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

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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 larger 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 the dependent variable) show that only five factors (out of ten potential determinants identified)—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 played an important role in explaining the greenhouse gas emissions per capita in Canada. Moreover, there were no significant differences among the patterns of the per capita greenhouse gas emissions in Canada after 2005.

Keywords: electricity generation intensity; greenhouse gas emissions; gas production; oil production

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1. Introduction

The world is facing a climate crisis due to high emissions 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 °C from the baseline year 1961 to 1990 due to human activities that produce greenhouse gases [1]. This rising temperature may affect various aspects of the economy, such as agriculture and forest productivity, marine life, recreational activities, and human health [2]. 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 [3])*

Climatic changes and greenhouse gas emissions due to human activity have led to Western Canada's 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*" [4]. It is also projected by Derksen et al. [5] 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*".

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 [6]). Canada has 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 [7]. Canada contains only 0.5% of the world's population, but it emits 1.6% of the world's total greenhouse gas emissions [8]. 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, as follows: Canada agreed to reduce its greenhouse gas emissions to 30% below its 2005 base level by 2030 under the Paris Agreement [6]. However, according to the Copenhagen Accord (United Nations Framework Convention on Climate Change [9]), Canada committed to reducing its greenhouse gas emissions by 17% of its 2005 base by 2020. Rogelj et al. [10] 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 [6]), most countries, including Canada, are far below this target emissions reduction set for 2030. *According to the Paris Agreement Article 2 (a)*, as follows: "*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 problem of how to reduce greenhouse gas emissions is a complex one. There is no one magic bullet to obtain 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 the Paris Agreement. In this context, geographic and climatic factors—inflexible national characteristics—may 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 and average age [11–20]. Climatic variables include maximum temperature, minimum temperature, heating degree days, cooling degree days, and precipitation [20–22]. The cost of heating (or cooling) varies quite a bit among the provinces in Canada as well. Gonzalez-Sanchez and Martin-Ortega [20] found 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) may have effects on regional greenhouse gas emissions [20,23,24]. Policymakers have a substantial role in controlling these factors. Further, prior studies consistently suggest that greenhouse gas emissions are a result of firms' production processes or energy consumption, which are more likely to be homogeneous within an industry [25,26]. However, the present study's main focus is to find the provincial-level determinants of greenhouse gas emissions in Canada, with an industry-level analysis being beyond the scope of this study.

Based on 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 [27]). The energy sector produces over 80% of the total greenhouse gas emissions in Canada, and energy sources include stationary combustion, transport, fugitive sources, and CO_2 transport and storage (Government of Canada [28]).

Canada is a decentralized federation, and climate change is a shared jurisdiction, so all provincial governments have their greenhouse gas emissions policies. It is quite possible that the variables identified do not capture the differences in greenhouse gas emissions in the most populous or more energy-rich provinces. This raises some concern about how colinear 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 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. In this context,

the main research question is as follows: what are the main determinants of per capita greenhouse gas emissions in Canada?

The rest of the paper is organized as follows: Section 2 briefly discusses past trends in greenhouse gas emissions in Canada and its provinces. The models, including the econometric model, and data are presented in Section 3, and the estimation results are presented and discussed in Section 4. The key findings are highlighted in Section 5.

2. Past Trends in Greenhouse Gas Emissions in Canada and Its Provinces

In light of the above discussion, it is very important to analyze past trends in greenhouse gas emissions in Canada and its provinces. These data further highlight the importance of the issue under discussion. Figure 1 presents the levels of greenhouse gas emissions in Canada and its provinces indexed at 1990 = 1.0, showing that over time the trend in greenhouse gas emissions has increased in Canada.

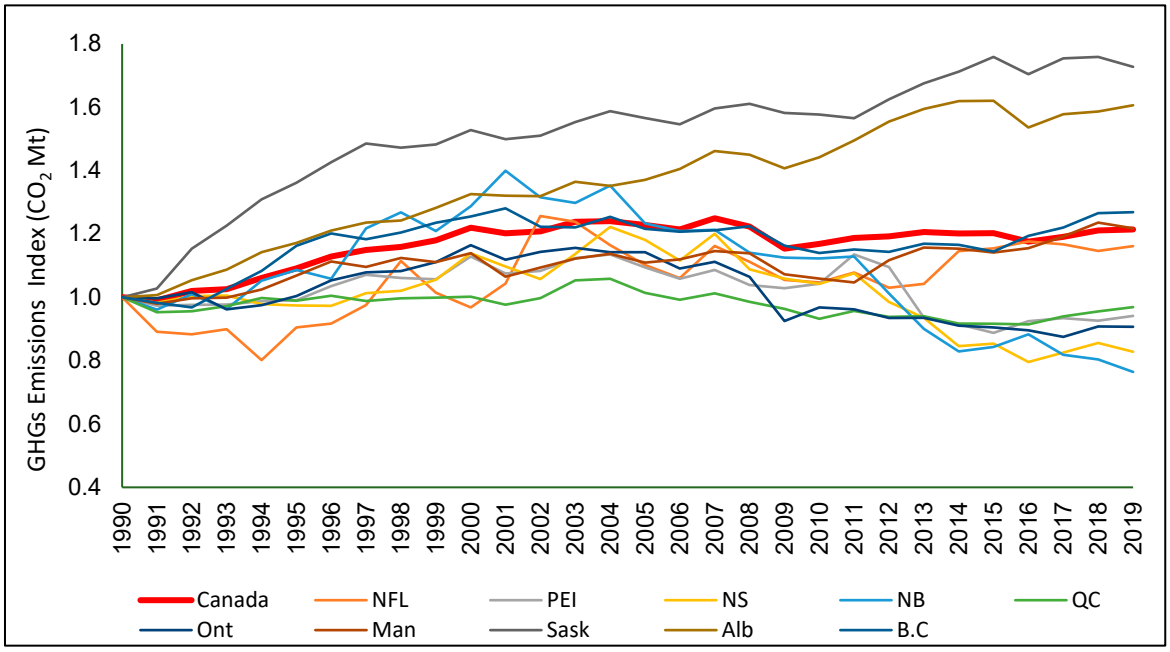

Figure 1. Greenhouse gas emissions (CO_2 Mt) index (1990 = 1.0). Source: National Inventory Report, Government of Canada [28]. NFL = Newfoundland and Labrador; PEI = Prince Edward Island; NS = Nova Scotia; NB = New Brunswick; QC = Quebec; Ont = Ontario; Man = Manitoba; Sask = Saskatchewan; Alb = Alberta; B.C = British Columbia.

