

# Foreign Direct Investment, Fiscal Decentralization and ICT: Pathways to Environmental Sustainability in Canada Under Geopolitical Uncertainty

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## Abstract

Balancing economic growth with environmental sustainability remains a pressing challenge for Canada, particularly in the face of rapid technological advancement, global integration and increasing geopolitical uncertainty. This study analyses the effects of economic growth, foreign direct investment, ICT development, trade openness, fiscal decentralization and geopolitical risk on Canada's CO<sub>2</sub> emissions from 1980 to 2022. Using the ARDL bounds test and Toda–Yamamoto causality method, the results confirm that economic growth and other macroeconomic and institutional factors significantly shape emission trends. FDI, trade openness, ICT development, fiscal decentralization and geopolitical risk all raise carbon emissions in the short and long run. Causality tests show a two-way link between economic growth and CO<sub>2</sub> emissions, while the other factors act as external drivers without feedback. These findings underscore the importance of strengthening environmental standards for FDI and trade, expanding clean energy to support digital infrastructure, enhancing intergovernmental coordination on fiscal matters and improving Canada's resilience to geopolitical disruptions. Overall, the study provides new empirical insights and actionable guidance for policymakers aiming to align Canada's economic aspirations with its carbon reduction commitments in an increasingly uncertain global environment.

**Keywords:** Fiscal decentralization, geopolitical uncertainty, economic growth, carbon emissions, ARDL, Toda–Yamamoto causality test

**JEL Classification:** Q54, F21, H77, O33, F50

## 1. Introduction

Environmental sustainability has emerged as a defining priority for governments, industries and communities worldwide, driven by the escalating threats of climate change, resource depletion and ecological degradation (Caglar *et al.*, 2024; Goodland *et al.*, 1993; Lasisi *et al.*, 2024; Zeng *et al.*, 2025). As one of the world's most developed economies, Canada faces a distinct challenge: balancing robust economic growth with an unwavering commitment to reduce carbon emissions and safeguard its diverse natural ecosystems (Government of Canada, 2024). Canada is striving to reduce its greenhouse gas emissions even though projections show an increase by 2030. The country grapples with pressing issues such as climate change, pollution and declining biodiversity (Carbon Click, 2023). Efforts are underway to shift from coal to renewable energy sources, enhance energy technologies and tighten building regulations. Despite these initiatives, significant challenges remain (Bai *et al.*, 2025; X. Li *et al.*, 2025; Vaillancourt *et al.*, 2014; Zhang *et al.*, 2024).

In this context, understanding the multifaceted determinants influencing Canada's carbon emissions is crucial. Among these determinants, foreign direct investment has attracted considerable scholarly and policy attention. FDI is widely recognized as a channel for economic development, innovation diffusion and capital accumulation (Borensztein *et al.*, 1998). FDI plays a significant role in sectors ranging from natural resources to advanced manufacturing. However, its environmental consequences remain ambiguous, as multinational corporations may introduce cleaner production technologies and stricter environmental management practices (Eweade, Karlilar *et al.*, 2024; Farooq *et al.*, 2025).

Beyond the role of foreign direct investment (FDI), the extent of a country's financial development plays a crucial role in shaping environmental impacts. Well-functioning financial systems help channel capital into sustainable infrastructure, green innovations and renewable energy ventures (Cone, 2025). More financial institutions and capital markets now integrate environmental, social and governance (ESG) standards, indicating a growing shift towards sustainability-oriented funding. However, whether financial development reliably results in lower emissions remains debatable, as profit-driven investment strategies may conflict with long-term ecological goals (L. Li *et al.*, 2025; Tamazian *et al.*, 2009).

Equally significant is the transformative potential of information and communication technology (ICT) development. ICT has emerged as a critical enabler of environmental sustainability by enhancing energy efficiency, supporting smart grids, enabling remote monitoring of emissions and fostering the growth of green innovations (Aebischer and Hilty, 2015). ICT infrastructure has seen remarkable expansion, with increasing investments in broad-

band access, digital platforms and smart city initiatives (Dalei and Roy, 2021). Although technological progress can help decouple economic growth from environmental degradation, the rebound effect – where increased efficiency leads to greater overall consumption – necessitates a careful assessment of ICT's true impact on the environment (Berkhout and Hertin, 2004).

Beyond economic and technological drivers, structural factors such as trade openness and fiscal decentralization further complicate Canada's sustainability equation. Trade openness is often argued to influence environmental quality through scale, composition and technique effects (Grossman and Krueger, 1995). Given Canada's strong integration with global markets, trade openness can support the diffusion of cleaner technologies through import channels and international cooperation. Nonetheless, in the absence of rigorous environmental standards, this openness could simultaneously drive up production volumes and transport-related emissions, potentially undermining sustainability efforts (Antweiler *et al.*, 2001).

In Canada, fiscal decentralization – the reassignment of fiscal responsibilities from the federal government to lower levels of government – has the potential to enhance the effectiveness of environmental policies by allowing them to be tailored to local needs (Oates, 1999). Provincial governments, endowed with significant authority over natural resources and environmental regulation, can serve as laboratories for policy innovation and experimentation. Nonetheless, decentralization can also produce uneven policy frameworks and enforcement gaps, raising concerns about inter-jurisdictional spillovers and possible “race to the bottom” dynamics (Fredriksson and Millimet, 2002). Geopolitical uncertainty has become a relevant yet insufficiently explored aspect of environmental studies. Heightened geopolitical tensions worldwide – from trade conflicts and armed confrontations to diplomatic standoffs such as the Russo-Ukrainian War and frequent unrest in the Middle East – have substantial impacts on energy security, capital flows and the management of environmental issues (De Groot *et al.*, 2022). These global events have direct domestic repercussions. For instance, the Russo-Ukrainian War has reshaped global energy markets, prompting Canada to expand oil and gas exports to fill supply gaps for European allies, which could challenge national emission reduction commitments.

Likewise, unrest in key oil-producing areas of the Middle East drives fluctuations in global oil prices, affecting the profitability of Canada's fossil fuel industry, shaping national energy security plans and affecting the rate of investment in renewable energy. These factors underscore that Canada's path towards lowering carbon emissions and maintaining economic stability is closely linked to international security conditions and remains exposed

to abrupt geopolitical shifts. Elevated geopolitical risks can disrupt supply chains, cause volatility on commodity markets and shift policy attention and resources away from long-term sustainability goals towards urgent economic or strategic priorities.

