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Does resource efficiency matter for environmental quality in Canada?

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In order to combat climate change, the OECD emphasized the need to minimize the environmental impact of material use, as well as promote resource efficiency and accelerate the creation of a circular economy. The present study objects to promote a new debate about Canadian environmental quality and resource efficiency. In other words, this paper aims to capture the effect of resource efficiency on environmental quality in Canada while controlling financial development, economic growth, and energy. Nonlinear ARDL bounds test results indicate the significant long-run linkage between environmental quality, resource efficiency, financial development, economic growth, and energy in Canada. Moreover, the asymmetric results underline that 1) resource efficiency mitigates environmental degradation; 2) economic growth and energy uses in Canada significantly increase consumption-based CO_2 emissions; 3) financial development positively contributes to environmental stability. Therefore, policymakers in Canada make sure that circular economies and resource efficiency can help reach net zero and combat climate change.

KEYWORDS

resource efficiency, environmental quality, Canada, nonlinear ARDL, economic growth

1 Introduction

The deterioration of the environment is directly caused by an increase in consumption and production, and reversing this trend is widely regarded as one of the most urgent challenges we face today (Raza et al., 2022; Lie et al. (2022). Economic and social demands far exceed the planet's capacity to absorb this level of consumption of natural resources, resulting in record-high consumption of numerous natural resources. Moreover, ecosystems are negatively affected by the overabundance of coals and other environmental assets. The rise in economic growth, urbanization, and industrialization directly contributes to the

Abbreviations: ADF, Augmented Dickey–Fuller; ARDL, Autoregressive Distributed Lag; BDS, Brock, Dechert and Scheinkman; C.CO2, Consumption-based CO2 emissions; CO2, Carbon Dioxide; COP26, 2021 Conference of the Parties; FD, Financial Development; GDP, Gross Domestic Product; N-ARDL, Nonlinear Autoregressive Distributed Lag; OECD, The Organisation for Economic Co-operation and Development; PEC, Primary energy consumption; RESEF, Resources efficiency.

oversaturation of the natural resources market (Topcu et al., 2020). Therefore, many of these resources are no longer available. The 2021 Conference of the Parties (COP26) clearly emphasizes the importance of resource efficiency for reducing global CO_2 emissions, yet empirical studies of the impact of resource efficiency on environmental sustainability are rare. Global warming issues were addressed at the COP26 and action plans were provided to achieve unprecedented feats in the drive towards a sustainable environment. By 2050, COP26 will establish new dimensions for reaching net-zero global warming (Kirikkaleli and Adebayo, 2022). "The COP26 prioritizes steps until 2030 to keep 1.5°C alive and bring CO_2 emissions to zero by the 2050 s; it calls on countries to accelerate the energy transition and diversification for increased energy security, adaptability, and affordable energy" (Ali et al., 2023). In light of renewable energy's carbon-free, eco-friendly, and sustainable attributes, accelerating a transition towards it is highly relevant in order to achieve the 2050 target.

A circular economy should be accelerated, and resources should be used more efficiently, according to the OECD. As part of its commitment to controlling climate change, the OECD stressed the importance of minimizing environmental impacts from material use and promoting resource efficiency as well as accelerating the creation of a circular economy (Domenech and Bahn-Walkowiak, 2019; Cainelli et al., 2020). In spite of its importance, the Paris

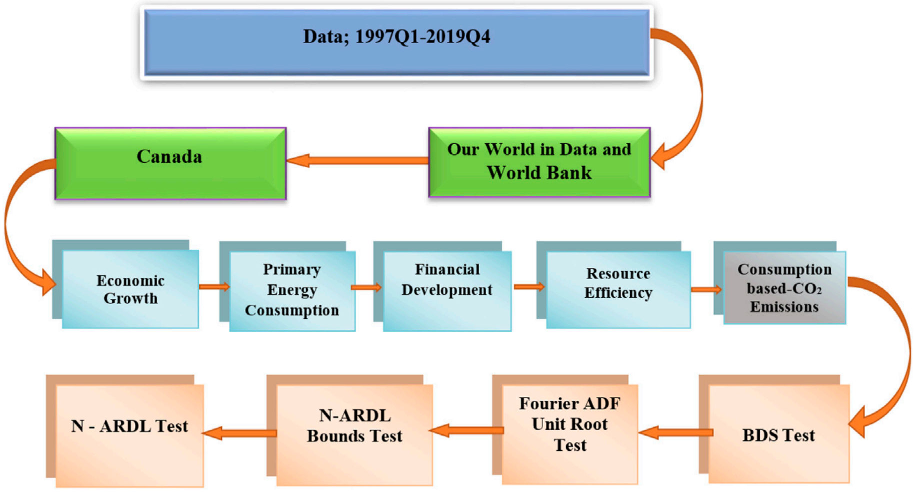

FIGURE 1
Analysis flowchart.

