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RESEARCH ARTICLE

Sustainable developments, renewable energy, and economic growth in Canada

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Abstract

The object of this paper is to investigate the dynamic causal relationship between economic growth and renewable energy in Canada. The causal relationship is examined under the neoclassical production function framework. We employed a panel autoregressive distributed lag model controlling for different states of the economy by incorporating a dummy variable, which indicates the economic peak and trough. The data set consists of annual real GDP, capital formation, labor, and electricity generation by renewables for nine Canadian provinces covering from 1981 to 2015. The empirical results find that there is a unidirectional causality from renewable energy to economic growth in the long run. In the short run, a unidirectional causality going from renewable energy to economic growth only during the expansion period is observed. Our study suggests that renewable energy policies should be designed and implemented in a way that takes into account the nonlinear relationship between renewable energy and economic growth. This could involve promoting the development and deployment of renewable energy sources as part of their economic stimulus packages during economic upturns.

KEYWORDS
Canada, economic growth, nonlinearity, renewable energy

1 | INTRODUCTION

Governments worldwide have been setting new climate change targets to be achieved by the middle of the century. Japan has recently announced its plan to eliminate all greenhouse gases; China and South Korea have declared that their economies will be carbon-neutral; the European Union unveiled a “net-zero” plan of its own; Britain and France have turned their targets into law; the new elected U.S. President has announced to put America on a similar path. As stated in the International Energy Outlook 2019 published by the U.S. Energy Information Administration (EIA, 2019), renewable energy is projected to collectively increase to 49% of global electricity generation by 2050.

Given that today around 85% of the world's industrial energy comes from fossil fuels, getting consumption to near zero will involve enormous economic shifts. It will require structural changes in how energy is generated and used, as well as requiring a sustained stream of innovations to improve how goods are made rather than how infrastructures are designed and managed. It is not surprising therefore that transitioning from economies relying on nonrenewable-energy sources (e.g., oil, natural gas, and coal) to renewable-energy sources (hydro, wind, bioenergy, solar, and geothermal) is as much welcome as it proves to be a challenging mechanism to be put in place.

The effects of energy on economic growth has attracted the attention of academics and policy-makers alike. Broadly speaking, four hypotheses have commonly been tested: (i) Growth hypothesis—a unidirectional causality going from energy use to economic growth; (ii) Conservation hypothesis—a unidirectional causality running from economic growth to energy use; (iii) Feedback effect hypothesis—a bidirectional causal link between economic growth and energy use; and finally (iv) Neutrality hypothesis—no causal relation between economic growth and energy use. Empirical results are contradictory and there is no consensus on the growth-energy nexus with results heavily relying on methodology and data sets used.

The relationship between economic growth and energy consumption has been debated and studied over the past four decades. A vast body of literature explores the relationship using various methodologies and data sets.

The literature has focused on examining the relationship between economic growth and different types of energy consumption. A considerable amount of research focuses on the causal link between total energy consumption and economic development. Kraft and Kraft (1978) first initiated research on the energy-economic growth nexus, which investigated the relationship between economic growth and total energy consumption in the United States. Numerous scholars have explored the causal relationship between different variables in various countries. Since then, scholars have investigated this causal relationship in various countries. For instance, Bartleet and Gounder (2010) examined New Zealand, Lee and Chang (2005) studied Taiwan, and Oh and Lee (2004) investigated South Korea. Due to population growth, urbanization, and the expansion of the manufacturing and service sectors in many countries, there has been a rapid increase in demand for electricity, which has led to a significant number of research papers exploring the potential causal relationship between electricity consumption and economic growth. For example, Bowden and Payne (2009) investigated this relationship in the United States, while Shahbaz et al. (2011) studied the same relationship in Portugal. As concerns about climate change and other environmental issues continue, many countries advocate for nonconventional energy, such as renewable and nuclear energy. The relationship between renewable and nuclear energy and economic growth has been increasingly studied in the literature. For example, Saad and Taleb (2018) investigated the link between renewable energy consumption and economic growth in Europe, Kasperowicz et al. (2020) examined the long-term impact of renewable energy consumption on economic growth in European countries, and Yoo and Ku (2009) studied the causal relationship between nuclear energy consumption and economic growth in South Korea. The impacts of various energy variables on economic growth have been a topic of recent interest in the literature. For instance, Gardiner and Hajek (2020) investigated the causal links between energy consumption, CO_2 emissions, and economic growth in EU countries. Asiedu et al. (2021) examined the causal effects of renewable and nonrenewable energy on economic growth in 26 European countries. Guang-Wen et al. (2022) explored the relationships between environmental pollution, financial development, renewable energy use, and economic growth in the BRICS nations. These studies highlight the importance of understanding the complex interactions among multiple energy variables for sustainable economic growth. Given that many countries are transitioning from fossil fuels to renewable energy, it is crucial for policymakers to understand the causal relationship between energy consumption and economic growth. By understanding this relationship, policymakers can make informed decisions that balance economic development with environmental sustainability. A comprehensive literature survey on the causal nexus can be found in Ozturk (2010) and Tiba and Omri (2017), and Waheed et al. (2019).

