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Pathway to cleaner environment: How effective are renewable electricity and financial development approaches?

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ABSTRACT

While Sustainable Development Goals (SDGs) 13 and 7 are increasingly being explored in climate change research, financialization remains a fundamental part of the discourse on clean and renewable energy development. This study focuses on a policy reconfiguration that may be necessary to further advance clean environment in Canada. More precisely, the research evaluates the co-movement of carbon dioxide (CO_2) emissions, financial development, renewable electricity and economic growth. The data, which encompass the quarterly periods from 1984Q1 to 2021Q4, are analysed via the novel wavelet local multiple correlation method. This method is capable of capturing the effect of two or three independent variables on the dependant variable at different frequencies and periods. In this study, the results show that economic growth intensifies ecological deterioration in all periods even as renewable electricity utilisation and financial development restrict ecological deterioration in the medium and long term. Additionally, financial development and renewable electricity consumption promote economic growth in the short, medium and long term. On the basis of these findings, a policy agenda that builds on the SDGs is proposed. Although this policy framework aims to achieve the objectives of SDG 13 and 7 in Canada, it may be extended to other developed countries.

1. Introduction

Developing a regularly updated intergenerational agreement on the issues of climate change remains a Herculean task due to the trend of global consumption, the trajectory of energy-driven economic expansion and the depletion of natural resources. The absence of such consensus is a potential barrier to sustainable growth and largely to the Sustainable Development Goals (SDGs) of the United Nations. The SDGs aim to reorient the current pattern of economic growth to restore the global climate balance. For instance, SDG 7 and 13, respectively, emphasise clean energy development and climate action without necessarily compromising future developments. However, with growth in industrial operations and populations across the world, the demand for commercial energy is also increasing. Burning of fossil fuels remains the main source of commercial energy, and it exacerbates the climate problem by causing more ambient air pollution. Moreover, achieving

Abbreviations: AMG, Augmented Mean Group; ARDL, Autoregressive Distributed Lag; BRCIS, Brazil, Russia, India, China, and South Africa; CO_2, Carbon Emissions; DOLS, Dynamic Ordinary Least Square; EKC, Environmental Kuznets curve; FD, Financial Development; FMOLS, Fully Modified Ordinary Least Square; GDP (Gross Domestic Product), Economic Growth; GMM, General Method of Moment; IMF, International Monetary Fund; MINT, Mexico, Indonesia, Nigeria and Turkey; NARDL, Nonlinear Autoregressive Distributed Lag; NDC, Nationally Determined Contribution; R&D, Research and Development; REC, Renewable Energy Consumption; SDGs, Sustainable Development Goals; VECM, Vector Error Correction Model; WLMC, Wavelet Local Multiple Correlation; WLMR, Wavelet Local Multiple Regression.

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SDG 7, which is concerned with finding inexpensive and sustainable energy solutions, is a must for realising SDG 13. Thus, finding and developing cleaner energy solutions is essential for addressing the current climatic concerns.

Energy system, especially its usage, is one of the best measures of a nation's performance in terms of sustainable development. The use of renewable energy appears to be a key component of energy efficiency, and a low demand for fossil fuels often acts as a buffer against the market's larger shocks. However, switching from non-renewable energy use to renewable energy consumption (REC) is difficult due to the high prices of renewable energy sources, which includes the cost of new infrastructure construction, startup and operations. Accordingly, a sound financial system is necessary to support and manage the uncertainties associated with the shift from non-renewable energy to renewable energy. Likewise, sound financial markets are necessary to increase capital allocation and mobility as well as industrial investments in the renewable energy sector (Kirikkaleli and Adebayo, 2021). Thus, financing plays a significant role in fostering the renewable energy sector. Since the shift to renewable energy is likely to affect the pattern of economic growth, it is essential that REC and financial development (FD) are integrated under a single policy agenda (Anwar et al., 2022).

The G7 economies have sound financial systems to support the transition, which country is performing better in terms of sustainable development. Given this scenario, a relevant question for Canada is 'How can the attainment of ecological sustainability be fast-tracked?' As the present guidelines in Canada have proven to be ineffectual in addressing this question, a policy reconfiguration that considers both FD and renewable energy generation is required. According to the global ecological policy discourse, this strategy realignment is necessary to accomplish the objectives of SDG 7 and 13. amongst the G7 nations, Canada's per capita CO_2 emission is second only to that of the United States (see Fig. 1). This situation highlights Canada's unsustainable ecological policy framework, and this study attempts to contribute to the existing body of knowledge by reorienting the policy agenda. Specifically, it addresses the following research questions: a) Can a shift in financial development secure Canada's environmental sustainability? and (b) Does renewable energy promote environmental sustainability in Canada?

With the Canadian government implementing its climate policy agenda, the country's emissions have begun to decline, but a substantial gap remains between the present policy goals and Canada's nationally determined contribution (NDC) target and 1.5 °C compliance (CAT, 2023). The closing of the gap will partially be accomplished through the execution of designed initiatives, but more efforts are needed. Canada's climate objectives, policies and financing status have all been rated as 'highly insufficient' by the CAT. The rating suggests that Canada's environmental initiatives and pledges do not align with the 1.5 °C temperature target stipulated in the Paris Agreement (CAT, 2023). According to the projected domestic emission patterns, Canada's 2030 NDC target is compatible with a global warming temperature of 2 °C. Canada's present plans, even if executed completely, would only be sufficient to limit global warming to 4 °C (CAT, 2023). The above-mentioned facts make an interesting case for evaluating the interrelationship between financial development, renewable electricity, economic growth and CO_2 emissions in Canada. Such an investigation will help determine whether and to what extent financial development and renewable energy policies are advancing the goal of a clean environment in Canada.

Meanwhile, it is crucial to keep in mind that the methodological approach used in the investigation could further complement the theoretical contribution of the study. Over the years, numerous studies (e.g. A.A. Alola et al., 2021; Bilgili et al., 2022; Ojekemi et al., 2022; Sharif et al., 2019; Xu et al., 2022) have been conducted on the impact of FD and REC on ecological sustainability. However, these studies have been constrained by the use of time-domain techniques, which do not yield information about the association between FD and REC at different frequencies and periods. Consequently, the policy suggestions in these studies have been limited. The present study deviates from prior investigations by relying on an advanced technique called the 'wavelet local multiple correlation (WLMC)' developed by Polanco-Martínez et al. (2020). Unlike conventional techniques, such as autoregressive distributed lag (ARDL), vector error correction model (VECM), fully

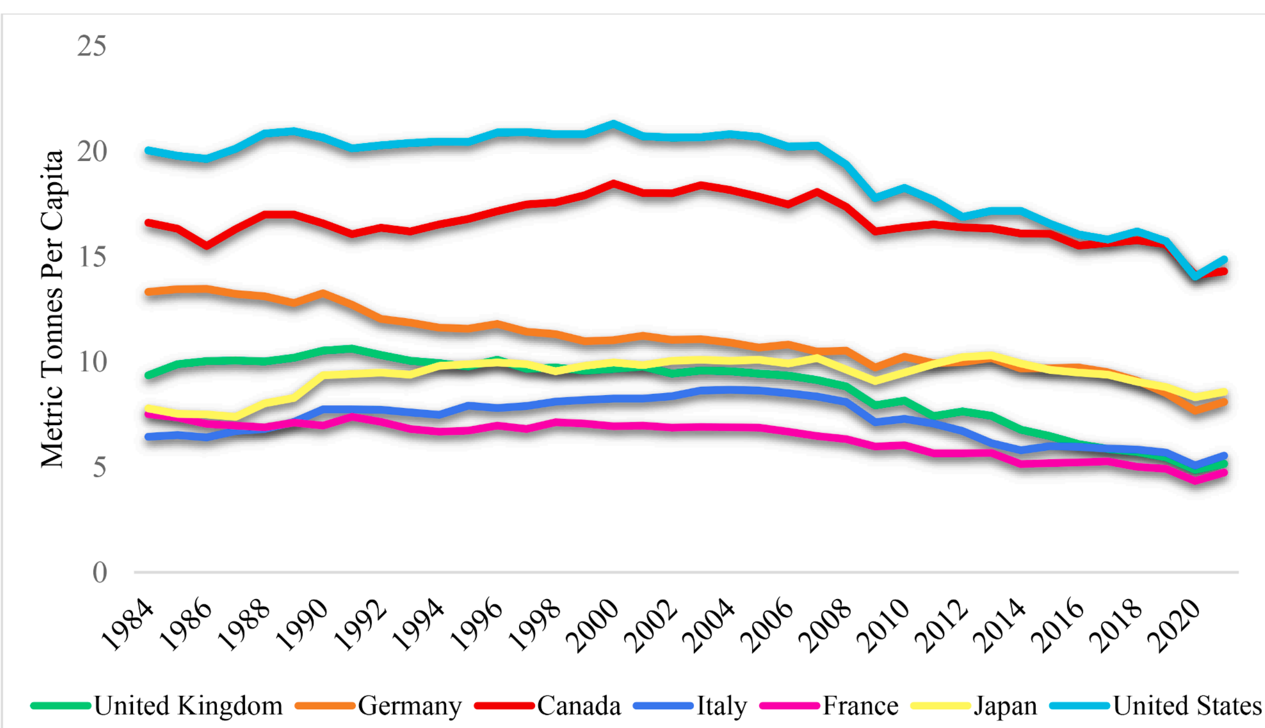


Fig. 1. CO_2 emission trends in G7 economies.

modified ordinary least square (FMOLS), dynamic ordinary least square (DOLS), general method of moment (GMM) and ordinary least square (OLS), this technique can capture the co-movement between variables at different frequencies and periods. Furthermore, it can capture the effect of two/three independent variables on the dependant variable at different frequencies and time periods. To the best of the authors' knowledge, this is the first paper that explores the nexus between CO_2, REC, FD, and gross domestic product (GDP) via the WLMC method. Thus, the present study maintains methodological complementarity.

The paper is divided into five sections: the second section evaluates prior research; the third section lists the data sources and describes the methodology. The fourth section presents the empirical findings, and the fifth section concludes the paper by discussing policy implications.

