Does Domestic Investment Have a Role in An Economy? An Analysis of the Connection Between CO2 Energy and Growth in the US and Canada

Yeboah Evans [1]

[1] Department of Statistics and Operation Analysis, Faculty of Business and Economics, Mendel University in Brno, Czech Republic
ORCID: 0000-0002-0934-3996
e-mail: yeboahevans869@gmail.com

Abstract
This study examines the relationship between domestic investment, economic growth, and carbon dioxide (CO2) emissions in the United States and Canada from 1990 to 2021 using ARDL bound testing. The findings reveal a long-run relationship between the variables in both countries. In the US, short-run results show a positive link between domestic investment and CO2 emissions, while economic growth has no significant impact. In the long run, only domestic investment positively influences CO2 emissions. Other factors such as trade openness exhibit positive short-run effects but long-run negative relationships with CO2 emissions, while fossil fuel consumption positively impacts emissions. Granger causality tests reveal bidirectional links between fossil fuel consumption and CO2 emissions, and a unidirectional causality from trade openness to CO2 emissions in the US economy. In Canada, positive short- and long-term connections exist between domestic investment and CO2 emissions. FDI and economic growth exhibit mixed short-run effects on emissions but positive long-term impacts. Fossil fuel consumption negatively affects emissions in both the short and long term, while trade openness shows a positive long-term effect. The findings stress the need for targeted policies to balance economic growth, investments, and environmental sustainability, including promoting renewable energy, sustainable trade, and clean technologies.

Key words
CO2 emissions, economic growth, domestic investment, fossil fuel, FDI

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Introduction

Carbon dioxide (CO_2) emissions have emerged as a critical global challenge with profound implications for environmental sustainability, public health, and economic development. As the primary greenhouse gas responsible for trapping heat in the Earth's atmosphere, CO_2 emissions play a significant role in driving climate change, contributing to rising global temperatures, melting ice caps, sea level rise, and extreme weather events (Blunier and Brook, 2001). The escalating levels of CO_2 emissions are primarily attributed to human activities, particularly the combustion of fossil fuels for energy production, industrial processes, and transportation (Carl-Friedrich et al., 2022). Recent scientific evidence emphasizes the urgency of addressing CO_2 emissions to mitigate the worst impacts of climate change and safeguard the planet for future generations. The Global Carbon Project reported a record high of 36.4 billion metric tons of CO_2 emissions in 2019, predominantly originating from the energy sector (Corinne et al., 2020). This relentless increase in CO_2 emissions poses a significant challenge to international climate goals, such as those outlined in the Paris Agreement, which aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels (Joeri et al., 2016). The impact of CO_2 emissions extends beyond environmental concerns to encompass social and economic dimensions. Climate change induced by CO_2 emissions exacerbates existing vulnerabilities, disproportionately affecting marginalised communities and exacerbating social inequalities (Blunier & Brook, 2001). Moreover, the economic costs of climate change, including damage to infrastructure, disruptions to supply chains, and increased healthcare expenses, pose significant risks to global prosperity (Solomon, et al., 2017). Recent advancements in scientific research have provided details into the complexity of CO_2 emissions and the challenges associated with mitigating them. Studies have examined the drivers of CO_2 emissions, including population growth, economic development, energy consumption patterns, and technological advancements (Davis, 2018). Additionally, research has explored the effectiveness of various mitigation strategies, such as renewable energy deployment, energy efficiency improvements, and reforestation efforts, in reducing CO_2 emissions and transitioning to a low-carbon economy (IEA, 2020; Felix et al., 2019). Moreover, energy transition efforts in regions such as the European Union, as highlighted in the energy transition in the EU briefing by the European Parliament, exemplify concerted efforts towards achieving climate neutrality by 2050, aligned with the European Green Deal. The briefing emphasises the significance of transitioning the energy sector, the largest source of greenhouse gas emissions in the EU, towards a net-zero economy. The economies of the United States and Canada are deeply intertwined with the issue of CO_2 emissions, given their significant contributions to global emissions. Both countries rely heavily on fossil fuels for energy production and transportation, leading to substantial carbon footprints. Recent studies have shown that the United States and Canada are among the world's largest emitters of CO_2 per capita, highlighting the magnitude of their impact on global emissions (World Bank, 2021). The extraction, production, and consumption of fossil fuels not only drive economic growth but also generate CO_2 emissions, posing a complex challenge for policymakers seeking to balance economic development with environmental sustainability (EPA, 2021). Despite the importance of domestic investment, economic growth, and environmental sustainability, there is a lack of comprehensive research that simultaneously examines the interactions among these factors, particularly within the specific contexts of the US and Canada. Given the significant economic and environmental implications of these countries' policies and practices, there is a pressing need for empirical studies that shed light on the complex relationships between domestic investment, economic growth, and CO_2 emissions. The research problem lies in comprehensively examining the relationship among domestic investment, economic growth, and CO_2 emissions in the US and Canada. The study seeks to answer the following research questions: What is the causal relationship between domestic investment, economic growth, and CO_2 emissions in the US and Canada? How do variations in domestic investment patterns impact economic growth and CO_2 emissions differently in the US and Canada? The study answers these questions through the Autoregressive Distributed Lag (ARDL) method, which helps to capture the short-and long-run relationships among these variables. This study's findings seek to provide valuable insights for policymakers, businesses, and civil society stakeholders to help them design strategies that promote sustainable development while fostering economic prosperity in both nations. The outline of this study is as follows: Section 2 is a literature review, Section 3 includes the materials and methods, Section 4 is the results and discussion, and Section 5 is the conclusion.

1. Literature review

The nexus between energy consumption, carbon emissions, and economic growth is a topic of significant interest and importance in the field of environmental economics and sustainable development. Research in this area has focused on understanding the complex relationships among these variables and their implications for policy-making and economic prosperity. Moreover, the role of domestic investment in shaping these dynamics has emerged as a critical factor that warrants further investigation. The literature emphasizes the need for further research to better understand the relationships between energy consumption, carbon emissions, economic growth, and domestic investment. Addressing these gaps in knowledge can contribute to evidence-based policy-making and foster sustainable development pathways in the United States, Canada, and beyond.

1.1. Energy Consumption, Carbon Emissions, and Economic Growth

Energy consumption, carbon emissions, and economic growth are interconnected components of modern industrial societies, each exerting influence on the others. Research exploring their relationships spans various disciplines, from economics to environmental science. The nexus between these factors is complex, with multiple feedback loops and dynamics shaping their interactions. Numerous studies have delved into the connection between energy consumption and economic growth. Energy is a fundamental input in production processes, driving industrialization, infrastructure development, and technological innovation (Stern, 2000). Soytas and Sari (2003) found empirical evidence suggesting that energy consumption Granger causes economic growth, particularly in developing countries. This implies that energy availability and utilization are crucial drivers of economic activity. However, economic growth often comes at the expense of increased carbon emissions. As economies expand, energy demand rises, leading to greater emissions of greenhouse gases. The Environmental Kuznets Curve (EKC) hypothesis offers a theoretical framework for understanding this relationship. Initially, economic growth is associated with rising emissions, but as societies become wealthier, they tend to adopt cleaner technologies and reduce emissions (Grossman & Krueger, 1995). Nonetheless, empirical studies provide mixed evidence regarding the validity of the EKC hypothesis, with some supporting its predictions (Cole, 2004; Haider and Amira, 2023) while others refuting it (Holtz-Eakin & Selden, 1995; Dogan & Seker, 2016). Energy efficiency emerges as a critical factor in decoupling economic growth from emissions growth. Improving energy efficiency can mitigate carbon emissions while sustaining economic development (Sharif et al., 2023). Investments in energy-efficient technologies, renewable energy sources, and cleaner production processes can reduce carbon intensity and enhance resource productivity, leading to more environmentally sustainable and economically resilient growth trajectories (Apergis & Payne, 2010; Ozturk & Acaravci, 2010). Policy interventions play a crucial role in shaping the relationship between energy consumption, carbon emissions, and economic growth. Governments worldwide are increasingly adopting measures to promote clean energy and mitigate climate change. Carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, aim to internalize the social and environmental costs of carbon emissions, incentivizing businesses and consumers to transition towards low-carbon alternatives (World Bank, 2018). Additionally, investments in clean energy infrastructure, research and development, and regulatory frameworks are essential for fostering innovation and facilitating the transition to a low-carbon economy (European Commission, 2019; IEA, 2021).