The causal relationship between energy variables and economic growth has been widely researched across various countries. However, there have been relatively few empirical studies investigating this relationship specifically for Canada, a country with unique characteristics that make it an interesting case study. As a major energy producer and consumer with abundant natural resources, both renewable and nonrenewable, Canada faces the challenge of balancing economic growth with reducing greenhouse gas emissions. While the country is committed to substantially lowering emissions by 2050, it is currently ranked in the top 10 economies for CO_2 emissions. Barrington-Leigh and Ouliaris (2017) suggest that renewable energy is likely to replace nonrenewable energy as the main energy source in Canada. There have been few empirical studies that specifically investigate Canada, with most research instead examining Canada as part of multicountry studies. Employing the Sim's and Granger causality tests, Erol and Yu (1987) examined the causal link between real gross national product (GNP) and total energy consumption for Japan, West Germany, Italy, Canada, France, and the United Kingdom. Both Sim's and Granger-causality tests revealed a unidirectional causality from real GNP to energy consumption for Canada. Murry and Nan (1994) applied the Granger-causality test to investigate the causal relation between economic growth and electricity consumption for 15 countries including Canada. They found a unidirectional causality going from electricity consumption to economic growth in Canada. Utilizing a similar neoclassical production function, Soytas and Sari (2006) explored the multivariate cointegration and Granger-causality using vector error correction model (VECM) for G-7 countries. The results of the cointegration and Granger-causality tests indicate a bidirectional causality running between economic growth and total energy use for Canada. Lee (2006) tested the causality between economic growth and total energy use with Toda and Yamamoto (TY) causality test under the vector autoregressive (VAR) model for 11 major industrialized countries. In regard to Canada, a bidirectional causality was found between economic growth and total energy use, supporting the findings of Soytas and Sari (2006). Balcilar et al. (2010) used bootstrap Granger causality tests for G-7 countries, excluding Germany, to analyze the causal nexus between economic growth and total energy consumption. The bootstrap Granger tests were applied to both full sample and rolling window subsamples. The result of the full sample indicated a unidirectional causality going from total energy consumption to economic growth in Canada. However, no causal relation was found for the result from the rolling window sub-samples in Canada. Rodrıguez-Caballero and Ventosa-Santaularia (2017) studied the causal link between economic growth and electricity consumption for 19 countries including Canada. The VECM with structure break was used. The result from Canada supported a unidirectional causality running from electricity consumption to economic growth.

Notice that the studies reviewed so far mainly focused on energy consumption as a whole therefore not disentangling the issue related to the nexus between economic growth and renewable energy, which will be the focus of the present paper. Two multicountries studies that explored the causal relation between renewable-energy consumption and economic growth are from Tugcu et al. (2012) and Al-Mulali et al. (2013). In a study of the G-7 countries, Tugcu et al. (2012) extended the classical Cobb–Douglas production function framework by adding renewable energy to the model. Using autoregressive distributed lag (ARDL) models, the authors found a long-run equilibrium between renewable-energy consumption and economic growth in the case of Canada; no evidence of short-run causal relationship was identified. Al-Mulali et al. (2013) investigated the long-run relationship between renewable-energy consumption and GDP growth in low-, middle-, and high-income countries applying the fully modified OLS (FMOLS) model. For the case of Canada, the results suggest a long-run equilibrium between renewable-energy consumption and GDP growth.