TABLE 1 Descriptive statistics.

Variable	LC.CO2	RESEF	LGDP	LPEC	LFD
	Consumption-based CO2	Resource Efficiency	GDP (constant 2015 US$) Per Capita	Primary Energy Consumption	Financial Development
Measure	Tonnes		US$		Index
Source	Our World in Data	Our World in Data and author calculation	World Bank	Our World in Data	World Bank
Mean	8.753039	1097.272	12.13304	3.580977	−0.084509
Median	8.760427	1227.984	12.14080	3.579178	−0.060836
Max	8.786900	1551.404	12.23140	3.613276	−0.035777
Min	8.714673	576.2605	12.00039	3.535624	−0.171059
Std. Dev	0.020720	339.6903	0.061880	0.021884	0.044916
Skewness	−0.181831	−0.386088	−0.381457	−0.367803	−0.485372
Kurtosis	1.800640	1.521772	2.283568	2.102351	1.553775
J-B	6.021075	10.66209	4.198705	5.163075	11.62999
Prob	0.049265	0.004839	0.122536	0.075658	0.002982

TABLE 2 BDS test.

LC.CO_2		LPEC		LGDP	
Dimension	BDS statistic	Dimension	BDS statistic	Dimension	BDS statistic
2	0.162209	2	0.183174	2	0.204035
3	0.265424	3	0.304855	3	0.346015
4	0.329886	4	0.384896	4	0.445641
5	0.372817	5	0.436443	5	0.516925
6	0.398592	6	0.474938	6	0.570489
	RESEF		LFD		
	Dimension	BDS Statistic	Dimension	BDS Statistic	
	2	0.195836	2	0.186801	
	3	0.330841	3	0.312314	
	4	0.423336	4	0.392995	
	5	0.485355	5	0.442140	
	6	0.526486	6	0.473026	

Agreement remains largely ignored, while resource efficiency takes a noteworthy role in reducing CO_2 emissions. Utilizing novel econometric approaches, this study seeks to open a new debate about resource efficiency and environmental quality in the case of Canada.

As a result of joining the landmark Paris Climate Agreement in 2015, the Canadian government has made considerable progress in combating climate change. As part of the Paris Climate Agreement, Canada has introduced pollution-reduction initiatives to reach a net-zero economy by 2050 (Bergero et al., 2022). Toward phasing out thermal coal worldwide, assisting emerging nations to transition quickly to green fuels, and reducing oil and gas pollution, the Canadian government introduced aggressive plans in 2021. As early as 2030, Canada aims to end the export of thermal coal.

As mentioned by Wu et al. (2017), due to economic development, natural resources are being consumed at an ever-increasing rate, causing serious concerns about the environment. Dong et al. (2017) argued that both developing and developed economies experience severe environmental challenges due to unsustainable resource use, including deforestation, water shortages, and climate change. Finance, education, healthcare, and telecommunications are supported by infrastructure, technology, and energy that are derived from natural resources. Therefore, the production and consumption of materials are increasing worldwide. In addition, population growth and economic growth are not enough to keep up with raw material extraction. According to OECD (2019), the result is more material is being wasted, and less is being used efficiently. It is estimated by the OECD (2019) that global resource extraction will rise by 110% by 2060 if things continue as they are. The use and production of unsustainable products depletes natural resources throughout their life cycle. These practices are used to extract, process, manufacture, consume, and dispose of resources. As a result of unsustainable consumption and production, global climate change, biodiversity loss, and pollution are occurring. In addition to excessive production and consumption, climate change is probably the most noticeable environmental problem. As such, it is necessary to dispose of and treat waste in mines, factories dealing with processing and manufacturing products, trucks, and ships, as well as after the consumption of products and services (Liu et al., 2022).