Against this intricate backdrop, this study seeks to answer three central research questions: firstly, to what extent do foreign direct investment, financial development and ICT development contribute to reducing or increasing carbon emissions in Canada? Secondly, how do trade openness and fiscal decentralization interact with Canada's carbon emissions and economic growth in the context of global sustainability targets? Thirdly, what is the moderating effect of geopolitical risk on the relationship between these economic and institutional drivers and Canada's environmental sustainability?

While existing literature has offered valuable insights into the individual effects of FDI, financial development or ICT on environmental outcomes, an integrated empirical analysis that simultaneously captures their combined impact alongside trade openness, fiscal decentralization and geopolitical risk remains scarce (see Adebayo, Eweade *et al.*, 2025; Adebayo, Saeed Meo *et al.*, 2024; Adebayo, Özkan *et al.*, 2024, 2025; Chu *et al.*, 2022; Eweade, Akadiri *et al.*, 2024; Eweade *et al.*, 2023; Eweade, Joof *et al.*, 2024; Farooq *et al.*, 2025; Parray *et al.*, 2024). The novelty of this study lies in bridging this gap by adopting an all-inclusive approach that situates Canada's environmental performance within its broader economic, institutional and geopolitical context, and by examining how these diverse factors interact to shape carbon emissions. The research generates comprehensive evidence that can guide policymakers in designing adaptive and resilient sustainability policies. Furthermore, by explicitly incorporating geopolitical risk, this study extends the discourse on how external shocks and uncertainties can moderate the effectiveness of domestic sustainability efforts.

## 2. Empirical Evidence

The environmental effects of foreign direct investment have been widely studied, but findings vary across countries, income groups and institutional contexts. Many studies highlight the complex nature of these relationships and the need for tailored policies to balance economic growth and environmental sustainability. For example, Sreenu (2025) showed that FDI contributes to CO<sub>2</sub> emissions in BRICS and OECD countries, supporting the pollution haven hypothesis – especially for countries such as Switzerland, Denmark and the UK, which shift emissions abroad through polluting investments. However, the study also found evidence for the pollution halo effect, suggesting that attracting cleaner FDI can help BRICS reduce emissions. Similarly, Akbar *et al.* (2025) found that China's outward FDI and trade openness help lower CO<sub>2</sub> emissions in 102 countries. Raihan *et al.* (2025) showed a mixed

pattern in Mexico, where GDP and energy use increase emissions, while FDI reduces them slightly, underscoring the potential of green investment and international cooperation.

Shobande and Asongu (2023) highlighted the critical role of ICT in boosting productivity and employment but also its significant contribution to carbon emissions. Using the STIRPAT model and VAR/VEC causality, they found that ICT supports environmental sustainability in South Africa but shows mixed effects in Nigeria. They recommended targeted investments in environmental infrastructure to address these challenges. X. Li *et al.* (2023) explored the link between ICT development and CO<sub>2</sub> emissions using data from 91 countries from 2007 to 2015. By constructing a comprehensive ICT index, they found robust evidence of an inverted U-shaped relationship, indicating that ICT initially raises but eventually reduces emissions. They highlighted that this pattern varies between BRI and non-BRI countries and under different environmental regulations, emphasizing the need for country-specific policies when addressing emissions alongside ICT growth.

Carrillo-Pulgar *et al.* (2025) found that fiscal decentralization generally raises CO<sub>2</sub> emissions across 40 countries, with revenue-side decentralization contributing to lower emissions, while expenditure-side decentralization tends to increase them. They also noted that renewable energy helps reduce emissions, whereas economic growth, resource rents and ICT slightly increase them, offering important insights for policy design. In contrast, Cai *et al.* (2025) showed that fiscal decentralization contributes to lower carbon emissions in 288 Chinese cities. However, weak environmental regulation creates a “green paradox”, where the intended benefits are undermined. The effect of decentralization also varies with levels of economic development and industrialization, and non-first-tier cities often face challenges due to poor enforcement. These results highlight the need for stronger oversight and a more balanced approach to decentralization to align economic growth with emission reduction goals. Similarly, J. Li *et al.* (2025) demonstrated that China’s digital economy significantly lowers carbon emission intensity, with a stronger impact in the Eastern regions. Moreover, fiscal decentralization amplifies this effect in a nonlinear manner. These findings support policies that promote green, low-carbon development and advance the goal of carbon neutrality.

Paramati *et al.* (2025) found that rising geopolitical risk increases carbon emissions and, combined, these heighten public health risks in 17 countries. Using quantile regression and robustness checks, they confirmed that these effects persist even when controlling for foreign direct investment (FDI), trade, financial development, income and population, highlighting the need for targeted policies to address these risks. Similarly, Ali *et al.* (2025) focused on Canada and showed that economic growth increases CO<sub>2</sub> emissions. However,

geopolitical risks continue to raise emissions, threatening sustainability. Their ARDL, KRLS and causality tests suggest that Canada should diversify energy sources, invest in renewables and promote low-carbon trade to mitigate such risks. Zhou *et al.* (2025) examined the relationship between trade openness and CO<sub>2</sub> emissions in emerging countries using FMOLS, DOLS, PMG-ARDL and robustness tests. They found that, in the long run, trade openness and economic growth help reduce emissions, while energy consumption increases them; however, the short-term effects differ. A two-way Granger causality exists between trade openness and emissions. They recommended enhancing the service sector, promoting technological innovation and strengthening international cooperation in green technologies to balance trade expansion with emission reduction.

Wang *et al.* (2025) extended this by analysing trade openness, industrialization and urbanization in 122 countries. Their results show that trade openness boosts economic growth. It also increases emissions, supporting the pollution haven hypothesis. Urbanization promotes growth across all income groups and raises emissions except in high-income countries. They also found one-way causality from trade openness to renewable energy use, offering nuanced policy advice tailored to countries at different development stages. Finally, Barkat *et al.* (2025) investigated the long-term impact of trade openness on CO<sub>2</sub> emissions in 20 OECD countries over 150 years using robust cointegration techniques. They revealed that trade openness directly raises emissions but indirectly reduces them through income growth, consistent with the EKC hypothesis. As income levels increase, the indirect, mitigating effect outweighs the direct effect, resulting in lower long-term emissions and providing valuable insights for sustainable development strategies.