2. Literature review

2.1. Economic growth and CO_2 emissions

Since Grossman & Krueger's (1995) ground-breaking work, many studies have been conducted on the interrelationship between environmental indicators and economic indicators such as income and GDP (Abbasi et al., 2021; Alam and Murad, 2020; Arain et al., 2020; Awodumi and Adewuyi, 2020; Aye and Edoja, 2017; Baz et al., 2020; Kirikkaleli et al., 2022; Sharif et al., 2019). Scholars have recently examined the connection between these two indicators from a number of angles. Specifically, the causes of CO_2 emissions have received considerable attention. For instance, Mikayilov et al. (2018), in their investigation using data from 1992 to 2013, explored the income–environment nexus in Azerbaijan within the framework of environmental Kuznets curve (EKC). The findings from ARDLBT, DOLS and FMOLS estimators showed that intensification of CO_2 emissions in Azerbaijan is caused by an upsurge in income. A similar finding was reported by Boukhelkhal (2022), who explored the role of real growth in CO_2 emissions in 35 African countries by using data from 1980 to 2016. An emission-increasing effect of income was detected in the long term, with the help of the DCCEMG estimator. Similarly, using panel estimators such as AMG and CCEMG, a study by Ağa et al. (2023) based on data from 1990 to 2018 on Mexico, Indonesia, Nigeria and Turkey (MINT) reported that the ecological deterioration in the MINT nations is caused by economic progress.

Contrarily, some studies have found an emission-reducing effect of economic growth. For example, Usman et al. (2020) analysed data from the United States (US) between 1984 and 2014 and documented an emission-decreasing effect of income, which implies that increase in income promotes ecological sustainability. Similarly, Adebayo (2022b) explored the income-emissions nexus in Canada using data from 1990 to 2018. The study based on the dynamic ARDL method showed that both a long- and short-run upsurge in income lessens CO_2 and as a result enhances ecological sustainability. Additionally, Dogan and Turkekul (2016) examined the connection between real output GDP and CO_2 emissions in the US from 1960 to 2010. The cointegration bounds testing showed that the studied indicators are cointegrated. In the long run, their findings did not support the EKC hypothesis for the US since real output results in ecological improvements. Further, it should be mentioned that the creation of effective energy regulations probably helps reduce CO_2 emissions without affecting economic growth. Likewise, in order to investigate the variables causing unfavourable greenhouse gas (GHG) emissions and their economic repercussions, Sarkodie and Strezov (2018) analysed the EKC hypothesis for China, Ghana, US and Australia between 1971 and 2013 and found that the results supported EKC.

2.2. Renewable energy, financial development and CO_2 emissions

The nexus between FD and REC and CO_2 has been explored by many scholars; however, conflicting results have been reported due to dissimilar economic situations of the nations as well as the use of differing time periods and techniques. Xu et al. (2022) investigated the drivers of CO_2 between 1990 and 2014 for 15 Asian economies using the FMOLS estimator and reported that REC dampens CO_2 emissions while FD increases CO_2 emissions. Likewise, using data from the Belt Road Initiative (BRI) countries and the GMM method, Sheraz et al. (2022) examined the nexus between FD, CO_2 and REC between 2003 and 2018. They found that REC decreases emissions whereas FD contributes to its increase. Batool et al. (2022) used the pooled mean group (PMG) method and data from 1985 to 2020 to inspect the factors driving CO_2 emissions in East and South Asia nations. The findings from the study showed that a decrease and increase in CO_2 is caused by REC and FD respectively; that is, REC enhances ecological quality while FD decreases ecological quality. Zoaka et al. (2022) also reported similar results by using AMG estimator and data from 1990 to 2019 for NICs. Likewise, using data from the Brazil, Russia, India, China, and South Africa (BRICS) countries for 1990–2019, Usman and Balsalobre-Lorente (2022) inspected the nexus between FD, EF and REC via the GMM method. They concluded that REC decreases the ecological footprint whereas FD contributes to its increase.

Additionally, some studies found that both FD and REC mitigate CO_2 emissions. For instance, using data from six emerging countries between 2000 and 2018, Haldar and Sethi (2022) inspected the effect of FD and REC on emissions via Driscoll-Kraay estimators. They found that both FD and REC lessen CO_2 and as a result improve ecological quality in all the six emerging countries. Usman et al. (2022) also reported similar findings after studying data from 1990 to 2017 for the Arctic countries. Moreover, Ramzan et al. (2022) explored the ecological footprint drivers in Pakistan using data from 1960Q1 to 2019Q4 and the novel non-parametric causality-in-quantiles method. They reported that FD and REC could predict CO_2 in majority of the quantiles in variance while the strength of causality was weak in the means. Table 1 presents a summary of the reviewed studies.

2.3. Research contributions

In the empirical literature, many studies (e.g., Anwar et al., 2022; Batool et al., 2022; Dogan and Turkekul, 2016; Kirikkaleli et al., 2022; Usman et al., 2022; Zoaka et al., 2022) have explored the connection between CO_2 and FD, REC and GDP. While several have explored this nexus using bivariate techniques such as wavelet coherence (Adebayo, 2022a; Adeshola et al., 2022; Bilgili et al., 2021; Le, 2022; Reboredo et al., 2017), none have explored the co-movement between two independent variables and the dependant variable. Unlike the above studies, the current study uses the WLMC approach proposed by Polanco-Martínez et al. (2020), which can capture the effect of two/three independent variables on the dependant variable at different frequencies and time periods. To the best of the investigators' knowledge, this is the first empirical investigation to explore the nexus between CO_2 and FD, GDP and REC at dissimilar frequencies and time periods using the newly introduced WLMC approach. Thus, the current study bridges a gap in the existing literature by exploring the nexus between CO_2 and FD, GDP and REC in Canada.

3. Data and methodology

The paper explores the nexus between CO_2 emissions (CO_2), FD, and REC in Canada between 1984 and 2020. Here, CO_2 is a proxy for ecological degradation, and REC is employed as a proxy for renewable electricity consumption. The data for both REC and CO_2 are obtained from the OurWorldinData database, and the data on FD are extracted from the International Monetary Fund (IMF) database. The GDP data have been obtained from the World Bank database. Table 2 presents the variables of research along with their measures. Given the short time period of the data, we followed the procedure used by Balciliar et al. (2020) and Pata et al. (2023) and converted all data into quarterly

Table 1
Synopsis of Prior Studies.

Author(s)	Nation (s)	Duration	Techniques	Result(s)
Xu et al. (2022)	G7 countries	1986–2019	NARDL and 2SLS	$REC^{+} \rightarrow CO_2 \downarrow$
Wu et al. (2022)	Nordic nations	1990–2019	Wavelet tools	$REC \rightarrow CO_2 \downarrow$,
Anwar et al. (2022)	15 Asian economies	1990–2014	FMOLS	$REC \rightarrow CO_2 \downarrow$, $FD \rightarrow CO_2 \uparrow$
Sheraz et al. (2022)	BRI countries	2003–2018	GMM	$REC \rightarrow CO_2 \downarrow$, $FD \rightarrow CO_2 \uparrow$
Haldar & Sethi (2022)	6 emerging countries	2000–2018	Driscoll-Kraay estimators	$REC \rightarrow CO_2 \downarrow$, $FD \rightarrow CO_2 \downarrow$
Batool et al. (2022)	East and South Asia nations	1985–2020	Pooled mean group (PMG)	$REC \rightarrow CO_2 \downarrow$, $FD \rightarrow CO_2 \uparrow$
Zoaka et al. (2022)	BRICS countries	1980–2018	PMG-ARDL	$REC \rightarrow CO_2 \downarrow$, $FD \rightarrow CO_2 \uparrow$
Usman & Balsalobre-Lorente (2022)	NICs	1990–2019	AMG	$REC \rightarrow EF \downarrow$, $FD \rightarrow EF \uparrow$
A.A. Alola et al. (2021)	EU-28	2000Q1–2017Q4	GMM panel-VAR	$REC \rightarrow GHGs \downarrow$, $FD \rightarrow GHGs \uparrow$
Kirikkaleli et al. (2022)	Chile	1990–2017	ARDL, FMOLS and DOLS	$REC \rightarrow CCO_2 \downarrow$, $FD \rightarrow CCO_2 \uparrow$
Ramzan et al. (2022)	Pakistan	1960Q1–2019Q4	Causality-in-quantiles	$REC \rightarrow EF$, $FD \rightarrow EF$
Usman et al. (2022)	Arctic countries	1990–2017	AMG	$REC \rightarrow CO_2 \downarrow$, $FD \rightarrow CO_2 \downarrow$
Mikayilov et al. (2018)	Azerbaijan	1992–2013	ARDLBT, DOLS and FMOLS	$GDP \rightarrow CO_2 \uparrow$
Aye & Edoja (2017)	31 developing countries	1990–2014	Dynamic panel threshold model	$GDP \rightarrow CO_2 \uparrow$
Ağa et al. (2023)	MINT countries	1990–2018	Panel estimators	$GDP \rightarrow CO_2 \uparrow$
Boukhelkhal (2022)	35 African countries	1980–2016	DCCEMG	$GDP \rightarrow CO_2 \uparrow$
Caglar et al. (2022)	BRICS countries	1990–2018	Panel estimators	$GDP \rightarrow CO_2 \uparrow$
Ullah et al. (2023)	United States	1965–2018	Wavelet tools	$GDP \rightarrow CO_2 \uparrow$

Table 2
Indicators Source and Measurement.

Indicators	Abbreviation	Measurement	Source
CO_2 emission	CO_2	Metric tons per capita	OurWorldinData Database
Renewable electricity consumption	REC	Renewable electricity per capita (kWh)	OurWorldinData Database
Financial development	FD	Index	IMF Database
Economic growth	GDP	GDP per capita US$ 2010 Constant	World Bank Database

frequencies, employing the quadratic match-sum method in Eviews 12, which offers the advantage of reducing point-to-point changes and adjusting seasonal fluctuations. Additionally, for consistent and accurate estimations, all series are transformed into their natural logarithms.