This study contributes to the literature in four major ways. The study considers how resource efficiency may impact the environment for the first time in the case of Canada. However, despite COP26 underscoring the importance of resource efficiency for reducing global CO_2 emissions, there is a lack of empirical research regarding the effect of resource efficiency on environmental sustainability. In addition, consumption-based CO_2 emissions (or trade-adjusted CO_2 emissions) were used for the study of Canada as an indicator of environmental sustainability. Third, this study uses novel econometrics approaches to analyze the long-term effects of resource efficiency on the environment in Canada. Finally, the study concludes by providing some policy recommendations to Canadian policymakers based on the findings of the empirical research.

2 Literature review

The potential drivers of CO_2 emission have been studied over the past few decades by researchers. Time series methods or country-based analysis have been used by some researchers, while panel analyses for a group of countries or regions have been used by others. The present study selected three important possible factors, namely, economic growth, energy, and financial development, which are likely to affect environmental degradation as a control variable while exploring the effect of resource efficiency on consumption-based CO_2 emission in Canada.

It has been suggested that CO_2 emissions and output are correlated. An economy that grows sustainably improves social

TABLE 3 Fourier ADF and ADF unit root tests.

Fourier ADF unit root test				
Variable	Frequency	Min. SST	FADF Test	F-Stat
At level				
LC.CO2	1.000000	0.002333	−3.475105	4.836036
LFD	1.000000	0.003382	−4.019305**	9.904453 **
LGDP	4.000000	0.000333	−2.562478	4.264468
LPEC	4.000000	0.000775	−1.601728	0.931111
RESEF	1.000000	102553.6	−2.881848	6.399239*
At the first difference				
DLC.CO2				
DLFD				
DLGDP				
DLPEC				
DRESERF	4.000000	101542.5	−7.275439***	
	Critical values			
Frequency	1%	5%	10%	
1	−4.95	−4.35	−4.05	
2	−5.68	−5.08	−4.78	
3	−6.33	−5.73	−5.42	
4	−6.94	−6.31	−6.00	
5	−7.52	−6.86	−6.54	
ADF Unit Root Test				
Variable	ADF	Break Point	Test critical values	
LC.CO_2	−3.247	2014Q1	1% level	−4.949133
LGDP	−4.128	2009Q1	5% level	−4.443649
LPEC	−3.499	2010Q1	10% level	−4.193627
LFD				
RESEF				
DLC.CO_2	−6.717***	2000Q1		
DLGDP	−6.038***	2009Q1		
DLPEC	−5.436***	1998Q1		
DLFD				
DRESEF				

Note: *** and ** indicate 1% and 5% significance levels.

TABLE 4 N - ARDL bounds and long run results.

Nonlinear-ARDL bounds results				
	F-statistics	4.553***		
	K	8		
N - ARDL Long Run Results				
Variable	Coefficient	Std. Error	t-Statistic	Prob
RESEF_POS	−0.0000290	0.0000164	−1.769139	0.0819
RESEF_NEG	0.0000276	0.0000126	2.194638	0.0320
LGDP_POS	0.644587	0.184953	3.485137	0.0009
LGDP_NEG	−2.011255	0.699908	−2.873599	0.0056
LPEC_POS	0.503976	0.185845	2.711810	0.0087
LPEC_NEG	1.606081	0.625243	2.568731	0.0127
LFD_POS	−0.465384	0.084901	5.481480	0.0000
LFD_NEG	0.714437	0.121866	−5.862495	0.0000
B-P-G Heteroskedasticity Approach				
F-statistic	1.080621	Prob	0.3906	
Serial Correlation LM Test				
F-statistic	0.128075	Prob	0.9431	