**Table 1: Tabular findings of empirical evidence**

| Author(s)                                   | Timeframe | Nation(s)                                               | Method(s)                       | Findings                                                                                    |
|---------------------------------------------|-----------|---------------------------------------------------------|---------------------------------|---------------------------------------------------------------------------------------------|
| <b>Raihan <i>et al.</i> (2025)</b>          | 1970–2022 | Mexico                                                  | ARDL                            | FDI ↓ CO <sub>2</sub> emissions                                                             |
| <b>Sreenu (2025)</b>                        | 2000–2003 | BRICS                                                   | Fixed GMM model                 | FDI ↓ CO <sub>2</sub> emissions                                                             |
| <b>Akbar <i>et al.</i> (2025)</b>           | 2003–2018 | 102 world economies                                     | GLS                             | FDI ↓ CO <sub>2</sub> emissions                                                             |
| <b>Shobande and Asongu (2023)</b>           | –         | Nigeria and South Africa                                | VAR/VEC Granger causality       | ICT ↑ CO <sub>2</sub> emissions                                                             |
| <b>X. Li <i>et al.</i> (2023)</b>           | 2007–2015 | BRI countries                                           | Sys-GMM                         | ICT has a positive impact on CO <sub>2</sub> emissions                                      |
| <b>Shahnazi <i>et al.</i> (2025)</b>        | 1995–2019 | 26 high-income countries and 24 middle-income countries | Threshold panel regression mode | ICT reduces CO <sub>2</sub> emissions                                                       |
| <b>Carrillo-Pulgar <i>et al.</i> (2025)</b> | 2000–2020 | 40 economies                                            | (MMQR)                          | Fiscal decentralization has a positive on CO <sub>2</sub> emissions                         |
| <b>Cai <i>et al.</i> (2025)</b>             | 2003–2021 | 288 Chinese cities                                      | Benchmark regression            | Fiscal decentralization cuts emissions                                                      |
| <b>J. Li <i>et al.</i> (2025)</b>           | 2011–2020 | China                                                   | Baseline regression             | Fiscal decentralization boosts the carbon-cutting effect of digital economy                 |
| <b>Paramati <i>et al.</i> (2025)</b>        | 1990–2018 | 17 countries                                            | Quantile regression             | Rising geopolitical risks elevate carbon emissions                                          |
| <b>Ali <i>et al.</i> (2025)</b>             | 1980–2022 | Canada                                                  | ARDL, KRLS and causality tests  | Geopolitical risks increase emissions                                                       |
| <b>Zhou <i>et al.</i> (2025)</b>            | –         | Emerging countries                                      | FMOLS, DOLS, PMG-ARDL           | Trade openness and economic growth help reduce emissions                                    |
| <b>Wang <i>et al.</i> (2025)</b>            | 1998–2018 | 122 countries                                           | FMOLS, DOLS                     | Trade openness raises growth for rich and poor, drops it for middle and increases emissions |
| <b>Barkat <i>et al.</i> (2025)</b>          | 1870–2019 | 20 OECD countries                                       | Panel regression                | Trade openness affects CO <sub>2</sub> emissions both directly and indirectly               |

Source: Author's own elaboration

### 3. Data and Methodology

#### 3.1 Data sources

This study analyses annual time series data for Canada from 1980 to 2022. The dependent variable is carbon emissions ( $CO_2$ ), while the explanatory variables include economic growth ( $GDP$ ), geopolitical risk ( $GPR$ ), fiscal decentralization ( $FID$ ), trade openness ( $TO$ ), ICT development ( $ICT$ ) and foreign direct investment ( $FDI$ ). To ensure consistency with standard approaches in growth, energy and emissions research, all the variables are logarithmically transformed to address heteroscedasticity and non-normality. Table 1 summarizes the findings of previous empirical studies, while Table 2 provides a detailed description of the variables, including their definitions and data sources.

**Table 2: Description of variables**

| Codes                    | Variables                 | Units of measurement                           | Sources                       |
|--------------------------|---------------------------|------------------------------------------------|-------------------------------|
| <b><math>CO_2</math></b> | Carbon emissions          | Tonnes per capita                              | OWD (2025) <sup>1</sup>       |
| <b><math>GDP</math></b>  | Economic growth           | GDP per capita 2015 constant USD               | WB (2025) <sup>2</sup>        |
| <b><math>GPR</math></b>  | Geopolitical risk         | Index                                          | Caldara and Iacoviello (2022) |
| <b><math>FID</math></b>  | Fiscal decentralization   | Index                                          | IMF (2025) <sup>3</sup>       |
| <b><math>TO</math></b>   | Trade openness            | Trade (% of GDP)                               | WB (2025) <sup>4</sup>        |
| <b><math>ICT</math></b>  | ICT development           | Mobile cellular subscriptions (per 100 people) | OWD (2025) <sup>5</sup>       |
| <b><math>FDI</math></b>  | Foreign direct investment | Net inflows (% of GDP)                         | OWD (2025) <sup>6</sup>       |

Source: Author's own elaboration<sup>1</sup>

#### 3.2 Model specification

To investigate how fiscal decentralization, foreign direct investment, ICT, trade openness and economic growth influence carbon emissions in the context of geopolitical risks, the econometric model used in this study is formulated as follows:

$$\ln CO_{2t} = \alpha + \beta_1 GDP_t + \beta_2 \ln FID_t + \beta_3 \ln GPR_t + \beta_4 \ln ICT_t + \beta_5 \ln FDI_t + \beta_6 \ln TO_t + \varepsilon_t \quad (1)$$

1 <https://ourworldindata.org/profile/co2/canada>

2 <https://data.worldbank.org/indicator/NY.GDP.MKTP.KD>

3 <https://data.imf.org/en/datasets/IMF.STA:FD>

4 <https://data.worldbank.org/indicator/NE.TRD.GNFS.ZS?locations=CA>

5 <https://ourworldindata.org/grapher/mobile-cellular-subscriptions-per-100-people>

6 <https://ourworldindata.org/grapher/foreign-direct-investment-net-inflows-as-share-of-gdp>

### 3.3 Stationarity test

We apply the unit root test of Zivot and Andrews (2002) because it outperforms conventional tests by endogenously identifying a single structural break in the series. The ZA test accommodates potential shifts due to policy changes, economic crises or technological innovations. This feature improves the accuracy and credibility of the stationarity results for time series likely to experience structural changes. The general form for testing a structural break in level and trend is:

$$\Delta X_t = \mu + \theta DU_t(\lambda) + \beta t + \gamma DT_t(\lambda) + \alpha X_{t-1} + \sum_{i=1}^k c_i \Delta X_{t-i} + \varepsilon_t \quad (2)$$

where  $X_t$  is the series being tested,  $DU_t(\lambda)$  is a dummy variable for a mean shift (0 before the break, 1 after),  $DT_t(\lambda)$  is a trend shift dummy (0 before the break,  $t - TB$  after),  $\mu$  is the intercept,  $t$  is the time trend,  $\alpha$  tests for unit roots,  $c_i$  are lag coefficients to correct for serial correlation,  $\lambda$  indicates the estimated break point and  $\varepsilon_t$  is the error term.