Ghali and El-Sakka (2004) and Wadstrom et al. (2019) focused their attention only on Canada. The former used a conventional production technology function approach adding total energy as input to capital stock and total employment, using annual data from 1961 to 1997. Their analysis indicates the existence of a long-run relationship between output, labor, capital, and energy use and a bidirectional Granger-causality between output and energy use in the short run in Canada. Wadstrom et al. (2019), using a quantile causality approach, found evidence of unidirectional causality running from industrial production to renewable-energy in the higher and lower quantiles (evidence of weak causality running from renewable energy to industrial production was also found). A nonlinear approach is motivated by the argument that, since causal relationships can vary depending on different market conditions, fitting regressions on different quantiles would be most appropriate to analyze the causal relationships for lower, middle and upper quantiles, which correspond to the various economic conditions.[1] The data used in their study consist of monthly observations for the period 1966–2015 on renewable-energy production and industrial production index, with results supporting the feedback hypothesis in the higher and lower quantiles.

The motivation of this paper is to investigate the causal relationship between renewable energy and economic growth in Canada. We advance the literature by adopting the extended neoclassical production function proposed by Ghali and El-Sakka (2004) including renewable energy as an input factor. The model is then empirically tested by means of an extended panel autoregressive distributed lag (ARDL) model. Our study contributes to various strands of the literature. Firstly, we investigate renewable energy and economic growth link in Canada by considering panel data consisting of nine Canadian provinces. To our knowledge, none has considered panel data analysis in Canada. Previous papers that mainly adopted time series analysis on national-level data, is expected to provide a better fit to the heterogeneous patterns observed across provinces. Panel data offers a more granular view of causal relationships than national-level data, capturing both the common and individual effects of provinces and leading to a more comprehensive understanding of the causal nexus. Second, to enhance our panel ARDL model, we incorporate a dummy variable that controls for the business cycle, enabling us to evaluate how variations in the business cycle affect the relationship between economic growth and renewable energy use. Previous studies have found evidence of nonlinearities in the dynamic linking energy and economic growth. By examining this relationship across different stages of the business cycle, we can gain a more detailed perspective of the underlying dynamics and test for potential structural breaks. Therefore, governments and policymakers can better understand how changes in the business cycle may affect the causal relationship and adjust their policies and forecasts accordingly. Finally, our paper provides an in-depth discussion of the Canadian renewable-energy state of play by province rather than at the national level.

The remaining parts of this paper are organized as follows. A by-province discussion of the renewable-energy production in Canada is presented in Section 2. Section 3 presents the theoretical model and the data set used. Section 4 discusses the empirical findings and Section 5 concludes offering some policy implications.

2 | THE CASE OF CANADA

As previously mentioned, despite Canada being the world's second-largest country by total area and having placed itself at the forefront of the groups of countries targeting a substantial reduction of emissions by supporting a greener economy, only a few empirical studies have thoroughly investigated its renewable energy-economic growth nexus.

2.1 | Canada's energy sources

The country enjoys abundant natural resources, which comprise renewable as well as nonrenewable sources; examples of the latter source are coal, oil, and natural gas, which are found mainly in Canada's seven major sedimentary basins, whereas the former source includes hydro, wind, bio-energy, solar, and geothermal. The report "Canada's Energy Future" released by Canada Energy Regulator (2021), provides information on electricity generation by various energy sources. In 2020, Canada generated 119 tW-h of electricity with nonrenewable energy, while renewable and nuclear energy contributed 509 tW-h. According to the report, hydro and tidal energy accounts for most of renewal-energy (RE) production, contributing 379 tW-h. The second largest renewable energy after hydro is wind, which is generated by the movement of wind turbines. Around 35 tW-h were generated from wind energy. With Canada's large landmass, wind energy has considerable growth potential. The biomass and geothermal energy generated about 8 tW-h. Biomass energy is generated by living organisms. Wood is the most used source of biomass, mainly used as fuel. A small portion of the biomass is used for generating electricity. Geothermal energy resources in Canada are primarily located in the western and northern regions. Geothermal power plants generate electricity by drilling into the earth to access hot water or steam, which is then used to power a generator turbine. The use of solar energy in Canada has been relatively small but has been increasing in recent years. In 2020, solar energy contributed two terawatt-hours of electricity generation.