The level of greenhouse gas emissions increased by 129 Megatons (Mt) from 1990 to 2019 in Canada. This sharp increase in greenhouse gas emissions was noted for the period 1990 to 2000, in which it jumped from 601 Mt to 733 Mt. After 2000, the greenhouse gas emissions showed a mixed trend and reached their peak in 2007 when the level of greenhouse gas emissions was 751 Mt in Canada. A sudden drop of 58 Mt (751 Mt to 693 Mt) in greenhouse gas emissions is noted from 2008 to 2009, which was 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, greenhouse gas emissions, again, start to increase and reached 730 Mt in 2019 in Canada.

If comparing over decades, greenhouse gas emissions increased by 13 Mt on average each year between 1990 and 2000, decreased by 3 Mt on average each year between 2000 and 2010, and again increased in the last decade by 3 Mt on average each year from 2010 to 2019. So, the overall level of greenhouse gas emissions increased 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, and New Brunswick) show a decreasing

trend, except for Newfoundland and Labrador, in which greenhouse gas emissions are increasing over time. Similar trends were found in Quebec and Ontario, where greenhouse gas emissions are decreasing over time. The greenhouse gas emissions in Manitoba, Saskatchewan, Alberta, and British Columbia showed increasing trends over time from 1990 to 2019.

It is noted from Figure 1 that there are large differences in the greenhouse gas emission 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 were contributed by two provinces: Alberta 275.8 Mt (37.8%) and Ontario 163.2 Mt (22.4%). An additional 31% of greenhouse gas emissions were 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 were contributed by all other provinces like Newfoundland and 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 centers. Larger cities may require longer commutes on average, and more populous provinces tend to have larger cities. In Canada, the average commute time by car ranges from 60 to 75 min, and approximately 32% of commuters experience longer times than this. In Ontario, the City of Toronto has the longest commute time (96 min, both ways) in North America and the 6th worst commute in the world. Over 1.8 million people commute to work in the Greater Toronto Area (GTA), which contributes to climate change. Across Canada, 28% of carbon emissions come from the transportation sector, but 35% of all greenhouse gas emissions in Ontario come from the transportation sector (Statistics Canada, 2016, https://www150.statcan.gc.ca/n1/en/type/data?MM=1 accessed on 23 April 2021).

Figure 2 presents the per capita greenhouse gas emissions of each province and for Canada overall, indexed at 1990 = 1.0. According to Figure 2, mixed trends are found in the greenhouse gas emissions per capita for Canada, showing an increasing trend over time from 1990 to 2000, whereby the per capita greenhouse gas emissions increased by 2.18 Mt, from 21.72 Mt in 1990 to 23.90 Mt in 2000, followed by a decreasing trend till 2019. Mixed trends are also found in the case of greenhouse gas emissions per capita in Canadian provinces. Alberta and Saskatchewan had higher per capita greenhouse gas emissions compared to overall Canada from 1990 to 2019. New Brunswick also had higher greenhouse gas emissions per capita than overall Canada up to 2013, after which it was lower due to a sharp decrease in the per capita greenhouse gas emissions.

On the other hand, Newfoundland and Labrador had lower greenhouse gas emissions per capita than overall Canada until 2014, when they became higher than overall Canada. Most oil-rich provinces (Alberta, Saskatchewan, and Newfoundland and Labrador) 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 had lower per capita greenhouse gas emissions compared to Canada overall.

All provinces show a negative trend in per capita greenhouse gas emissions from 1990 to 2019 except for Saskatchewan and Newfoundland and Labrador where the population increase is slower than greenhouse gas emissions in these provinces (see Table 1). Looking at column 1, the greenhouse gas emissions changes from the 1990 level to 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 and Labrador. On the other hand, it increased from the 1990 level in the western provinces. So, it is noted that there were large differences in the changes in greenhouse gas emissions from the 1990 base levels to those in 2019 among the provinces.