### 3.4 ARDL bound testing approach

The study adopts the ARDL bounds testing approach by Pesaran (2006, 2015). The ARDL model tests for cointegration and estimates both short-run and long-run relationships reliably (Narayan, 2005). It also includes an error-correction term that measures how quickly short-run deviations adjust back to equilibrium (Engle and Granger, 1987; Phillips, 1991). The econometric formulation of the ARDL model for this study is as follows:

$$\begin{aligned} \Delta \ln CO_{2t} = & \beta_0 + \partial_1 \Delta \ln CO_{2(t-1)} + \partial_2 \ln GPR_{(t-1)} + \partial_3 \ln GDP_{(t-1)} + \partial_4 \ln FDI_{(t-1)} \\ & + \partial_5 \ln TO_{(t-1)} + \partial_6 \ln FID_{(t-1)} + \partial_7 \ln ICT_{(t-1)} \\ & + \sum_{i=1}^n \phi_{1i} \Delta \ln GPR_{(t-i)} + \sum_{i=1}^n \phi_{2i} \Delta \ln FDI_{(t-i)} + \sum_{i=1}^n \phi_{3i} \Delta \ln FDI_{(t-i)} \\ & + \sum_{i=1}^n \phi_{4i} \Delta \ln TO_{(t-i)} + \sum_{i=1}^n \phi_{5i} \Delta \ln GDP_{(t-i)} + \sum_{i=1}^n \phi_{6i} \Delta \ln ICT_{(t-i)} \\ & + \mu_{1t}. \end{aligned} \quad (3)$$

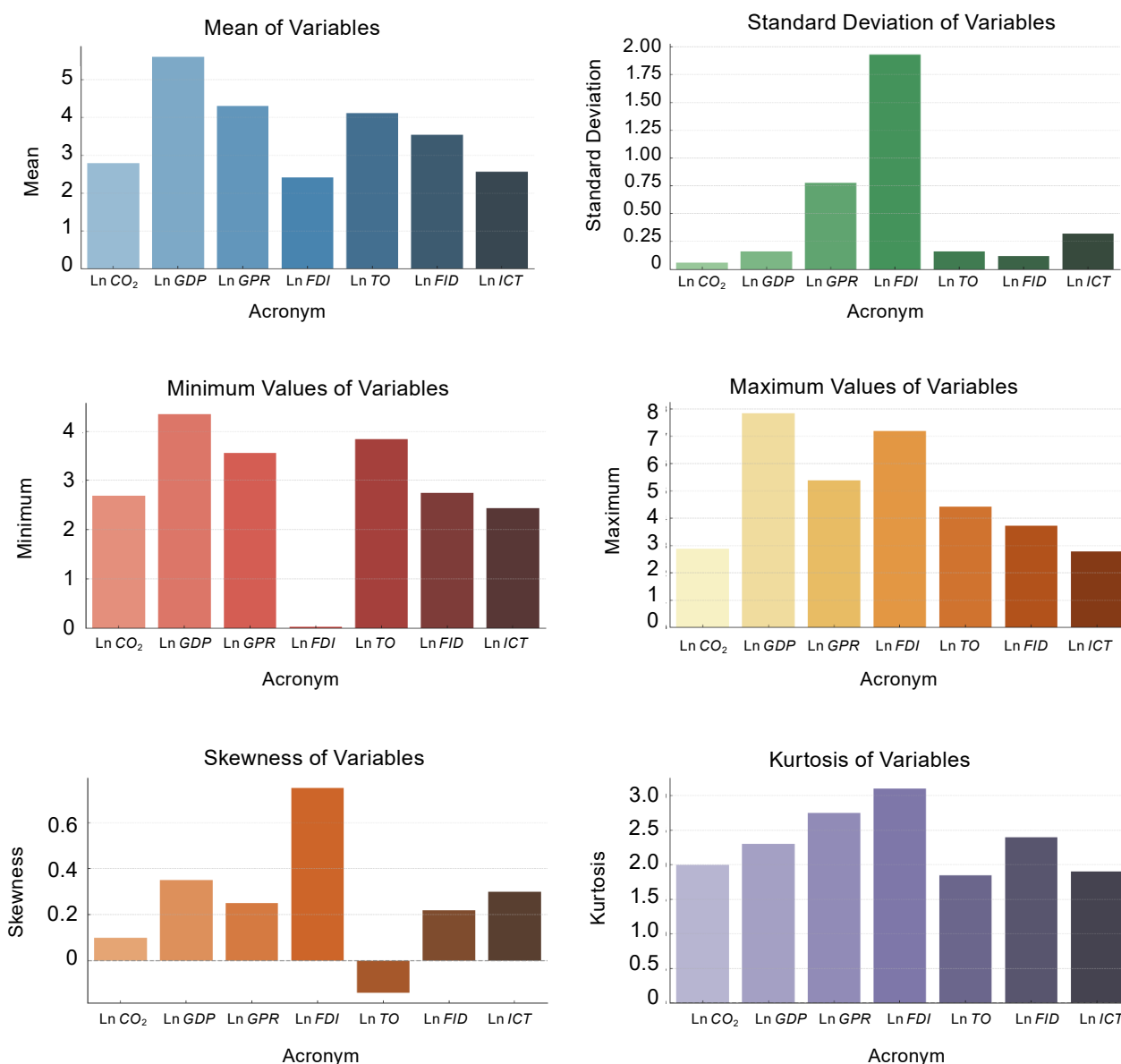
where  $\Delta \ln CO_{2t}$  is the first difference of the log of carbon emissions,  $GPR$  stands for geopolitical risk,  $GDP$  is economic growth,  $FDI$  is foreign direct investment,  $TO$  is trade openness,  $FID$  is fiscal decentralization,  $ICT$  denotes ICT development,  $\beta_0$  is the intercept term, while  $\partial$  and  $\phi$  are coefficients.