Descriptive statistics are shown in Table 3. The mean of LnGDP (10.642) is the highest, which is followed by LnREC (9.3459), $LnCO_2$ (2.8242) and LnFD (−0.3800). Moreover, FD is highly volatile compared to the other indicators. The skewness value of LnFD and LnREC is negative, which shows evidence of a long-left tail and more lower values. Contrarily, the skewness value of $LnCO_2$ and LnGDP is positive, which shows evidence of a long right tail and more higher values. The Jarque-Bera P-value shows that only LnREC has normal distribution.

Table 3
Descriptive Statistics.

	$LnCO_2$	LnFD	LnGDP	LnREC
Mean	2.8242	−0.3800	10.642	9.3459
Median	2.8120	−0.3009	10.605	9.3470
Std. Dev.	0.0562	0.2793	0.1480	0.0334
Skewness	0.3016	−0.6105	0.1096	−0.1675
Kurtosis	1.9759	1.8969	1.4004	2.3178
Jarque-Bera	8.7113	16.696	16.074	3.5623
Probability	0.0128	0.0002	0.0003	0.1684

Using the average values presented by kurtosis, the Jarque-Bera probability and the skewness values, the normality test is evaluated. Evaluation based on these criteria indicates that with the exemption of LnREC, all the variables are not distributed normally.

A boxplot shows a graphical representation of the sample's distribution. It displays the data's shape, variability and central tendency. Fig. 2a shows the data distribution in box plots. Each plot has a percentage of 25, 50, and 75, with the maximum and minimum values represented by the upper and lower lines; the median by the circle; and the mean values by the square. Further, the scatter plot is presented in Fig. 2b. The study function is shown by Eq. (1).

$$CO_{2t} = f(GDP_t,\ REC_t, FD_t), \tag{1}$$

where CO_2, REC, FD and GDP denote CO_2 emissions, renewable electricity use, financial development and economic growth, respectively.

The primary motive of all energy use is constant economic growth (Acheampong et al., 2022). Canada's economy is expanding rapidly, driven mainly by heavy fossil fuel use. As Canada's economy expands and the standard of living rises, its fossil fuel-based economic trajectory contributes to environmental degradation, which is a negative externality. The simplest, realistic and empirically backed approach to addressing the health and environmental issues caused by fossil fuel use is the use of renewable energy. The deployment of renewable energy as a steady and consistent substitute for fossil fuels has not only been highlighted in COP27 and other climate conferences but also confirmed via empirical evidence (Reboredo et al., 2017; Shahbaz et al., 2016; Sharma et al., 2021). Consequently, we anticipate a negative relationship between REC and CO_2.

Theoretically, two opposing views exist regarding the impact of FD on ecological deterioration. Firstly, FD may have a positive impact on ecological sustainability. Investments in renewable energy can support the building of infrastructure that is ecologically friendly and viable in the long run (Anwar et al., 2022; Kirikkaleli et al., 2022). Additionally, FD can enable nations to employ cutting-edge technologies for green and eco-friendly production and thereby improve global and regional

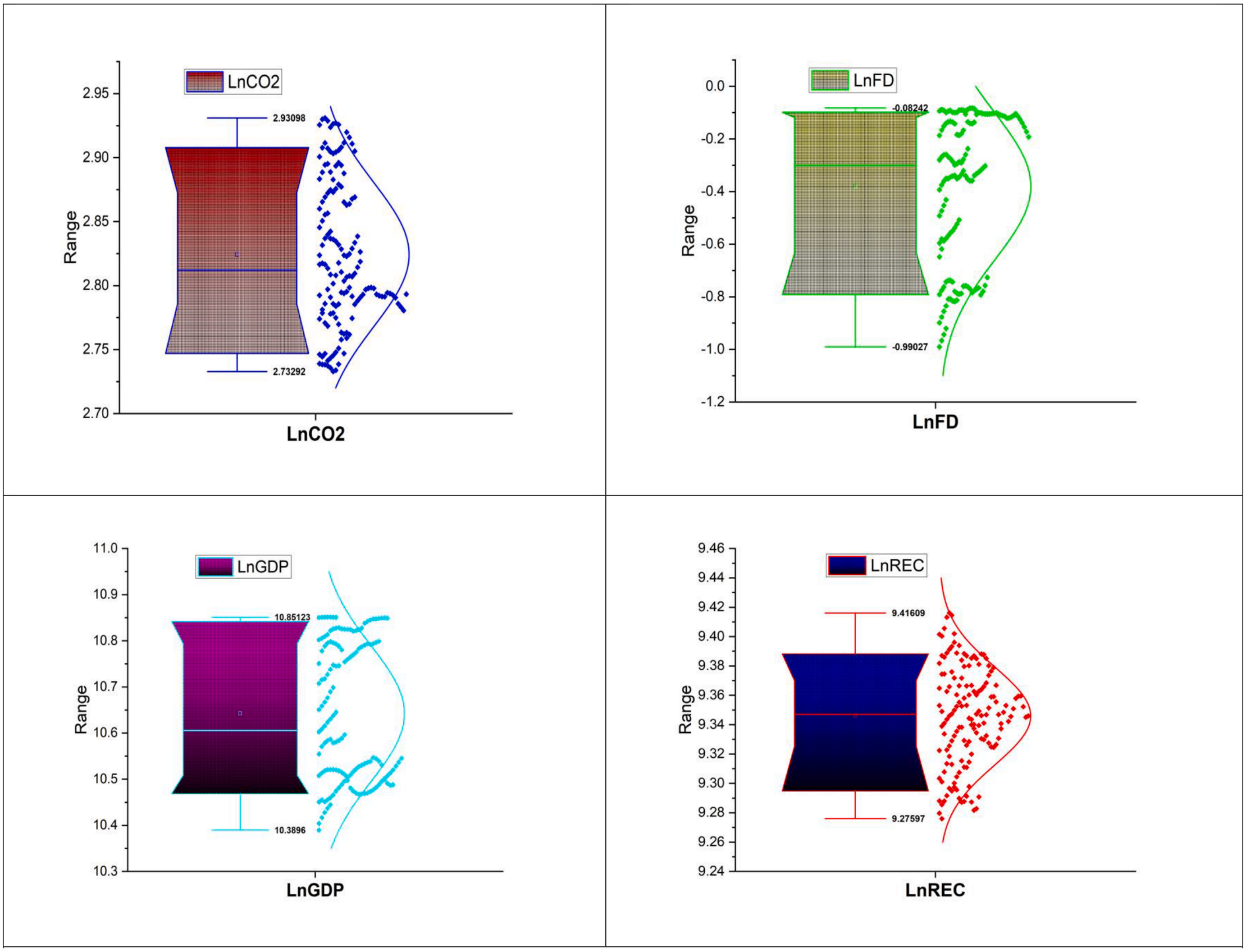


Fig. 2. a: Scatter plot
b: Scatter plot.

ecological sustainability (Ağa et al., 2022). On the other hand, a high level of FD can worsen the ecosystem. According to Xu et al. (2022), FD simplifies the process for individuals and businesses to access low-cost financing, which in turn allows them to launch new ventures or grow current ones. This results in higher energy use, which has a negative influence on ecological quality.

3.1. Research methodology

This paper utilises the wavelet local multiple correlation (WLMC) approach proposed by Polanco-Martínez et al. (2020) to explore the nexus between CO_2 emissions, financial development, renewable electricity consumption and economic growth in Canada.

The WLMC method is an improvement over the wavelet local multiple regression (WLMR), which was first introduced by Fernández-Macho (2019b). Let X represent the multivariate series of n dimension noticed at $t = 1,\ldots T$. As stated by Fernández-Macho (2019b), $x_i \in X$, which is a local regression, can be employed in minimising the weighted sum of squared errors.

$$S_s = \sum_t \theta(t-s)\left[f_s\left(X_{-i,t}\right) - x_{it}\right]^2, \tag{2}$$

where fs($X - i$) is a local function of {X\xi} concerning s, and θ(x) is a predetermined moving average weight function that relies on the interval between observations Xt and Xs. While s is allowed to move through time, the appropriate local coefficients of determination are provided by:

$$R_s^2 = 1 - \frac{R_w SS_s}{TWSS_s}, \ = s = 1\ldots.T, \tag{3}$$

where the terms RwSSs and TwSSs represent the residual and total weighted sum of squares, respectively.

Let W_{jt} = (w1jt, ...,wnjt) be the coefficients of the wavelet for scale j assembled by applying the maximal overlap discrete wavelet transformation to each series xi ∈ X, where $i = 1, \ldots, n$. At each wavelet scale j, the WLMC coefficient $\varphi_{X,s}(\lambda_j)$ can be calculated as the coefficient of determination of the regression for the linear mix of series wij, $i = 1, ., n$, where the determination of such coefficients is maximum.

$$\widehat{\varphi} X_r\left(\lambda_j\right) = \sqrt{R_{js}^2}, j = 1, \ldots.j \ s = 1, \ldots..T \tag{4}$$

Also, the $\widehat{z}_i$ multiple local regression (MLR) coefficients of a qi on the other system series are comparable to the square linkage between fitted values and qi multiple local regression values. Z^2 is the coefficients in the multiple local regression of a qi. Also, MLR denotes the multiple local regression. Eq. (5) displays the WLMC estimator.