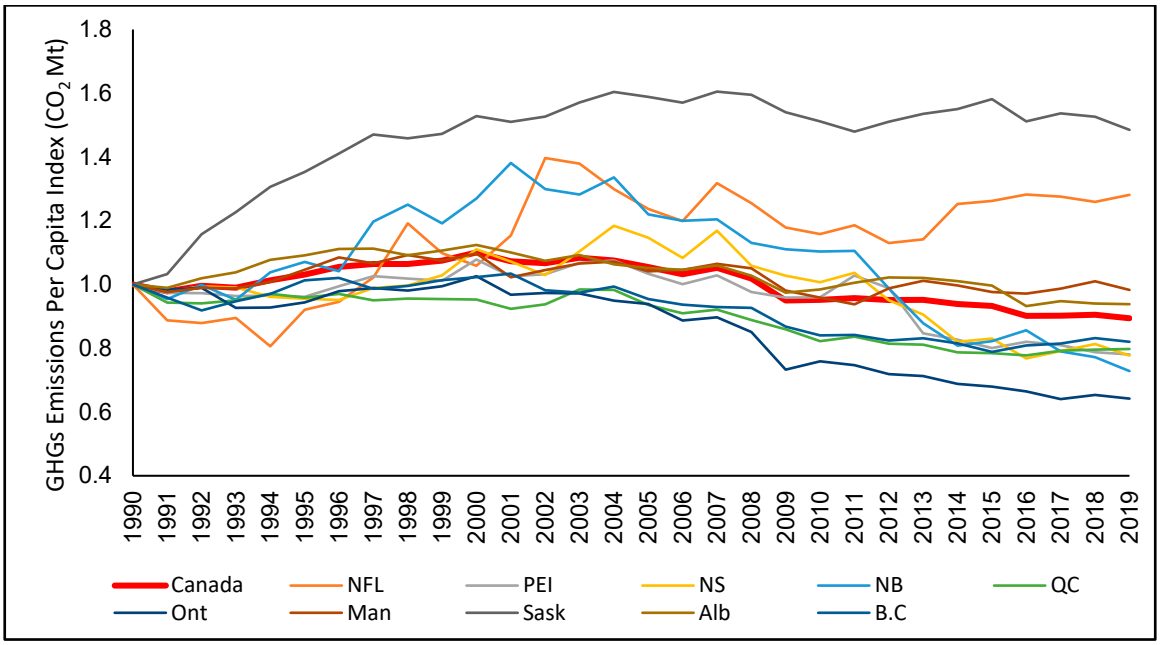

Figure 2. Greenhouse gas emissions per capita (CO_2 Mt) index (1990 = 1.0). Source: Statistics Canada. Population Table: 17-10-0005-01 and greenhouse gas emissions were taken from the National Inventory Report, Government of Canada [28]. NFL = Newfoundland and Labrador; PEI = Prince Edward Island; NS = Nova Scotia; NB = New Brunswick; QC = Quebec; Ont = Ontario; Man = Manitoba; Sask = Saskatchewan; Alb = Alberta; B.C = British Columbia.

Table 1. Levels of greenhouse gas emissions and population changes from 1990 and 2005 to 2019.

Province	Change from 1990 to 2019			Change from 2005 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 emissions were taken from the National Inventory Report, Government of Canada [28]. 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 differences further increase if we incorporate the population effect for Newfoundland and Labrador, where the per capita greenhouse gas emissions increased because of the negative population growth observed from 1990 to 2019. Saskatchewan experienced less population growth compared to greenhouse gas emissions growth in the same period. The biggest change in per capita greenhouse gas emissions was in Ontario (−35.8%) to below its 1990 level, and this difference is reduced (−31.6%) if we measure the per capita greenhouse gas emissions from its 2005 level. 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 its 1990 level led to a decrease in the per capita greenhouse gas emissions of 10.6%.

As noted above, Canada agreed to reduce its greenhouse gas emissions to 30% below its 2005 base level by 2030 under the Paris Agreement (United Nations Framework Convention on Climate Change [6]). The changes in greenhouse gas emissions from the 2005 levels range between 17.1% (highest increase in Alberta, followed by Saskatchewan and Manitoba) to −38.0% (largest decrease in New Brunswick). This asserts that greenhouse gas emissions decreased from the 2005 levels in the Atlantic and central provinces, except for Newfoundland and Labrador; however, greenhouse gas emissions increased from the 2005 levels in the western provinces. Only two provinces (Nova Scotia and New Brunswick) have already achieved this target compared to the total greenhouse gas emissions. This result indicates that most of the provinces are moving in the right direction, except for the oil-rich provinces, which produced more greenhouse gas emissions than their base levels in 2005. This result leads to the identification of other factors, such as demographics, climate, and energy sources, that contributed to the remaining differences between the provinces' greenhouse gas emissions.

3. Model, Data, and Econometric Methodology

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, may have a significant effect on a country's greenhouse gas emissions. On the other hand, many flexible national and regional characteristics (such as energy sources, industrial and agricultural variables, and provincial government policies) might have a substantial effect on regional greenhouse gas emissions. Thus, in this section, I adapt a model from a study by Gonzalez-Sanchez and Martin-Ortega [20] for the empirical analysis, describe all of the variables based on the past literature and their data sources, and describe suitable methods to estimate the econometric model.

3.1. Model

On the basis of the inflexible and flexible national and regional characteristics, the present study specified an econometrics model, which has been empirically tested in many studies (e.g., [11–14,16,19,20,29]) and takes the following simple form:

$$ghg_{it} = f\left(Pop_{it}\right) \quad (1)$$

where $i = 1, \ldots, 10$ denotes a province, $t = 1, \ldots, 30$ 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 analyzed the effect of population on greenhouse gas emissions and found a positive relationship between population and greenhouse gas emissions. They argued that an increase in population largely leads to higher levels of consumption and production of goods and services (such as increased demand for food, freshwater, timber, fiber, and fuel), which produces more greenhouse gas emissions. These findings support the United Nations [30], which found, in 2016, that the top ten emitter countries comprised 51% of the world's population and 67% of the greenhouse gas emissions.

Other demographic factors may affect greenhouse gas emissions, such as the average age, as described by O'Neill et al. [15]. For the analysis of Canadian provincial differences in greenhouse gas emissions, the present study considered the average age as an additional variable [31]. It has been found that, according to the effect of age, greenhouse gas emissions are limited for the elderly compared to the young. So, it is expected that provinces with a younger population emit more greenhouse emissions. Many studies [14,18,32] suggest that not only demographic factors are responsible for greenhouse gas emissions; other economic factors are also responsible for these emissions such as household income. A household's consumption increases as its income increases, which means the more money a household has, the greater the consumption of goods and services (transportation, housing, etc.) that emit more greenhouse gases.

