase in greenhouse gas emissions is noted for the period 1990 to 2000 where it jumps from 601 Mt to 733 Mt. After 2000, the greenhouse gas emissions show a mixed trend and reach their peak in 2007 when the level of greenhouse gas emissions is 751 Mt in Canada. A sudden fall of 58 Mt (751 Mt to 693 Mt) in greenhouse gas emissions is noted from 2008 to 2009 which is mainly (34 Mt out of 58 Mt) due to the closure of coal-fired electricity generation plants in the province of Ontario. But after 2009, the greenhouse gas emissions again start to increase and reaches 730 Mt in 2019 in Canada.

By comparing over decades, the greenhouse gas emissions increased by 13 Mt on average each year between 1990 to 2000, decreased by 3 Mt on average each year between 2000 to 2010, and again increased in the last decade by 3 Mt on average each year from 2010 to 2019. So, the overall greenhouse gas emissions are increasing by 5.3 Mt on average each year from 1990 to 2019.

The greenhouse gas emissions across provinces show a mixed trend. The Atlantic provinces (Prince Edward Island, Nova Scotia, New Brunswick) show a decreasing trend except for Newfoundland & Labrador where greenhouse gas emissions are increasing over time. A similar trend is found in Quebec and Ontario, where greenhouse gas emissions are decreasing over time. The greenhouse gas emissions in Manitoba, Saskatchewan, Alberta, and British Columbia show an increasing trend over time from 1990 to 2019.

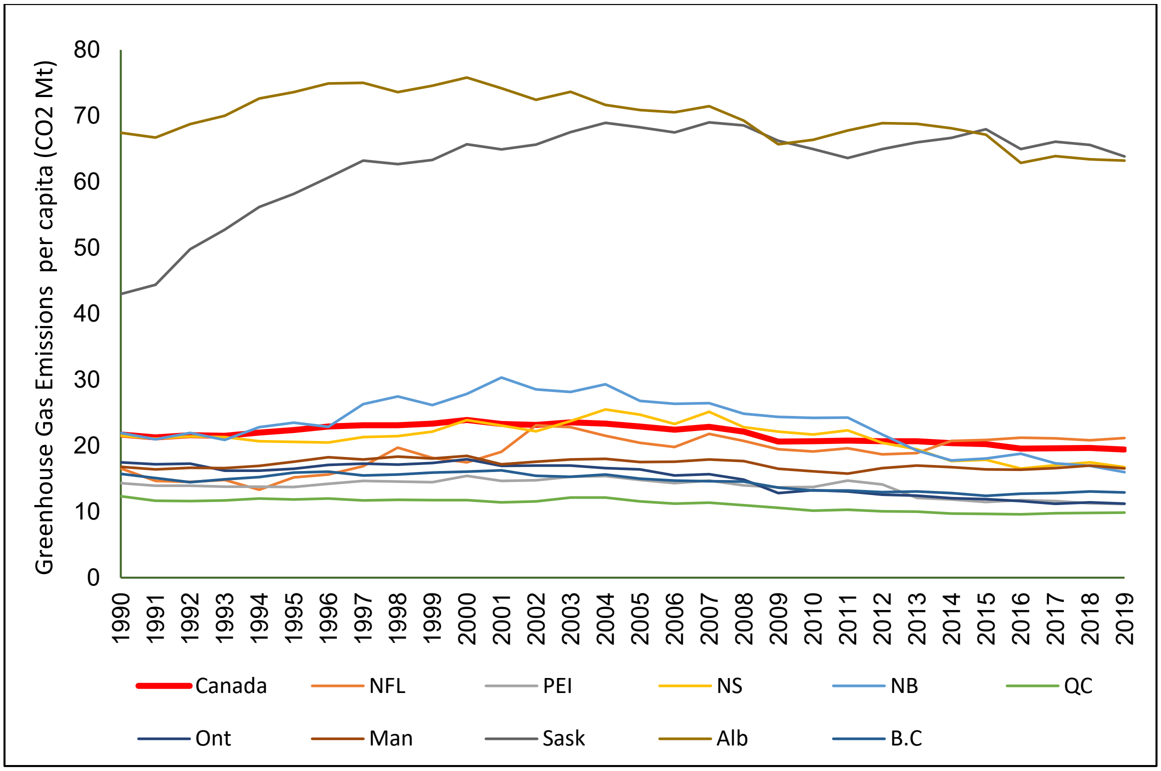
It is noted from Figure 1 that there are large differences in the provinces' greenhouse gas emissions trends of the most populous (Ontario) or more energy-rich (Alberta) provinces. Further, it is also noted that 60% of the 2019 greenhouse gas emissions in Canada are contributed by two provinces: Alberta 275.8 Mt (37.8%) and Ontario 163.2 Mt (22.4%). An additional 31% of greenhouse gas emissions are accounted for by Quebec (11.5%), Saskatchewan (10.2%), and British Columbia (9.0%). The remaining 9% of the 2019 greenhouse gas emissions in Canada are contributed by all other provinces:

Newfoundland & Labrador, Prince Edward Island, Nova Scotia, New Brunswick, and Manitoba.

Canada is a sparsely populated country and has a higher demand for transportation which leads to longer travel times in some densely populated provinces, like Ontario. Presumably, it mostly depends upon the travel between and within major population centres. Larger cities may require longer commutes on average and more populous provinces tend to have larger cities. In Canada, the average commute time in cars ranges from 60 to 75 minutes and approximately 32 % of the commuters spend a longer time than this. In Ontario, the city of Toronto has the largest commute time (96 minutes, both ways) in North America and the 6th worst commute in the world. Over 1.8 million people commuted to work in the Greater Toronto Area (GTA) which harms climate change. Across Canada, 28% of carbon emissions come from the transportation sector but 35% of all the greenhouse gas emissions in Ontario come from the transportation sector (Statistics Canada, 2016).

Figure 2 presents the per capita greenhouse gas emissions of each province and overall Canada. According to Figure 2, a mixed trend is found in greenhouse gas emissions per capita in Canada. Canada shows an increasing trend over time from 1990 to 2000 where per capita greenhouse gas emission is increased by 2.18 Mt, from 21.72 Mt in 1990 to 23.90 Mt in 2000, followed by a decreasing trend in per capita greenhouse gas emissions until 2019. Mixed trends are also found in the case of greenhouse gas emissions per capita in Canadian provinces. Alberta and Saskatchewan have higher per capita greenhouse gas emissions as compared to overall Canada from 1990 to 2019. New Brunswick also has higher greenhouse gas per capita than Canada up to 2013, and after that, it is lower than Canada due to a sharp decrease noted in per capita greenhouse gas emissions.

Figure 2: Greenhouse Gas Emissions per capita (CO_2 Mt)



Source: Statistics Canada: Population Table: 17-10-0005-01 and greenhouse gas emission is taken from National Inventory Report, Government of Canada (2021b); NFL = Newfoundland and Labrador, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, QC = Quebec, Ont = Ontario, Man = Manitoba, Sask = Saskatchewan, Alb = Alberta, B.C = British Columbia.

On the other hand, Newfoundland & Labrador had lower greenhouse gas emissions per capita than the overall Canada average until 2014, when it became higher than the Canadian average. Thus, most oil-rich provinces (Alberta, Saskatchewan, and Newfoundland & Labrador) have produced more per capita greenhouse gas emissions compared to overall Canada. According to Figure 2, Nova Scotia, Prince Edward Island, New Brunswick, Ontario, Quebec, Manitoba, and British Columbia have lower per capita greenhouse gas emissions as compared to Canada.

All provinces show a negative trend in per capita greenhouse gas emissions from 1990 to 2019 except for Saskatchewan and Newfoundland & Labrador where the population increase is slower than greenhouse gas emissions (see Table 1). Looking at column 2, greenhouse gas emissions changes between 1990 and 2019 range between 72.7% (highest increase for Saskatchewan followed by Alberta and B.C.) to -23.6% (large decrease for New Brunswick). These data demonstrate that greenhouse gas emissions have decreased from the 1990 level in the Atlantic and central provinces except for Newfoundland & Labrador. On the other hand, emissions increased from the 1990 level in the western provinces. So, it is noted that there is a large difference between the changes in greenhouse gas emissions between 1990 and 2019 across the provinces.

Table 1: Greenhouse Gas Emissions and Population Changes from 1990 and 2005 levels to 2019.

Provinces	Change from 1990 level to 2019			Change from 2005 level to 2019		
	Greenhouse gas	Population	Greenhouse gas per capita	Greenhouse gas	Population	Greenhouse gas per capita
NFL	16.1%	-9.3%	28.1%	5.4%	1.8%	3.6%
PEI	-5.9%	20.6%	-22.0%	-14.0%	13.9%	-24.5%
NS	-17.2%	6.5%	-22.3%	-29.9%	3.4%	-32.2%
NB	-23.6%	5.0%	-27.2%	-38.0%	3.9%	-40.3%
QC	-3.1%	21.5%	-20.2%	-4.4%	12.1%	-14.8%
Ont	-9.3%	41.3%	-35.8%	-20.6%	16.1%	-31.6%
Man	21.8%	23.9%	-1.7%	9.8%	16.2%	-5.6%
Sask	72.7%	16.3%	48.5%	10.3%	18.0%	-6.5%
Alb	60.6%	71.2%	-6.2%	17.1%	31.3%	-10.8%
B.C	26.9%	54.6%	-18.0%	4.3%	21.3%	-14.0%
Canada	**21.4%**	**35.8%**	**-10.6%**	**1.1%**	**16.6%**	**-15.2%**

Source: Statistics Canada: Population Table: 17-10-0005-01 and greenhouse gas emission is taken from National Inventory Report, Government of Canada (2021b); NFL = Newfoundland and Labrador, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, QC = Quebec, Ont = Ontario, Man = Manitoba, Sask = Saskatchewan, Alb = Alberta, B.C = British Columbia.