welfare. Due to the contributions of CO_2 emissions to global temperature rise and climate change, economic growth is a major determinant of environmental degradation. Ilhan et al. (2022) investigated Saudi Arabia's pilgrimage tourism and CO_2 emissions nexus. They underlined that CO_2 emissions are positively influenced by energy consumption, pilgrimage, and oil prices, while CO_2 emissions are negatively impacted by GDP. ECO member countries were examined by Shabani et al. (2022) for their CO_2 emissions, economic growth, energy consumption, and urbanization. As urbanization contributes significantly to CO_2 emissions, it is important to provide welfare and financial facilities to the rulers to prevent migration. According to Ayhan et al. (2023), uncertainty, energy uses, and economic growth contribute to CO_2 emissions in G7 countries. A growing economy generally contributes to the increase of CO_2 emissions, but it contributes to a smaller effect in Japan, Germany, France, and Italy at lower quantiles and a smaller effect at higher quantiles. With data spanning from 1981 to 2016, Odugbesan and Adebayo (2020) found that economic growth and energy consumption had positive effects on CO_2 emissions in Nigeria. In OECD countries, Teng et al. (2021) found that economic growth and energy consumption have a positive impact on CO_2 emissions. An analysis of the impact of ICT, renewable energy consumption, and financial development on CO_2 emissions in East and South Asia was conducted by Batool et al. (2022). Their findings reveal that developing ICT and improving financial sectors positively contribute to environmental degradation. Sunday Adebayo et al. (2022) explored the nexus between financial development and CO_2 emissions and concluded that from financial development to CO_2 emissions, there is a one-way causal relationship. Moreover, Shoaib et al. (2020) investigated the causal relationships between financial development and CO_2 emissions in G8 and D8 countries and concluded that there is a

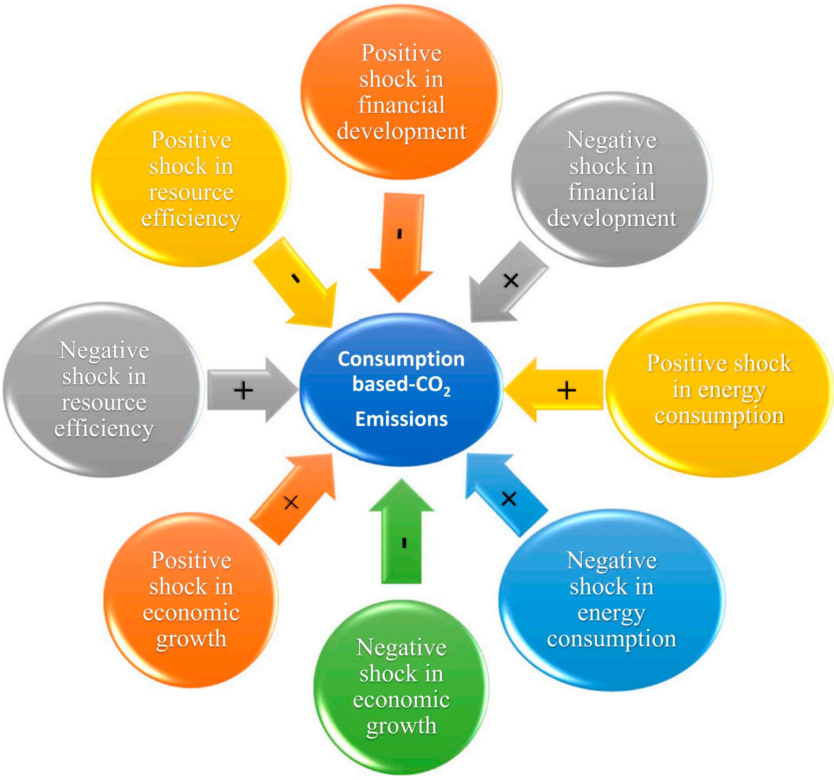

FIGURE 2
The main outcomes of the present study.

long-term positive impact of financial development on carbon emissions in both panels.

Growth in economic activity leads to industrialization, which leads to a decline in agricultural production and rapid depletion of natural resources. Natural resources are also used widely through agriculture, forestry, and mining, which affects the ecosystem. In various studies (Gylfason and Zoega, 2006; Zallé et al., 2019; Epo and Nochi Faha, 2020; Shabbir et al., 2020; Kwakwa et al., 2022), the effect of natural resources on economic growth has been explored, but only a few studies have examined its effect on carbon dioxide emissions. Moreover, natural resources have mixed effects on CO_2 emissions, according to current research. Natural resources have been shown to increase CO_2 emissions (Hussain et al., 2020; Tauseef et al., 2021; Agboola et al., 2021; Caglar et al., 2022; Li et al., 2023), while others have found that natural resources can decrease CO_2 emissions (Khan et al., 2020; Azam et al., 2023). The study of Sarkodie and Strezov (2018) underlined that natural resources are exploited more intensively and environmental sustainability is negatively affected by rapid economic development. Despite this abundance of natural resources, reducing carbon emissions can be achieved by controlling fossil fuel imports. As part of an efficient energy policy, it would also be effective to reduce both fossil fuel dependence and energy intensity, reducing the CO_2 emissions in the process (Danish et al., 2017; Domingos et al., 2017).