The error-correction representation can be expressed as:

$$\begin{aligned} \Delta \ln CO_{2t} = & \beta_0 + \sum_{i=1}^n \phi_{1i} \Delta \ln CO_{2(t-i)} + \sum_{i=1}^n \phi_{2i} \Delta \ln GDP_{(t-i)} + \sum_{i=1}^n \phi_{3i} \Delta \ln GPR_{(t-i)} \\ & + \sum_{i=1}^n \phi_{4i} \Delta \ln FID_{t-i} + \sum_{i=1}^n \phi_{5i} \Delta \ln FDI_{(t-i)} + \sum_{i=1}^n \phi_{6i} \Delta \ln TO_{(t-i)} \\ & + \sum_{i=1}^n \phi_{7i} \Delta \ln ICT_{(t-i)} + \mu_t \end{aligned} \quad (4)$$

## 4. Results and Discussion

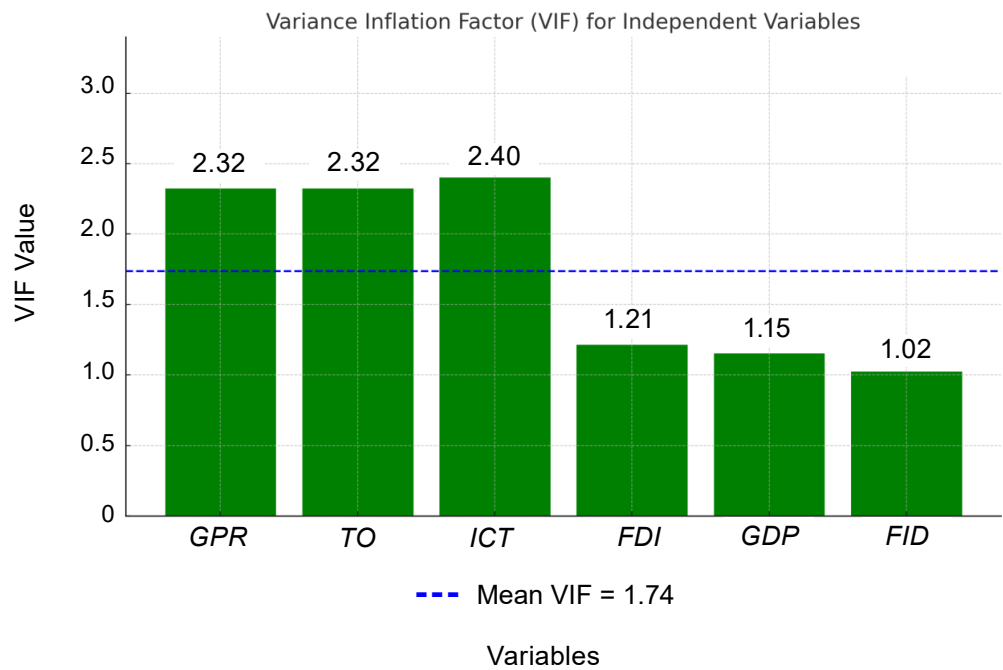
The descriptive statistics show that Canada's economic growth has the highest mean, reflecting stable and strong performance, while carbon emissions, FDI and ICT development have lower averages. The standard deviations indicate that *FDI* is the most volatile variable, influenced by global markets and geopolitical events, while *GDP* and emissions remain relatively stable. Minimum and maximum values confirm steady baseline levels for *GDP* and trade openness, with occasional dips in *FDI*. Skewness and kurtosis values suggest that most variables are nearly symmetric and close to normal distribution, with few extreme outliers. Overall, the results indicate homogeneity and suitability for robust econometric analysis, capturing both Canada's stable economic and trade trends and the occasional shocks from FDI and geopolitical risks.

**Figure 1: Descriptive statistics of variables**

Source: Author's own elaboration

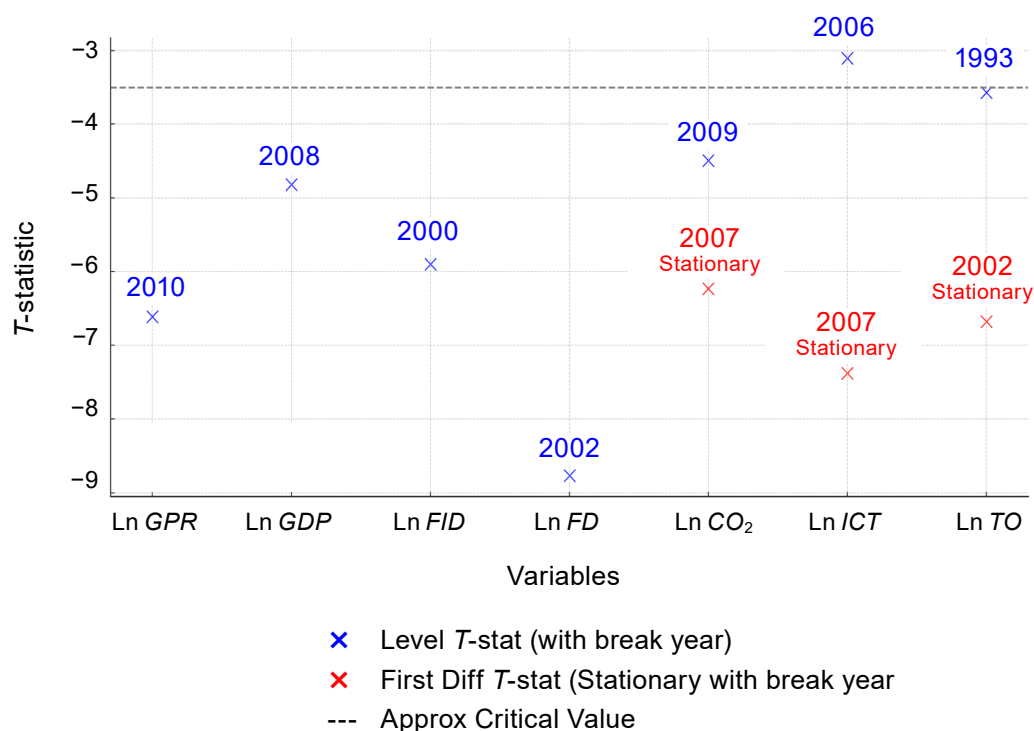
Figure 2 shows the VIF values for the independent variables used in the model. All the VIFs are well below the common threshold of 10, with values ranging from 1.02 to 2.40. The mean VIF, indicated by the dashed blue line, is approximately 1.74, confirming negligible multicollinearity. This suggests that the predictors – geopolitical risk (*GPR*), trade openness (*TO*), ICT development (*ICT*), foreign direct investment (*FDI*), *GDP* and fiscal decentralization (*FID*) – are sufficiently independent of each other, ensuring stable and reliable coefficient estimates for the ARDL analysis.