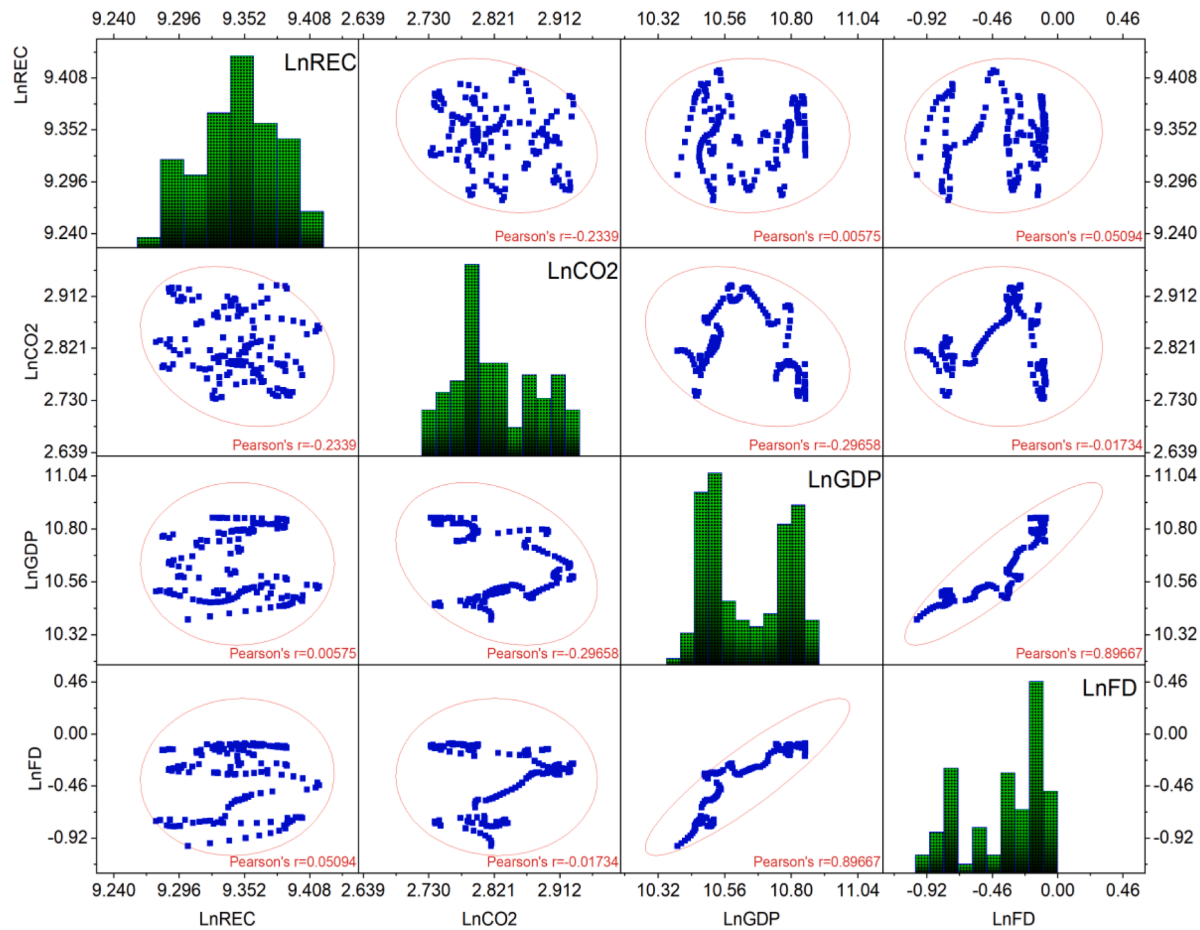


Fig. 2. (*continued*).

$$\widehat{\varphi}X_s(\lambda_j) = corr\ (\vartheta((t-r))^{1/2}W_{ij,}\ \sqrt{Z_r^2},\ \vartheta(t-s))^{1/2}W_{ij}\ s = 1, \ldots T. \quad (5)$$

The six frequently employed weighted functions for smoothing and averaging are measured by the wavemulcor package together with WLMC. The six weighted functions are Gaussian window, Bartlett triangular window, Cleveland's tricube window, uniform window, Wendland's truncated power window and Epanechnikov's window. However, Epanechnikov's and Cleveland's tricube parabolic may not be particularly suitable because of the existence of negative values in their respective spectral functions (Polanco-Martínez et al., 2020). Furthermore, Fernández-Macho (2019a) supported the use of Wendland's truncated power, Bartlett's triangular windows and Gaussian windows.

4. Findings

This section presents the results from the techniques employed, starting with the pre-estimation results and followed by the main estimations.

4.1. Pre-estimation test results

Firstly, the Brock-Dechert-Scheinkman (BDS) test (see Table 4) is used to evaluate the series normality attributes. The results indicate that the Ho hypothesis of normal distribution is rejected for all the series (CO_2, REC, GDP and FD); that is, the variables do not show normal distribution. The use of linear techniques with series that are not normally distributed can produce inaccurate results (Ağa et al., 2023; Sinha et al., 2018; Balcilar et al., 2017). Hence, this study uses the WLMC approach, which is a nonlinear technique, to evaluate the nexus between CO_2, REC, GDP and FD.

Table 4
BDS Test.

	$LnCO_2$	LnREC	LnGDP	LnFD
M2	0.1841*	0.1490*	0.1999*	0.2030*
M3	0.3057*	0.2368*	0.3368*	0.3436*
M4	0.3833*	0.2827*	0.4306*	0.4404*
M5	0.4303*	0.3011*	0.4946*	0.5065*
M6	0.4569*	0.3057*	0.5382*	0.5516*

Note:.
[*] represents 1%.

We then examine the correlation between CO_2, REC, GDP and FD (see Table 5). The results show that both REC and FD have a negative correlation with CO_2, while a positive correlation exist between CO_2 and GDP. Furthermore, a positive, albeit weak, correlation exists between GDP and REC. Finally, FD and GDP are positively correlated. Fig. 3

Table 5
Correlation Results.

	$LnCO_2$	LnREC	LnGDP	LnFD
$LnCO_2$	–	−0.2339*	0.2965*	−0.0173*
LnREC	−0.2339*	–	0.0057*	0.0509*
LnGDP	0.2965*	0.0057*	–	0.8966*
LnFD	−0.0173*	0.0509*	0.8966*	–

Note:.
[*] represents 1%.

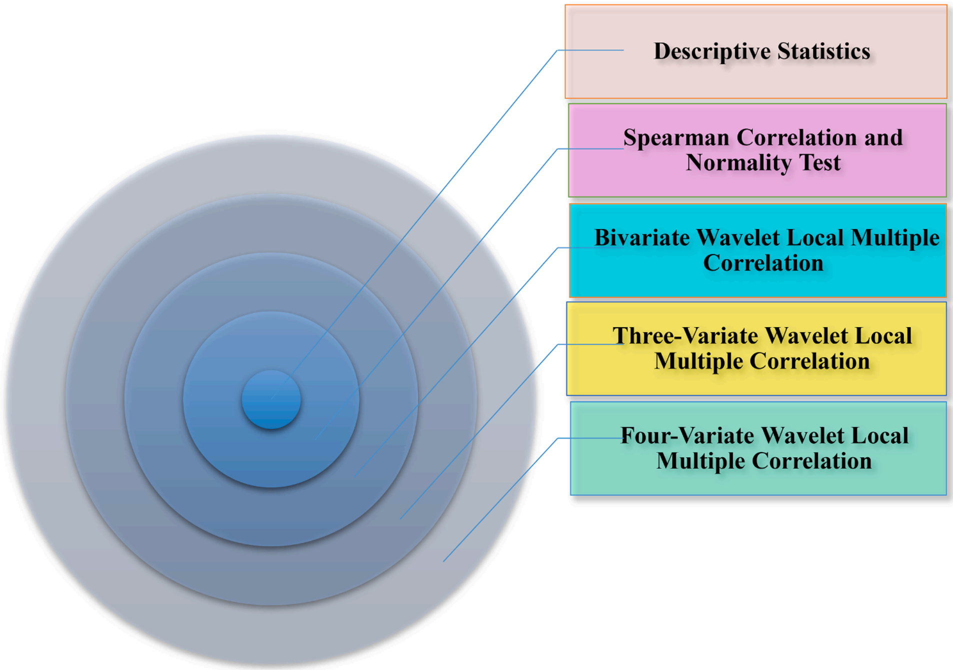


Fig. 3. Analytical design of the study.

4.2. Bivariate nexus between economic growth, renewable electricity consumption and financial development

Figs. 4, 5 and 6 show the WLMC for bivariate, three-variate and four-variate cases, taking into account the nexus between economic growth, renewable electricity consumption and financial development. First, the bivariate analysis shows the overall picture of the co-movement between the two series at several timeframes (i.e., long, medium and short term). The vertical axis in each of the figures represents time frequencies, while the horizontal axis shows periods. The WLMC identifies the region in which two series interact at various time frequencies. Black lines represent the correlation between the two series, whereas blank regions represent insignificant correlation at various time frequencies and periods. In the time-frequency domain, warmer and colder hues denote the strongest and weakest connections, respectively. The spectral correlation values are shown on a vertical sidebar, ranging from warmer/strong/positive correlation to colder/low/ negative correlation.

Fig. 4a presents the WLMC between FD and REC. In the medium and short term, evidence of negative coherence is seen during 1987Q1–1990Q4, 2000Q1–2006Q4 and 2016Q1–2020Q4. This indicates that in the short and medium term, FD drives REC negatively. However, in the long term, from 1984Q1 to 2020Q4, FD promotes REC in Canada. These results offer a fascinating understanding of the FD–REC interconnection in the long term for Canada. This result is expected given the strength and resilience of Canada's financial sector (Bank of Canada, 2023). Increased investment in renewable energy projects is more likely in the event of strong performance of financial institutions. Investors are more inclined to finance renewable energy projects when the financial markets are more reliable, given the associated low risk and high profit opportunities. This may result in more clean energy projects being funded, thus increasing the use of renewable energy sources. Moreover, financial development can encourage innovation in the field of green energy. With more funds available, businesses may engage in research and development (R&D) and build new technologies that can increase the efficiency, accessibility and affordability of renewable energy. Thus, these results show that the financial sector in Canada favours a shift to renewable energy sources, and these results are in line with economic intuition. Further, they confirm that FD significantly influences REC in Canada. These findings are in agreement with those of Wu and Broadstock (2015) for developing countries, Cetin and Bakirtas (2020) for developing economies, and Anton and Afloarei Nucu (2020) for 28 EU economies, all of whom noted the critical role that financial development plays in encouraging REC.