Organization for Economic Cooperation and Development (OECD, 2023) reported that renewable energy accounted for 11.92% of the primary energy supply in OECD countries in 2020. Canada's share of RE supply is 17.29%. In 2021, 60% of electricity generation was from moving water, making Canada the fourth highest in the world in the share of hydroelectricity reported by International Hydropower Association (2021). In the following, we provide an overview of the energy source profiles for each Canadian province. The information has been summarized from Canada Energy Regulator (2017). In 2007, British Columbia announced a target to achieve 90% electricity generation from RE sources. In 2016, hydro, wind, and biomass accounted for 98.4% of electricity generation in British Columbia. In 2007, Alberta established legislation targeted towards large industrial emitters to reduce greenhouse gas emissions. Alberta's renewable-energy sources generated 12.3% electricity in 2016 from a 7% in 2005. SaskPower, the principal electric utility in Saskatchewan, has opened several programs promoting the use of renewable. On the other hand, natural gas increased from 9.3% to 33.7%. In 2012, Manitoba introduced an emissions tax on coal and petroleum coke. The revenue of the carbon tax is expected to be used to support the coal user's transition to green energy sources. Manitoba had a 99.3% of renewable in electricity generation in 2016. Hydro generates 97.1% and wind generates 2.2%. In the same year, Quebec had the highest share of electricity provided via renewable generation (99.6%). Hydro and wind accounted for 95.9% and 3.6% of generation, respectively. In 2016, Quebec announced the new energy policy, which further increases the use of renewable and improves energy efficiency. Ontario launched its long-term energy plan in 2010 to phase out the use of coal-fired electricity generation. In 2016, renewable energy sources accounted for 91.7% of electricity generation. Nuclear and hydro accounted for the most share, which is pegged at 58.3% and 22%, respectively. New Brunswick set a plan to meet 40% of provincial electricity demand with renewable by 2020. In 2016, 59.9% of electricity generation was from renewable energy sources. The primary source of electricity, which was 29.9%, is of nuclear type. In 2010, Nova Scotia unveiled a renewable electricity standard, which was designed to increase electricity generation from renewable. Due to the increase in wind electricity generation from 1% in 2005 to 10.6% in 2016, renewable generation increased from 14.2% to 23.8%. In 2007, Newfoundland and Labrador outlined their long-term energy plan, which was to reduce the carbon emission to between 75% and 80% below the level in 2001. In 2016, 94.3% of electricity generation was from renewable, which were almost entirely from hydro.

In the remaining of this paper, we investigate the different targets achieved by the largest Canadian provinces, most of whom have introduced green-energy policies aimed at supporting the energy transition to a greener economy. With the exception of Alberta, all provinces that are part of our study showed a consistent trend towards an economy driven more and more by renewable inputs. The observed pattern further motivates the need for a better understanding of the extent to which such a transition leads or lags economic growth.

2.2 | Green energy acts by province

Canada has recognized the wide range of impacts of climate change and has taken actions to tackle it. The country joined the United Nations Framework Convention (UNFCCC) on Climate Change together with other 153 nations to address climate change in 1992. The first agreement under the UNFCCC was Kyoto Protocol, which established legally binding obligations for nations to reduce emissions. Canada's target in Kyoto Protocol was to reduce emissions by 6% compared to 1990 levels by 2012. However, Canada has missed the target and withdrew from the treaty. In 2016, Canada signed the Paris Agreement within the UNFCCC. Canada's target under the Paris Agreement is a 30% reduction below its 2005 emission levels by 2030. To help meet the target in the Paris Agreement, the Pan-Canadian Framework on Clean Growth and Climate Change was adopted in 2016. The Pan-Canadian Framework is a collaborative plan between provincial, territorial, and federal governments to reduce emissions and build a low-carbon future. Provinces and territories design their own policies and actions to fulfill the emission target. The federal government supports the provinces and territories by providing funds and technologies. The Pan-Canadian Framework is built on four pillars: pricing carbon pollution, complementary actions to reduce emissions across the economy, adaptation and climate resilience, and clean technology, innovation, and jobs. For pricing carbon pollution, provinces and territories are free to design their own carbon pricing system. Pricing carbon pollution is not sufficient to reduce emissions. Provinces and territories should make new strategies in various aspects, for example, increasing renewable and nonemitting energy sources, improving energy efficiency, and building low-carbon transportation systems. Lastly, government investment in clean energy technologies helps to meet emission reduction targets, creates more job opportunities, and expands the economy.