The difference is further increased when we incorporate the population effect for Newfoundland & Labrador, where per capita greenhouse gas emissions increased due to the negative population growth observed from 1990 to 2019. Saskatchewan experienced lower population growth as compared to greenhouse gas emissions growth in the same period. The biggest change in per capita greenhouse gas emissions is in Ontario (-35.8%)

below its 1990 level and this difference is reduced (-31.6%) when we measure per capita greenhouse gas emissions from the 2005 level in Ontario. Overall, in Canada, greenhouse gas emissions increased by 21.4% in 2019 from the 1990 level, and the large increase in the population (35.8%) from the 1990 level has led to a decrease in the per capita greenhouse gas emissions by 10.6%.

As noted above, Canada agreed to reduce its greenhouse gas emissions by 30% below its 2005 base level by 2030, under the Paris Agreement (United Nations Framework Convention on Climate Change, 2015). The greenhouse gas emissions change from the 2005 level ranges between 17.1% (highest increase in Alberta followed by Saskatchewan and Manitoba) to -38.0% (largest decrease is New Brunswick). This asserts that the greenhouse gas emissions reduced from the 2005 level in the Atlantic and central provinces except for Newfoundland & Labrador, however, the greenhouse gas emissions increased in the western provinces from the 2005 level. Only two provinces (Nova Scotia and New Brunswick) have already achieved this target when compared to total greenhouse gas emissions. This result indicates that most of the provinces are going in the right direction except for oil-rich provinces that produced more greenhouse gas emissions than the base level in 2005. This result leads to identifying the other factors, such as demographics, climate, and energy sources, that contribute to the remaining differences between the provinces' greenhouse gas emissions.

CHAPTER 3: Literature Review

The determinants of greenhouse gas emissions have been extensively studied in the literature (Commoner, 1972; Dietz and Rosa, 1997; Shi, 2003., York et al., 2003; Cole & Neumayer, 2004; Fan et al., 2006; Alegria et al., 2016; Cui et al., 2018; Tavakoli, 2018; Gonzalez-Sanchez & Martin-Ortega, 2020, etc.). According to this literature, the main variable that determines the greenhouse gas emissions is the population of the country under study. As the population rises it generates more economic activity leading to more emissions of greenhouse gases in the environment. For instance, Shi (2003) finds that population change exerts a more than proportional change in emissions using data for 93 countries from 1975 to 1996. He also finds that this result is more pronounced in developing countries than in developed countries.

Cole and Neumayer (2004) use data from 86 countries, from 1975 to 1998, to examine the links between population and carbon dioxide emissions. The main finding suggests that population growth is one of the primary drivers boosting greenhouse gas emissions in most countries. York et al. (2003) and Fan et al. (2006) find that population and economic growth had the highest impact on greenhouse gas emissions for countries at different income levels over the period 1975-2000.

A study conducted by Song et Al. (2019) points out that wealthier families have greater greenhouse gas emitters than poorer families and a household's carbon emissions increases with its income. Another study conducted by Dalton et al. (2008) estimates that the rapidly aging population may reduce CO_2 emissions in the United States due to the level of final demand for consumer goods that are energy-intensive such as less use of cars, gasoline, etc.

A recent study conducted by Gonzalez-Sanchez and Martin-Ortega (2020) on a group of 28 European countries uses panel data from 1990 to 2017 by employing a multiple regression model to identify the potential drivers of greenhouse gas emissions. They find that GDP and energy intensity are the main drivers for the reduction of greenhouse gas emissions in Europe, however, energy prices are not a significant contribution to the greenhouse gas emissions reduction in Europe at the country level. They also find that heating and cooling degree days are significant determinants of greenhouse gas emissions in European countries. They explain that, due to colder temperatures in the winter, extensive use of the heating system produces much of the greenhouse gases in these countries. In Canada, the provinces that face a long winter season pay more for heating. Similarly, some provinces that face hot summers (e.g., Ontario) pay more for cooling. So heating and cooling degree days might be identified as one of the potential factors that contribute to the greenhouse gas emissions in Canada.

On the other hand, at the country level, Yang (2012, 2013) comprehensively analyzes the relationship between the agricultural sector's greenhouse gas emissions and agricultural population and uses some additional control variables with Chinese regional data. He finds that the agricultural population boosts the agriculture sector's greenhouse gas emissions. Another two studies were conducted on Chinese cities by Cui et al. (2018) and Wang et al. (2017). They find that population was not a significant determinant of per capita greenhouse gas emissions when using Pooled OLS and Fixed Effect Models. However, the population has a negative relationship with per capita greenhouse gas emissions when using the ALD (Asymmetric Laplace Distribution) and LAD (Least Absolute Derivation) models, and they find per capita greenhouse gas emissions elasticities of -0.19 to -0.20, respectively. This result is consistent with the study of Meng and Huang (2018); they find a negative elasticity of population (-0.149) for Chinese cities with per capita greenhouse gas emissions, and similar results are found in the study conducted by Zheng et al. (2016) for China.

A recent study was conducted by Wei et al. (2021) to keep track of greenhouse gas emissions reduction targets in 167 cities worldwide. They identify that city with a large population size, fast development of transportation infrastructure, and a high level of travel demand have produced more greenhouse gases. Similar results are found in previous studies (Ehrlich, 2017 and Liang et al., 2017) which suggest that the greenhouse gas emissions of transportation are closely relevant to the size of the population.

Another study conducted by Andres and Padilla (2018) on European Union (EU-28) countries identifies that the transport sector is regarded as one of the key sectors that contributed (21%) significantly to the EU-28 countries' greenhouse gas emissions. This result is consistent with the study conducted by Papagiannaki and Diakoulaki (2009). They find that the number of motor vehicles registered per capita in Greece is the main factor behind a significant increase in greenhouse gas emissions during 1990–2005.

Alegria et al. (2016) study the power sector of Spain and find that trends in the level of the economy and the renewable energy sources are the main drivers of greenhouse gas emissions. They also find that the new legislation and technological changes introduced in 2012 were effective to limit greenhouse gas emissions in the power sector of Spain. This result is consistent with the study of Zagheni (2011) which concludes that technology is an important variable in explaining greenhouse gas emissions such as CO_2 emissions, however, it may play a key role in the future by reducing the electricity generation intensity that may offset the effect of increasing consumption due to aging population.

In terms of the Canadian economy, to the best of my knowledge, none of the empirical studies found in the literature identify the factors responsible for the greenhouse gas emissions in Canada alone. But a few panel studies of which Canada is part (such as G7 countries, top 10 greenhouse gas emitter countries, OECD, etc.) were found in the literature that identified the factors responsible for greenhouse gas emissions. Liddle and Lung (2010) examine how population and different age groups have greater environmental impacts on aggregate carbon emissions and the carbon emissions from the transport sector. They find that overall, in OECD countries (including Canada), the population age structure is significant and varies across different age groups. For the transportation sector, the total population was greenhouse gas-intensive, and all other population groups had a negative relationship with transportation sector carbon emissions. For aggregate carbon emissions, the age structure has an inverted U-shaped relationship and varies from youngest (20-34) that has a positive elasticity (0.17) to all other age groups [middle-aged, (35-49), older (50-64), and oldest (65-79)] that have a negative elasticity. These results conclude that countries with younger populations emit more carbon than countries with older populations.

On the other hand, Liddle (2011, 2013, 2015) conducted a series of studies on OECD countries and Canada was included in this group. At the country level, Canada's population has a positive relationship with both sectors' (transport and residential electricity) greenhouse gas emissions. In all studies, they find that greenhouse gas emissions' elasticity with respect to income appears significantly less than one in OECD countries while carbon and income are proportional for non-OECD countries.

In another study conducted on 21 OECD countries, Lim et al. (2020) find that the effect of age is limited in elderly people as compared to the young. They also find that until the age of 5-9, people have a low rate of greenhouse gas emissions but as they get older, they emit more greenhouse gases. The age group in their late 20s, especially 25-29 years old, emit the highest rate of greenhouse gas emissions.

Calbick and Gunton (2014) conducted a study to find the causes of the differences between the per capita greenhouse gas emissions in the OECD countries. They find that population is not a significant determinant in explaining the per capita greenhouse gas emissions in the OECD countries. However, Bargaoui et al. (2014) examine the determinants of greenhouse gas emissions on different groups of countries in different geographical regions of the world using data from 1980 to 2010. They find that population, economic activity, and industrial activity have a significant positive effect on the greenhouse gas emissions for all groups of countries and geographical regions, and Canada was included in the North American region, which showed the same results.

Tavakoli (2018) conducted a study on the top ten greenhouse gas emitting countries, and Canada was included in this group, to identify the factors responsible for greenhouse gas emissions. He finds that in Canada, economic activity and energy intensity are responsible for a more than proportional change in greenhouse gas emissions, as the elasticities were 1.14 and 1.07, respectively. Population and carbon intensity are found to have a less than proportional effect, as the elasticities were 0.75 and 0.33, respectively, in greenhouse gas emissions over the period 1971-2012.

In terms of Canada alone, most of the descriptive studies are conducted by Environment Canada, which publishes an annual National Inventory Report (NIR) on greenhouse gas emissions. These reports show greenhouse gas emissions sources by sector and region, identifying where these greenhouse gas emissions come from in the total economy. Similar studies are conducted by Climate Canada under the title “National Report on Climate Change.”

The latest National Inventory Report (Government of Canada, 2021b) report identifies the energy sector as the main source of greenhouse gas emissions in Canada, contributing almost 81% of the total greenhouse gas emissions of Canada. Agriculture is the second-largest source of greenhouse gas emissions with 8%, Industrial Processes and Product Use (IPPU) contributes 7%; the remaining 4% of greenhouse gas emissions come from the waste sector. However, in terms of provinces, Alberta is the largest producer (38%) of greenhouse gas emissions, with Ontario (22%), Quebec (11.5%), Saskatchewan (10%), British Columbia (9%) following, and all other provinces contributed less than 10% of total greenhouse gas emissions in Canada.