Although the OECD stressed the importance of minimizing environmental impacts from material use, promoting resource efficiency, and accelerating the creation of a circular economy, the impact of resource efficiency on the environment has not been comprehensively explored in the empirical literature. To open a debate and to close the gap in the empirical literature, the present study explores this linkage in the case of Canada.

3 Data and methodology

A description of the variables used in the model estimates and the methodology used to reach the study's goals is provided in this section. A key objective of this study is to investigate the asymmetric effects of resource efficiency on the quality of the environment in Canada between 1997Q1 and 2019Q4, while controlling for GDP, financial development, and energy consumption.

This study estimates the following equation based on the main purpose of the study;

$$C.CO_2 = f\,(RESEF, GDP, PEC, FD) \quad (1)$$

Where $C.CO_2$, RESEF, GDP, PEC, and FD stand for consumption-based CO_2 emissions (the data is obtained from Global Carbon Project), resources efficiency (the data is calculated by the author), Gross domestic product (the data is obtained from World Bank), primary energy consumption (the data is obtained from Our World in Data), financial development (the data is obtained from World Bank), respectively. In addition to the calculation method used by Wang et al. (2022), the present study calculated resource efficiency for Canada based on gross domestic product divided by material footprint (Wang et al., 2022). To conduct empirical analysis, this model is converted into a regression form as follows:

$$LC.CO_{2t} = \beta_0 + \beta_1 LGDP_t + \beta_2 RESEF_t + \beta_3 LPEC_t + \beta_4 LFD_t + \varepsilon_t \quad (2)$$

Where L for each variable stands for natural logarithm, expect the RESEF variable. Natural logarithms are used to transform time series variables to stabilize variances. Moreover, an outlier or extreme value can be reduced using a log transformation. This can make it easier to identify patterns and trends in the data. In addition, log transformations can also improve the accuracy of analysis by reducing variance and removing exponential trends from datasets. Figure 1 illustrates the study design, while Table 1 provides descriptive statistics and measures of variables. To obtain the negative outcomes in the skewness values indicates that the tail is on the left side of the distribution for the LC. CO2, RESEF, LGDP, LPEC, and LFD varaibles. The Kurtosis outcome in Table 1 shows that all the data series exhibit a platykurtic distribution, hence, do not produce outliers. To test for normal distribution, the study adopted the Jarque-Bera test statistic which is reported in Table 1. The outcome reveals that at a 5% significance level, LGDP and LPEC seem normally distributed, while the null hypothesis of the normal distribution for the LC.CO2, RESEF, and LFD variables can be rejected (implying that these variables are not normally distributed).

4 Empirical findings

To close gap in the empirical literature regarding the effect of resource efficiency on the quality of environment for the case of Canada, the present study used novel econometric approaches. As an initial step, the present study checked the nonlinearity behavior of the LC.CO2, RESEF, LGDP, LPEC, and LFD variables using the BDS test of Broock (1996) whose outcomes are reported in Table 2 with BDS statistics. The outcome clearly proves the nonlinearity behavior of the LC. CO2, RESEF, LGDP, LPEC, and LFD variables. As mentioned by Lanrui et al. (2022), Khan et al. (2021), and Sarwar et al. (2020), using linear estimators is likely to lead to biased outcomes. Therefore, the present study employed a nonlinear ARDL estimator in order to capture the effect of resource efficiency on the quality of the environment in the case of Canada.