1.2. Domestic Investment, Economic Growth, and CO2 Emissions

Domestic investment is widely recognized as a critical driver of economic growth and development. Scholars such as Romer (1986) argue that investments in physical and human capital lead to productivity gains and technological progress, fostering long-term economic prosperity. Barro (1991) emphasizes the importance of investment in infrastructure, education, and innovation in stimulating economic growth. However, the impact of domestic investment on environmental sustainability, particularly in terms of CO2 emissions, is a subject of ongoing debate. Research on the relationship between domestic investment and CO2 emissions yields mixed findings. While investment in energy-intensive industries and infrastructure may initially contribute to emissions growth, technological progress and efficiency improvements can mitigate these effects over time (Nadya & Daryn, 2022). However, empirical evidence regarding the direct impact of domestic investment on CO2 emissions is inconclusive. Some studies suggest a positive relationship (Ang, 2007), while others find no significant correlation (Halicioglu, 2009). Furthermore, economic growth has long been associated with increased CO2 emissions. The Environmental Kuznets Curve (EKC) hypothesis posits an inverted U-shaped relationship between income and environmental degradation, suggesting that as economies develop and reach higher income levels, they become more environmentally conscious and adopt cleaner technologies (Grossman & Krueger, 1995). However, empirical studies provide mixed evidence regarding the validity of the EKC hypothesis, with some supporting its predictions (David, 2004) while others refute it (Wang & He, 2019). The complexities of the relationship between domestic investment, economic growth, and CO2 emissions extend beyond simple causal links. Factors such as the composition of investment, technological innovation, and policy interventions play crucial roles in shaping emission trajectories. For example, investments in renewable energy and energy efficiency can promote sustainable growth while reducing emissions intensity (Zhikang & Weisheng, 2023). Similarly, the adoption of stringent environmental regulations and carbon pricing mechanisms can incentivize businesses to invest in cleaner technologies and practices (Ugur, 2018). Moreover, the impact of domestic investment on CO2 emissions may vary across different sectors and regions. Energy-intensive industries, such as manufacturing and transportation, are more likely to contribute to emissions growth, whereas investments in service-oriented sectors may have lower environmental footprints (Berna and Gülin, 2020). Additionally, regional disparities in economic development and energy infrastructure can influence emission patterns, highlighting the importance of context-specific analyses in understanding the relationship between investment, growth, and emissions (Kao & Wan, 2017). Understanding the relationship between domestic investment, economic growth, and CO2 emissions is essential for designing effective policy interventions to promote sustainable development. Policymakers should prioritize investments in renewable energy, energy efficiency, and clean technologies to decouple economic growth from emissions growth (Sovacool & Dworkin, 2015). Additionally, implementing carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, can incentivize low-carbon investments and encourage businesses to internalize the social and environmental costs of CO2 emissions (Ugur, 2018).

1.3. Energy-Growth-Emission Dynamics in the United States

The relationship between energy consumption, economic growth, and carbon emissions in the United States has been the subject of extensive research, reflecting the country's significant role in global energy markets and its impact on climate change. This literature review aims to provide a comprehensive overview of existing studies that examine the relationship among energy consumption, economic growth, and carbon emissions in the US. Numerous studies have investigated the relationship between energy consumption and economic growth in the United States. Research by Kraft & Kraft (1978) found evidence of a long-run equilibrium relationship between energy consumption and GDP, suggesting that energy is a crucial input in driving economic activity. Similarly, Andrew (2019) employed a cointegration analysis to demonstrate a positive relationship between energy consumption and economic growth in the US over the long term. However, the environmental consequences of increased energy consumption, particularly in terms of carbon emissions, have raised concerns about the sustainability of economic growth. The United States is one of the largest emitters of carbon dioxide (CO2) globally, primarily due to its heavy reliance on fossil fuels for energy generation and transportation. Research by Schmalensee et al. (1998) highlighted the role of energy-related CO2 emissions in contributing to climate change and emphasized the need for policy interventions to mitigate emissions growth. While early studies provided mixed evidence regarding the existence of an inverted U-shaped relationship between per capita income and emissions (Selden &Song, 1994) more recent research suggests that income growth alone may not be sufficient to curb emissions without targeted policy interventions (Grossman & Krueger, 1995; Galeotti et al.,2006). Energy efficiency emerges as a critical factor in decoupling economic growth from emissions growth in the United States. Investments in energy-efficient technologies, renewable energy sources, and clean transportation infrastructure have the potential to reduce carbon intensity and enhance resource productivity (Sorrell et al., 2010). Policy initiatives, such as fuel economy standards for vehicles and energy efficiency regulations for buildings, have contributed to improvements in energy efficiency and emissions reductions across various sectors. The role of renewable energy in mitigating emissions while sustaining economic growth has garnered increasing attention in the United States. Studies have demonstrated the economic benefits of transitioning to renewable energy sources, including job creation, reduced air pollution, and enhanced energy security (Wei et al., 2010). Government incentives, such as tax credits and subsidies, have played a crucial role in promoting renewable energy deployment and driving down costs (Feldman et al., 2015).

1.4. Energy-Growth-Emission Dynamics in Canada

The linkage between energy consumption, economic growth, and carbon emissions in Canada has garnered significant attention from researchers, policymakers, and stakeholders due to its implications for both economic development and environmental sustainability. Several studies have explored the relationship between energy consumption and economic growth in Canada. Researchers such as Dickey & Fuller (1979) found evidence of a long-run equilibrium relationship between energy consumption and GDP in Canada, suggesting that energy plays a crucial role as a driver of economic activity. Similarly, Mahamat (2012) employed a panel cointegration approach to demonstrate a bidirectional causality between energy consumption and economic growth in Canada over the long term. However, the environmental consequences of increased energy consumption, particularly in terms of carbon emissions, pose significant challenges for Canada's sustainability objectives. Canada is one of the largest per capita emitters of greenhouse gases globally, primarily due to its reliance on fossil fuels for energy production and transportation. Research by Anthony and Wolfram (2016) highlighted the role of energy-related carbon emissions in contributing to climate change and indicated the urgency of transitioning to cleaner energy sources. The EKC hypothesis has been frequently examined in the Canadian context to understand the relationship between economic growth and environmental degradation, including carbon emissions. While some studies suggest evidence of an inverted U-shaped relationship between income and emissions (Edward et al., 2018), others argue that the relationship may be more complex and contingent on various factors such as energy policies and technological advancements (Cleeren et al.,2016). Energy efficiency emerges as a critical factor in decoupling economic growth from emissions growth in Canada. Investments in energy-efficient technologies, renewable energy sources, and clean transportation infrastructure have the potential to reduce carbon intensity and enhance resource productivity. Policy initiatives, such as carbon pricing mechanisms and regulatory standards for energy efficiency, play a crucial role in promoting sustainable energy practices and emissions reductions across various sectors. The role of renewable energy in mitigating emissions while sustaining economic growth has gained traction in Canada. Studies have demonstrated the economic benefits of transitioning to renewable energy sources, including job creation, reduced air pollution, and enhanced energy security (Tansu et al., 2022).

2. Methodology

The estimation method employed in this study utilizes identical model equations for both countries, utilizing the same dataset and chosen variables. However, the Autoregressive Distributed Lag (ARDL) estimation technique incorporates distinct lag lengths tailored to each country, ensuring optimal model specification and accuracy. This approach allows for a complex examination of each country's economic performance, precluding the use of a panel method. The underlying assumption is that the economic dynamics and policy influences driving each economy are distinct and necessitate individualized analysis.