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

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

where age_{it} represents the average age in years, and $avgy_{it}$ is the average income of an individual at constant dollars in 2019. The above Equation (2) is a basic model, but there are many important differences among 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 the provinces' greenhouse gas emissions: the energy sector (hydrocarbon products, such as oil, and gas production), the transportation sector, and the agricultural sector.

According to the National Inventory Report, submitted to the United Nations Framework Convention on 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 the 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 [28]). 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 (i.e., oil and gas production) variables in Equation (2), it becomes as follows:

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

where oil_{it} is oil production measured in thousands of cubic meters, and gas_{it} is gas production measured in millions of cubic meters. After including the transport sector variable (number of motor vehicles registered) and the agriculture sector variable (livestock, in thousands) in Equation (3), it becomes as follows:

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

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

As discussed above, climatic variables are also some of the main contributors to greenhouse gas emissions, as the temperature (winter or summer) substantially varies among Canadian provinces. To capture the effect of climatic differences, many proxy variables have been used in previous studies, such as maximum/minimum temperature, precipitation, and heating/cooling degree days. Gonzalez-Sanchez and Martin-Ortega [20] identified heating/cooling degree days as important determinants of greenhouse gas emissions in European countries. For the present study, the differences among provincial greenhouse gas emissions may 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 developed countries generate electricity from the combustion of fossil fuels, and the electricity that we use at home and at work has a considerable impact on greenhouse gas emissions [33].

But it is still possible that some variables are not included in the model, which would explain some of the provincial differences in greenhouse gas emissions. In this respect, we included 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 its 2005 levels by 2020 and to net-zero by 2050. We also introduced two trend variables that represent the general trend and the specific trend that started in the year 2005, which represents a trend that might allow for the gradual roll-out of energy-savings incentives or regulations, which

would result in a different trajectory. After adding these variables, the final Equation (5) can be written as follows:

$$ghg_{it} = f\begin{pmatrix} Pop_{it}, age_{it}, avgy_{it}, oil_{it}, gas_{it}, mv_{it}, livest_{it}, elecint_{it}, hdd_{it}, cdd_{it} \\ D2005_{it}, trend, T_{2005} \end{pmatrix} \quad (5)$$

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

Econometric Model

As noted above, there is significantly large variation in the greenhouse gas emissions among Canadian provinces. To circumvent this issue, the natural logs of all the quantity variables used in the model were taken, and an error term, ε_{it}, was added. Equation (2) can be rewritten econometrically as follows:

$$lnghg_{it} = \beta_0 + \beta_1 lnPop_{it} + \beta_2 lnage_{it} + \beta_3 lnavgy_{it} + \varepsilon_{it} \quad (6)$$

It is quite possible that these new variables do not capture the differences in the greenhouse gas emissions in the most populous (i.e., Ontario) or more energy-rich (i.e., Alberta) provinces. For example, Alberta might have consistently higher emissions than Ontario, and most other provinces have consistently lower emissions than Ontario, which raises concerns about how colinear some of the variables must appear, given the relative sizes of the provinces. So, in this respect, the use per capita values for every quantity variable (ghgpc, oilpc, gaspc, mvpc, livestpc, etc.) were used instead, which may mean more energy use per capita if a province has a bigger population with longer commuting times. After taking the natural logs of all quantity variables and adding the error term ε_{it}, the Equation (5) can be written econometrically as follows:

$$\begin{aligned} lnghgpc_{it} = \beta_0 \quad &+ \quad \beta_1 lnPop_{it} + \beta_2 lnage_{it} + \beta_3 lnavgy_{it} + \beta_4 lnoilpc_{it} + \beta_5 lngaspc_{it} \\ &+ \quad \beta_6 lnmvpc_{it} + \beta_7 lnlivestpc_{it} + \beta_8 lnelecint_{it} + \beta_9 lnhdd_{it} + \beta_{10} lncdd_{it} + \beta_{11} D2005_{it} \\ &+ \quad \beta_{12}\, trend + \beta_{13} T_{2005} + \varepsilon_{it} \end{aligned} \quad (7)$$

The expected signs for the coefficients in Equation (7) will be $\beta_1 > 0$, $\beta_2 < 0$, $\beta_3 > 0$, $\beta_4 > 0$, $\beta_5 > 0$, $\beta_6 > 0$, $\beta_7 > 0$, $\beta_8 > 0$, $\beta_9 > 0$, $\beta_{10} > 0$, $\beta_{11} < 0$, $\beta_{12} > 0$ and $\beta_{13} < 0$. Before estimating the final Equation (7), the present study included a different set of variables (such as hydrocarbon production, transportation sector, agricultural sector, and heating/cooling degree days) in the basic model (as represented above by Equations (3)–(5)) to determine the relative importance of the provincial differences in greenhouse gas emissions.

3.2. Data

The present study tested the different sets of greenhouse gas emissions determinants, which were examined using provincial panel data for a better comparison over time. The study period was from 1990 to 2019 for the populations of 10 Canadian provinces (see Table 2). All three territories were excluded from the sample because of large fluctuations in the data for some variables, and data are also missing for several years in the time period used in this study.

Table 2. List of Canadian provinces.

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

Total of 10 cross-sections (10 provinces).

The data on population are reported in millions, the average age in years, the average income in constant dollars at 2019, the value of oil and gas is taken as a percentage of GDP, the number of motor vehicles registered, the number of livestock in thousands, and the agricultural value-added is in the percentage of GDP, which were taken from the Statistics Canada website. Population and average age were taken from Table: 17-10-0005-01, the average income was taken from Table: 11-10-0238-01, number of motor vehicles registered were taken from Table: 23-10-0067-01, the value of oil and gas as a percentage of GDP was taken from Table: 36-10-0402-01, the number of livestock was taken from Table: 32-10-0130-01, and the agricultural value-added as a percentage of GDP was taken from Table: 32-10-0048-01.