Fig. 4b shows the WLMC between FD and GDP. In the short and long term, a positive correlation exists between FD and GDP, with an average coefficient value of 0.4 from 1984Q1 to 2002Q4. However, in the short and medium term, the correlation between FD and GDP is insignificant from 2008Q1 to 2018Q4. Further, from 2008Q1 to 2020Q4, there is a positive correlation between FD and GDP in the long term with an average coefficient of 0.6. These results can be interpreted as follows. The availability of capital, such as credit for businesses, especially small and medium enterprises (SMEs) that might have restricted access to finance, could improve with financial development. Because of improved access to credit, firms may be able to invest in new machinery, processes and technologies, which should enhance output and spur economic expansion. Moreover, financial development may facilitate international trade by opening up access to trade finance such as guarantees and letters of credit. This can ease the flow of products and services across borders and lower the risks involved in business transactions. Thus, the development of the financial sector in Canada plays a major role in facilitating economic growth. Wang et al. (2021) reported similar findings for China.

Fig. 4c shows the WLMC between REC and GDP. A positive correlation exists between REC and GDP with an average coefficient of 0.4 during 1984Q1–1987Q1, 1991Q1–1996Q1, 2000Q1–2007Q4 and 2018Q1–2020Q4 in the short and medium term. However, a strong and significantly positive co-movement exists between REC and GDP with an average coefficient of 0.90 in the long term. In Canada, during the entire period under investigation, economic growth has had a positive long-term influence on the use of renewable energy; however, its short- and medium-term effects have been positive and insignificant. Energy consumption may rise because of economic expansion, which may present more opportunities for renewable energy development given the country's energy transition plan. Renewable energy sources can assist with meeting this rising demand while lowering the carbon footprint of the energy industry. As individuals become wealthier, they are typically

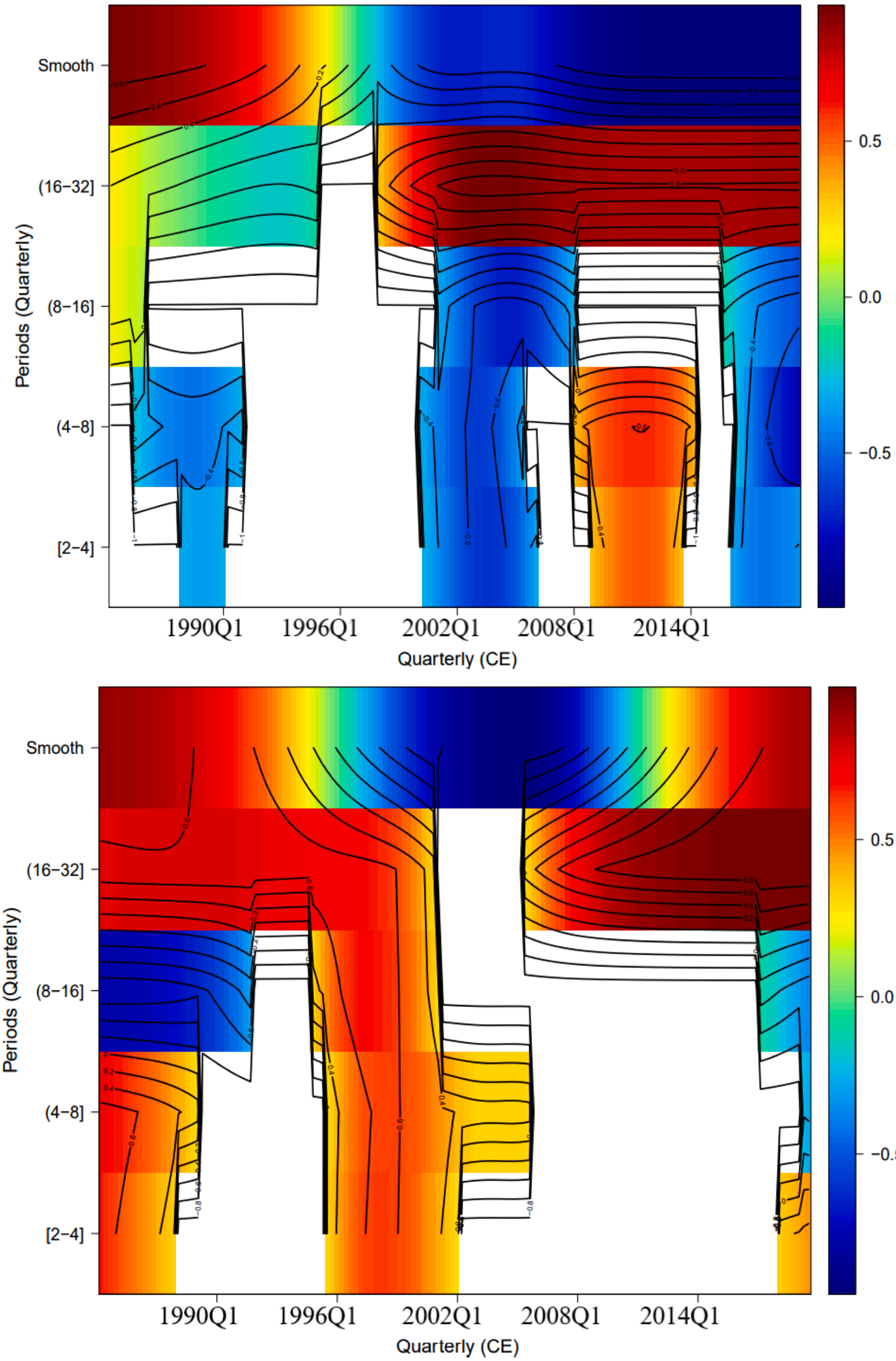


Fig. 4. a: Financial development and Renewable energy
b: Financial development and economic growth
c: Economic growth and renewable energy.

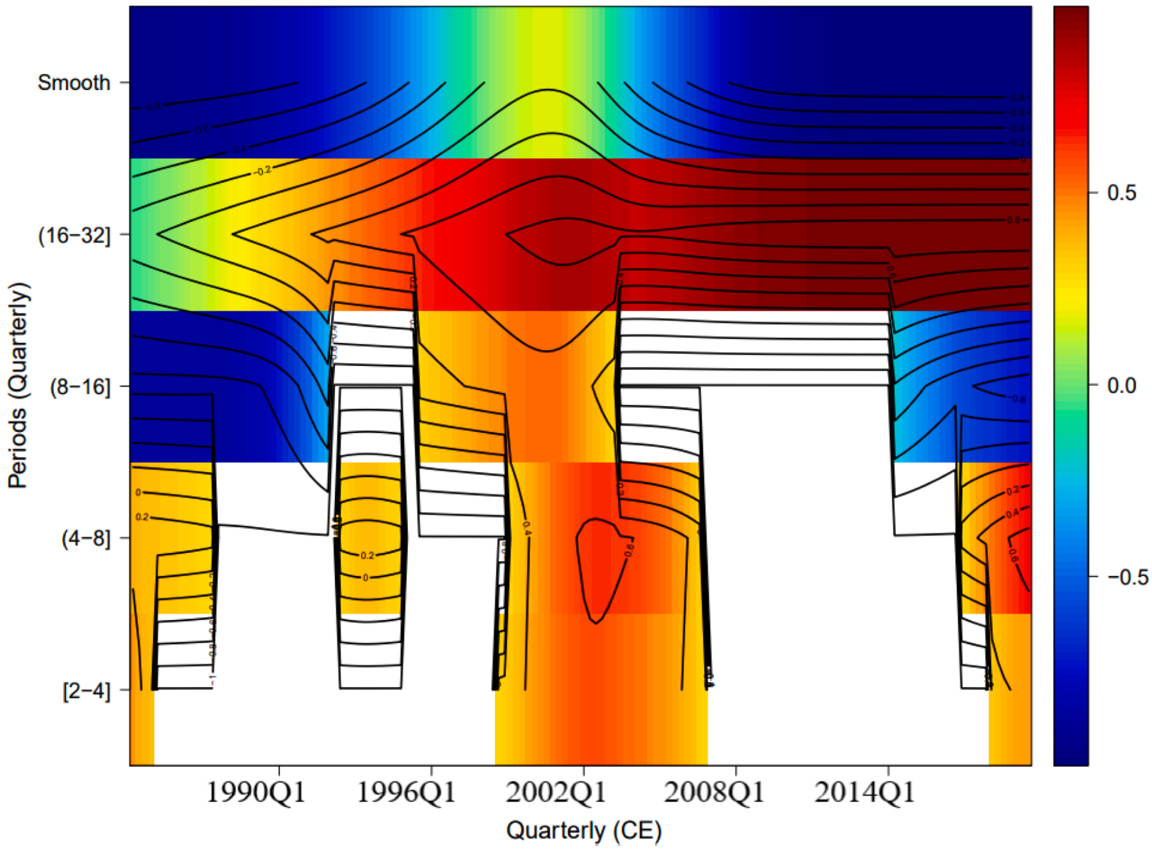


Fig. 4. (*continued*).

expected to consume more eco-friendly products. Moreover, technological advances that increase the efficiency and cost-effectiveness of renewable energy can also be pursued as a result of economic expansion. For instance, greater funding for R&D might result in advancements in green energy technologies. Thus, maintaining consistent and healthy economic growth may both foster the development of the financial sector and stimulate technical advancements in the field of renewable energy. These results clearly indicate that GDP contributes to the intensification of REC in Canada. Baz et al. (2021) and Li et al. (2021) have reported similar findings. In summary, as the economy grows, so does the utilisation of renewable energy sources.