2.1. Data Source and Model specification

The study employed annual time series data extracted from the World Development Indicators (WDI) spanning from 1990 to 2021. The selected variables encompass CO2 emissions, fossil fuel consumption, gross domestic product (GDP) per capita growth, gross fixed capital formation, foreign direct investment (FDI) inflows, and trade openness. CO2 emissions are measured in metric tons per capita. GDP per capita growth is quantified as an annual percentage, while gross fixed capital formation is expressed as a percentage of GDP. Fossil fuel consumption and FDI are represented as proportions of GDP. Trade openness is determined by the ratio of GDP to the sum of exports and imports. However, domestic investment in the study is denoted by gross fixed capital formation. To assess the presence of a long-term relationship among the variables, the research utilized the autoregressive distributed lag (ARDL) bound test developed by (Pesaran et al., 2001). This method has been widely adopted by scholars such as Thobekile et al. (2022), Rathnayaka et al. (2021) and Hao (2023) within the framework of the single-equation total growth model. These studies have explored the relationship between CO2 emissions, fossil fuel consumption, and various control factors on economic growth. The estimated model is in Equation 1.

$$CO2_t = \beta_0 + \beta_1 FFC_t + \beta_2 TOP_t + \beta_3 GFCF_t + \beta_4 GDPPC_t + \beta_5 FDI_t + \varepsilon_t \tag{1}$$

In Equation 1, CO2 represents energy emissions, FFC denotes fossil fuel consumption, TOP signifies trade openness, GFCF stands for gross fixed capital formation, GDPPC represents gross domestic per capita growth, FDI indicates foreign direct investment, and ε_t is the error term. The rationale for including each variable in Equation 1 is that CO2 emissions represent a critical environmental concern influenced by various economic activities, making them pivotal for studying the relationship between economic growth and resource consumption. Non-renewable resource consumption, particularly fossil fuels, is intricately linked to CO2 emissions. Trade openness impacts economic growth by facilitating the exchange of goods and services across borders, shaping production patterns, energy use, and emissions. Gross fixed capital formation, entailing investment in infrastructure and capital, is essential for economic growth and can influence resource consumption and environmental sustainability. GDP per capita reflects a country's economic development level and consumption patterns, which can in turn affect CO2 emissions. FDI brings capital and technology, impacting economic growth and potentially influencing resource use and environmental sustainability. However, since this research aims to evaluate the significance of these variables separately within each country, it necessitated the identification of the appropriate model specifications for each nation. To achieve the correct model specification for the estimated model in the United States, the variables CO2, fossil fuel consumption, and trade openness were transformed using natural logarithms. This transformation helps to stabilize the data and addresses potential issues related to non-linear relationships. On the other hand, for the accurate model specification in Canada, the variable CO2 was converted into logarithmic form. This adjustment aims to ensure that the model appropriately captures the relationship between CO2 emissions and other variables within the Canadian context. By adapting the model specifications to the specific characteristics of each country, the study aims to provide more robust and insightful analyses of the factors influencing energy emissions and economic dynamics in the United States and Canada.

2.2. Estimation Technique

To investigate the long-term and short-term relationships between the series, this study used the ARDL-bound testing approach introduced by Pesaran et al. (2001). In this analysis, the relationship between GDP per capita growth and gross fixed capital formation (representing domestic investment) with CO2 emissions in Canada and the USA is deemed crucial, as these factors contribute significantly to the gross national product. The ARDL model has gained prominence in recent years owing to its advantages over other econometric models. One notable advantage is its ability to accommodate variables with different orders of integration, namely I (0) and I (1), and to handle limited sample sizes effectively (Tong et al., 2020; Mohammed & Ruslee, 2015). The specification of the ARDL model for this study is in Equation 2. However, the estimation method employed is consistent for both countries (Canada and the US), using the same set of variables. This approach ensures comparability and allows for a comprehensive examination of the relationship between economic factors and CO2 emissions in both nations.

$$\Delta CO2_t = a + \sum_{i=1}^{k} \delta_i \, \Delta CO2_{t-i} + \sum_{i=1}^{\rho} \phi_i \, \Delta FFC_{t-i} + \sum_{i=1}^{\tau} \varrho_i \, \Delta TOP_{t-i} + \sum_{i=1}^{\varsigma} \varphi_i \, \Delta GFCF_{t-i} + \sum_{i=1}^{\sigma} \theta_i \, \Delta GDPPC_{t-i} + \sum_{i=1}^{\pi} \delta_i \, \Delta FDI_{t-i} + \varepsilon_t \quad (2)$$

In the assessment of ARDL bound testing cointegration, the methodology proposed by Pesaran & Shin (1999) is employed. This approach uses Wald statistics within the model to assess the significance of variable lag coefficients. The F-statistic, derived from the correlation coefficient in the F-test, is then compared to the critical value of the ARDL cointegration coefficient. This critical value is determined based on the maximum asymptotic spread of the F-statistic, aiding in the decision to accept or reject the null hypothesis (Pesaran et al., 2001). However, due to the smaller sample size selected for analysis, it becomes imperative to compare the model's F-statistic value with the threshold value suggested by Narayan (2005) for the asymptotic distribution of the F-statistic. This adjustment ensures that the conclusions drawn from the analysis are robust and reliable even with the limitations posed by the sample size. The expression for ARDL bound testing cointegration is presented in Equation 3, encapsulating the statistical framework utilized to assess the presence of cointegration among the variables under consideration.

$$\Delta CO2_t = a + \sum_{i=1}^{k} \delta_i \Delta CO2_{t-i} + \sum_{i=1}^{\rho} \phi_i \Delta FFC_{t-i} + \sum_{i=1}^{\tau} \varrho_i \Delta TOP_{t-i} + \sum_{i=1}^{\varsigma} \varphi_i \Delta GFCF_{t-i} + \sum_{i=1}^{\sigma} \theta_i \Delta GDPPC_{t-i} + \sum_{i=1}^{\pi} \epsilon_i \Delta FDI_{t-i} + \lambda_1 CO2_{t-1} + \lambda_2 FFC_{t-1} + \lambda_3 TOP_{t-1} + \lambda_4 GFCF_{t-1} + \lambda_5 GDPPC_{t-1} + \lambda_6 FDI_{t-1} + \varepsilon_t \quad (3)$$

In this context, δ, ϕ, ϱ, φ, and ϵ stand for the short-term parameters to be calculated, while $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, and\ \lambda_6$ denote the long-run relationship. The determination of cointegration hinges on rejecting the null hypothesis, which asserts that $(\lambda_1{}^1 \lambda_2{}^1\ \lambda_3{}^1\ \lambda_4{}^1 \lambda_5{}^1 \lambda_6 = 0)$ are not all equal to zero. During ARDL bound testing, the confirmation of a cointegration relationship among variables occurs when the F-statistic of the estimated model surpasses the highest critical value listed for I (1) in the model's critical values table. Conversely, if it falls below the lowest critical bound for I (0), it indicates the absence of a cointegration relationship. However, it's important to estimate the error correction model due to the presence of at least one causal relationship among the variables, as indicated by the F-statistic of the long-run estimation and the error correction model lag. The short-run economic activity parameters are deduced by estimating the error-correction model concerning the long-run estimation. The error correction estimated model is in Equation 4.

$$\Delta CO2_t = a + \sum_{i=1}^{k} \delta_i \Delta CO2_{t-i} + \sum_{i=1}^{\rho} \phi_i \Delta FFC_{t-i} + \sum_{i=1}^{\tau} \varrho_i \Delta TOP_{t-i} + \sum_{i=1}^{\varsigma} \varphi_i \Delta GFCF_{t-i} + \sum_{i=1}^{\sigma} \theta_i \Delta GDPPC_{t-i} + \sum_{i=1}^{\pi} \delta_i \Delta FDI_{t-i} + \Omega ECT_{t-1} + \varepsilon_t \quad (4)$$

where ΩECT_{t-1} represents the error correction term to be estimated. The symbol Ω signifies the pace of adjustment dynamics from the short run to the long run equilibrium.

However, as per the ARDL error correction model criteria, the error correction coefficient must be negative and statistically significant to establish a long-run relationship.