From the previous literature, it is concluded that a wide variety of factors influence the level of greenhouse gas emissions around the world and in Canada that include geography, demographic changes in country population, and different levels of income. It is also concluded from the past literature that two types of studies are found; one type of study is performed using cross-country data (panel studies such as EU, EU-28, OECD, a group of 86 countries, etc.), and the second type of study focuses on country-specific analyses (time series, such as China, Spain, etc.), but a few studies also investigate the determinants of greenhouse gas emissions at the provincial or city level (such as China). Although there are many studies found in the literature that identified the determinants of greenhouse gas emissions at a global level, a gap still exists in the case of Canada. To fill this gap, the present study's main objective is to identify the factors responsible for greenhouse gas emissions in Canadian provinces; the basic model where the population is the main variable of interest is used with its extended form, according to the available data for different factors found in the literature.

CHAPTER 4: Model, Data and Econometric Model

The previous chapter reviewed past studies to analyze the determinants of greenhouse gas emissions in developed and developing countries. The main question of the present study, as discussed above, is why do provinces' greenhouse gas emissions differ? In this context, the geographic and climatic factors, which are also known as inflexible national characteristics, might have a significant effect on a region's greenhouse gas emissions. On the other hand, many flexible national and regional characteristics (such as energy sources, industrial and agricultural variables, provincial government policy variables) might have a substantial effect on the regional greenhouse gas emissions. Thus, in this chapter, I develop a model that will be used for empirical analysis, describe all the variables and their data sources, and then specify the econometric model and describe suitable methods to estimate the econometric model.

4.1 Model

Based on these inflexible and flexible national and regional characteristics, the present study specifies an econometric model that is empirically tested in many studies (e.g., Dietz & Roza, 1997; Shi, 2003; York et al., 2003; Cole & Neumayer, 2004; Fan et al., 2006; Jones & Kammen, 2014; Tavakoli, 2018, Gonzalez-Sanchez & Martin-Ortega, 2020, etc.) which is modelled under the simple form as follows:

$$ghg_{it} = f\ (Pop_{it}) \qquad (1)$$

where *i* = 1, …, 10 denotes a province, t = 1, …, 30 denotes a time period, ghg_{it} are the greenhouse gas emissions (Mt CO_2 equivalent) and Pop_{it} is the population in millions. The above-stated studies have analyzed the effect of population on greenhouse gas emissions and found a positive relationship between population and greenhouse gas emissions. They argue that increased population largely leads to higher levels of consumption and production of goods and services (such as increased demand for food, fresh water, timber, fiber, fuel, etc.), which would produce more greenhouse gas emissions. These findings support the United Nations (UN) findings in 2016 that the top ten emitter countries comprised 51% of the world population and 67% of the greenhouse gas emissions.

Other demographic factors might affect the greenhouse gas emissions such as the average age described by O'Neill et al. (2012). For the analysis of Canadian provincial differences in greenhouse gas emissions, the present study considers the average age as an additional variable as in Lim et al (2020). They find that the effect of age on greenhouse gas emissions is limited in elderly people as compared to the young. So, it is expected that provinces with a younger population emit more greenhouse emissions. Many studies (Fan et al., 2006; Feng et al., 2015, Song et. al, 2019) suggest that not only demographic factors are responsible for greenhouse gas emissions; some other economic factors are also responsible for these emissions such as household income. A household's consumption increases as income increases, which means the more money a household has, the more consumption of goods and services (transportation, housing, etc.) that emit more greenhouse gases.

After incorporating the average age and average income in the basic model of equation (1), equation (2) becomes as follows:

$$ghg_{it} = f\,(Pop_{it}, age_{it}, avgy_{it}) \qquad (2)$$

where age_{it} represents the average age in years and $avgy_{it}$ is the average income of an individual in constant dollars in 2019. The above equation (2) is a basic model, but there are many important differences between the provinces other than their demographic and economic factors, and there are three types of factors that might explain some of the remaining differences in provinces' greenhouse gas emissions: the energy sector (hydrocarbon products such as oil, and gas production), the transportation sector, and the agriculture sector.

According to the National Inventory Report submitted to the United Nations Framework Convention of Climate Change (UNFCCC) in 2021 by different countries, the energy sector is the main source of greenhouse gas emissions in most developed countries, accounting for 50-60% of total greenhouse gas emissions, and the oil and gas productions are the main contributors in these greenhouse gas emissions. In this respect, Canada is not exceptional, with approximately 51% of greenhouse gas emissions contributed by the energy sector (Government of Canada, 2021b). Within the energy sector, hydrocarbon products alone are the main source of greenhouse gas emissions, having contributed 33% of the total greenhouse gas emissions in Canada. After including hydrocarbon production (oil and gas production) variables into equation (2), it becomes as follows:

$$ghg_{it} = f\ (Pop_{it}, age_{it}, avgy_{it}, oil_{it}, gas_{it}) \qquad (3)$$

where oil_{it} is oil production measured in thousands of cubic meters and gas_{it} is gas production measured in million cubic meters.

After the energy sector, the transportation and agriculture sectors are the major contributors to greenhouse gas emissions. The transport sector (which includes all types of transportation, such as aviation, all road transportation, railways, marine, and all other transportation) is regarded as one of the key sectors that contributed (21%) significantly to the EU-28 countries' greenhouse gas emissions, as identified by Andres and Padilla (2018) and the European Environment Agency (2018). According to the National Inventory Report (Government of Canada, 2021b), both sectors accounted for approximately 38%

(30% transport sector and 8% agriculture sector) of the total greenhouse gas emissions at the national level.

After including the transport sector variable (motor vehicles registered in numbers) and the agriculture sector variable (livestock in thousands) into equation (3), it becomes as follows:

$$ghg_{it} = f\ (Pop_{it}, age_{it}, avgy_{it}, oil_{it}, gas_{it}, mv_{it}, livest_{it}) \qquad (4)$$

where mv_{it} is motor vehicles registered in numbers and $livest_{it}$ is the livestock in thousands.

As discussed above, the climatic variables are also one of the main contributors to greenhouse gas emissions, as temperature (winter or summer) substantially varies between the Canadian provinces. To capture the effect of climatic differences, many proxy variables are used in the previous studies such as maximum/minimum temperature, precipitation, heating/cooling degree days, etc. Gonzalez-Sanchez and Martin-Ortega (2020) identify heating/cooling degree days as important determinants of greenhouse gas emissions in European countries. For the present study, the differences between the provincial greenhouse gas emissions might be captured by including the heating/cooling degree days in the model.

Another variable that might be a source of greenhouse gas emissions is electricity generation intensity, as most of the developed countries get their electricity from the combustion of fossil fuels and the electricity that we use at the home and work has a considerable impact on greenhouse gas emissions (International Energy Agency, 2012). In Canada, almost 11% of greenhouse gas emissions come from electricity generation by using fossil fuels. After including the heating/cooling degree days and electricity generation intensity variables in the above equation (4), the final equation (5) will become as follows:

$$ghg_{it} = f\,(Pop_{it}, age_{it}, avgy_{it}, oil_{it}, gas_{it}, mv_{it}, livest_{it}, elecint_{it}, hdd_{it}, cdd_{it}) \quad (5)$$

where $elecint_{it}$ is electricity generation intensity measured in carbon dioxide equivalent per KWh (g CO_2 eq / kWh) and hdd_{it}, cdd_{it} are the heating and cooling degree days (18°C) respectively, measured in numbers (at the provincial principal city) that are equal to the number of degrees Celsius a given day's mean temperature is below /above 18°C. 18°C is the temperature below/above which heating/cooling is required to maintain a comfortable temperature inside buildings, places, etc. It is a measure of how much heating/cooling is required in a year. For example, if on any given day the mean temperature is 12°C (degrees Celsius), then the heating degree days value will be 6°C (18-12=6). Similarly, a mean temperature on a summer day of 30°C would count for 12-degree days of cooling.

But it is still possible that some of the variables are not included in the model, which would explain some of the provincial differences in greenhouse gas emissions. In this respect, we include a dummy variable that signifies the year 2005 and after, as Canada signed the Paris Agreement to reduce its greenhouse gas emissions by 30% from 2005 levels by 2020 and net-zero by 2050. We also introduce two trend variables that represent the general trend and the specific trend starting in the year 2005 which represents the trend that might allow for the gradual roll-out of energy-saving incentives or regulations, which would result in a different trajectory. After adding these variables, the final equation (6) can be written as follows:

$$ghg_{it} = f\begin{pmatrix} Pop_{it}, age_{it}, avgy_{it}, oil_{it}, gas_{it}, mv_{it}, livest_{it}, elecint_{it}, hdd_{it}, cdd_{it} \\ D2005_{it}, trend, T_{2005} \end{pmatrix} \quad (6)$$

where $D2005_{it}$ is a dummy variable for the years beginning in 2005, which is equal to 1 for the year 2005 to 2019 and equal to zero otherwise. The $trend$ is a general trend by putting the value equal to zero starting from 1990 up to 29 for the year 2019 and T_{2005} is a specific trend by putting the value equal to 1 for the year 2005 up to 15 for the year 2019.

4.2 Data

The present study tests different sets of greenhouse gas emission determinants that are examined using provincial panel data for better comparison over time. The study period is from 1990 to 2019 for the population of 10 Canadian provinces (see Table 2). All three territories are excluded from the sample due to large fluctuations in data for some variables, and data are also missing for a few years for the sample period used in this study.

Table 2: Canadian Provinces List

1	Newfoundland and Labrador	6	Ontario
2	Prince Edward Island	7	Manitoba
3	Nova Scotia	8	Saskatchewan
4	New Brunswick	9	Alberta
5	Quebec	10	British Columbia

Note: Total 10 cross-sections (10 provinces).

The data on population are reported in millions, average age in years, average income in constant 2019 dollars, the value of oil and gas as a percentage of GDP, motor vehicles registered in numbers, livestock in thousands, and the agriculture value-added in the percentage of GDP, all taken from the Statistics Canada website. Population and average age are taken from Table 17-10-0005-01 (formerly CANSIM 051-0001), the average income is taken from Table 11-10-0238-01 (formerly CANSIM 206-0051), motor vehicles registered is taken from Table 23-10-0067-01 (formerly CANSIM 405-0004), the value of oil and gas as a percentage of GDP is taken from Table 36-10-0402-01, the livestock is taken from Table: 32-10-0130-01 (formerly CANSIM 003-0032), and the agriculture value-added as a percentage of GDP is taken from Table: 32-10-0048-01 (formerly CANSIM 002-0004).