Figure 2: Variance inflation factor



Source: Author’s own elaboration

Prior to conducting the regression analysis, a series of diagnostic tests were performed to examine the statistical properties of the data. Table 3 and the accompanying diagram present the results of the Zivot and Andrews (2002) unit root test, which allows for endogenously determined structural breaks within the series. The findings show that geopolitical risk ( $\ln GPR$ ), economic growth ( $\ln GDP$ ), fiscal decentralization ( $\ln FID$ ) and foreign direct investment ( $\ln FDI$ ) are stationary at level  $[I(0)][I(0)][I(0)]$ , while carbon emissions ( $\ln CO_2$ ), ICT development ( $\ln ICT$ ) and trade openness ( $\ln TO$ ) become stationary at first difference  $[I(1)][I(1)][I(1)]$ . Structural breaks are detected in most variables, particularly during the late 1990s and 2000s, coinciding with major global economic disruptions such as the Asian financial crisis and the global financial crisis. These breaks highlight periods of significant policy shifts and economic adjustments, which can affect the stability and dynamics of the relationships under investigation. By explicitly accounting for these breaks, the study ensures more accurate estimation and interpretation of the short-run and long-run relationships among the variables, thus improving the robustness of the empirical results.

**Figure 3: Structural breaks**

Source: Author's own elaboration

The ARDL cointegration test results presented in Table 3 show that the calculated  $F$ -statistic is 10.017, which exceeds Pesaran's upper bound critical value at the 1% significance level. This finding leads to the rejection of the null hypothesis of no cointegration, confirming that long-run relationships exist among the variables. Consequently, the study proceeds to estimate both the short-run and long-run coefficients of the regressors on carbon emissions. To determine the optimal lag structure for the ARDL model, the Bayesian information criterion (BIC) is employed. Prior research indicates that the BIC often provides more robust results than the Akaike information criterion (AIC) (Salahuddin *et al.*, 2020) and performs better with small sample sizes (Burnham and Anderson, 2004). Accordingly, the selected optimal lags for each variable in this study are as follows: carbon emissions (1 lag), economic growth (1 lag), geopolitical risk (1 lag), fiscal decentralization (2 lags), trade openness (1 lag), foreign direct investment (0 lags) and ICT development (1 lag). By explicitly specifying the lag lengths, this research ensures transparency and replicability of the ARDL estimation process.

Table 3: Cointegration test results

| Variable           |      | Function                                             |      | F-stat    | Decision     |
|--------------------|------|------------------------------------------------------|------|-----------|--------------|
| ln CO <sub>2</sub> |      | $f(GDP, \ln GPR, \ln FID, \ln FDI, \ln TO, \ln ICT)$ |      | 10.017*** | Cointegrated |
| 10%                |      | 5%                                                   |      | 1%        |              |
| I(0)               | I(1) | I(0)                                                 | I(1) | I(0)      | I(1)         |
| 2.67               | 4.36 | 3.12                                                 | 2.41 | 6.17      | 3.02         |

Note: \*\*\* denotes statistical significance at the 1% level.

Source: Author’s own calculations

Table 4 presents the results of the ARDL estimation, capturing both the long-run and short-run effects of the key variables on carbon emissions in Canada. The long-run estimation results indicate that economic growth exerts a negative and statistically significant influence on CO<sub>2</sub> emissions ( $-0.373, p < 0.01$ ), suggesting that higher economic development is associated with reduced emissions, possibly due to cleaner technologies and improved energy efficiency at higher income levels (Adebayo, Özkan *et al.*, 2024; Eweade, Akadiri *et al.*, 2024; Zeng *et al.*, 2025). In contrast, geopolitical risk has a positive and significant effect ( $0.035, p < 0.01$ ), implying that heightened geopolitical instability tends to raise emissions by undermining investment in green infrastructure and energy security (Ali *et al.*, 2025; Chu *et al.*, 2022). Fiscal decentralization is also found to increase emissions ( $0.329, p < 0.01$ ), which aligns with findings that local fiscal autonomy can sometimes weaken unified environmental policies (Arikan, 2004). Foreign direct investment ( $\ln FDI$ ) shows a positive and significant coefficient ( $0.426, p < 0.01$ ), providing evidence consistent with the pollution haven hypothesis, where increased  $FDI$  inflows may be associated with lenient environmental enforcement (Borensztein *et al.*, 1998; Cole *et al.*, 2017; Eweade, Karlilar *et al.*, 2024; Eweade and Güngör, 2024).

Trade openness ( $\ln TO$ ) further contributes positively to CO<sub>2</sub> emissions ( $0.567, p < 0.01$ ), reflecting that greater integration into global trade may amplify industrial activity and energy demand (Shahbaz *et al.*, 2013). ICT development ( $\ln ICT$ ) also shows a slight but significant positive effect ( $0.015, p < 0.01$ ), indicating that the expansion of digital technologies may marginally increase energy consumption in the long run (Abdi *et al.*, 2024; Barkat *et al.*, 2025; Zhou *et al.*, 2025). Overall, the long-run model explains a substantial portion of the variance in CO<sub>2</sub> emissions, as reflected by an adjusted  $R^2$  of 0.762.

In the short-run estimation, the coefficients of the differenced variables reveal that short-term fluctuations in economic growth, geopolitical risk, fiscal decentralization, foreign direct investment, trade openness and ICT development all significantly increase CO<sub>2</sub> emissions, highlighting that immediate changes in these factors tend to elevate environmental pressures. The negative and highly significant error correction term (ECM<sub>*t*-1</sub>) value of -0.377 ( $p < 0.01$ ) verifies a stable long-run equilibrium relationship among the variables. This result indicates that roughly 37.7% of short-run deviations from the long-run equilibrium are corrected each period, ensuring the gradual return of the system to stability (Pesaran *et al.*, 2001). The short-run model also demonstrates a satisfactory fit, with an  $R^2$  of 0.763. The diagnostic tests presented at the bottom of Table 4 further confirm the model robustness. The  $\chi^2$  serial test indicates no serial correlation in the residuals ( $p = 0.672$ ), the  $\chi^2$  arch test shows no evidence of heteroscedasticity ( $p = 0.561$ ) and the  $\chi^2$  Ramsey test supports that the model is correctly specified ( $p = 0.782$ ) (Burnham and Anderson, 2004). Collectively, these results affirm that the ARDL model provides reliable and statistically sound estimates for analysing the environmental impacts of macroeconomic, institutional and technological factors in Canada.