3. Research results

The descriptive statistics for all observations of both countries are displayed in Tables 1 and 2. Table 1 delineates the results for the US, while Table 2 corresponds to Canada. The data in Table 1 reveals that the mean gross fixed capital formation exhibits the highest value among the selected variables. However, the means of CO2 emissions, fossil fuel consumption, trade openness, GDP per capita growth, and FDI are relatively close, suggesting a low degree of variability among them. Specifically, the average CO2 emissions in the US amount to 2.88 metric tons per capita annually, while the gross fixed capital formation stands at 21 percent. These statistics provide the central tendencies and variability of the variables under examination, offering a foundational understanding of their distribution and characteristics within the respective countries. The correlation matrix presented in

Table 1 reveals relationships within the US economy. Firstly, the coefficient value of fossil fuel consumption (FFC) stands at 0.921, indicating a strong positive correlation with CO2 emissions.

Table 1. Descriptive Statistics and Pairwise Correlation Matrix-USA.

Parameters	CO_2	FFC	TOP	GFCF	GDPPC	FDI
Mean	2.875	4.428	3.213	21.00	3.595	1.602
Median	2.944	4.448	2.216	21.00	3.720	1.505
Maximum	3.018	4.459	3.428	23.00	10.530	3.410
Minimum	2.567	4.291	2.985	18.00	-2.830	0.460
Std.Dev	0.126	0.040	0.134	1.295	2.321	0.752
Skewness	-0.733	-1.811	-0.096	-0.090	-0.377	0.065
Kurtosis	2.280	5.811	1.983	2.461	6.274	2.811
Jarque-Bera	3.557	28.03	1.425	0.430	15.05	2.303
Probability	0.168	0.001	0.490	0.806	0.000	0.316
Sum	92.02	141.71	102.81	672.00	115.06	51.29
Sum Sq. Dev	0.498	0.050	0.564	52.00	167.09	17.56
Observation	32	32	32	32	32	32
Correlation matrix						
CO_2	1.000					
FFC	0.921	1.000				
TOP	-0.505	-0.319	1.000			
GFCF	0.458	0.253	-0.189	1.000		
GDPPC	0.233	-0.204	-0.057	0.347	1.000	
FDI	0.022	-0.025	0.472	0.316	0.201	1.000

Source: created by authors.

This suggests that higher levels of fossil fuel consumption are associated with increased CO2 emissions. Conversely, trade openness demonstrates a negative moderate association (coefficient of 0.505) with CO2 emissions, implying that greater trade openness is correlated with lower CO2 emissions.

Table 2. Descriptive Statistics and Pairwise Correlation Matrix-Canada.

Parameters	CO_2	FFC	TOP	GFCF	GDPPC	FDI
Mean	2.758	74.484	66.176	21.625	3.238	2.805
Median	2.757	74.715	66.165	22.000	2.915	2.285
Maximum	2.855	76.550	82.770	24.000	20.780	9.170
Minimum	2.610	71.700	49.220	18.000	-14.440	0.140
Std.Dev	0.053	1.254	7.964	1.913	8.112	1.957
Skewness	-0.369	-0.391	-0.040	-0.236	0.080	1.615
Kurtosis	3.333	2.332	3.007	1.593	2.822	6.026
Jarque-Bera	0.876	1.412	0.009	2.935	0.076	26.122
Probability	0.645	0.493	0.995	0.230	0.962	0.000
Sum	88.28	2383	2117	692.1	103.2	89.77
Sum Sq. Dev	0.088	48.76	1966	113.5	2043	118.7
Observation	32	32	32	32	32	32
Correlation matrix						
CO_2	1.000					
FFC	0.532	1.000				
TOP	0.586	0.574	1.000			
GFCF	-0.069	0.171	-0.239	1.000		
GDPPC	0.445	0.257	0.158	0.002	1.000	
FDI	0.465	0.317	0.509	0.223	0.099	1.000

Source: created by authors.

The coefficient for gross fixed capital formation (GFCF) is 0.458, indicating a minimal positive linkage with CO2 emissions. This suggests that higher levels of domestic investment may lead to slightly increased CO2 emissions. Additionally, the GDP per capita growth rate exhibits a weak positive relationship with CO2 emissions, while foreign direct investment (FDI) displays the weakest correlation with the dependent variable. However, in Table 2, which depicts the descriptive statistics for Canada, indicate that CO2 emissions, GDP per capita, and FDI display closely clustered mean values, indicating lower variability among these variables. The average CO2 emissions per capita annually amount to 2.758 metric tons. Fossil fuel consumption boasts the highest mean value at 74.48%, followed by trade openness at 66.18%, and gross fixed capital formation at 21.63% yearly. In the context of Canada, the correlation coefficients between fossil fuel consumption and CO2 emissions (0.532), as well as between trade openness and CO2 emissions (0.586), indicate a moderate positive relationship. This suggests that higher levels of fossil fuel consumption and trade openness are associated with increased CO2 emissions in Canada. Conversely, the coefficients for GDP per capita (0.445) and FDI (0.465) display a medium-weak association with energy emissions. This indicates that while there is a positive relationship between GDP per capita growth and FDI with CO2 emissions, the strength of this relationship is relatively weaker compared to fossil fuel consumption and trade openness. Interestingly, the coefficient for gross fixed capital formation (-0.069) exhibits a negative and weakest relationship with CO2 emissions in the Canadian economy. This suggests that higher levels of domestic investment in fixed capital may be associated with slightly lower CO2 emissions. However, the strength of this relationship is shows weaker compared to other factors such as fossil fuel consumption and trade openness.

3.1. Stationarity test

Before applying the ARDL bound test for cointegration, the unit root tests proposed by Dickey & Fuller (1981) and Phillips & Perron (1988) were utilized to assess the characteristics of the selected variables. These tests are instrumental in determining the order of integration for the time series data, providing insights into their stationarity properties. According to the criteria outlined by Dickey & Fuller (1981) and Phillips & Perron (1988), a unit root is considered present when the asymptotic p-value exceeds the 5% critical value. The inclusion of an intercept term in these tests enables an examination of the underlying dynamics within the series. Upon conducting the unit root tests at a 5% significance level, it was observed that all variables were found to be non-stationary and integrated at the first difference. The results of the stationarity test are presented in Tables 3 and 4.

Table 3. Unit root test-USA.

Variable	Level	ADF	PP	Variable	Level	ADF	PP
CO_2	0	1.595	0.314	GFCF	0	-2.362	-1.789
CO_2	1	-7.061***	-6.212***	GFCF	1	-3.974***	-3.866***
FFC	0	2.487	-0.617	GDPPC	0	-4.952***	-4.959***
FFC	1	-13.450***	-7.230***	FDI	0	-3.662***	-2.439
TOP	0	-1.929	-1.851	FDI	1	-5.599***	-9.197***
TOP	1	-5.975***	-6.096***				

Note: ***1%.
Source: created by authors.

Specifically, Table 3 illustrates the outcomes of the unit root tests for the variables about the US. The tests indicated that CO2 emissions, fossil fuel consumption, trade openness, and gross fixed capital formation were non-stationary at the levels, necessitating the application of first differencing to achieve stationarity. However, for FDI, while the ADF test at the level suggested stationarity, the Phillips-Perron (PP) test yielded contrary results, indicating non-stationarity. Therefore, the first differencing was employed to ensure that FDI is fully integrated at order one. Additionally, the variable GDP per capita was found to be stationary at the level, suggesting it follows an I (0) process.

Table 4. Unit root test-Canada.

Variable	Level	ADF	PP	Variable	Level	ADF	PP
CO_2	0	-1.753	-1.680	GFCF	0	-0.836	-0.962
CO_2	1	-6.294***	-6.303***	GFCF	1	-5.236***	-6.276***
FFC	0	-2.082	-2.072	GDPPC	0	-3.953***	-3.952***
FFC	1	-6.053***	-6.034***	FDI	0	-4.142***	-2.807*
TOP	0	-2.091	-2.188	FDI	1	-5.154***	-10.300***
TOP	1	-3.678***	-3.702***				

Note: ***1%, *10%.
Source: created by authors.