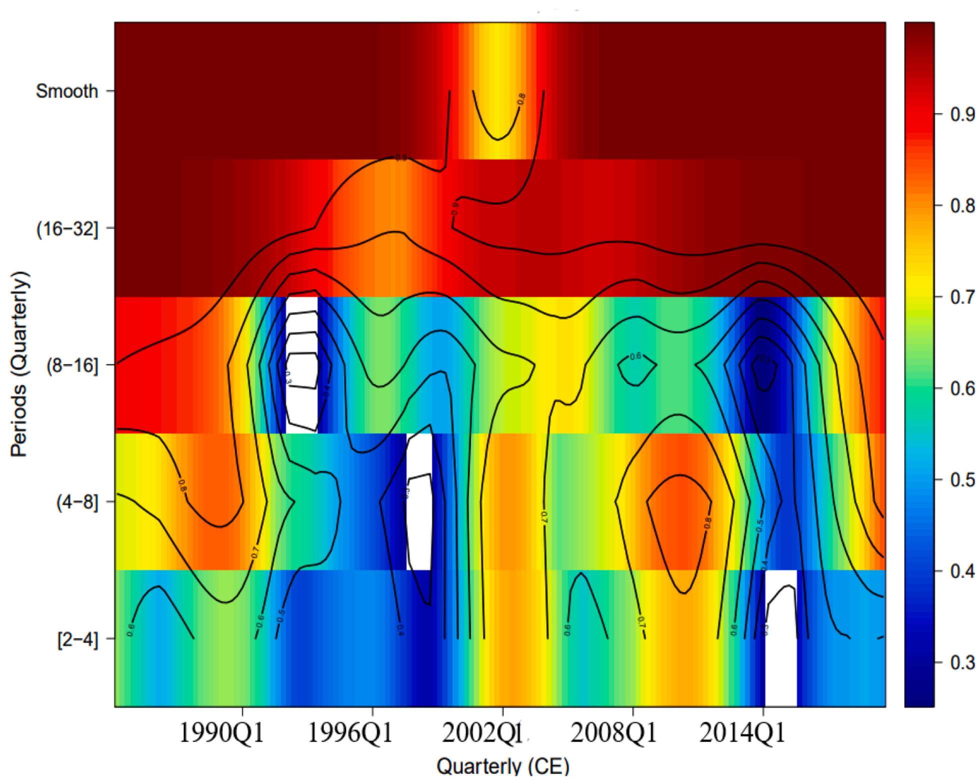
4.3. Three-variate nexus for economic growth, renewable electricity consumption and financial development

The three-variate version of the correlation is shown in Figs. 5a and 5b. The linkage between the variables is considerably improved in this multivariate correlation, which also accurately determines the primary (dominant) series. The other variables in each frequency are then described using the primary variable to optimise the multiple linkages. Fig. 5a displays the three-variate correlation in this situation. The outcomes indicate long-term co-movement between FD and GDP and REC; however, in the short and medium terms, a positive and weak correlation exists amongst the series.

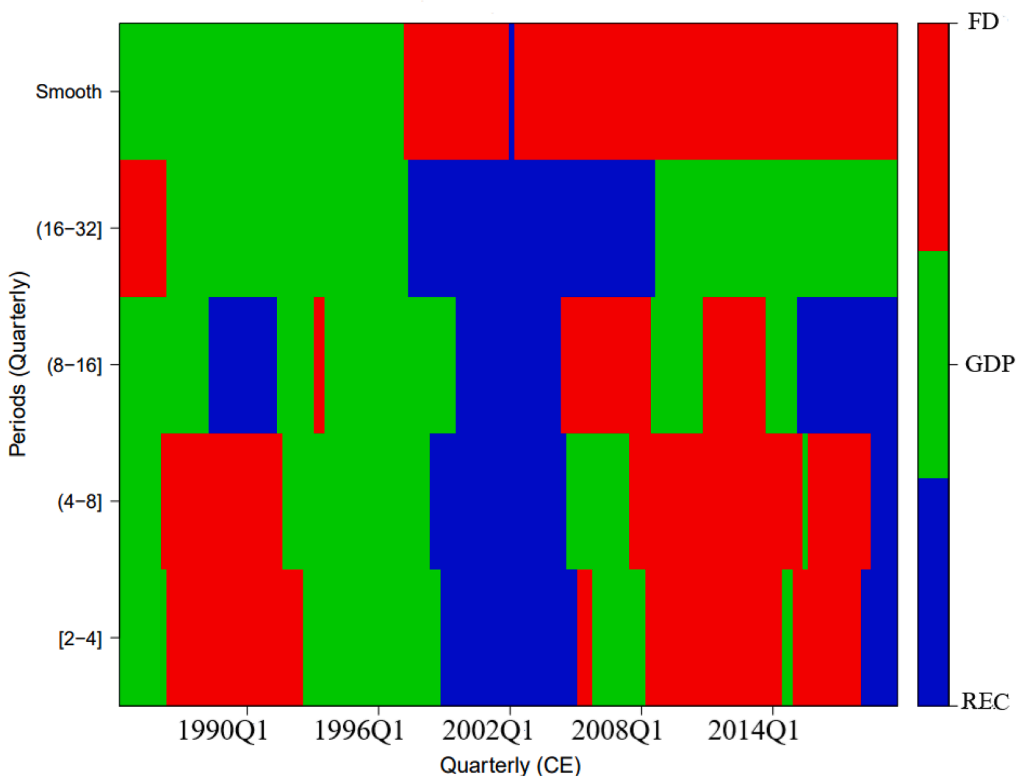
According to Fig. 5b, the medium term, GDP is the most relevant (dominant) component. Additionally, GDP is a dominant series in both the short- and long-term time-frequency domains, but its dominance is greater in the long term (16–32). The dynamics of the connections are also primarily driven by GDP, followed by FD and REC, in terms of contributions to the short-, medium- and long-term correlations. By providing the necessary capital and investment for renewable energy projects, financial development may play a significant role in fostering the adoption of renewable energy. Additionally, financial institutions may create cutting-edge financial products like green loans and green bonds that can be used to facilitate renewable energy projects. Thus, financial development can boost the renewable energy sector, promoting economic growth and development. Given Canada's economic expansion, the overwhelming role of GDP in the correlation is self-explanatory.

4.4. Bivariate nexus for economic growth, renewable electricity consumption and financial development vs CO_2 emissions

Fig. 6a displays the WLMC between FD and CO_2. At all frequencies, a negative correlation exists between FD and CO_2 from 1984Q1 to1996Q4 and from 2006Q to 2013Q4. However, in the short and medium frequencies from 2015Q1 to 2020Q4, a positive connection exists between FD and CO_2. In summary, the negative effect of FD on CO_2 is dominant. The results show that FD in Canada enhances ecological quality by decreasing CO_2 emissions. This result is as expected given the fact that the financial system in Canada is mature. By encouraging technological progress in energy supply, the financial sector also contributes significantly to reducing pollution. This implies that FD, which represents the access enjoyed by banks and stock markets to financial resources for operational purposes and project financing networks, may contribute positively to the fight against environmental decline, particularly by reducing CO_2. In addition, FD promotes R&D, attracts foreign direct investment and accelerates business activities, thereby influencing ecological quality through investments in renewable energy initiatives. A strong financial sector lowers financing costs and reduces the spread of emissions by improving the efficiency of the energy industry. This finding is in agreement with those reported by Kirikkaleli and Adebayo (2021) for the world, Usman et al. (2020) for the United States and Wu et al. (2022) for the Nordic nations. However, it contradicts the results of



a: Financial development, economic growth and renewable energy



b: Heat map of financial development, economic growth and renewable energy

Fig. 5. a: Financial development, economic growth and renewable energy
b: Heat map of financial development, economic growth and renewable energy.

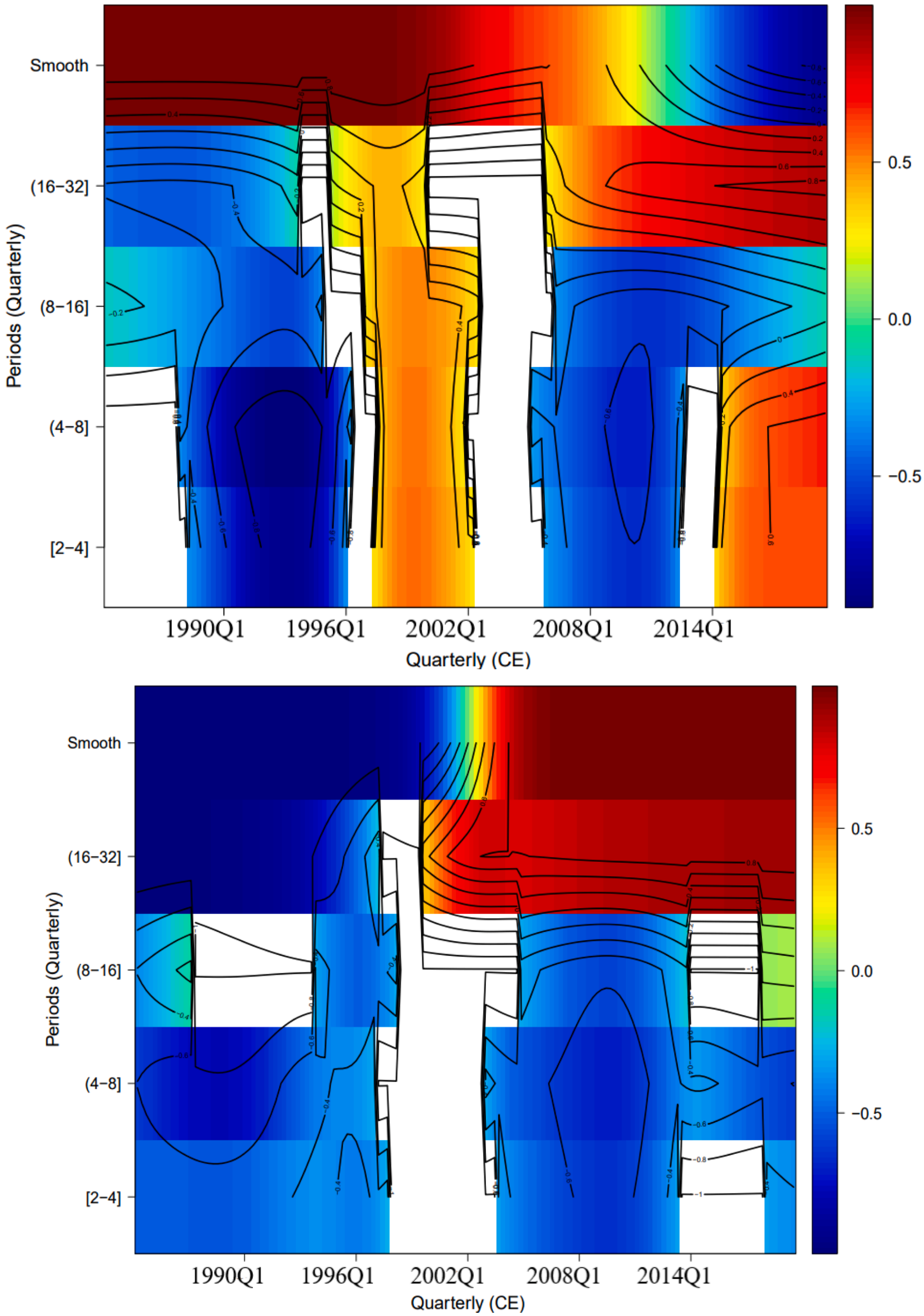


Fig. 6. a: Financial development vs CO_2 emissions
b: Renewable energy vs CO_2 emissions
c: Economic growth vs CO_2 emissions.