The data on oil production, gas production, electricity generation intensity (g CO_2 eq/kWh), and greenhouse gas emissions (Mt) were taken from the various National Inventory Reports (Government of Canada [28]). Some provinces had produced zero oil and gas for some years, which made it impossible to take the log of these two variables, and the production of oil and gas in other provinces differs by many orders of magnitude. To overcome these problems, I adjusted by adding one (+1) to each value in both series, such as for the log (1 + value of oil/gas production), where 1 prevents the log (1 + value of oil/gas production) from turning into negative values. Data on the heating/cooling degree days were taken from Environment and Climate Change Canada data sources (weatherstats.ca, accessed on 23 April 2021) for the principal city in each province. Some quantity variables, such as greenhouse gas emissions, oil production, gas production, motor vehicles, and livestock, used the per capita value instead of their levels. The value of oil and gas was taken as a percentage of GDP due to the large variations (zero percent for Prince Edward Island and 40 percent for Newfoundland and Labrador) found in the values for oil and gas production among the provinces.

The descriptive statistics on all these variables are presented in Table 3, including the mean, standard deviation, maximum, and minimum for all variables in the model and for the per capita greenhouse gas emissions. There is significant variation in the greenhouse gas emissions among 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. 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 among (78.8 Mt) the provinces is quite a bit larger than within (11.86 Mt) provinces.

A similar variation exists in greenhouse gas emissions per capita (per person), and, on average, greenhouse gas emissions are 26.8 megatons CO_2 equivalent per million persons, and there are large variations (standard deviation (SD) is 21.2 Mt) among 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 variables such as population, gas production per capita, agricultural value-added (% of GDP), and livestock per capita, whereby the overall variation is less than the variation found among the provinces. All other variables display the 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, and heating/cooling degree days, for which the overall variation is greater than among and within provinces. Similarly, a large variation exists among the provinces compared to within the provinces

for these variables, except for average age and average income, for which large variations exist within the provinces instead of among the provinces.

Table 3. Panel descriptive statistics.

Variable		Mean	Std. Dev.	Min	Max	Observations
Greenhouse gases (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 gases 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	39,032.67	6739.868	25,500	58,900	N = 300
	between		4401.365	34,473.33	47,723.33	n = 10
	within		5285.139	28,309.33	51,152.67	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	13,193.23	0	55,944.37	N = 300
	between		13,458.18	0	4.31×10^4	n = 10
	within		3241.284	−8391.85	1.86×10^4	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 × 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 × 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

One observation is a province and year. The sample includes ten provinces and 30 years of data from 1990 to 2019, and the total number of observations is 300. The abbreviation "pc" means the variable is taken as the per capita; units for each variable are in the parentheses.

After analyzing the summary statistics for all of the variables used in the models, it is very important to further analyze any statistical relationships that exist among them. To test for statistical relationships among the variables, the best way is to check for correlation

among them, which avoids the problem of multicollinearity. The correlation analysis is presented in Table 4.

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

lnghgpc, lnpop, lnage, lnavgy, lnoilpc, lngaspc, vog/gdp lnmvpc, lnlivestpc, agv/gdp, lnelecint, lnhdd, and lncdd denote 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.

There is a positive correlation between the per capita greenhouse gas emissions and all other variables, except for average age of the population 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 are moderately correlated (ranging between 0.4 and 0.8) with greenhouse gas emissions in all provinces. There are positive correlations found between per capita greenhouse gas emissions and oil production per capita (0.76), gas production per capita (0.67), electricity generation intensity (0.67), livestock per capita (0.58), transportation sector (0.55), and heating degree days (0.47). There are low correlations (ranging between 0.25 and 0.35) found between greenhouse gas emissions per capita and average income (0.25), population (−0.07), cooling degree days (−0.31), and average age (−0.35).

In terms of the independent variables, there are low correlations found between all of the variables, except oil and gas production as a percentage of GDP, and the log of oil production per capita (0.82), and between agricultural value-added as a percentage of GDP and the log of livestock per capita (0.80), which suggest that one of the highly correlated variables should be used in the model to avoid the collinearity problem. Otherwise, no collinear variables were identified that affect the interpretation of the regression results. It is also noted that correlation is only a statistical relationship between two variables, and this does not mean that a variable that has a positive correlation contributed to greenhouse gas emissions.

3.3. Econometric Methodology

To estimate the above models, the study used a suitable econometrics methodology after discussion of the econometrics issues (e.g., cross-section dependence and heterogeneity) that may be faced at the time of estimation. The results of the cross-sectional dependence test and slope heterogeneity test were used to choose among 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 [34], is more efficient in dealing with both cross-sectional dependence and slope heterogeneity. If the slopes are not heterogeneous across provinces, only exhibiting cross-sectional dependence across provinces, then the mean group (MG), pool mean group (PMG), and dynamic fixed effects (DFE), developed by Pesaran et al. [35], are more efficient. But if there is no cross-sectional dependence and slope heterogeneity, then the pooled ordinary least squares method provides more reliable

estimates. The results of the cross-sectional dependence and slopes heterogeneity tests are provided below in this section.

Before applying a regression analysis, first, it is very important to test the cross-section dependence (CSD), as there are ten cross-sections (i.e., provinces) and 30 years (1990–2019) of data used in the analysis. Thus, it is more likely that there are spillover effects and common shocks such as recessions that affected most of the provinces at the same time, (e.g., the global financial crisis in 2008). To avoid spuriousness and identification problems in the regression, the cross-sectional dependence was tested, first, by employing the cross-section dependence test (using a null hypothesis of weak cross-sectional dependence), proposed by Pesaran [36], on the individual variable series (for example, if we are interested in analyzing as a pre-estimation of the cross-sectional dependence of the data). To investigate the cross-sectional dependence in the logs of all individual variables in this test, the results are presented in Table 5.