Data on oil production, gas production, electricity generation intensity (g CO_2 eq / kWh), and greenhouse gas emissions (Mt) are taken from the various National Inventory Reports (Government of Canada, 2021b). Some provinces produce zero oil production and gas production for some years, which makes it impossible to take the log of these two variables and the production of oil and gas of other provinces differ by many orders of magnitude. To prevent this problem, I adjust by adding one (+1) to each value in both series such as log (1+value of oil/gas production) where the 1 prevents the log (1+value of oil/gas production) from going into negative values. Data on heating/cooling degree days are taken from the Environment and Climate Change Canada data sources (weatherstats.ca) for the principal city of each province.

Some quantity variables such as greenhouse gas emissions, oil production, gas production, motor vehicles, and livestock are used per capita instead of at their levels. The value of oil and gas is taken as a percentage of GDP due to a large variation (zero percent for Prince Edward Island and 40 percent for Newfoundland and Labrador) found in the values of oil and gas production in the provinces.

The descriptive statistics on all these variables are presented in Table 3. Table 3 includes the mean, standard deviation, maximum, and minimum for all the variables included in the model and for the per capita greenhouse gas emissions. There is a significant variation in the greenhouse gas emissions in Canadian provinces (1.65 Mt to 278 Mt); the standard deviation is 75.8 Mt, and the overall average greenhouse gas emissions are 69.8 Mt in Canadian provinces. The largest deviation in greenhouse gas emissions below the mean number is -62 Mt, and the largest deviation above the mean is 45 Mt. The variation between (78.8 Mt) the provinces is quite a bit larger than within (11.86 Mt) provinces.

Table 3: Panel Descriptive Statistics

Variable		Mean	Std. dev.	Min	Max	Observations	
Greenhouse gas (Mt CO_2)	overall	69.7619	75.8367	1.65618	278.394	N =	300
	between		78.82275	1.910529	233.84	n =	10
	within		11.8651	7.706871	114.3159	T =	30
Greenhouse gas pc (Mt per million)	overall	26.75566	20.37931	9.602015	75.80859	N =	300
	between		21.18963	11.07081	69.77959	n =	10
	within		3.140752	7.047381	33.68259	T =	30
Population (million)	overall	3.219379	3.789237	0.130369	14.54472	N =	300
	between		3.955624	0.139462	12.35036	n =	10
	within		0.478489	1.164851	5.413737	T =	30
Average age (years)	overall	38.49533	2.5764	32.7	44.5	N =	300
	between		1.234103	35.78	39.73333	n =	10
	within		2.294024	32.24867	43.84867	T =	30
Average income (2019 Constant dollars)	overall	39032.67	6739.868	25500	58900	N =	300
	between		4401.365	34473.33	47723.33	n =	10
	within		5285.139	28309.33	51152.67	T =	30
Oil prod. pc (thousands of cubic meters)	overall	5.556261	9.577695	0	40.11189	N =	300
	between		8.814558	0	22.23689	n =	10
	within		4.644521	-13.3734	26.73848	T =	30
Gas prod. pc (million cubic meters)	overall	5793.941	13193.23	0	55944.37	N =	300
	between		13458.18	0	4.31E+04	n =	10
	within		3241.284	-8391.85	1.86E+04	T =	30
Value of Oil and Gas (% of GDP)	overall	5.332829	9.79865	0	40.58358	N =	300
	between		8.148443	0	21.06209	n =	10
	within		6.004688	-15.7293	24.85431	T =	30
Motor vehicles pc (number)	overall	0.644379	0.098627	0.447311	0.854097	N =	300
	between		0.083328	0.53624	0.765905	n =	10
	within		0.058799	0.492468	0.792478	T =	30
Agri. Value added (% of GDP)	overall	4.542566	4.358636	0.293533	20.31718	N =	300
	between		4.413317	0.368905	13.38401	n =	10
	within		1.1872	0.511851	11.47574	T =	30
Livestock pc (number)	overall	0.613433	0.75032	0.013791	3.059889	N =	300
	between		0.774089	0.018864	2.3232	n =	10
	within		0.14793	0.077423	1.350122	T =	30
Electricity generation intensity (g CO_2 eq / kWh)	overall	383.2927	476.9216	1.1	3903	N =	300
	between		381.348	3.53	887.6667	n =	10
	within		310.0529	-384.204	3516.796	T =	30
Heating deg. days (degrees °C x days)	overall	4485.987	879.9061	2497	6707	N =	300
	between		874.367	2780.4	5699.267	n =	10
	within		289.5989	3663.52	5531.753	T =	30
Cooling deg. days (degrees °C x days)	overall	149.62	107.3604	15	520	N =	300
	between		101.4288	44.26667	350.1333	n =	10
	within		47.28929	-95.5133	319.4867	T =	30

Notes: An observation is a province and year. The sample includes ten provinces and 30 years of data from 1990-2019, and the total number of observations is 300. The word pc means the variable is taken per capita and units for each variable are in parentheses.

A similar variation exists in greenhouse gas emissions per capita (per person); on average, greenhouse gas emissions are 26.8 Mega tonnes CO_2 equivalent per million persons, and there is a large variation (standard deviation (SD) is 21.2 Mt) between the provinces. The largest deviation in terms of per capita greenhouse gas emissions below the mean number is -19.7 Mt per capita, and the largest deviation above the mean is 7 Mt per capita.

A similar pattern exists for the variables such as population, gas production per capita, agricultural value-added (% of GDP), and livestock per capita, where overall variation is less than the variation found between the provinces. All other variables have an opposite pattern, such as average age, average income, oil production per capita, the value of oil and gas (% of GDP), motor vehicles per capita, electricity generation intensity, heating/cooling degree days, where overall variation is greater than between and within provinces. Similarly, a large variation exists between the provinces as compared to within the provinces for these variables, except average age and average income where a large variation exists within the provinces instead of between the provinces.

After analysing the summary statistics for all the variables used in the models, it is very important to further analyse any statistical relationship that exists between the variables. To test the statistical relationship between the variables, the best way is to check the correlation between these variables which also leads to avoiding the multicollinearity problem. The correlation analysis is presented in Table 4.

There is a positive correlation between the per capita greenhouse gas emissions and all other variables except for the population average age and cooling degree days. Hydrocarbon products (such as oil and gas production), the transportation sector (motor vehicles registered), and the agriculture sector (livestock) are the main variables that have a moderate correlation (ranging between 0.4 and0.8) with greenhouse gas emissions in all provinces. There is a positive correlation found between per capita greenhouse gas emissions and oil production per capita (0.76), with gas production per capita (0.67), electricity generation intensity (0.67), livestock per capita (0.58); for the transportation sector it is 0.55, and with the heating degree days, it is 0.47. There is a low correlation (ranging between 0.25 and 0.35) found between greenhouse gas emissions per capita and average income (0.25), with population (-0.07); with cooling degree days, it is -0.31, and with average age, it is -0.35.

Table 4: Correlation Analysis

	lnghgpc	lnpop	lnage	lnavey	lnoilpc	lngaspc	vog/gdp	lnmvpc	lnlivestpc	agv/gdp	lnelecint	lnhdd	lncdd
lnghgpc	1.000												
lnpop	-0.070	1.000											
lnage	-0.353	-0.081	1.000										
lnavey	0.250	0.472	0.421	1.000									
lnoilpc	0.759	-0.133	-0.136	0.228	1.000								
lngaspc	0.674	0.335	-0.224	0.473	0.473	1.000							
vog/gdp	0.536	-0.112	0.073	0.283	0.820	0.282	1.000						
lnmvpc	0.552	-0.076	0.027	0.368	0.362	0.510	0.265	1.000					
lnlivestpc	0.579	-0.017	-0.373	0.275	0.291	0.485	0.022	0.403	1.000				
agv/gdp	0.410	-0.341	-0.132	0.154	0.354	0.198	0.081	0.323	0.801	1.000			
lnelecint	0.670	-0.254	-0.273	-0.041	0.279	0.369	0.165	0.336	0.295	0.152	1.000		
lnhdd	0.469	-0.381	-0.290	-0.133	0.443	-0.118	0.266	0.295	0.468	0.594	0.101	1.000	
lncdd	-0.316	0.404	0.186	0.254	-0.440	-0.269	-0.361	-0.056	0.151	0.067	-0.155	-0.014	1.000

Note: lnghgpc, lnpop, lnage, lnavgy, lnoilpc, lngaspc,vog/gdp lnmvpc, lnlivestpc, agv/gdp, lnelecint, lnhdd, and lncdd denotes the log of greenhouse gas emissions per capita, log of population, log of age, log of average income, log of oil production per capita, log of gas production per capita, the value of oil and gas production as a percent of GDP, log of motor vehicles registered per capita, log of livestock per capita, agricultural value-added as a percent of GDP, log of electricity generation intensity, log of heating degree days, and log of cooling degree days respectively.

In terms of the independent variables, there is a low correlation found between all the variables except for oil and gas production as a percentage of GDP with the log of oil production per capita (0.82) and agricultural value-added as a percentage of GDP with the log of livestock per capita (0.80) which suggests using one of the highly correlated variables in the model to avoid the collinearity problem. Otherwise, there is no collinear variable that is identified that affects the interpretation of the regression results. It is also noted that correlation is just a statistical relationship between two variables, and it does not imply that the variable which has a positive correlation contributed to the greenhouse gas emissions.

Before applying regression analysis, first, it is very important to test the Cross-Section Dependence (CSD), as there are ten cross-sections (provinces) and 30 years (1990-2019) of data used for the analysis. Thus, it is more likely that spillover effects and some common shocks such as recessions that affected most of the provinces at the same time (e.g., the global financial crisis in 2008) also might affect the Canadian provinces at the same time. To avoid the spurious and identification problem in the regression, cross-section dependence is tested first by employing the cross-section dependence test (under the null hypothesis of weak cross-section dependence) proposed by Pesaran (2015), which is employed on the individual variable series (for example, if we are interested in analyzing for the pre-estimation of the cross-section dependence in the data). To investigate the cross-section dependence in the log of all individual variables under this test, the results are represented in Table 5 below.