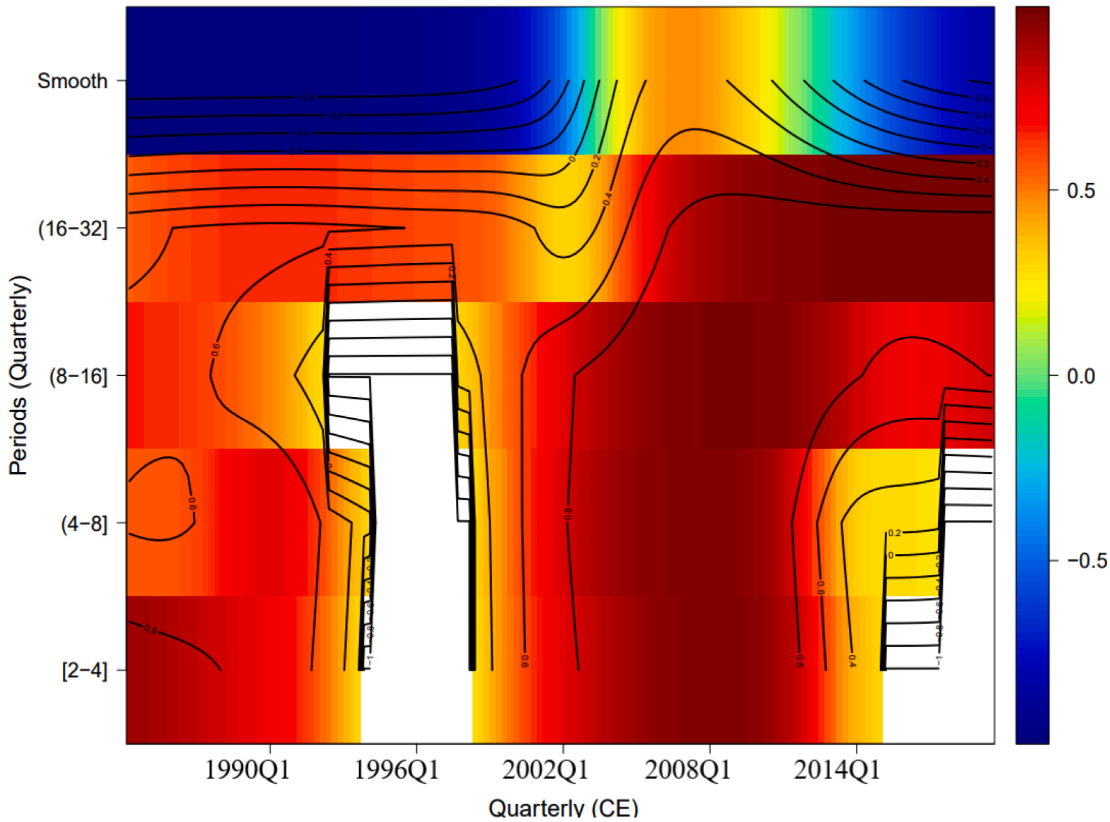


Fig. 6. (*continued*).

Irfan et al. (2022) for the United Kingdom and Usman et al. (2022), who reported a positive finance–emissions connection. It also contradicts the finding of Zhang et al. (2021) for Malaysia, who reported an insignificant finance–emissions nexus.

Fig. 6b displays the WLMC between REC and CO_2 in Canada. At all frequencies from 1984Q1 to 1997Q1, there is evidence of negative coherence between REC and CO_2 with an average coefficient of −0.6, which indicates that REC contributes to a decline in CO_2 in these periods and timeframes. Similarly, from 2005Q1 to 2020Q4, the effect of REC on CO_2 is negative, suggesting that a decrease in CO_2 is accompanied by an upsurge in REC at all frequencies. These results are unsurprising given that Canada has continuously made investments in renewable energy. In fact, renewable energy accounts for 17% of Canada's total primary energy supply, making the country a global leader in its production and consumption. Canada has made a strong commitment to using renewable energy: 66.6% of its electricity (81.6% from non-GHG emitting sources) and 18.9% of its energy supply come from renewables, versus the global average of 13.4%. These outcomes are supported by the studies of Alam and Murad (2020), Ajide and Mesagan (2022), Kirikkaleli and Adebayo (2021), Reboredo et al. (2017) and Sheraz et al. (2022). The abovementioned studies support the environmental sustainability role of REC. Additionally, REC is eco-friendly and reduces CO_2 emissions. It is a sustainable source of energy in that it has the ability to satisfy the energy demands of both the present and the future generations.

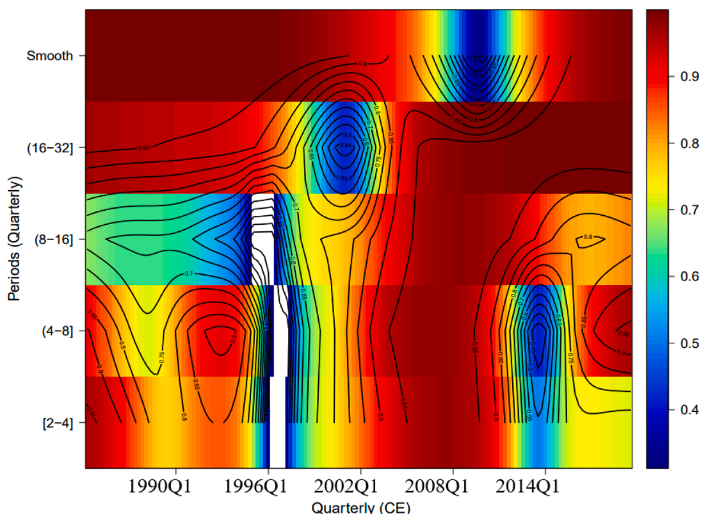
Fig. 6c shows the WLMC between GDP and CO_2 in Canada. At all frequencies (i.e., short and long term), there is positive coherence between CO_2 emissions and GDP from 1984Q1 to 2020Q4. These results suggest that the growth witnessed in Canada's economy is not sustainable. Rising economic output and GDP have resulted in challenges since GDP has a considerable and favourable influence on CO_2 emissions. Energy consumption may rise as a result of economic expansion, which may also increase CO_2 emissions. Individuals who are affluent tend to consume more energy, and this energy is often produced using fossil fuels, which are significant CO_2 emitters. Moreover, growth in the economy may also bring about industrialisation and urbanisation, which can raise the level of CO_2 emissions. Large amounts of energy are frequently needed for industrial operations, and as industrialisation and urbanisation progress, energy demand tends to rise, along with CO_2 levels. This finding concurs with those of Acheampong et al. (2022), Aye and Edoja (2017), Adedoyin et al. (2020), Ahmad et al. (2020), Appiah et al. (2022), Balcilar et al. (2020) Boukhelkhal (2022), and Charfeddine and Kahia (2019), who found that economic expansion is insufficient to stop ecological decline. However, the studies of Usman et al. (2020) for the United States and Adebayo (2022b) refute this finding by establishing a negative linkage between CO_2 emissions and real output.

4.5. *Three-variate case for economic growth, renewable electricity consumption and financial development vs CO_2 emissions*

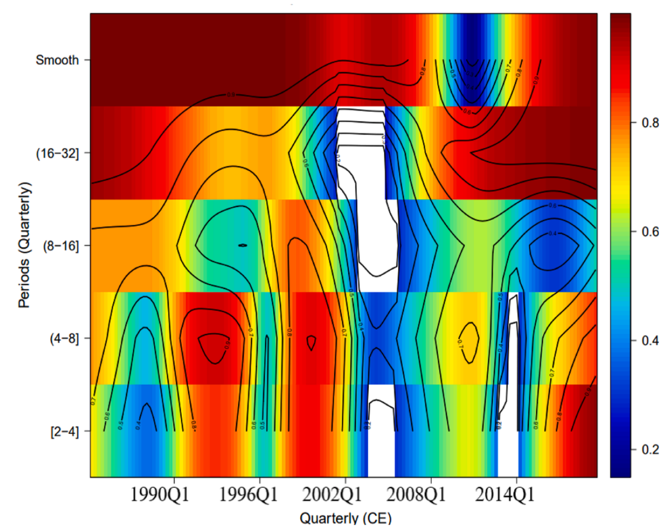
Fig. 7a shows the coherence between FD and GDP vs CO_2. Fig. 7b depicts the correlation between REC and GDP vs CO_2, and Fig. 7c shows the correlation between REC and FD vs CO2. The results show evidence of positive coherence between FD and GDP vs CO_2 (see Fig. 7a), REC and GDP vs CO_2 (see Fig. 7b) and REC and FD vs CO_2 (see Fig. 7c). This multivariate analysis yields some interesting results compared to the bivariate evaluation. Each variable, when examined separately, shows several interconnections (negative and positive) with other variables in the bivariate evaluation. However, in the three-variate (multivariate) analysis, the variables exhibit comparably positive correlations. Ağa et al. (2023) explain this as the effect of the dominant series.