To identify the integration of the order of the LC.CO2, RESEF, LGDP, LPEC, and LFD variables, the present study used the Fourier ADF Unit Root test which was developed by Enders and Lee (2012). The Fourier ADF unit root test "uses a parsimonious number of parameters, the test can avoid the problem of losing power that can be found from unit root tests using too many dummy variables". "The test is useful in the presence of unknown multiple breaks in a nonlinear fashion" (Enders and Lee, 2012). The F-test is used to determine the significance of the trigonometric terms before interpreting the Fourier ADF test results. As reported in Table 3, the F-test shows for the time series variables that the Fourier function is significant only for LC.CO2 and RESEF. The outcome of the Fourier ADF test is shown in Table 3, which clearly shows that the RESEF variable seems stationary at the first difference while the LFD variable is stationary at the level, for the LC.CO2, LGDP, and LPEC variables, the integration of order is determined using the traditional ADF unit root test. The outcomes reveal that the LC.CO2, LGDP, and LPEC variables are I(1). Consequently, a nonlinear ARDL model is selected for use as the main estimator of this study due to its superior performance over traditional estimators at stations of nonlinearity and mixed integration.

To capture cointegration equations in the estimated model, the nonlinear ARDL bounds test is implemented, reported in Table 4, respectively. The F-statistics (4.553) of nonlinear ARDL bound test results to reveal the null hypothesis of no cointegration between LC.CO2, RESEF, LGDP, LPEC, and LFD variables can be rejected. As a result, the nonlinear ARDL approach can be used in the present study to capture the asymmetric effects of resource efficiency on environmental quality in Canada.

The outcomes of the nonlinear ARDL test for the estimated Eq. 2 are reported in Table 4. While a positive shock to resource efficiency has a significant negative impact on consumption-based CO_2 emissions, a negative shock to resource efficiency has a significant positive impact on it, implying that resource efficiency contributes to the reduction of environmental degradation in Canada. As COP26 pointed out, circular economies and resource efficiency can help reach net zero and combat climate change. Material efficiency strategies will allow G7 countries to reduce 35%–40% of home lifecycle emissions in 2050, according to Hertwich et al. (2020). Thus, policymakers in Canada should continue to raise awareness about resource efficiency. Positive shock in economic growth causes an increase in environmental degradation while negative shock in economic growth causes a decrease in it, implying that economic growth in Canada significantly increases consumption-based CO_2 emissions. This is in line with the outcome of Batool et al. (2022), Alhassan et al. (2022) and Usman et al. (2023). Thus, the government in Canada and policymakers, rather than targeting slowing down economic growth (which is not rational), should reduce the CO_2 intensity of GDP. In other words, to achieve a win-win scenario, a lower energy density and a lower CO_2 intensity in GDP would lead to a higher per-unit energy consumption and CO_2 productivity in Canada. In addition, there is a positive and significant relationship between primary energy consumption and consumption-based CO_2 emissions in Canada. To mitigate environmental degradation in Canada, energy consumption from non-renewable sources should be reduced as much as possible. In addition, a reduction in non-renewable energy use would not only protect the environment but would also ensure sustainable resources. Finally, Table 4 reveals that a 1% upsurge in the financial development index leads to a decline in consumption-based CO_2 emissions in Canada by 0.46%, while a 1% increase in the financial development index causes a 0.71% increase in consumption-based CO_2 emissions. In light of the empirical results of the present study, it is important that Canada continues to increase green finance activities while facilitating environment-friendly projects. By implementing environmental-friendly financial development policies, Canadian pollution levels can be reduced. The graphical illustration of the nonlinear ARDL model is reported in Figure 2. Moreover, diagnostic results for the estimated model in Figure A1, Figure A2 and Table 4 prove the stability of the model.

Conclusion

The OECD stressed the need to minimize the environmental footprint of material use, promote resource efficiency, and accelerate the transition to a circular economy in order to combat climate change. Canadians have made substantial progress against global warming since the Paris Climate Agreement was signed in 2015. To achieve a net-zero target by 2050, Canada has introduced pollution-reduction initiatives through the Paris Climate Agreement. In order to achieve this goal, however, there is a long road ahead. Even though resource efficiency is important for environmental quality, there is a lack of empirical evidence about its impact on the environment. Thus, the present study aims to promote a new debate about Canadian environmental quality and resource efficiency and close this gap in the empirical literature. To achieve this objective, the present study employed the nonlinear ARDL bounds test for the sample period between 1997Q1 and 2019Q4.

The outcome of this empirical study reveals that 1) there is a long-run linkage between environmental quality, resource efficiency, financial development, economic growth and primary energy consumption in Canada; 2) resource efficiency and financial development contribute to the reduction of environmental degradation in Canada; 3) economic growth and primary energy consumption increase the consumption based-CO_2 emissions.