Table 5: Cross-section dependence test (Pesaran, 2015)

Variable	Test Stat.	p.value
lnghgpc	36.72	0.000
lnpop	-2.12	0.034
lnage	36.74	0.000
lnavey	36.74	0.000
lnoilpc	17.51	0.000
lngaspc	8.71	0.000
lnmvpc	35.55	0.000
lnlivestpc	8.81	0.000
lnelecint	34.43	0.000
lnhdd	36.74	0.000
lncdd	36.58	0.000

Note: Pesaran's (2015) cross-section dependence statistics assume the null hypothesis of weak cross-sectional dependence.

According to the Pesaran cross-section dependence test, we can reject the null hypothesis of weak cross-section dependence for all the variables; with all p-values under 0.01 except for the population variable, which is below0.05, this indicates that there is cross-sectional dependence that leads to the inappropriateness of the pooled ordinary least square regression method.

As indicated above, there is cross-sectional dependence in all the panel series, but it might be possible that the estimated residuals are not cross-sectional dependent which is tested by the Pesaran (2015) cross-section dependence test, based on the residuals of the estimated models instead of the individual series. Before applying this cross-section dependence test, I first specify the econometric models which are discussed in the next section.

4.3 Econometric Model

As noted above, there is a significant large variation in the greenhouse gas emissions in Canadian provinces. To circumvent this issue, the natural logs of all the quantity variables are used in the models. After taking the natural logs of all the quantity variables and adding the error term ε_{it}, equation (2) can be written econometrically as follows:

$$lnghg_{it} = \beta_0 + \beta_1 lnPop_{it} + \beta_2 lnage_{it} + \beta_3 lnavgy_{it} + \varepsilon_{it} \qquad (7)$$

It is quite possible that the new variables do not capture the provinces' greenhouse gas emissions differences in the most populous (Ontario) or more energy-rich (Alberta) provinces. For example, Alberta might be consistently higher than Ontario, and most other provinces are consistently lower than Ontario, which will raise a little concern about how co-linear some of the variables must appear given the relative sizes of the provinces. So, in this respect, I use per capita values of every quantity variable (i.e., ghgpc, oilpc, gaspc, mvpc, livestpc, etc.) instead of at their levels, which might be more energy use per capita if the province has a bigger population due to the greater commuting time. After taking the natural logs of all the quantity variables and adding the error term ε_{it}, equation (6) can be written econometrically as follows:

$$lnghgpc_{it} = \beta_0 + \beta_1 lnPop_{it} + \beta_2 lnage_{it} + \beta_3 lnavgy_{it} + \beta_4 lnoilpc_{it} + \beta_5 lngaspc_{it} + \beta_6 lnmvpc_{it} + \beta_7 lnlivestpc_{it} + \beta_8 lnelecint_{it} + \beta_9 lnhdd_{it} + \beta_{10} lncdd_{it} + \beta_{11} D2005_{it} + \beta_{12}\, trend + \beta_{13} T_{2005} + \varepsilon_{it} \quad (8)$$

The expected signs for the equation (8) coefficients are $\beta_1 > 0$, $\beta_2 < 0$, $\beta_3 > 0$, $\beta_4 > 0$, $\beta_5 > 0, \beta_6 > 0$, $\beta_7 > 0$, $\beta_8 > 0$, $\beta_9 > 0$, $\beta_{10} > 0$, $\beta_{11} < 0$, $\beta_{12} > 0$ *and* $\beta_{13} < 0$. Before estimating the final equation (8), the present study included a different set of variables (such as hydrocarbon production, transportation sector, agricultural sector, and heating/cooling degree days, etc.) in the basic model (such as represented above by equations 3, 4, and 5) to determine the relative importance of provincial differences in greenhouse gas emissions.

To estimate the above models, the study has been using a suitable econometrics methodology after discussing some econometrics issues (e.g., cross-section dependence, heterogeneity, etc.) that can be faced at the time of estimation. The results of the cross-section dependence test and slopes heterogeneity test will be used to choose between the different estimators available in the literature for estimating the models. If there is cross-sectional dependence and slope heterogeneity present in the panels, then the Augmented Mean Group (AMG) estimator developed by Eberhardt and Teal (2010) is more efficient in dealing with both cross-sectional dependence and slope heterogeneity. If the slopes are not heterogeneous across provinces but there is only cross-sectional dependence across the provinces, then the Mean Group (MG), Pool Mean Group (PMG), and Dynamic Fixed Effects (DFE) methods developed by Pesaran et al. (1999) are more efficient. But if there is no cross-sectional dependence and slope heterogeneity, then the pooled ordinary least square method gives more reliable estimates. The results of the cross-sectional dependence and slopes heterogeneity tests are provided in the next section.

4.4 Econometric Tests

As indicated above in the last section that there is a cross-section dependence in all the panels' individual series, the study also applied the Pesaran (2015) cross-section dependence test, which is based on the residuals of the estimated models instead of the individual series; the results are provided in the last row (CSD) of all the estimation Tables' (7 to 11). The large value of the test statistic indicates that the residuals are not weakly cross-section dependent. After determining that the residuals are not cross-sectional dependent, next, we will test if the slope coefficients are homogeneous across provinces. There are ten provinces, so it is most likely that the slopes will be heterogeneous. To address the slope heterogeneity, the study also applied the slope heterogeneity test proposed by Pesaran and Yamagata (2008), which is a standardized version of Swamy's (1970) test for slope heterogeneity. This test assumed that all the slope coefficients are identical across cross-sections; the results are reported in Table 6 below.

Table 6: Slope Heterogeneity Test (Pesaran and Yamagata, 2008)

	Delta	p.value	Delta	p.value	Delta	p.value	Delta	p.value
Equations	**(1)**		**(2)**		**(3)**		**(4)**	
At level	-1.365	0.172	0.661	0.508	-0.295	0.768	0.155	0.877
Adjusted	-1.441	0.15	0.712	0.476	-0.318	0.75	0.171	0.865
Equations	**(5)**		**(6)**		**(7)**		**(8)**	
At level	-1.061	0.289	-1.187	0.235	-1.59	0.112	-1.153	0.249
Adjusted	-1.191	0.233	-1.333	0.183	-1.826	0.068	-1.343	0.179
Equations	**(9)**		**(10)**		**(11)**		**(12)**	
At level	-1.794	0.073	-0.831	0.406	-0.794	0.427	-1.802	0.072
Adjusted	-2.108	0.035	-0.976	0.329	-0.957	0.339	-2.17	0.03
Equations	**(13)**		**(14)**		**(15)**		**(16)**	
At level	0.217	0.828	-0.883	0.377	-0.120	0.904	-0.212	0.832
Adjusted	0.269	0.788	-1.091	0.275	-0.152	0.879	-0.286	0.775
Equations	**(17)**		**(18)**		**(19)**			
At level	-.249	0.803	0.148	0.883	0.183	0.855		
Adjusted	-0.346	0.729	0.205	0.837	0..263	0.793		

Note: H0: slope coefficients are homogenous.

The results of the slope heterogeneity test proposed by Pesaran and Yamagata (2008) show that the null hypothesis of slope homogeneity cannot be rejected, as small values of the test statistic are estimated, and the respective p values are greater than the 5% standard level of significance. Therefore, it is concluded that the slopes are homogeneous across cross-sections (provinces). So, it is concluded that there is no cross-sectional dependence and slope heterogeneity across provinces, the pooled ordinary least square method gives more reliable estimates, and the results of pooled ordinary least square regressions are provided in Tables 7 to 11 in the next chapter.

CHAPTER 5: Results and Discussion

The results of the pooled ordinary least squares regressions for the basic models are presented in columns 1, 2, 3, and 4 of Table 7, with the dummy specification (with Ontario as the base category) in columns 1a, 2a, 3a, and 4a.

Table 7: Pooled Ordinary Least Square Estimates for Basic Model (Dependent Variable _Log of Greenhouse Gas)

VARIABLES	(1)	(1a)	(2)	(2a)	(3)	(3a)	(4)	(4a)
lnpop	0.967***	0.360***	0.953***	0.360***	0.886***	0.237***	0.762***	0.248***
	(0.0273)	(0.0752)	(0.0256)	(0.0882)	(0.0294)	(0.0904)	(0.0238)	(0.0879)
lnage	-	-	-3.281***	0.00118	-	-	-6.613***	-0.957***
			(0.492)	(0.121)			(0.444)	(0.229)
lnavgy	-	-	-	-	1.279***	0.131**	2.789***	0.503***
					(0.219)	(0.0542)	(0.194)	(0.103)
Dummy for provinces (Base category - Ontario)								
NFL		-1.772***		-1.774***		-2.125***		-1.970***
		(0.237)		(0.279)		(0.277)		(0.272)
PEI		-2.949***		-2.951***		-3.470***		-3.306***
		(0.338)		(0.397)		(0.398)		(0.389)
NS		-1.299***		-1.300***		-1.591***		-1.451***
		(0.195)		(0.231)		(0.228)		(0.225)
NB		-1.347***		-1.348***		-1.661***		-1.507***
		(0.212)		(0.250)		(0.247)		(0.243)
QC		-0.602***		-0.602***		-0.641***		-0.556***
		(0.0451)		(0.0515)		(0.0475)		(0.0505)
Man		-1.347***		-1.348***		-1.618***		-1.560***
		(0.177)		(0.206)		(0.209)		(0.203)
Sask		-0.145		-0.146		-0.439**		-0.391*
		(0.188)		(0.218)		(0.222)		(0.216)
Alb		0.709***		0.708***		0.538***		0.464***
		(0.102)		(0.115)		(0.123)		(0.121)
B.C		-0.716***		-0.717***		-0.841***		-0.781***
		(0.0854)		(0.100)		(0.0992)		(0.0975)
Constant	3.087***	4.303***	15.06***	4.300***	-10.38***	3.213***	-2.143	2.697***
	(0.0371)	(0.190)	(1.798)	(0.378)	(2.302)	(0.488)	(1.829)	(0.491)
Obs.	300	300	300	300	300	300	300	300
R-squared	0.808	0.994	0.833	0.994	0.828	0.994	0.901	0.995
CSD	**4.86**	**11.21**	**5.96**	**11.20**	**10.02**	**11.35**	1.36	**17.14**

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All specifications represented by the letter 'a' (i.e., 1(a)) are estimated with dummy variables used for provinces, and Ontario is the base category, and NFL = Newfoundland and Labrador, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, QC = Quebec, Man = Manitoba, Sask = Saskatchewan, Alb = Alberta, B.C = British Columbia, while lnpop, lnage, and lnavgy denote the log of population, log of age and log of average income respectively. CSD is a test statistic (t-stat) Pesaran's (2015) residual-based cross section dependence test, while the bold letter shows p<0.05.