**Table 4: ARDL estimation**

| Long-run estimation results  |                |            |                |
|------------------------------|----------------|------------|----------------|
| Variable                     | Coeff.         | Std. error | T-stat [Prob]  |
| Constant                     | 8.981          | 0.234      | 1.234 [0.000]  |
| ln GDP                       | −0.373         | 0.762      | −6.451 [0.000] |
| ln GPR                       | 0.035          | 0.671      | 6.673 [0.000]  |
| ln FID                       | 0.329          | 0.780      | 4.750 [0.000]  |
| ln FDI                       | 0.426          | 0.136      | 8.452 [0.000]  |
| ln TO                        | 0.567          | 0.349      | 5.451 [0.000]  |
| ln ICT                       | 0.015          | 0.156      | 7.400 [0.000]  |
| R <sup>2</sup>               | 0.349          |            |                |
| Adjusted R <sup>2</sup>      | 0.762          |            |                |
| Short-run estimation results |                |            |                |
| Variable                     | Coeff.         | Std. error | T-stat [Prob]  |
| Constant                     | 23.521         | 0.542      | 4.452 [0.000]  |
| ln GDP                       | 0.532          | 0.111      | 5.461 [0.000]  |
| ln GPR                       | 0.941          | 0.081      | 7.783 [0.000]  |
| ln FID                       | 0.925          | 0.893      | 6.327 [0.000]  |
| ln FDI                       | 0.452          | 0.874      | 1.842 [0.001]  |
| ln TO                        | 0.731          | 0.742      | 8.856 [0.000]  |
| ln ICT                       | 0.452          | 0.367      | 4.987 [0.000]  |
| ECM <sub>t−1</sub>           | −0.377         | 0.147      | −6.764 [0.000] |
| R <sup>2</sup>               | 0.763          |            |                |
| Adjusted R <sup>2</sup>      | 0.355          |            |                |
| F-statistic                  | 43.893 [0.000] |            |                |
| D.-W. stat.                  | 1.453          |            |                |
| Diagnostic tests             |                |            |                |
| Test                         | F-statistic    | p-value    |                |
| χ <sup>2</sup> serial        | 1.545          | 0.672      |                |
| χ <sup>2</sup> arch          | 0.842          | 0.561      |                |
| χ <sup>2</sup> Ramsey        | 0.383          | 0.782      |                |

Source: Author's own calculations

Table 5 presents the results of the Toda–Yamamoto causality test, which examines the direction of causality between the key variables and carbon emissions. The results indicate a bidirectional causality between economic growth and CO<sub>2</sub> emissions, as both the null hypotheses of no causality from *GDP* to *CO<sub>2</sub>* ( $\chi^2 = 8.472$ ,  $p < 0.05$ ) and from *CO<sub>2</sub>* to *GDP* ( $\chi^2 = 12.119$ ,  $p < 0.01$ ) are rejected.

This suggests that not only does economic growth influence emissions, but emissions also feedback to affect economic performance, consistent with the environmental Kuznets curve hypothesis (Shahbaz *et al.*, 2013). Furthermore, the test reveals unidirectional causal links from geopolitical risk (*GPR*), fiscal decentralization (*FID*), trade openness (*TO*), foreign direct investment (*FDI*) and ICT development to CO<sub>2</sub> emissions, as the null hypotheses for these directions are rejected at the 1% level. However, no significant reverse causality is found from CO<sub>2</sub> emissions back to these variables, as their corresponding  $p$ -values are all above conventional significance thresholds. For example, while *GPR* significantly causes changes in CO<sub>2</sub> emissions ( $\chi^2 = 15.011$ ,  $p < 0.01$ ), CO<sub>2</sub> does not significantly cause changes in *GPR* ( $\chi^2 = 3.367$ ,  $p = 0.823$ ). Similarly, fiscal decentralization shows a strong causal influence on emissions ( $\chi^2 = 14.238$ ,  $p < 0.01$ ) without a feedback effect. These findings imply that changes in geopolitical stability, decentralization policies, openness to trade, *FDI* inflows and ICT development primarily act as exogenous drivers of carbon emissions in Canada, with no detected short-run feedback effects from emissions to these drivers. This pattern highlights the importance of policy interventions targeting these macroeconomic and institutional factors to effectively manage environmental sustainability without adverse short-run feedback loops complicating the policy landscape. Figure 4 shows the causality test.