Due to the study's emphasis on resource efficiency as a means to reduce consumption-based CO2 emissions, policymakers in Canada make sure that circular economies and resource efficiency help achieve net zero emissions. The importance of material efficiency for reducing around 40% of home lifecycle emissions in 2050 is already underlined by the study of Hertwich et al. (2020). Based on this perspective, it is important for Canadian policymakers to continue to raise awareness about resource efficiency. Moreover, Canada should target to reduce lower GDP's energy density and CO_2 intensity in order to increase per-unit energy consumption and CO_2 productivity since it is not rational to slow down economic activities. Canada should carry on to increase green finance activities while facilitating environment-friendly projects since the empirical results of the present study underline that Canadian pollution levels can be reduced by implementing environmentally-friendly financial development policies.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

DK: Conceptualization, Investigation, Methodology, Writing–original draft. RC: Data curation, Funding acquisition, Project administration, Supervision, Writing–review and editing. RD: Project administration, Resources, Validation, Visualization, Writing–review and editing. SY: Investigation, Project administration, Resources, Supervision, Visualization, Writing–original draft. ZA: Data curation, Writing–original draft, Resources, Project administration, Methodology, Investigation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer TSA declared a past co-authorship with the author DK to the handling editor.

Publisher's note

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Appendix A

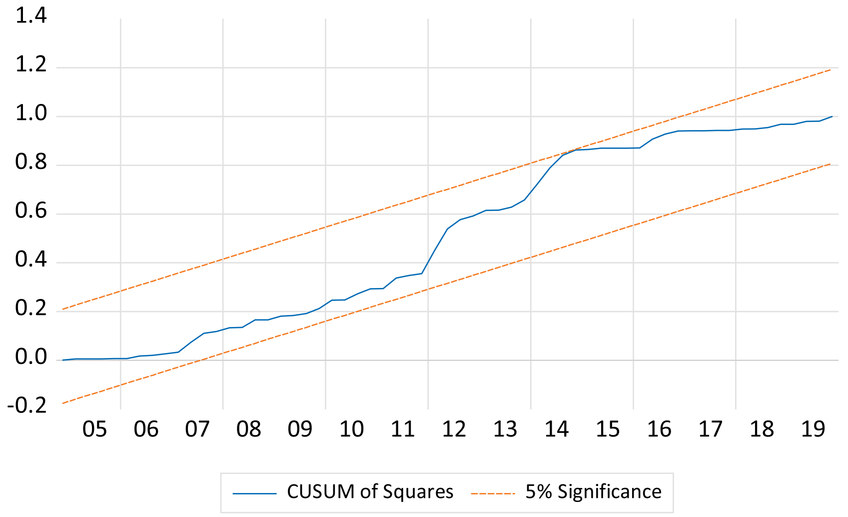

FIGURE A1
CUSUM of squares.

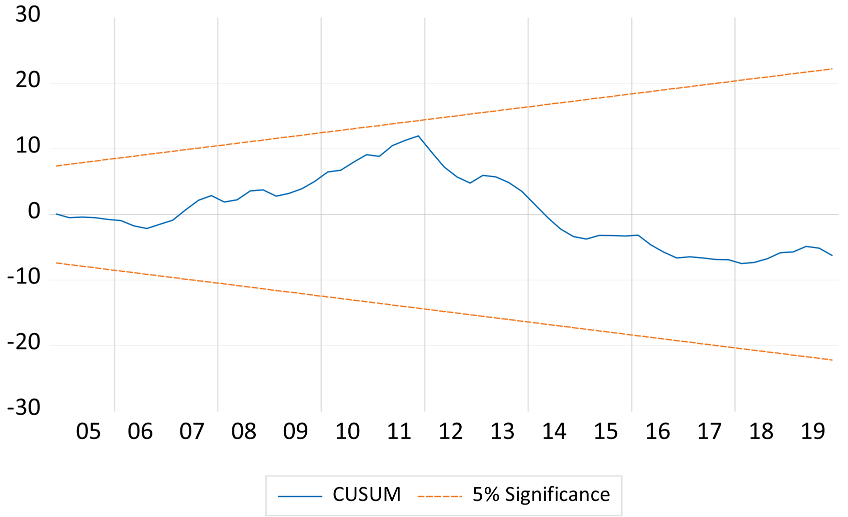

FIGURE A2
CUSUM.