Looking at column 1, we see that the greenhouse gas emissions increase almost proportionately (0.96) with the population of provinces. So, a one percent increase in the population will increase greenhouse gas emissions by 0.96 percent. This result is also consistent with the study conducted by Tavakoli (2018), which found that population is the main driver of greenhouse gas emissions in the world's top ten emitter countries (which includes Canada). This result also indicates that a one million population increase leads to an average increase in greenhouse gas emissions by approximately 21.91 Mt (i.e., ghg = e^3.087 pop^0.967, so ghg = 21.91 pop) in Canadian provinces. But, when we look at column 1a, we see that there are many important differences between the provinces other than their populations (although these are important). In particular, Newfoundland and Labrador, Prince Edward Island, Nova Scotia, New Brunswick, and Manitoba, are considerably lower than Ontario but Quebec, Saskatchewan, and British Columbia are a bit lower than Ontario; however, Alberta is higher than Ontario.

One provincial difference that might explain the remaining pattern is the difference in the average age (column 2), which indicates that older provinces don't produce as much greenhouse gas emissions after the population has been accounted for. However, column 2a shows that there are far larger differences between the provinces than their average ages, and the other effects overwhelm the effects of age differences. Column 3 shows that average income has a positive effect on greenhouse gas emissions. Column 4 shows the same pattern; those provinces with greater population, younger ages, and more income produce more greenhouse gas emissions. However, column 4a shows that there are still provincial differences from this broad pattern. These results are consistent with the studies of Alegria et al. (2016) for Spain and Cui et al. (2018) for China.

As discussed above, it is quite possible that the new variables do not capture the provinces' greenhouse gas emission differences in the most populous (Ontario) or more energy-rich (Alberta) provinces. For example, Alberta might be consistently higher than Ontario, and most other provinces are consistently lower than Ontario, which will raise a little concern about how co-linear some of the variables must appear given the relative sizes of the provinces.

Table 8: Pooled Ordinary Least Square Estimates for Extended Model (Dependent Variable _Log of per capita Greenhouse Gas)

VARIABLES	(5)	(5a)	(6)	(6a)	(7)	(7a)	(8)	(8a)
lnpop	-0.113***	-0.240**	-0.225***	-0.790***	-0.130***	-0.199*	-0.171***	-0.444***
	(0.0193)	(0.105)	(0.0196)	(0.0902)	(0.0171)	(0.116)	(0.0229)	(0.0933)
lnage	-4.358***	-1.516***	-3.979***	-0.830***	-3.077***	-1.600***	-6.185***	-3.182***
	(0.358)	(0.222)	(0.427)	(0.239)	(0.345)	(0.243)	(0.475)	(0.236)
lnavgy	1.535***	0.412***	1.408***	0.480***	0.878***	0.418***	1.869***	0.758***
	(0.164)	(0.0953)	(0.197)	(0.104)	(0.161)	(0.0957)	(0.193)	(0.0886)
lnoilpc	0.271***	0.136***	-	-	0.217***	0.142***	-	-
	(0.0172)	(0.0180)			(0.0163)	(0.0194)		
lngaspc	-	-	0.0788***	-0.0150*	0.0519***	0.00699	-	-
			(0.00660)	(0.00832)	(0.00560)	(0.00822)		
vog/gdp	-	-	-	-	-	-	0.0229***	0.0082***
							(0.00244)	(0.0014)
Dummy for provinces (Base category - Ontario)								
NFL		-0.716**		-2.147***		-0.578*		-1.001***
		(0.299)		(0.288)		(0.341)		(0.289)
PEI		-1.020**		-3.534***		-0.812		-1.788***
		(0.468)		(0.408)		(0.529)		(0.419)
NS		-0.173		-1.607***		-0.0432		-0.493**
		(0.267)		(0.240)		(0.307)		(0.244)
NB		-0.0759		-1.633***		0.0471		-0.453*
		(0.293)		(0.252)		(0.326)		(0.265)
QC		-0.310***		-0.628***		-0.266***		-0.312***
		(0.0566)		(0.0641)		(0.0770)		(0.0525)
Man		-0.480**		-1.698***		-0.368		-0.855***
		(0.235)		(0.217)		(0.270)		(0.217)
Sask		0.434*		-0.401*		0.475**		0.268
		(0.226)		(0.215)		(0.231)		(0.227)
Alb		0.765***		0.535***		0.745***		0.548***
		(0.118)		(0.127)		(0.120)		(0.120)
B.C		-0.268**		-0.741***		-0.264**		-0.358***
		(0.112)		(0.0996)		(0.112)		(0.102)
Constant	2.557*	4.417***	2.556	2.622***	4.706***	4.529***	5.886***	7.323***
	(1.384)	(0.504)	(1.555)	(0.491)	(1.242)	(0.521)	(2.176)	(0.445)
Obs.	300	300	300	300	300	300	230	230
R-squared	0.722	0.977	0.656	0.973	0.785	0.977	0.676	0.988
CSD	0.763	**16.99**	**1.966**	**16.37**	**2.448**	**17.168**	-1.057	**7.627**

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Ontario is the base category, and NFL = Newfoundland and Labrador, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, QC = Quebec, Man = Manitoba, Sask = Saskatchewan, Alb = Alberta, B.C = British Columbia, while lnpop, lnage, lnavgy, lnoilpc, lngaspc, and vog/gdp denotes the log of population, log of age, log of average income, log of oil production per capita, log of gas production per capita, and value of oil and gas production as a percent of GDP respectively. CSD is a test statistic (t-stat) Pesaran's (2015) residual-based cross section dependence test, while the bold letter shows p<0.05.

For the extended models, when all the quantity variables are included in per capita terms, the results are presented in Table 8 which includes the hydrocarbon variables such as oil production per capita and gas production per capita. For robust results, the study uses the value of oil and gas production as a percentage of GDP instead of oil and gas production per capita, which are presented in columns 8 and 8a.

The results for the extended models using pooled ordinary least squares are presented in columns 5, 6, 7, and 8, with dummy specifications (Ontario taken as the base category) in columns 5a, 6a, 7a, and 8a. Looking at column 5, there is a significant negative relationship between population and per capita greenhouse gas emissions, as expected. A one percent increase in the population leads to a decrease in per capita greenhouse gas emissions by 0.113 percent. Column 5a indicates that there are still provincial differences from this broad pattern and there are many important differences between the provinces other than their populations, ages, income, and oil production per capita. In particular, Newfoundland and Labrador and Prince Edward Island are considerably lower than Ontario, but Nova Scotia, New Brunswick, Quebec, Manitoba, and British Columbia are a bit lower than Ontario. However, Saskatchewan and Alberta have higher emissions per capita than Ontario.

After including gas production per capita as an explanatory variable, columns 6 and 6a have the same results as expected, except now Alberta is the only province that has higher per capita greenhouse gas emissions than Ontario. When both gas and oil production per capita is included in the same model (columns 7 and 7a), it gives qualitatively similar results as models 5 and 5a, and models 8 and 8a also produced the same results when replacing the value of oil and gas production as a percentage of GDP instead of using oil and gas production per capita variables. So, the present study keeps the variables of oil production per capita and gas production per capita for further analysis, instead of the value of oil and gas production as a percentage of GDP due to the collinear relationship between oil production per capita and the value of oil and gas production as a percentage of GDP.

Table 9: Pooled Ordinary Least Square Estimates for Extended Model 1

VARIABLES	**(9)**	**(9a)**	**(10)**	**(10a)**	**(11)**	**(11a)**	**(12)**	**(12a)**
lnpop	-0.0974***	-0.222*	-0.0910***	0.211**	-0.0647***	0.190*	-0.099***	-0.226*
	(0.0176)	(0.116)	(0.0191)	(0.103)	(0.0192)	(0.103)	(0.0206)	(0.118)
lnage	-2.990***	-1.642***	-2.056***	-0.618***	-2.086***	-0.656***	-3.010***	-1.621***
	(0.331)	(0.244)	(0.415)	(0.219)	(0.400)	(0.220)	(0.361)	(0.264)
lnavey	0.659***	0.481***	0.458**	0.204**	0.300	0.253***	0.670***	0.470***
	(0.161)	(0.102)	(0.186)	(0.0815)	(0.183)	(0.0871)	(0.179)	(0.115)
lnoilpc	0.217***	0.140***	0.228***	0.0683***	0.227***	0.0675***	0.217***	0.139***
	(0.0156)	(0.0194)	(0.0161)	(0.0173)	(0.0155)	(0.0173)	(0.0157)	(0.0197)
lngaspc	0.0405***	0.00719	0.0468***	0.00560	0.0368***	0.00576	0.0405***	0.00710
	(0.00582)	(0.00819)	(0.00559)	(0.00681)	(0.00577)	(0.00680)	(0.00584)	(0.00821)
lnmvpc	0.667***	-0.111*	-	-	0.619***	-0.0845	0.667***	-0.110*
	(0.131)	(0.0648)			(0.129)	(0.0538)	(0.131)	(0.0653)
lnlivestpc	-	-	0.0694***	0.467***	0.0619***	0.465***		
			(0.0167)	(0.0409)	(0.0161)	(0.0408)		
Agv/gdp	-	-	-	-	-	-	-0.00066	0.00114
							(0.00473)	(0.00559)
Dummy for provinces (Base category - Ontario)								
NFL		-0.629*		1.806***		1.752***		-0.642*
		(0.341)		(0.351)		(0.352)		(0.347)
PEI		-0.892*		0.344		0.276		-0.921*
		(0.529)		(0.450)		(0.451)		(0.549)
NS		-0.0992		1.130***		1.080***		-0.112
		(0.308)		(0.275)		(0.276)		(0.315)
NB		0.0269		1.258***		1.235***		0.0123
		(0.326)		(0.291)		(0.290)		(0.334)
QC		-0.265***		-0.162**		-0.162**		-0.270***
		(0.0767)		(0.0645)		(0.0643)		(0.0806)
Man		-0.411		-0.226		-0.260		-0.430
		(0.270)		(0.224)		(0.224)		(0.285)
Sask		0.453*		0.463**		0.446**		0.432*
		(0.231)		(0.192)		(0.192)		(0.254)
Alb		0.739***		0.493***		0.490***		0.734***
		(0.120)		(0.102)		(0.102)		(0.122)
B.C		-0.279**		0.205**		0.190*		-0.284**
		(0.112)		(0.102)		(0.102)		(0.115)
Constant	7.024***	4.010***	5.496***	3.090***	7.561***	2.704***	6.986***	4.061***
	(1.277)	(0.601)	(1.223)	(0.450)	(1.256)	(0.512)	(1.307)	(0.651)
Obs.	300	300	300	300	300	300	300	300
R-squared	0.803	0.977	0.797	0.984	0.812	0.985	0.803	0.977
CSD	**1.967**	**15.915**	0.286	**5.276**	0.750	**4.629**	**2.154**	**15.395**