The government of Canada recognizes the diversity of the provinces and territories' economies and supports the flexible energy policy and strategy for each region. We briefly discuss the key actions taken by provinces and territories to meet the targets in Pan-Canadian Framework.[2] To move toward a low-carbon future, Alberta launched Alberta's Climate Leadership Plan in 2015, which aims to produce at least 30% of the electric energy from renewable energy resources by the end of 2030. The key actions are: limiting oil sand emissions at 100 megatons per year; implementing a price on greenhouse gas emissions; phase-out emissions from the coal-fired plan; reducing methane emissions from industry by 45% by 2025. The government of British Columbia introduced British Columbia's Climate Leadership Plan in 2016. The target of the plan is to reduce emissions by 80% against 2007 levels. The plan is consists of adopting natural gas, reducing the impact of transportation, taking actions in forestry and agriculture, building resilient infrastructure, and developing energy-efficient industries. In 2018, the government of Prince Edward Island released a five-year Climate Change Action Plan, which targets to reduce the emissions by 30% below 2005 levels by 2030. The plan prioritizes five areas: adapting to climate change, reducing greenhouse gas emissions, carbon sequestration, education and capacity building, and research and knowledge building. In 2016, Manitoba adopted the Made-in-Manitoba Climate and Green Plan to develop a sustainable economy. Four pillars including climate, jobs, water, and nature are outlined in the plan. The climate pillar focuses on the objective of reducing emissions, investing in green technologies, and adopting carbon pricing. The jobs pillar concentrates on using sustainable development to help create new jobs. As water is essential to our life, the water pillar addresses the challenges of water quality and water quantity. The mission of the natural pillar is to respect nature in all its majesty and vulnerability. New Brunswick came up with Climate Change Action Plan in 2016 to combat climate change. The plan sets the targets on total emission outputs of 10.7 megatons by 2030 and 5 megatons by 2050. In addition to the reduction targets, New Brunswick will make efforts in building resilience into communities, businesses, infrastructures, and natural resources. The Made-in-New Brunswick carbon pricing mechanism will be implemented. Newfoundland and Labrador set the targets in Energy Plan in 2007 to reduce emissions by 10% compared to 1990 levels by 2020 and reduce emissions to 75%–80% below 2001 levels by 2050. To follow the PanCanadian Framework, Newfoundland and Labrador launched the Provincial Governmental climate change action plan: the Way Forward on Climate Change, in 2019. The new plan involves 33 actions to reduce emissions and 17 strategies to build climate-resilient infrastructures. Northwest Territories introduced Climate Change Strategic Framework in 2018. The framework has three goals: reducing emissions by 20% below 2005 levels, improving the knowledge of climate change impacts Northwest Territories, and building climate resilience. To achieve the emission reduction targets, the provincial government of Nova Scotia implemented the Cap-and-Trade Program in 2018. In 2019, Nova Scotia passed the Sustainable Development Goals Act, which sets three consecutive targets to reduce emissions. Nunavut developed the Climate Change and Adaption strategy in 2011 with four focuses: partnership building, research and monitoring, education and outreach, and government policy and planning. Ontario launched Made-in-Ontario Environment Plan in 2018. The plan targets a reduction of 30% against 2005 levels by 2030. There are four actions suggested by the plan: creating an emission performance standard, launching an emission reduction fund, building a carbon reduction auction system, and increasing the renewable content requirement in gasoline to 15%. Quebec established the 2030 Energy Policy to build a low-carbon economy. The policy set the following goals to achieve by 2030: improving energy efficiency by 15%; reducing petroleum products demand by 40%; eliminating the use of thermal coal; boosting renewable energy output by 25%; expanding bio-energy output by 40%. As Saskatchewan did not implement a carbon tax, the government released the Made-in-Saskatchewan Climate Change Strategy in 2017 to outline the Strategy to reduce emissions without a carbon tax. The strategy emphasized that climate resilience is crucial to address the emissions. Five areas including natural systems, physical infrastructure, economic sustainability, community preparedness, and human well-being should be focused to build climate resilience. In 2020, Yukon launched Our Clean Future strategy to reduce emissions by 30% below 2010 levels by 2030. Further, the strategy aims to have 97% of the electricity from renewable resources and 50% heating needs from renewable resources by 2030. We summarize the green energy actions in response to the Pan-Canadian Framework for all provinces and territories in Table 1. The name of green energy policies/acts by province is provided in the second column. The key targets of the policies/acts are highlighted in the third column.