Upon applying the same unit root tests to the variables for Canada, the findings mirrored those obtained for the US, as illustrated in Table 4. The results of the stationarity test revealed that the variables exhibit a mixture of order one integration I (1) and order zero integration I (0). This suggests that some variables require first differencing to achieve stationarity, while others are already stationary in their original form. This outcome implies that the ARDL model can indeed be applied to the dataset for Canada, similar to the situation observed for the US. The presence of both I (0) and I (1) variables indicates that the dataset possesses the necessary characteristics for the ARDL framework, enabling the investigation of long-term relationships among the variables while accounting for short-term dynamics.

3.2. ARDL-bound test of cointegration

In examining the presence of long-term cointegration among the variables, the ARDL bound test is employed. Before conducting the ARDL bound test, it is crucial to select an appropriate lag length to ensure the accuracy of the results. To accomplish this, difference estimation equations are formulated using various information criteria, and the most suitable one is chosen. In this study, the Akaike Information Criterion (AIC) is utilized due to its efficiency in optimizing expected outcomes. The AIC is renowned for its consistency and effectiveness in capturing changes in the relationships between variables. Tables 5 and 6 present the outcomes of the bound test for cointegration. Drawing upon theories from Pesaran et al. (2001) and Narayan (2005), a common approach is adopted in this study. However, given the limited number of observations utilized, the study leans towards Narayan's (2005) method to determine the existence of cointegration among the variables. In this framework, the null hypothesis posits no long-run cointegration, which is indicated by an F-statistic coefficient lower than the 5% upper critical value. As demonstrated in Tables 5 and 6, the F-statistic of CO2 exceeds the upper critical value, suggesting a long-term relationship among the variables.

Table 5. ARDL Bound test cointegration results-USA.

Test Statistic	Value	Significance	I (0)	I (1)
F-statistic	8.630	10%	2.08	3.00
		5%	2.39	3.38
		1%	3.06	4.15

Note: AIC selection criterion (1,0,2,2,1,2) for optimum lag selection.
Source: created by authors.

This implies that CO2 emissions, fossil fuel consumption, gross fixed capital formation, GDP per capita, FDI, and trade openness exhibit long-term interdependence.

Table 6. ARDL Bound test cointegration results-Canada.

Test Statistic	Value	Significance	I (0)	I (1)
F-statistic	19.263	10%	2.08	3.00
		5%	2.39	3.38
		1%	3.06	4.15

Note: AIC selection criterion (4,1,0,3,3,3) for optimum lag selection.
Source: created by authors.

3.3. ARDL results for the US

Table 7 indicates both the long and short-run coefficients of the variables, along with an adjusted R-squared value indicating that 98% of the variation in the dependent variable is explained by the explanatory variables.

Table 7. ARDL results-USA.

Long Run	Coefficient	Std. Error	t-statistic	Prob.
FFC	2.720***	0.216	12.540	0.000
TOP	-0.314***	0.059	-5.254	0.000
GFCF	0.021***	0.007	3.124	0.006
GDPPC	-0.014	0.105	-1.352	0.195
FDI	0.006	0.012	0.528	0.604
Constant	-8.586***	1.055	-8.131	0.000
		Short Run		
ΔTOP	0.090*	0.051	1.764	0.096
ΔTOP (-1)	-0.118**	0.048	-2.439	0.026
ΔGFCF	0.011**	0.004	2.489	0.024
ΔGFCF (-1)	0.010***	0.003	2.950	0.009
ΔGDPPC	-0.002	0.001	-1.538	0.143
ΔFDI	0.001	0.004	0.261	0.796
ΔFDI (-1)	0.021***	0.004	4.950	0.000
ECT (-1)	-0.634***	0.069	-9.114	0.000
Diagnostic test				
χ^2 Reset			0.441	0.516
χ^2 Normality			0.114	0.944
χ^2 Serial correlation			1.014	0.388
χ^2 ARCH			2.025	0.153

Note: ***1%, **5%, *10%; AIC (1,0,2,2,1,2); Adjusted R^2 =0.98; DW = 2.075. χ^2 Normality – normality test for residuals, χ^2 Serial, LM serial correlation test, χ^2 Arch, autoregressive conditional heteroscedasticity, χ^2 Reset, Ramsey reset test. The probability values are provided in parentheses.
Source: created by authors.

The analysis reveals intriguing details, particularly regarding the variable of trade openness and its relationship with CO2 emissions in the US economy. In the short run, the coefficient of trade openness demonstrates a mixed positive and negative effect on CO2 emissions. The short run coefficient (0.09) suggests a positive relationship, indicating that an increase in trade openness initially corresponds to a rise in CO2 emissions. This could be attributed to heightened economic activity and increased production accompanying greater trade integration. However, the subsequent coefficient (0.12) of trade openness exhibits a negative effect on CO2 emissions in the short run, suggesting a reversal in the relationship after a lag of one year. This reversal may stem from factors such as technological advancements, efficiency gains, or adjustments in production processes, which could mitigate the environmental impact of trade over time. Remarkably, in the long run, the coefficient (0.31) of trade openness unveils a negative association with CO_2 emissions. This suggests that as economies become more open to trade over time, there emerges a mitigating effect on CO_2 emissions. This phenomenon could be linked to mechanisms such as the diffusion of cleaner technologies, the adoption of more stringent environmental regulations spurred by international trade agreements or shifts in consumption patterns towards less carbon-intensive goods. These findings emphasize the complex connection between globalization, economic development, and environmental sustainability. While trade openness may initially exacerbate environmental pressures, particularly in the short term, the observed long-term negative relationship suggests the potential for trade integration to act as a catalyst for environmental improvement. This aligns with the Environmental Kuznets Curve hypothesis, which posits that environmental degradation initially worsens with economic growth but eventually improves as societies reach higher income levels and prioritize environmental protection.

However, the insignificant short and long-run coefficient of GDP per capita growth shows a negative relationship with CO_2. In the short run, the first difference and one-period lag coefficients (0.01) and (0.01) of gross fixed capital formation have a positive relationship with CO_2. It implies that an increase in gross fixed capital formation leads to an expansion in CO_2. On the other hand, the coefficient (0.02) of gross fixed capital formation has a positive association with CO_2 in the long run. It shows that a rise in gross fixed capital formation leads to an increase in CO_2 in the long run. In the short run, the observed positive correlation between the one-period lag coefficients of gross fixed capital formation (0.01) and CO_2 emissions unveils a dynamic relationship between investment in physical assets and environmental outcomes. This suggests that in the immediate aftermath of an increase in gross fixed capital formation, there is a corresponding expansion in CO_2 emissions. This finding emphasizes, the inherent carbon intensity often associated with the initial stages of economic development and investment-driven growth trajectories. The positive association between capital formation and CO_2 emissions in the short run may stem from factors such as increased industrial activity, infrastructure development, and energy consumption, all of which tend to exert upward pressure on carbon emissions. Conversely, the long-run coefficient (0.02) of gross fixed capital formation reveals a sustained positive association with CO_2 emissions over extended periods. This indicates that as economies undergo structural transformations and mature over time, higher levels of investment in fixed capital continue to drive up CO_2 emissions. This phenomenon can be attributed to the persistence of carbon-intensive production processes, the expansion of energy-intensive industries, and the lagged effects of infrastructure investments on emissions. Additionally, the long-term positive relationship between gross fixed capital formation and CO_2 emissions underlines the challenges associated with decoupling economic growth from environmental degradation, particularly in the context of capital-intensive development pathways. The coefficient of (0.02) of FDI shows a positive relationship with CO_2 in the short run. This implies that an expansion in FDI inflows increases CO_2 in the short run. This finding reflects the immediate impact of FDI on economic activities that are typically energy-intensive or carbon-emitting, such as manufacturing or heavy industries. In the short term, the influx of foreign investment may stimulate production and industrial activities, thereby driving up carbon emissions. On the contrary, the positive long-run coefficient of FDI is not statistically significant which shows that it does not influence CO_2. This implies that the influence of foreign direct investment on CO_2 emissions is not robust over extended periods. Several factors could contribute to this outcome, including the potential for technological advancements, changes in production processes, or shifts in consumption patterns that mitigate the environmental impact of FDI over time. Furthermore, there is a possibility that other intervening variables or structural changes in the economy may dampen the long-term relationship between FDI and CO2 emissions. The coefficient (2.72) of fossil fuel consumption indicates a positive connection with CO2 in the long run. It shows that an increase in fossil fuel consumption expands CO2 emission in the long term in the US economy. The coefficient of fossil fuel consumption signifies a robust positive relationship with CO2 emissions in the long run. This finding shows the significant impact of fossil fuel consumption on carbon dioxide emissions within the US economy over extended periods. As fossil fuels remain the primary source of energy for various sectors such as transportation, industry, and electricity generation, an increase in their consumption invariably leads to higher CO2 emissions. This positive association between fossil fuel consumption and CO2 emissions reflects the carbon-intensive nature of the US economy's energy infrastructure and highlights the challenges associated with transitioning to cleaner and more sustainable energy sources. The ARDL error correction coefficient (-0.634) indicates that when a deviation occurs the target variable has to adjust by 63.4% annually. This coefficient reflects the speed at which the system returns to its equilibrium state following a shock or disturbance. In this case, a negative coefficient indicates that the adjustment process is towards restoring equilibrium, with a magnitude indicating the pace of adjustment.