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Ontario is the base category, and NFL = Newfoundland and Labrador, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, QC = Quebec, Man = Manitoba, Sask = Saskatchewan, Alb = Alberta, B.C = British Columbia, while lnpop, lnage, lnavgy, lnoilpc, lngaspc, lnmvpc, lnlivestpc, and agv/gdp denotes the log of population, log of age, log of average income, log of oil production per capita, log of gas production per capita, log of motor vehicles registered per capita, log of livestock per capita, and agriculture value-added as a percent of GDP respectively. CSD is a test statistic (t-stat) Pesaran's (2015) residual-based cross section dependence test, while the bold letter shows p<0.05.

So, it is noted that there are many important differences still unexplained between the provinces other than their populations, ages, income, oil production per capita, and gas production per capita. Some of the remaining differences are explained by adding the transport sector variable (motor vehicles registered per capita) and agriculture sector variable (livestock per capita) in column 7 of Table 8. The results are presented in Table 9. All variables' coefficients show qualitatively similar results to column 7 of Table 8 and the new included variables (motor vehicles registered per capita and livestock per capita) show significant positive results in column 11. However, these additional variables are unable to explain the remaining provincial differences in greenhouse gas emissions per capita, as shown by column 11a. Similar results are found when the agricultural value-added as a percentage of GDP is included instead of livestock per capita in column 12, except for the average income that is a significant determinant of the greenhouse gas emissions. However, there is still unexplained variation indicated by the significance in some of the provincial dummies as shown by column 12a.

So, to try putting different variables (such as electricity generation intensity, heating and cooling degree days, and a dummy variable for the year 2005 and after) in the above model, the results are presented in Table 10. Starting from column 13 when electricity generation intensity is included in the model, all variables' coefficients are qualitatively similar results to column 12 of Table 9, and the new included variable of electricity generation intensity shows a significant positive sign as expected. Similarly, when the new variable of heating degree days is included instead of electricity generation intensity in column 12 of Table 9, it shows a significant positive sign as expected (column 14). In addition, when the new variable of cooling degree days is included instead of heating degree days in column 12 of Table 9, the new included variable cooling degree days shows a significant positive sign as expected (column 15).

Table 10: Pooled Ordinary Least Square Estimates for Extended Model 2

VARIABLES	(13)	(13a)	(14)	(14a)	(15)	(15a)	(16)	(16a)
lnpop	0.0231	0.167	-0.0666***	0.192*	-0.0891***	0.191*	0.0398**	0.251**
	(0.0141)	(0.104)	(0.0183)	(0.103)	(0.0241)	(0.103)	(0.0166)	(0.104)
lnage	-0.989***	-0.628***	-1.650***	-0.669***	-2.294***	-0.655***	-0.398	-0.430*
	(0.282)	(0.220)	(0.389)	(0.221)	(0.419)	(0.220)	(0.305)	(0.222)
lnavey	0.148	0.266***	0.364**	0.251***	0.317*	0.253***	0.201	0.374***
	(0.126)	(0.0873)	(0.174)	(0.0871)	(0.182)	(0.0875)	(0.132)	(0.0897)
lnoilpc	0.239***	0.0691***	0.157***	0.0667***	0.234***	0.0676***	0.168***	0.0667***
	(0.0107)	(0.0173)	(0.0193)	(0.0173)	(0.0161)	(0.0174)	(0.0129)	(0.0169)
lngaspc	0.0129***	0.00394	0.0677***	0.00576	0.0444***	0.00576	0.0363***	0.00714
	(0.00418)	(0.00688)	(0.00777)	(0.00680)	(0.00732)	(0.00681)	(0.00614)	(0.00677)
lnmvpc	0.450***	-0.0960*	0.276**	-0.0829	0.561***	-0.0844	0.166*	-0.0749
	(0.0889)	(0.0542)	(0.137)	(0.0539)	(0.133)	(0.0539)	(0.0918)	(0.0533)
lnlivestpc	0.0769***	0.438***	0.00284	0.466***	0.0421**	0.464***	0.0355**	0.443***
	(0.0111)	(0.0444)	(0.0186)	(0.0409)	(0.0200)	(0.0409)	(0.0145)	(0.0435)
lnelecint	0.108***	0.00928					0.110***	0.00493
	(0.00599)	(0.00605)					(0.00560)	(0.00602)
lnhdd			0.762***	-0.0588			0.721***	-0.104
			(0.136)	(0.0749)			(0.0894)	(0.0774)
lncdd					0.0620*	-0.00148	-0.0447*	-0.0136
					(0.0373)	(0.0134)	(0.0239)	(0.0138)
D2005							-0.00418	-0.0740***
							(0.0377)	(0.0186)
Dummy for provinces (Base category - Ontario)								
NFL		1.627***		1.777***		1.750***		1.931***
		(0.360)		(0.354)		(0.353)		(0.361)
PEI		0.201		0.292		0.278		0.608
		(0.452)		(0.451)		(0.452)		(0.453)
NS		0.986***		1.089***		1.080***		1.227***
		(0.282)		(0.276)		(0.276)		(0.282)
NB		1.153***		1.252***		1.236***		1.418***
		(0.294)		(0.291)		(0.291)		(0.295)
QC		-0.141**		-0.154**		-0.162**		-0.0847
		(0.0656)		(0.0652)		(0.0644)		(0.0661)
Man		-0.246		-0.235		-0.259		-0.00995
		(0.224)		(0.227)		(0.225)		(0.228)
Sask		0.452**		0.471**		0.446**		0.674***
		(0.191)		(0.194)		(0.192)		(0.196)
Alb		0.515***		0.505***		0.489***		0.612***
		(0.103)		(0.104)		(0.103)		(0.105)
B.C		0.191*		0.175*		0.188*		0.202*
		(0.102)		(0.104)		(0.104)		(0.105)
Constant	4.655***	2.426***	-1.369	3.252***	7.776***	2.699***	-4.113**	1.349
	(0.877)	(0.542)	(1.991)	(0.866)	(1.258)	(0.514)	(1.813)	(0.979)
Obs.	300	300	300	300	300	300	300	300
R-squared	0.912	0.985	0.830	0.985	0.814	0.985	0.929	0.986
CSD	-0.723	**4.342**	**3.502**	**4.546**	**2.317**	**4.423**	**2.279**	**2.411**

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Ontario is the base category, and NFL = Newfoundland and Labrador, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, QC = Quebec, Man = Manitoba, Sask = Saskatchewan, Alb = Alberta, B.C = British Columbia, while lnpop, lnage, lnavgy, lnoilpc, lngaspc, lnmvpc, lnlivestpc, lnelecint, lnhdd and lncdd denotes the log of population, log of age, log of average income, log of oil production per capita, log of gas production per capita, log of motor vehicles registered per capita, log of livestock per capita, log of electricity generation intensity, log of heating degree days and log of cooling degree days respectively. While the D2005 is a dummy variable that signifies the years beginning with 2005, as Canada signed the Paris Agreement to reduce its greenhouse gas emissions by 30% from 2005 levels by 2020 and net-zero by 2050. CSD is a test statistic (t-stat) Pesaran's (2015) residual-based cross section dependence test, while the bold letter shows p<0.05.

When all four variables (electricity generation intensity, heating degree days, cooling degree days, and 2005 dummy variable) are included in the model, all variables' coefficients show qualitatively similar results (except average age and average income that are become insignificant) to column 12 of Table 9. The new included variables of heating degree days and electricity generation intensity show significant positive results in column 16. However, cooling degree days has a significant negative sign which is not expected; the wrong sign might indicate that cooling degree days is not capturing extra electricity use due to air conditioning.

It is probably the cooling degree days are taken as the number of days multiplied by the mean temperature above 18 degrees Celsius on a specific day which captures times when heating is not required, rather than times when air conditioning is required. One possible explanation for this negative sign is explained by Holmes et al. (2017) that there are uncertainties associated with cooling degree days from the selection of the base temperatures, and the estimations of residential energy consumption and CO_2 emissions are affected by various factors (economic development, income growth, population density, and technology) other than climate change. So cooling degree days can be excluded from the models estimated in Table 11, due to not capturing extra electricity use due to air conditioning. However, the additional variables included in the extended model 1 results assert that there are still unexplained differences in greenhouse gas emissions at the provincial level by the significance in some of the provincial dummies as shown by column 16a.

So, the remaining provincial characteristics might explain some of these remaining differences by including both trend variables (time trend and specific trend starting in the year 2005) in the model, and the final results are presented in Table 11.