Table 5. Pesaran cross-sectional dependence test.

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

Cross-sectional dependence statistics assume a null hypothesis of weak cross-sectional dependence.

According to the Pesaran's cross-section dependence test, we can reject the null hypothesis of weak cross-sectional dependence for all of the variables, indicating there were test statistic p-values < 0.01, except for the population variable, for which $p < 0.05$, indicating that there is cross-sectional dependence that leads to the inappropriateness of the pooled ordinary least squares regression method.

As indicated above, there is cross-sectional dependence in all of the panels' series, but it could be possible that the estimated residuals are not cross-sectionally dependent, which is tested for with the Pesaran [36] cross-section dependence test and based on the residuals of the estimated models instead of the individual series. The results are discussed below.

As indicated above, there is a cross-sectional dependence in all the panels' individual series, and the study also applied the Pesaran [36] cross-section dependence test, which is based on the residuals of the estimated models instead of the individual series, and the results are provided in the last row (CSD) of all of the estimation tables in Section 4. The large value of the test statistic indicates that the residuals are not weakly cross-sectionally dependent.

Next, we tested whether the slopes of the coefficients are homogeneous across provinces. There are ten provinces, so it is most likely that the slopes are heterogeneous. To address this, the study also applied the slope heterogeneity test, proposed by Pesaran and Yamagata [37], which is a standardized version of Swamey's [38] test for slope heterogeneity. This test assumes that all slope coefficients are identical across cross-sections; the results are reported in Table 6.

Table 6. Slope heterogeneity test.

	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	−0.249	0.803	0.148	0.883	0.183	0.855		
Adjusted	−0.346	0.729	0.205	0.837	0.263	0.793		

H0: slope coefficients are homogenous.

The results of the slope heterogeneity test show that the null hypothesis of slope homogeneity cannot be rejected, as the 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 determined that the slopes are homogeneous across cross-sections (i.e., provinces). It is concluded that there is no cross-sectional dependence and slope heterogeneity across provinces; therefore, the pooled ordinary least squares method will provide more reliable estimates, and the results are provided in tables in Section 4.

4. Results and Discussion

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

Looking at column 1, we see that the greenhouse gas emissions increased almost proportionately (0.96) with the population of the provinces. So, a one percent increase in the population increase greenhouse gas emissions by 0.96 percent. This result is also consistent with a study conducted by Tavakoli (2018), who 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 population increase of one million 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 among the provinces other than their populations (although these are important). In particular, NFL, PEI, NB, NS, and Man are considerably lower than Ontario, but QC, Sask, and B.C are a slightly lower than Ontario; however, Alberta is higher than Ontario.

One provincial difference that might explain the remaining pattern is the average age (column 2), which indicates that older provinces do not produce as much greenhouse gas emissions after accounting for the population. However, column 2a shows that there are far larger differences among the provinces than their average ages, and the other effects overwhelm the effect 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 (4a), there are still provincial differences from this broad pattern. These results are consistent with studies by Alegria et al. [39] on Spain, Cui et al. [40] on China, and Cole and Neumayer [13] for 86 countries, and their main finding suggests that

population growth is one of the primary drivers boosting greenhouse gas emissions in most countries.

Table 7. Pooled ordinary least squares estimates for the 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 ***
lnage	-	-	−3.281 ***	0.00118	-	-	−6.613 ***	−0.957 ***
lnavgy	-	-	-	-	1.279 ***	0.131 **	2.789 ***	0.503 ***
Dummy for provinces (base category—Ontario)								
NFL		−1.772 ***		−1.774 ***		−2.125 ***		−1.970 ***
PEI		−2.949 ***		−2.951 ***		−3.470 ***		−3.306 ***
NS		−1.299 ***		−1.300 ***		−1.591 ***		−1.451 ***
NB		−1.347 ***		−1.348 ***		−1.661 ***		−1.507 ***
QC		−0.602 ***		−0.602 ***		−0.641 ***		−0.556 ***
Man		−1.347 ***		−1.348 ***		−1.618 ***		−1.560 ***
Sask		−0.145		−0.146		−0.439 **		−0.391 *
Alb		0.709 ***		0.708 ***		0.538 ***		0.464 ***
B.C		−0.716 ***		−0.717 ***		−0.841 ***		−0.781 ***
Constant	3.087 ***	4.303 ***	15.06 ***	4.300 ***	−10.38 ***	3.213 ***	−2.143	2.697 ***
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**

*** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. All specifications represented by the letter "a" (e.g., 1(a)) are estimated with dummy variables used for provinces, with Ontario as the base category. 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. 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) of Pesaran's (2015) residual-based cross section dependence test. Bold letters indicate $p < 0.05$.

As discussed above, it is quite possible that the new variables do not capture the differences in greenhouse gas emissions for the most populous (Ontario) or more energy-rich (Alberta) provinces. For example, Alberta might have consistently higher emissions than Ontario, and most other provinces have consistently lower emissions than Ontario, which raises some concern about how colinear some of the variables must appear, given the relative sizes of the provinces.

For the extended models, in which all quantity variables used the per capita values, the results are presented in Table 8, including the hydrocarbon variables, such as oil production per capita and gas production per capita. For robust results, the study used 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 of pooled ordinary least squares for the extended models are presented in columns 5, 6, 7, and 8, and with the dummy specifications (Ontario taken as a 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 the 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 among the provinces other than their populations, ages, income, and oil production per capita. In particular, NFL and PEI have considerably lower emissions than Ontario, but NB, NS, QC, Man, and B.C have slightly lower emissions 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. If both gas and oil production per capita are included in the same model (columns 7 and 7a), this provides qualitatively

similar results as models 5 and 5a, and models 8 and 8a also produce 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 kept the variables oil production per capita and gas production per capita for further analysis instead of the values of oil and gas production as percentages of GDP due to the collinear relationship between oil production per capita and the values of oil and gas production as percentages of GDP.