3.4. ARDL outcome for Canada

Table 8 presents the estimated long- and short-run coefficients of the selected variables from the ARDL model, along with an adjusted R-squared value indicating that 97% of the variation in the dependent variable is explained by the regressors.

Table 8. ARDL results-Canada.

Long Run	Coefficient	Std.Error	t-statistic	Prob.
FFC	-0.134*	0.064	-2.154	0.063
TOP	0.030*	0.014	2.030	0.076
GFCF	0.042*	0.019	2.140	0.064
GDPPC	0.022**	0.001	2.596	0.032
FDI	0.055*	0.027	2.071	0.072
Constant	9.896**	3.434	2.881	0.021
		Short Run		
Δ CO_2 (-1)	-0.330***	0.073	-4.563	0.002
Δ CO_2 (-2)	0.256***	0.075	3.416	0.009
Δ CO_2 (-3)	-0.715***	0.081	-8.778	0.000
ΔFFC	-0.011***	0.002	-4.517	0.002
ΔGFCF	0.005**	0.002	2.404	0.043
ΔGFCF (-1)	0.006**	0.002	3.201	0.012
ΔGFCF (-2)	-0.004	0.002	-1.679	0.132
ΔGDPPC	0.003***	0.000	15.395	0.000
ΔGDPPC (-1)	-0.002***	0.000	-6.123	0.000
ΔGDPPC (-2)	-0.001***	0.000	-5.274	0.000
ΔFDI	0.002**	0.001	2.954	0.018
ΔFDI (-1)	-0.013***	0.001	-10.419	0.000
ΔFDI (-2)	-0.012***	0.002	-8.767	0.000
ECT (-1)	-0.247***	0.016	-15.361	0.000
Diagnostic test				
χ^2 Reset			0.362	0.728

Long Run	Coefficient	Std.Error	t-statistic	Prob.
χ^2 Normality			1.639	0.441
χ^2 Serial correlation			0.136	0.722
χ^2 ARCH			1.836	0.172

Note: ***1%, **5%, *10%; AIC (4,1,0,3,3,3); Adjusted R^2 =0.97; DW=2.145; χ^2 Normality – normality test for residuals, χ^2 Serial – LM serial correlation test; χ^2 Arch – autoregressive conditional heteroscedasticity; χ^2 Reset – Ramsey reset test. The probability values are provided in parentheses.
Source: created by authors.

The analysis shows the dynamics of CO2 emissions in the Canadian economy. In the short run, the coefficients of the one-period lag and previous 3-years of CO2 emissions exhibit a negative influence on the current CO2 emissions, with coefficients of 0.33 and 0.72, respectively. This suggests a counterintuitive trend within the Canadian economy, where recent and relatively distant past levels of CO2 emissions exert a dampening effect on present emissions. Conversely, the coefficient of the two-period lag of CO2 emissions shows a positive relationship with present CO2 emissions in the short term, with a coefficient of 0.26. This suggests a delayed rebound effect, wherein CO2 emissions from two years ago positively influence current emissions. This could include delayed impacts of economic activities on emissions or the persistence of carbon-intensive practices despite efforts to mitigate emissions. Furthermore, the coefficient of fossil fuel consumption exhibits a negative short-run relationship with CO2 emissions, indicating that an expansion in fossil fuel consumption decreases CO2 emissions in the short term. This unexpected finding may be attributed to temporary shifts in energy consumption patterns or short-term fluctuations in economic activity affecting emissions levels. In contrast, the negative long-run coefficient of fossil fuel consumption suggests a more consistent and sustained relationship with CO2 emissions over extended periods. This indicates that as fossil fuel consumption increases in the long term, there is a corresponding decline in CO2 emissions within Canada's economy. This may include the adoption of cleaner technologies, improvements in energy efficiency, or shifts towards renewable energy sources, gradually reducing the carbon intensity of fossil fuel consumption over time.

However, as indicated in Table 8, the first different and previous 2-year coefficients (0.01) and (0.01) of gross fixed capital formation have positive short-run association with CO2 in the short run. It implies that an increase in gross fixed capital formation expands the CO2 in the short term. On the contrary, the gross fixed capital formation coefficient (0.04) has a positive association with CO2 in the long term. This means that in the long run, an increase in fixed capital formation leads to a rise in CO2 in Canada. The positive short-run association observed between the first difference and the previous 2-year coefficients of gross fixed capital formation and CO2 emissions suggests that an increase in gross fixed capital formation contributes to an expansion of CO2 emissions in the short term within Canada's economy. This indicates that immediate increases in investment in physical assets, such as infrastructure or machinery, tend to lead to higher levels of CO2 emissions. This relationship likely arises due to the energy-intensive nature of construction activities or industrial production processes associated with capital formation. Conversely, the positive long-run coefficient of gross fixed capital formation reveals a sustained positive association with CO2 emissions over extended periods. This implies that in the long term, as the accumulation of fixed capital continues, there is a corresponding increase in CO2 emissions within Canada. This long-term trend may be attributed to factors such as the persistent use of carbon-intensive technologies, the expansion of energy-intensive industries, or the lagged effects of infrastructure investments on emissions.

However, the first difference in GDP per capita coefficient (0.003) has a positive relationship with CO_2 in the short run. On the other hand, the previous one-year and two-year GDP per capita coefficients (0.002) and (0.001) have a negative association with CO_2 emissions. In the long run, the GDP per capita coefficient (0.02) has a positive connection with CO_2. The positive short-run relationship observed between the first difference in GDP per capita coefficient and CO_2 emissions suggests that an increase in GDP per capita leads to higher CO_2 emissions in the short term within the economy. This finding indicates that immediate increases in economic activity and prosperity tend to be accompanied by higher levels of CO_2 emissions, likely due to increased consumption, industrial production, and energy usage. Conversely, the negative association between the previous one-year and two-year GDP per capita coefficients (0.002 and 0.001, respectively) and CO_2 emissions implies that in the short term, past levels of GDP per capita are associated with lower CO_2 emissions. This suggests a lagged effect wherein improvements in economic efficiency or shifts in consumption patterns may lead to reduced emissions over time. In the long run, the positive connection between the GDP per capita coefficient and CO_2 emissions indicates that as the economy grows and becomes more prosperous over extended periods, there is a corresponding increase in CO_2 emissions. This long-term trend may be attributed to factors such as increased energy consumption, industrialization, and transportation needs associated with economic development. Conversely, the first difference in the FDI coefficient (0.002) has a positive short-run relationship with carbon dioxide emission. The previous one-year and two-year coefficients (0.01) and (0.01) of FDI have a negative linkage with CO_2 in the short term. In the long run, the FDI coefficient (0.06) has a positive association with CO_2.The positive short-run relationship observed between the first difference in FDI coefficient (0.002) and carbon dioxide emissions indicates that an increase in foreign direct investment leads to higher CO_2 emissions in the short term. This finding suggests that immediate inflows of foreign investment may stimulate carbon-intensive economic activities, such as industrial production or infrastructure development, resulting in higher emissions. Conversely, the negative linkage between the previous one-year and two-year coefficients of FDI (0.01) and CO_2 emissions in the short term implies that past levels of foreign direct investment are associated with lower CO_2 emissions. This suggests a lagged effect wherein previous investments in cleaner technologies or shifts in production processes may lead to reduced emissions over time. In the long run, the positive association between the FDI coefficient (0.06) and CO_2 emissions suggests that as foreign direct investment accumulates over extended periods, there is a corresponding increase in CO_2 emissions. This long-term trend may be attributed to factors such as the adoption of carbon-intensive technologies, the expansion of energy-intensive industries, or the increasing demand for transportation and infrastructure associated with foreign investment-driven economic growth. Additionally, in the long run, the trade openness coefficient (0.03) has a positive relationship with carbon dioxide. The positive relationship between the trade openness coefficient (0.03) and carbon dioxide emissions in the long run indicates that as trade openness increases over extended periods, there is a corresponding rise in CO_2 emissions. This finding suggests that the integration of economies through trade may lead to increased economic activity and industrial production, resulting in higher emissions of carbon dioxide. Several factors may contribute to this long-term positive association between trade openness and CO_2 emissions. For instance, increased trade may lead to higher energy consumption for transportation and logistics, as well as increased production in carbon-intensive industries to meet growing demand from international markets. Additionally, trade liberalization may lead to the relocation of industries to countries with less stringent environmental regulations, resulting in higher emissions. The error correction coefficient (-0.247) indicates that in terms of a disequilibrium, the target variable has to adjust 24.7% per annum. This coefficient quantifies the speed at which the system returns to its long-run equilibrium following a deviation. This means that the system adjusts relatively slowly to deviations from its long-run equilibrium, with only a fraction of the gap being closed each year.