Table 11: Pooled Ordinary Least Square Estimates for Extended Model 3

VARIABLES	(17)	(17a)	(18)	(18a)	(19)	(19a)
lnpop	0.0255*	0.192	0.00988	0.326***	0.0172	0.0142
	(0.0136)	(0.127)	(0.0134)	(0.0918)	(0.0133)	(0.109)
lnage	-0.956**	-0.594*	-0.355	-0.472**	-1.355***	-1.506***
	(0.408)	(0.318)	(0.295)	(0.196)	(0.406)	(0.284)
lnavey	0.0776	0.334***	0.412***	0.742***	0.152	0.629***
	(0.167)	(0.0996)	(0.148)	(0.0894)	(0.163)	(0.0891)
lnoilpc	0.176***	0.0630***	0.164***	0.0982***	0.167***	0.0869***
	(0.0129)	(0.0174)	(0.0129)	(0.0154)	(0.0126)	(0.0150)
lngaspc	0.0409***	0.00686	0.0447***	0.00632	0.0417***	0.00570
	(0.00536)	(0.00678)	(0.00523)	(0.00598)	(0.00520)	(0.00575)
lnmvpc	0.149	-0.0712	0.125	-0.0468	0.198**	0.00309
	(0.0915)	(0.0541)	(0.0886)	(0.0471)	(0.0893)	(0.0465)
lnlivestpc	0.0242*	0.453***	0.00992	0.196***	0.0126	0.203***
	(0.0126)	(0.0458)	(0.0127)	(0.0474)	(0.0125)	(0.0456)
lnelecint	0.109***	0.00529	0.104***	0.00273	0.105***	0.00246
	(0.00555)	(0.00601)	(0.00553)	(0.00532)	(0.00543)	(0.00511)
lnhdd	0.672***	-0.0875	0.801***	0.0573	0.695***	0.0413
	(0.0985)	(0.0743)	(0.0925)	(0.0668)	(0.0956)	(0.0643)
dd5	-0.0136	-0.0732***	0.0235	-0.0532***	-0.00830	-0.0642***
	(0.0396)	(0.0187)	(0.0380)	(0.0163)	(0.0384)	(0.0159)
trend	0.00524	0.00202			0.0169***	0.0136***
	(0.00414)	(0.00302)			(0.00479)	(0.00279)
T2005			-0.0115***	-0.0195***	-0.0203***	-0.0239***
			(0.00391)	(0.00218)	(0.00458)	(0.00228)
Dummy for provinces (Base category - Ontario)						
NFL		1.796***		1.643***		0.704*
		(0.410)		(0.321)		(0.364)
PEI		0.337		1.335***		-0.0808
		(0.574)		(0.408)		(0.489)
NS		1.095***		1.403***		0.629**
		(0.335)		(0.250)		(0.288)
NB		1.263***		1.609***		0.742**
		(0.358)		(0.261)		(0.308)
QC		-0.115		-0.00780		-0.149**
		(0.0748)		(0.0588)		(0.0636)
Man		-0.166		0.573***		-0.188
		(0.302)		(0.211)		(0.257)
Sask		0.520*		1.413***		0.632**
		(0.288)		(0.192)		(0.245)
Alb		0.530***		1.141***		0.683***
		(0.166)		(0.110)		(0.141)
B.C		0.174		0.350***		0.0340
		(0.128)		(0.0912)		(0.109)
Constant	-0.669	2.293	-7.384***	-4.398***	-0.254	1.363
	(3.032)	(1.844)	(2.172)	(1.067)	(2.939)	(1.567)
Obs.	300	300	300	300	300	300
R-squared	0.928	0.985	0.930	0.989	0.933	0.990
CSD	**2.105**	**2.385**	1.436	1.760	**2.191**	**2.223**

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Ontario is the base category, and NFL = Newfoundland and Labrador, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, QC = Quebec, Man = Manitoba, Sask = Saskatchewan, Alb = Alberta, B.C = British Columbia, while lnpop, lnage, lnavgy, lnoilpc, lngaspc, lnmvpc, lnlivestpc, lnelecint, and lnhdd denotes the log of population, log of age, log of average income, log of oil production per capita, log of gas production per capita, log of motor vehicles registered per capita, log of livestock per capita, log of electricity generation intensity, and log of heating degree days respectively. D2005 is a dummy variable that signifies the years beginning with 2005, as Canada signed the Paris

Agreement to reduce its greenhouse gas emissions by 30% from 2005 levels by 2020 and net-zero by 2050. The trend represents the general trend while the variable T2005 represents the trend starting in the year 2005 and might allow for the gradual roll-out of energy-saving incentives or regulations, which would result in a different trajectory. CSD is a test statistic (t-stat) Pesaran's (2015) residual-based cross section dependence test, while the bold letter shows $p<0.05$.

Starting from column 17, when only the time trend variable is included in the model, all variables have the expected signs, and most of the variables are significant except for average income, motor vehicles registered per capita, the dummy variable (D2005), and the trend variable. However, average age plays a significant role in reducing greenhouse gas emissions per capita in Canada. Now greater population leads to producing more greenhouse gas emissions per capita in Canada after all other factors are accounted for. However, the magnitude of the population coefficient is low (0.026), which indicates that a one percent increase in the population leads to a 0.026 percent increase in greenhouse gas emissions per capita.

In column 18, after including the trend starting in 2005 instead of a general trend, the results remain the same, except that average income plays a significant role and population, average age, and livestock per capita have no role in determining the greenhouse gas emissions per capita in Canada. However, there is a significant negative effect of the specific trend variable.

The final model is estimated in column 19, which shows that population has a positive but insignificant relationship with greenhouse gas emissions per capita, leading to the conclusion that the population has no role in determining the greenhouse gas emissions per capita in Canada. This result is consistent with the studies of Cui et al. (2018) and Want et al. (2017) who find that population is not a significant determinant of per capita greenhouse gas emissions when using the pooled ordinary least squares method on Chinese cities.

The average age variable has a significant negative relationship with per capita greenhouse gas emissions. A one percent increase in the average age will lead to a 1.36 percent decrease in the per capita greenhouse gas emissions, which asserts that an older population produces less greenhouse gas emissions than a younger one. This result is consistent with Dalton et al. (2008), who estimated that the rapid aging population may reduce CO_2 emissions in the United States.

All other variables, such as oil production per capita, gas production per capita, motor vehicles registered per capita, electricity generation intensity, and heating degree days, have a significant positive relationship with greenhouse gas emissions, except livestock per capita, which is insignificant. However, heating degree days (hdd) is the main producer of greenhouse gas emissions in Canada as the elasticity of greenhouse gas emissions with respect to heating degree days is 0.695. The elasticity of greenhouse gas emissions with respect to gas production per capita is 0.042, with respect to electricity generation intensity is 0.105, and with respect to oil production per capita is 0.167.

The transport sector (motor vehicles per capita) is less responsive to greenhouse gas emissions per capita (elasticity = 0.198) as compared to heating degree days in Canada at a general level, and this result is consistent with the study conducted by Papagiannaki and Diakoulaki (2009). They find that motor vehicles per capita in Greece are the main factor behind a significant increase in levels of greenhouse gas emissions during 1990–2005. However, these results contradict those found in the previous studies (Ehrlich, 2017 and Liang et al., 2017) which suggest that the greenhouse gas emissions of transportation are closely relevant to the size of the population.

The dummy variable (D2005) indicates that there is not a significant difference between the pattern of greenhouse gas emissions per capita in Canada after 2005. In column 19, both trend variables are significant with the expected signs, indicating that they play an important role in explaining greenhouse gas emissions per capita in Canada. However, some of the collinear variables (such as both trend variables having a high correlation, 0.91) lead to the population and average income variables being insignificant in the final model. In addition, the results of column 19a indicate that there still are significant differences between the provinces, so there are probably still missing variables that can explain the remaining pattern of per capita greenhouse gas emissions in Canada.

CHAPTER 6: Conclusion

The objective of this research was to identify the potential factors that are responsible for greenhouse gas emissions per capita in Canada by using the pooled ordinary least squares approach on the 10 Canadian provinces' data spanning from 1990 to 2019. The study finds a significant positive relationship between population and greenhouse gas emissions in the basic model. It is also found that there are far larger differences between the provinces than their average ages, and the other effects overwhelm the effects of age. It is also found that average income has a positive effect on greenhouse gas emissions, which remains a pattern even once provincial differences are accounted for. So, it is concluded that provinces with greater population, younger ages, and more income produce more greenhouse gas emissions. However, there are still provincial differences from this broad pattern in the basic model. So, in this respect, the extended model has been used to identify the other potential factors that are accounted for this provincial difference.

The extended model, in which per capita greenhouse gas emissions is used as the dependent variable, produced qualitatively similar results as the basic model. The final model (extended model 3, column 19) in which all the additional variables (population, average age, average income, oil production per capita, gas production per capita, livestock per capita, motor vehicles registered per capita, electricity generation intensity, heating degree days, dummy variable, time trend, and a specific trend for the year 2005) are included qualitatively produced similar results except for population, average income, and livestock per capita, which play no role in determining the greenhouse gas emissions per capita in Canada. However, both trend variables play an important role in explaining greenhouse gas emissions per capita in Canada. Moreover, there is no significant difference between the pattern of greenhouse gas emissions per capita in Canada after 2005.

From an extended list of ten potential determinants identified above, five factors (oil production per capita, gas production per capita, motor vehicles registered per capita, electricity generation intensity, and heating degree days) are significant predictors for explaining per capita greenhouse gas emissions in Canada. Average age has a negative relationship with per capita greenhouse gas emissions, which indicates that the provinces with an older population decrease the per capita greenhouse gas emissions instead of boosting them. However, population and average income have no role in determining the greenhouse gas emissions per capita in Canada.

There are limitations with the present study, as the study only considers the data available from 1990. If more historical data were available, the results would be more reliable. The other caveat of the present study is that it does not control for any other determinants of greenhouse gas emissions, such as sector-wise data and structural change. So, in this respect, future studies can be extended to investigate whether the identified factors of greenhouse gas emissions found in this study play a role in the comparative significance of structural vs. efficiency changes, which is beyond the scope of the present study.

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