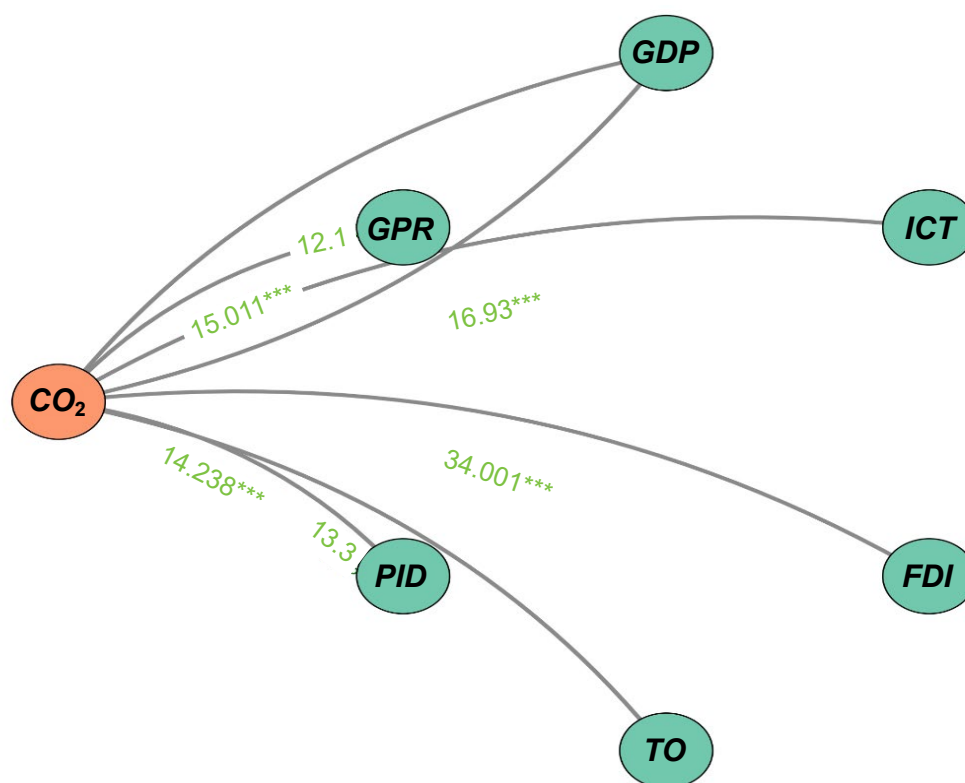
**Table 5: Causality test results**

| Causality direction                  | $\chi^2$ | $p$ -value | Causality Direction                  | $\chi^2$ | $p$ -value |
|--------------------------------------|----------|------------|--------------------------------------|----------|------------|
| $\Delta GDP \rightarrow \Delta CO_2$ | 8.472    | 0.000**    | $\Delta CO_2 \rightarrow \Delta GDP$ | 12.119   | 0.000***   |
| $\Delta GPR \rightarrow \Delta CO_2$ | 15.011   | 0.000***   | $\Delta CO_2 \rightarrow \Delta GPR$ | 3.367    | 0.823      |
| $\Delta FID \rightarrow \Delta CO_2$ | 14.238   | 0.000***   | $\Delta CO_2 \rightarrow \Delta FID$ | 2.238    | 0.435      |
| $\Delta TO \rightarrow \Delta CO_2$  | 13.345   | 0.000***   | $\Delta CO_2 \rightarrow \Delta TO$  | 5.132    | 0.235      |
| $\Delta FDI \rightarrow \Delta CO_2$ | 34.001   | 0.000***   | $\Delta CO_2 \rightarrow \Delta FDI$ | 6.201    | 0.265      |
| $\Delta ICT \rightarrow \Delta CO_2$ | 16.93    | 0.000***   | $\Delta CO_2 \rightarrow \Delta ICT$ | 9.012    | 0.451      |

Note: \*\*, \*\*\* denote statistical significance at the 5% and 1% levels, respectively.

Source: Author's own calculations

**Figure 4: Causality test**



Source: Author's own elaboration

## 5. Conclusions and Policy Recommendations, Limitations and Future Studies

### 5.1 Conclusion

This study comprehensively investigated the complex interplay between economic growth, foreign direct investment (FDI), ICT development, trade openness, fiscal decentralization and geopolitical risks in shaping Canada's carbon emissions from 1980 to 2022, using the robust ARDL bounds testing approach and the Toda–Yamamoto causality framework. The determinants, namely FDI, trade openness, fiscal decentralization, ICT development and geopolitical risks, consistently exhibit positive and statistically significant effects on  $CO_2$  emissions in both the short and long run. This outcome suggests that while economic expansion can be aligned with environmental sustainability in the long term, the simultaneous pressures of globalization, local fiscal autonomy, digitalization and external geopolitical uncertainties can undermine emission reduction efforts if not properly managed. The causality analysis further highlights that economic growth and  $CO_2$  emissions share a bidirectional relationship, whereas variables such as FDI, trade openness, ICT development, fiscal decentralization

and geopolitical risks predominantly act as exogenous drivers of emissions without evidence of reverse causality.

## **5.1 Policy recommendations**

In light of the empirical evidence, this study proposes targeted policy actions to help Canada reconcile economic growth with its carbon reduction commitments in an increasingly globalized and uncertain geopolitical context. Firstly, policymakers should strengthen environmental oversight associated with foreign direct investment. It is essential to attract green FDI by offering incentives for environmentally friendly technologies and enforcing strict compliance with national emission standards to prevent Canada from becoming a pollution haven. Secondly, the positive impact of trade openness on emissions suggests that Canada should integrate enforceable environmental safeguards into bilateral and multilateral trade agreements. Promoting sustainable trade practices and supporting the transition of export-oriented industries towards low-carbon production can mitigate the environmental consequences of expanded trade flows. Thirdly, as ICT development has been shown to marginally increase emissions due to higher energy demand, Canada should prioritize investments in clean and renewable energy sources to power its expanding digital infrastructure. Additionally, policies that encourage businesses and households to adopt energy-efficient ICT solutions can help balance technological progress with emission control.

Fourthly, the finding that fiscal decentralization exacerbates carbon emissions highlights the need for stronger coordination between federal and provincial governments. Establishing clear national guidelines for local environmental management and providing capacity-building support to provinces can ensure that decentralization does not lead to fragmented climate governance or regulatory inconsistencies. Finally, the significant role of geopolitical risks necessitates that Canada enhances its energy security and resilience to global shocks. Diversifying the energy portfolio towards renewables, building strategic reserves and fostering international partnerships for clean energy technology transfer can buffer the economy against supply disruptions while supporting the country's sustainability goals. By implementing these integrated measures, Canada can achieve balanced and inclusive economic growth while effectively managing carbon emissions, reinforcing its commitment to global climate targets and sustainable development.

## **5.2 Limitations and future studies**

Despite providing valuable insights, this study has a few limitations. Firstly, it relies on national-level data, which may overlook regional differences across Canada's provinces. Secondly, the use of annual time series data may not fully capture short-term or seasonal fluctu-

ations in emissions and economic activity. Thirdly, the chosen econometric methods assume linear relationships and limited structural breaks, which may not account for all complexities in the data. Lastly, factors such as renewable energy use or sector-specific emissions were not included and could enhance future analyses. Recognizing these limitations, this study serves as a foundation for more detailed future research.

Building on these limitations, future research could explore the growth–environment nexus at provincial levels to account for local policy differences and industrial structures. Employing higher-frequency or sector-specific data may reveal more nuanced short-run dynamics. Additionally, future studies could incorporate variables such as renewable energy adoption, green technology innovation and policy stringency indices to enrich the analysis. Exploring nonlinear models and accounting for multiple structural breaks could also provide deeper insights into Canada’s pathway towards sustainable development.

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