3.5. Models stability Diagnostic

The results from the recursive tests indicate that the estimated models in this study demonstrate stability and consistency. This conclusion is drawn from the observation that the lines representing the cumulative sum and cumulative sum of squares of the recursive residuals remain within the 5% critical bounds. However, the deviations of the estimated model's parameters from their expected values do not exhibit significant departures over time, suggesting that the model remains reliable and consistent throughout the analysis period. This stability and consistency of the estimated model are crucial for ensuring the validity and robustness of the findings and conclusions drawn from the analysis. It provides confidence in the reliability of the estimated relationships between the variables and enhances the credibility of the study's results. Figures 1 (a,b) show the recursive CUSUM and recursive CUSMSQ tests for the ARDL estimated results for the US economy while Figures 1 (c,d) are for Canada.

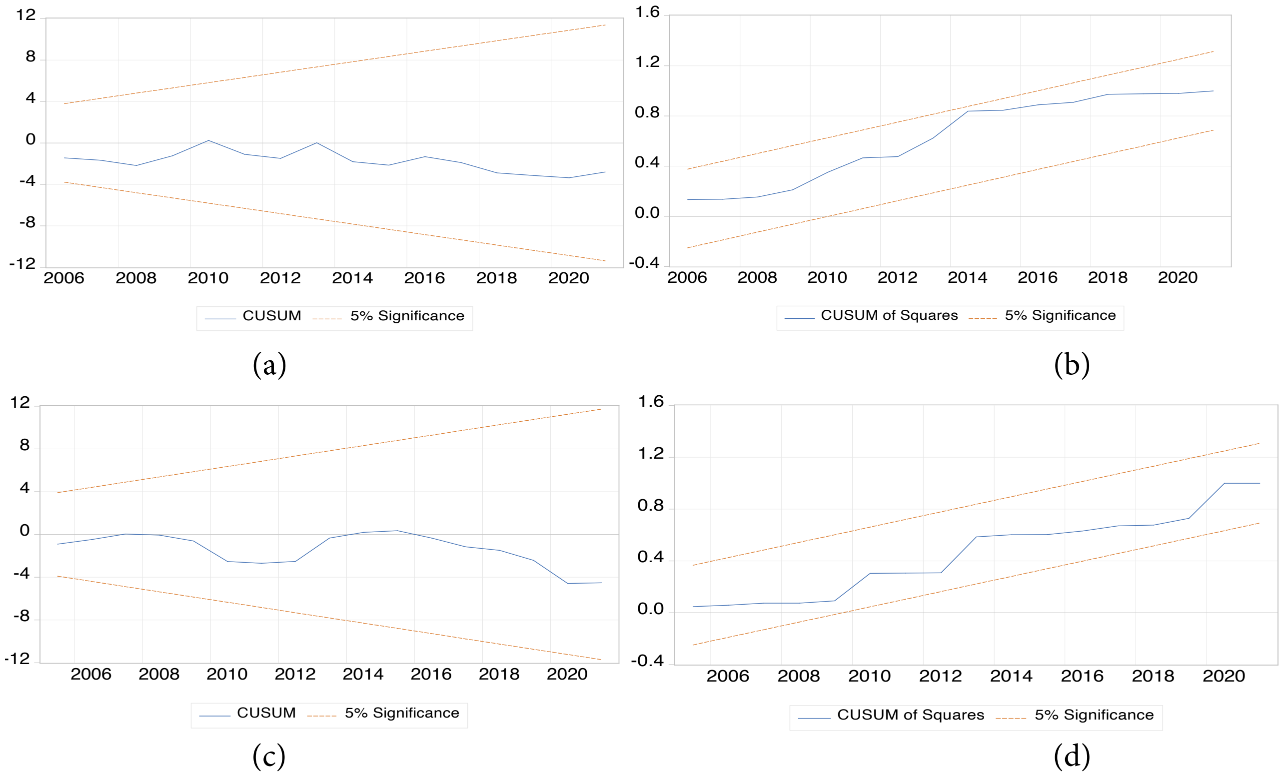

Figure 1. Cumulative sum of recursive residuals and squares of recursive residuals for USA (a and b) and Canada (c and d).

Source: created by authors.

3.6. Granger causality test

The outcomes of the Granger causality test in Tables 9 and 10 are for the US and Canada, respectively. In the context of the Granger (1969) causality test, the null hypothesis states that no causality exists between the variables under consideration. This null hypothesis is rejected when the

F-statistics p-value falls below a predetermined significance level, typically set at 0.1. If the p-value is below this threshold, it indicates that there is sufficient evidence to reject the null hypothesis, suggesting the presence of causal relationships between the variables. By employing the Granger causality test with a significance level of 0.1, helps to determine whether one variable can be considered a predictor of another, thereby informing decision-making processes and policy formulation. This helps in understanding the dynamics of the system under study and aids in making informed choices regarding future actions and interventions. However, the outcome of the Granger causality in Table 9 for the US, shows that there is a bidirectional causality relationship between fossil fuel consumption and CO2 emissions. This indicates that changes in fossil fuel consumption can lead to changes in CO2 emissions, and vice versa. This finding shows the intertwined nature of these variables, where the combustion of fossil fuels contributes significantly to carbon dioxide emissions, while the resulting emissions, in turn, reflect the level of fossil fuel consumption. The findings established a unidirectional causal relationship running from trade openness to CO2 emissions. This suggests that changes in trade openness can influence CO2 emissions. The unidirectional nature of this causality relationship implies that factors related to trade openness, such as increased economic activity or changes in production patterns due to trade integration, have a discernible impact on carbon dioxide emissions.

Table 9. Granger causality test results-US.

Null Hypothesis	F-Statistic	Prob.	Decision
FFC does not Granger Cause CO2	7.272	0.011	Rejected
CO2 does not Granger Cause FFC	12.937	0.000	Rejected
TOP does not Granger Cause CO2	7.498	0.010	Rejected
CO2 does not Granger Cause TOP	0.141	0.711	Not rejected
GFCF does not Granger Cause CO2	0.091	0.764	Not rejected
CO2 does not Granger Cause GFCF	0.158	0.693	Not rejected
GDPPC does not Granger Cause CO2	2.739	0.109	Not rejected
CO2 does not Granger Cause GDPPC	0.010	0.919	Not rejected
FDI does not Granger Cause CO2	2.148	0.153	Not rejected
CO2 does not Granger Cause FDI	0.031	0.861	Not rejected

Source: created by authors.