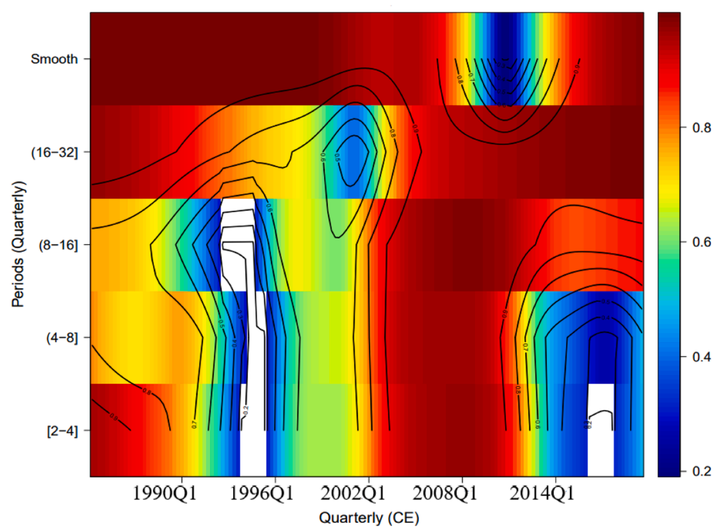
4.6. *Four-variate case for economic growth, renewable electricity consumption and financial development vs CO_2 emissions*

Fig. 8 shows a four-variate correlation analysis between GDP, REC



a: financial development and economic growth vs CO_2 emissions





b: renewable energy and economic growth vs CO_2 emissions

Fig. 7. a: Financial development and economic growth vs CO_2 emissions
b: renewable energy and economic growth vs CO_2 emissions
c: financial development and financial develoment vs CO_2 emissions.

and FD vs CO_2. All indicators are positively correlated during the course of the study period. In addition, significant positive co-movement is observed at all frequencies i.e., the short and long term. These results are supported by the studies of Anwar et al. (2022), A.A. Alola et al. (2021), Haldar and Sethi (2022), Ramzan et al. (2022) and Usman and Balsalobre-Lorente (2022). As previously established, the dominant variable has a significant influence on multivariate correlations and has the power to sever linkages with the series. Economic expansion is the dominant series and has a positive correlation with the other factors in our research. Economic growth lowers ecological integrity by raising CO_2 emissions. Canada's unsustainable growth is the major cause of the increase in CO_2 emissions. Its renewable energy share is not enough to counter the dominant role of GDP. Thus, intensifying the share renewable energy in Canada may play a major role in lowering the strength of GDP.

5. Conclusion and policy implications

In this study, we explored the time and frequency nexus between FD, REC, economic growth and CO_2 emissions in Canada. The study employed quarterly data spanning from 1984 to 2020. Unlike prior studies, the current study used the WLMC approach proposed by Polanco-Martínez et al. (2020), which is capable of capturing the effect of two/three independent variables on the dependant variable at different frequencies and time periods. To the best of the investigator's knowledge, this is the first empirical investigation to explore the nexus between CO_2 emissions and FD, economic growth and REC at different frequencies and time periods using the newly introduced WLMC method. Thus, the current study fills the void in the available literature on the subject. The results obtained show that economic growth drives CO_2 emissions positively at all frequencies, while REC and FD drive CO_2 emissions negatively, majorly in the long term. In addition, REC and FD drive economic growth positively in the short, medium and long term.

5.1. Policy ramifications

Owing to the inconsistent effects of REC, FD and economic growth on CO_2 emissions, harmonisation of the policy framework is crucial. The problem of ambient air pollution and other ecological issues may worsen if Canada continues to rely on conventional fossil fuel-based energy

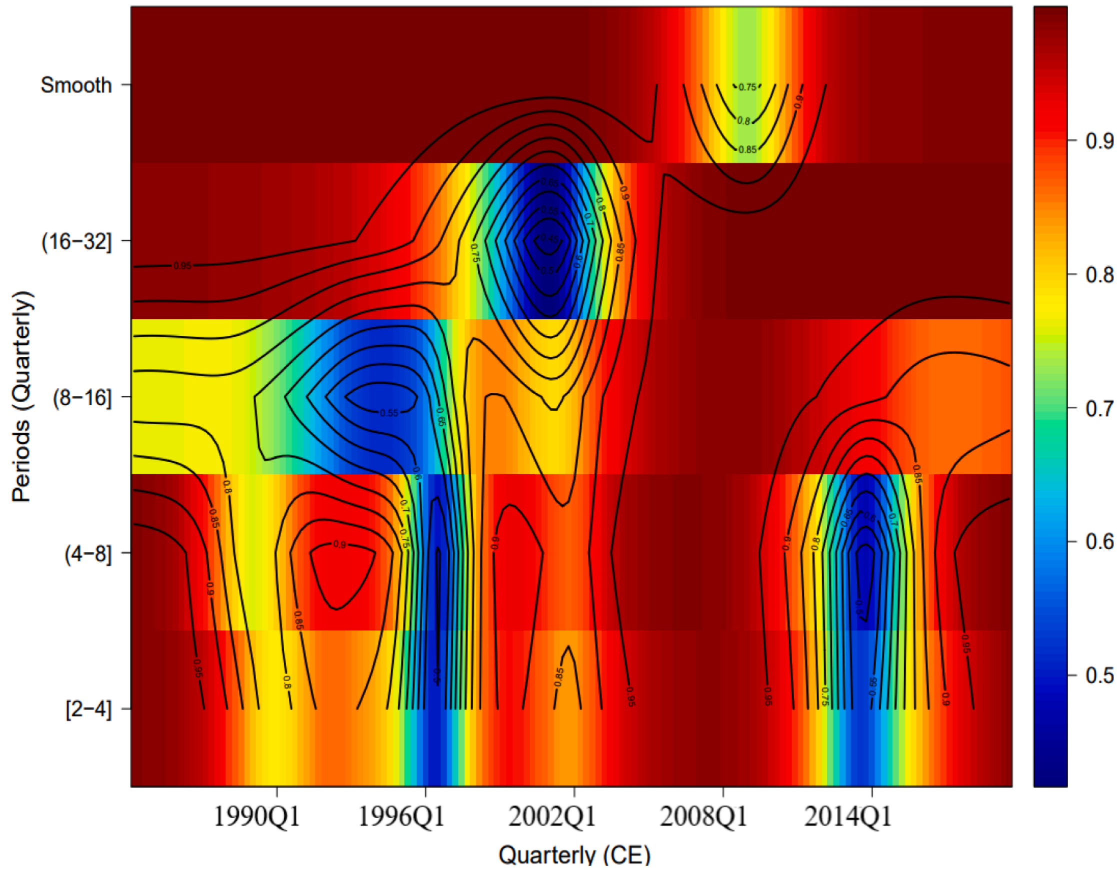


Fig. 8. Financial development, renewable energy and economic growth vs CO_2 emissions.

sources. Therefore, policymakers should continue to recommend the use of renewable energy options. Since an aggressive switch to greener methods of production may be difficult to achieve because of the large costs of implementation, a phased transition should be considered while designing the policy framework. Although Canada's financial sector is known for its resilience, as demonstrated over the years and especially during the periods of global uncertainty arising from the Covid-19 pandemic and the earlier global financial crisis (Bank of Canada, 2023), a phase-based approach to adopting renewable energy would be helpful during such uncertain episodes.

Furthermore, local municipal governments should be more deliberate about promoting financial inclusion, such as granting interest rate holiday to impoverished households at a pro-rata rate. Thus, with the help of subsidies, the interest holiday generated by the companies could be used to enhance renewable energy options. Moreover, at a later stage, medium and high-income households could also receive interest incentives at a pro-rata rate, which may be far greater than the rate outlined for the impoverished households. The interest rate vacation offered to them could last anywhere between one and two years. The loss of income from the families can be compensated after the phase-wise transition, so that the country will not have to deal with a revenue shortfall and a subsequent economic downturn.

Cooperation between the businesses, government and financial institutions is necessary to further control environmental degradation. Importantly, public–private cooperation on green financial systems, such as a green fund, while the government alters its monetary, environmental and financial policies is vital. Such partnership could bolster cutting-edge green financial products that encourage the growth of businesses while utilising renewable energy sources. This could also help to expand the opportunities for financing options, such as the green credit, green bonds and green insurance, in order to pursue clean and renewable energy development. Accordingly, it is recommended that cleaner technologies are encouraged through regulatory institutions such as the stock exchange because financial development also increases the demand of renewable energy.

Finally, improving awareness and public knowledge of the negative effects of fossil fuel use as well as the advantages of renewable energy sources is essential. Policymakers should concentrate on supporting public–private partnerships that aim to raise individuals' levels of ecological consciousness. This will enable policymakers to pursue their plans, especially at the local levels with minimal opposition or push back from the society. It will also allow greener manufacturing methods and ideas to be easily introduced across all industries as people will be more aware of consumption habits that are environmentally sustainable. In essence, this will propel Canada's progress towards achieving SDG 12. In the event that these goals are achieved, the issue of ecological deterioration will naturally diminish, which is the goal of SDG 13.

5.2. Limitations of the study and future directions

This work has some constraints, which offer avenues for future research. First, the nexus between FD, economic growth, renewable energy, and CO_2 was explored using time-series data. However, future studies can consider other potential environmental indicators while also implementing panel-based investigations for cross-country dimensions. Second, the current study used CO_2 emissions as a proxy of ecological deterioration. However, CO_2 emissions only capture air pollutants. Future studies could consider using ecological footprint and/or biocapacity, which are broader measures of ecological deterioration/quality. Lastly, future studies may also implement other relevant econometric tools such as wavelet coherence to support the wavelet local multiple correlation approach.

Credit author statement

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Bangyong Hu: Writing - original draft and Revision.

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Muhammad Zubair Tauni: Writing - original draft and Revision.

Shujaat Abbas: Writing - original draft and Revision.

Data availability

Data will be made available on request.

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