Table 8. Pooled ordinary least squares estimates for the 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 ***
lnage	−4.358 ***	−1.516 ***	−3.979 ***	−0.830 ***	−3.077 ***	−1.600 ***	−6.185 ***	−3.182 ***
lnavgy	1.535 ***	0.412 ***	1.408 ***	0.480 ***	0.878 ***	0.418 ***	1.869 ***	0.758 ***
lnoilpc	0.271 ***	0.136 ***	-	-	0.217 ***	0.142 ***	-	-
lngaspc	-	-	0.0788 ***	−0.0150 *	0.0519 ***	0.00699	-	-
vog/gdp	-	-	-	-	-	-	0.0229 ***	0.0082 ***
Dummy for provinces (base category—Ontario)								
NFL		−0.716 **		−2.147 ***		−0.578 *		−1.001 ***
PEI		−1.020 **		−3.534 ***		−0.812		−1.788 ***
NS		−0.173		−1.607 ***		−0.0432		−0.493 **
NB		−0.0759		−1.633 ***		0.0471		−0.453 *
QC		−0.310 ***		−0.628 ***		−0.266 ***		−0.312 ***
Man		−0.480 **		−1.698 ***		−0.368		−0.855 ***
Sask		0.434 *		−0.401 *		0.475 **		0.268
Alb		0.765 ***		0.535 ***		0.745 ***		0.548 ***
B.C		−0.268 **		−0.741 ***		−0.264 **		−0.358 ***
Constant	2.557 *	4.417 ***	2.556	2.622 ***	4.706 ***	4.529 ***	5.886 ***	7.323 ***
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**

*** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. CSD is a test statistic (*t*-stat) of Pesaran's (2015) residual-based cross-section dependence test. 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. The bold letters indicate $p < 0.05$.

So, it is noted that there are many important differences still unexplained among 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 (motors vehicles registered per capita) and agriculture sector variable (livestock per capita) in column 7 of Table 8. The results are presented in Supplementary Table S1. 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 in column 11a. Similar results are found if the agricultural value-added as a percentage of GDP is included instead of livestock per capita in column 12, except for the average income which is a significant determinant of greenhouse gas emissions. However, there are still unexplained variations indicated by the significances of some of the provincial dummies, as shown in column 12a, which assert that there are still unexplained provincial differences.

So, different variables (such as electricity generation intensity, heating and cooling degree days, and a dummy variable for the year 2005 and after) were put into the above model, and the results are presented in Supplementary Table S2. Starting from column 13, if electricity generation intensity is included in the model, all variables' coefficients are qualitatively similar to the results in column 12 of Table S1, and the newly included

variable shows a significant, positive sign as expected. Similarly, if the new variable heating degree days is included instead of electricity generation intensity in column 12 of Table S1, it shows a significant, positive sign as expected (column 14). In addition, if the new variable cooling degree days is included instead of heating degree days in column 12 of Table S1, it shows a significant, positive sign as expected (column 15).

When all four variables (i.e., electricity generation intensity, heating degree days, cooling degree days, and the dummy variable) are included in the model, all variables' coefficients show qualitatively similar results (except average age and average income, which become insignificant) to column 12 of Table S1. The newly included variables heating degree days and electricity generation intensity show significant, positive results in column 16. However, the cooling degree days have a significant, negative sign, which was not expected; the wrong sign might indicate that cooling degree days are not capturing the extra electricity use due to air conditioning.

It is likely that 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), as follows: 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 9, because the extra electricity use due to air conditioning is not captured. However, with the additional variables included in the extended model 1, the results assert that there are still unexplained differences in greenhouse gas emissions at the provincial level according to the significance of some of the provincial dummies, as shown in 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 9.

Starting from column 17, if only the time trend variable is included in the model, all variables indicate the expected signs, and most of the variables are significant, except for average income, motors vehicles registered per capita, dummy variable (D2005), and the trend variable. However, average age plays a significant role in reducing greenhouse gas emissions per capita in Canada. Now, a greater population leads to producing more greenhouse gas emissions per capita in Canada after all other factors are accounted. 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 the general trend, the results remain the same, except for the average income, which plays a significant role, and population, average age, and livestock per capita have no roles 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, which concludes that the population has no role in determining the greenhouse gas emissions per capita in Canada. This result is consistent with studies by Cui et al. [40] and Wang et al. [41], who found that population was not a significant determinant of per capita greenhouse gas emissions when using the pooled ordinary least squares method on the 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. [42], 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 nonsignificant.

Table 9. Pooled ordinary least squares 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
lnage	−0.956 **	−0.594 *	−0.355	−0.472 **	−1.355 ***	−1.506 ***
lnavey	0.0776	0.334 ***	0.412 ***	0.742 ***	0.152	0.629 ***
lnoilpc	0.176 ***	0.0630 ***	0.164 ***	0.0982 ***	0.167 ***	0.0869 ***
lngaspc	0.0409 ***	0.00686	0.0447 ***	0.00632	0.0417 ***	0.00570
lnmvpc	0.149	−0.0712	0.125	−0.0468	0.198 **	0.00309
lnlivestpc	0.0242 *	0.453 ***	0.00992	0.196 ***	0.0126	0.203 ***
lnelecint	0.109 ***	0.00529	0.104 ***	0.00273	0.105 ***	0.00246
lnhdd	0.672 ***	−0.0875	0.801 ***	0.0573	0.695 ***	0.0413
D2005	−0.0136	−0.0732 ***	0.0235	−0.0532 ***	−0.00830	−0.0642 ***
trend	0.00524	0.00202			0.0169 ***	0.0136 ***
T2005			−0.0115 ***	−0.0195 ***	−0.0203 ***	−0.0239 ***
Dummy for provinces (base category—Ontario)						
NFL		1.796 ***		1.643 ***		0.704 *
PEI		0.337		1.335 ***		−0.0808
NS		1.095 ***		1.403 ***		0.629 **
NB		1.263 ***		1.609 ***		0.742 **
QC		−0.115		−0.00780		−0.149 **
Man		−0.166		0.573 ***		−0.188
Sask		0.520 *		1.413 ***		0.632 **
Alb		0.530 ***		1.141 ***		0.683 ***
B.C		0.174		0.350 ***		0.0340
Constant	−0.669	2.293	−7.384 ***	−4.398 ***	−0.254	1.363
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**

*** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Ontario is the base category, while lnpop, lnage, lnavgy, lnoilpc, lngaspc, lnmvpc, lnlivestpc, lnelecint, and lnhdd denote 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. 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-savings incentives or regulations, resulting in a different trajectory. CSD is a test statistic (*t*-stat) of Pesaran's (2015) residual-based cross-section dependence test. 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. Bold letters indicate $p < 0.05$.

However, the 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). One reason for the high elasticity of heating degree days is the colder weather in Canada and colder temperatures imply more intensive use of heating systems that produce higher levels of greenhouse gas emissions. The elasticity of greenhouse gas emissions with respect to gas production per capita (0.042), electricity generation intensity (0.105), and 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) compared to heating degree days in Canada on a general level, and this result is consistent with a study conducted by Papagiannaki and Diakoulaki [43]. They found that motor vehicles per capita in Greece are the main factor behind a significant increase in the levels of greenhouse gas emissions during 1990–2005. However, these results contradict those found in previous studies [44,45], which suggest that the greenhouse gas emissions due to transportation are closely related to the size of the population.

The dummy variable (D2005) indicates that there is not a significant difference among the patterns of per capita greenhouse gas emissions in Canada after 2005. In column 19, both trend variables are significant and indicate the expected signs, playing important roles in explaining greenhouse gas emissions per capita in Canada, especially the specific trend (T2005) variable, which was negative and significant, which might allow for the gradual roll-out of energy-savings incentives or regulations, resulting in a different trajectory. However, some of the collinear variables (such as both trend variables having a high correlation, 0.91) lead to population and average income variables being insignificant in the final model.

But, when we look at column 19a, we see that there are many important differences among the provinces other than their populations, age, income, oil and gas production per capita, livestock, energy intensity, heating and cooling degree days (although these are important). In particular, QC has slightly lower emissions than Ontario, while NFL, NB, NS, Sask, Alberta have considerably higher emissions than Ontario; however, there are no significant differences between PEI, Man, and B.C. and Ontario. Column 19a also indicates that there are still provincial differences from this broad pattern, and there are many important differences among the provinces other than all of the variables used in this study, so there are probably still missing variables that can explain the remaining pattern of per capita greenhouse gas emissions in Canada and its provinces.

5. Conclusions

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

The extended model, in which the per capita of greenhouse gas emissions was used as the dependent variable, produced qualitatively similar results as the basic model. The final model (extended model 3, column 19), in which all 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) were included, qualitatively produced similar results, except for population, average income, and livestock per capita, which play no roles in determining greenhouse gas emissions in Canada. However, both trend variables play important roles in explaining greenhouse gas emissions per capita in Canada. Moreover, there was no significant difference between the patterns of per capita greenhouse gas emissions in Canada after 2005. The results show that heating degree days are the main producer of greenhouse gas emissions in Canada, as the elasticity of greenhouse gas emissions, with respect to heating degree days, was (0.695). One reason for the high elasticity of the heating degree days is the colder weather in Canada, and colder temperatures imply more intensive use of heating systems that produce higher levels of greenhouse gas emissions. The elasticity of the greenhouse gas emissions, with respect to gas production per capita (0.042), electricity generation intensity (0.105), and oil production per capita, was 0.167.

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 the 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 older populations experience a decrease in per capita greenhouse gas emissions instead of a boost. However, population and average income have no roles in determining the greenhouse gas emissions per capita in Canada.

The policy implications of the present analysis are that the government of Canada and its provinces should gradually roll-out of energy-savings incentives and regulations instead of using more efficient energy-savings technology to reduce GHG emissions per capita over time. Also, it should shift toward low-carbon electricity and reduce the amount of carbon per unit of energy, as well as move towards renewables sources. The way forward for Canada to achieve the desired target of net-zero emissions by 2050 is to improve energy efficiency and shift towards low-carbon energy use in sectors such as the transportation, for example, with electrical vehicles. There is a dire need to follow the decarbonization path that will lead to achieving the desired targets, such as the use of new technologies to extract oil and gas that will emit less GHG emissions, use of thermal electricity generation instead of other sources of high GHG emissions, new battery technologies for vehicles, and electric heat pumps for heating needs. Thus, a dire need exists for a national energy strategy in consultation with provincial and territorial governments, as well as meaningful engagement with Canadians, on climate policy and carbon pricing. The main concern for Canadian policymakers is that Canada is a decentralized federation and climate change is a shared jurisdiction, so all provincial governments have their own GHG emissions policies. A collective consensus is needed, and governments at all levels, federal, provincial, and territorial must take fundamental actions to make progress on reducing GHG emissions.

There are limitations with the present study, as the study only considers 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 the other determinants of greenhouse gas emissions that may affect this relationship, such as sector-wise data and structural changes. In this respect, future studies can be extended to investigate whether the identified factors of greenhouse gas emissions found in this study play roles in the comparative significance of structural vs. efficiency changes, which is beyond the scope of the present study.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16062498/s1, Table S1: Pooled Ordinary Least Square Estimates for Extended Model 1. Table S2: Pooled Ordinary Least Square Estimates for Extended Model 2.

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