However, the outcome Granger causality test for Canada in Table 10, shows a unidirectional causality running from fossil consumption to carbon dioxide emission in the Canadian economy.

Table 10. Granger causality test results-Canada.

Null Hypothesis	F-Statistic	Prob.	Decision
FFC does not Granger Cause CO2	4.024	0.031	Rejected
CO2 does not Granger Cause FFC	1.838	0.179	Not rejected
TOP does not Granger Cause CO2	1.478	0.247	Not rejected
CO2 does not Granger Cause TOP	4.924	0.015	Rejected
GFCF does not Granger Cause CO2	2.049	0.149	Not rejected
CO2 does not Granger Cause GFCF	0.487	0.619	Not rejected
GDPPC does not Granger Cause CO2	0.501	0.611	Not rejected
CO2 does not Granger Cause GDPPC	1.704	0.202	Not rejected
FDI does not Granger Cause CO2	0.298	0.744	Not rejected
CO2 does not Granger Cause FDI	1.481	0.246	Not rejected

Source: created by authors.

This finding suggests that changes in fossil fuel consumption led to corresponding changes in carbon dioxide emissions, indicating the significant role of fossil fuels in driving greenhouse gas emissions within the Canadian economy. The results revealed a unidirectional causality from CO2 emissions to trade openness. This indicates that changes in carbon dioxide emissions influence trade openness. This relationship emphasizes the potential impact of environmental factors, particularly carbon emissions, on trade dynamics within the Canadian economy.

4. Discussion

The empirical results from both short- and long-run estimations and the Granger causality tests reveal consistent implications. They suggest that the use of fossil fuels as an energy source significantly influences CO2 emissions. Specifically, a 1% increase in fossil fuel energy usage is associated with a subsequent long-term increase in CO2 emissions in the USA. However, in Canada, the findings indicate that both short-term and long-term fossil fuel energy use is associated with a reduction in CO2 emissions. These findings align with previous studies by Chen et al. (2019), Zhang et al. (2019), Li & Haneklaus (2021), and Liu (2021), which examined the significant positive influence of non-renewable energy on China's CO2 emissions. Similarly, Munir & Riaz (2020), Abokyi et al. (2021), and Lin & Agyeman (2019) have established a significant association between fossil fuels and carbon emissions generation in cross-country analyses involving the United States. Conversely, the negative impact of fossil fuel on CO2 emissions in Canada validates the results of Ehigiamusoe (2020), who found a negative relationship with CO2 in African countries. According to the ARDL output, economic growth has a significant impact on pollution levels primarily in the long run in Canada, where it materially increases pollution over time. In the short run, economic growth in Canada positively and negatively influences CO2 emissions. However, in the United States, there is no significant effect of economic growth on CO2 emissions observed in either the short run or the long run. The current study's findings regarding the impact of GDP on CO2 emissions align with the results of a similar study by Adeleye et al. (2021), which also found a significant positive effect of GDP on CO2 emissions in both the short run and long run. These findings support the Environmental Kuznets Curve (EKC) hypothesis, suggesting that as economies develop, environmental degradation initially worsens but eventually improves as income levels rise.

The Granger causality checks also indicate a bidirectional causality between CO2 and fossil fuel emissions in the United States, while a unidirectional causality is observed between fossil fuel and CO2 emissions in Canada. This finding is consistent with previous research by Minlah & Zhang (2021), which similarly identified a unidirectional causality between these variables. However, the estimated results show that while FDI does not have a significant influence on CO2 emissions in the long run in the United States, it does have a positive short-run effect. Conversely, in Canada, FDI has a positive impact on CO2 emissions in the long run, but its effects are mixed in the short run, with both positive and negative effects observed. The Granger causality test found no causal relationship between FDI and CO2 emissions in both countries. These findings contradict the outcomes from studies by Salahuddin et al. (2018) and Sarkodie (2018), which found a unidirectional causality between FDI and CO2. Trade openness has a negative impact on CO2 emissions in the long run in the United States, while exhibiting a mixed positive and negative influence in the short run. Conversely, in Canada, there is a positive effect of trade openness on CO2 emissions in the long run. The Granger causality test found a unidirectional relationship between CO2 and trade openness in both countries. These findings provide support for the EKC hypothesis, suggesting that as economies develop, environmental degradation initially worsens but eventually improves as income levels rise.

The findings suggest that gross fixed capital formation has significant impacts on pollution levels in both the short and long run in both economies. However, despite these observed impacts, the Granger causality test did not establish a causal relationship between gross fixed capital formation and pollution. Kobayakawa (2022) suggested that countries which prioritize investment in carbon-intensive capital formation tend to experience accelerated economic growth.

Conclusions

The study investigates the dynamic relationship among domestic investment, GDP per capita, and carbon dioxide (CO_2) emissions in the United States and Canada. Utilizing annual time series data spanning from 1990 to 2021 sourced from the World Bank, the analysis employs the Autoregressive Distributed Lag (ARDL) bound testing to cointegration approach. The findings from the bound test cointegration reveal a long-run relationship between the selected variables in both countries. In the United States, the ARDL short-run results indicate a positive relationship between FDI and gross fixed capital formation with carbon dioxide emissions, while GDP per capita shows no significant impact. However, in the long run, only gross fixed capital formation is found to positively influence CO_2 emissions, with FDI and GDP per capita growth showing no significant effects. Notably, other independent variables such as trade openness exhibit a positive short-run effect and a long-run negative relationship with CO_2 emissions, while fossil fuel consumption is found to positively impact carbon dioxide emissions. The Granger causality test established a bidirectional relationship between fossil fuel consumption and carbon dioxide while a unidirectional causality from trade openness to CO_2 emissions was found in the US. In the context of Canada, there is a positive short-run and long-term linkage observed between gross fixed capital formation and CO_2 emissions. The short-run findings also reveal a mixed positive and negative effect of FDI and GDP per capita on carbon dioxide emissions in the Canadian economy. However, in the long run, both FDI and GDP per capita are found to have a positive impact on CO_2 emissions. Conversely, fossil fuel consumption exhibits negative short- and long-term effects on carbon dioxide emissions in Canada, while a positive effect from trade openness is observed in the long run. The Granger causality test indicated a unidirectional relationship among CO_2 emissions, fossil fuel consumption, and trade openness in Canada's economy.

The study findings suggest policy interventions to address the complex dynamics between economic growth, foreign investment, and environmental sustainability in both the United States and Canada. Given the positive linkage observed between gross fixed capital formation and CO_2 emissions, policymakers should prioritize investments in renewable energy sources such as solar, wind, and hydroelectric power to mitigate carbon emissions and promote sustainable energy generation. Additionally, the mixed effects of FDI and GDP per capita on carbon dioxide emissions emphasize the importance of improving energy efficiency measures. Policies aimed at incentivizing energy-efficient technologies and practices in industries and households can help reduce carbon emissions while supporting economic growth. Furthermore, the positive effect of trade openness on carbon emissions observed in the long run in both countries calls for policies that promote sustainable trade practices. Implementing carbon pricing mechanisms, enforcing environmental regulations, and promoting eco-certifications in international trade agreements can help mitigate the environmental impact of trade activities. Moreover, given the positive relationship between fossil fuel consumption and carbon dioxide emissions, policymakers should prioritize investments in clean technologies and alternative fuels. Research and development funding for technologies such as carbon capture and storage (CCS), hydrogen fuel cells, and sustainable biofuels can facilitate the transition to a low-carbon economy. Finally, public awareness and education campaigns are essential for fostering a culture of environmental sustainability. Governments and non-governmental organizations should collaborate to raise awareness about the environmental consequences of consumption patterns, encourage sustainable lifestyle choices, and promote community-based initiatives for environmental conservation.

While the study offers significant details, it has limitations. It relies on annual data from 1990 to 2021, which may have constraints in availability and accuracy. The methodology used may not fully capture the complexity of the relationship between variables. The findings are specific to the US and Canada, limiting generalizability. Other factors influencing CO2 emissions, such as government policies and technological advancements, were not included. Alternative methodologies could offer different insights. These limitations suggest areas for future research.

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