3 | METHODOLOGY AND DATA

In this section, we discuss the production function, representing the theoretical foundation of our empirical analysis, followed by a brief description of the econometric model used.

3.1 | Theoretical framework

Neoclassical production technology has been widely used in the study of energy economics. For instance, Bhattacharya et al. (2016) investigated the causal effect of renewable energy consumption on economic growth for 38 countries under the neoclassical production technology framework. Pao and Fu (2013) also examined the relationship between renewable energy, nonrenewable-energy consumption, and economic growth in Brazil. Similarly, Lee and Jung (2018) employed neoclassical production technology to explore the relationship between renewable energy consumption and economic growth in South Korea.

Following Ghali and El-Sakka (2004), we extend the standard neoclassical one-sector aggregate production technology function, by adding RE as a third input factor in addition to capital (K) and labor force (LF). The production function has the form

$$Y = aK^{b}\mathrm{LF}^{c}\mathrm{RE}^{d}, \tag{1}$$

where Y is the aggregate output (or GDP); K denotes the capital formation; LF is the labor force; and RE is renewable-energy indicator. Taking the natural logarithm on both sides of Equation (1), we have

$$\ln Y = \ln a + b\ln K + c\ln \mathrm{LF} + d\ln \mathrm{RE}. \tag{2}$$

3.2 | Econometric methodology

3.2.1 | Preliminary concepts

In our study we use a panel Autoregressive Distributed Lag (ARDL) framework to investigate the long-run and short-run relationship

TABLE 1 Energy acts by province.

Region	Name[a]	Key target	Introduced year
Canada	Paris Agreement	Reduce 30% emissions by below 2005 levels by 2030.	2016
	Pan-Canadian Framework	Meet emissions reduction targets in Paris Agreement; Grow Canadian economy; Build resilience to a changing climate.	2016
Alberta	Alberta's Climate Leadership Plan	Establish at least 30% of the electric energy from renewable energy resources by 2030; Phase out emissions from coal-fired plan by 2030.	2015
British Columbia	British Columbia's Climate Leadership Plan	Reduce emissions by 80% below 2007 levels by 2050	2016
Manitoba	Made-in-Manitoba Climate and Green Plan	Become Canada's cleanest, greenest, and most climate resilient province.	2016
New Brunswick	New Brunswick's Climate Change Action Plan	Reduce emissions by 35% below 1990 levels by 2030; Reduce emissions by 80% below 2001 levels by 2050.	2016
Newfoundland and Labrador	The Way Forward on Climate Change	A 5-year plan to reduce emissions and build climate-resilient Infrastructure.	2019
Northwest Territories	Climate Change Strategic Framework	Reduce emissions by 20% below 2005 levels by 2030; Improve knowledge of climate change; Build resilience and adapt to a changing climate.	2018
Nova Scotia	Sustainable Development Goals Act	Reduce emissions by 10% below 1990 levels by 2020; Reduce emissions by 53% below 2005 levels by 2030; Achieve emissions at net zero by 2050.	2019
Nunavut	Climate Change Impacts and Adaptation in Nunavut	Build partnership to facilitate a coordinated approach to climate change; Strengthen research and monitoring partnerships; Increase awareness of the climate change impacts; Integrate climate change considerations into all government decision making.	2011
Ontario	Made-in-Ontario Environment Plan	Reducing emissions by 30% below 2005 levels by 2030.	2018
Prince Edward Island	Climate Change Action Plan for Prince Edward Island	Reduce emissions by 30% below 2005 levels by 2030.	2018
Quebec	2030 Energy Policy	Enhance energy efficiency by 15% by 2030; Reduce by 40% the amount of petroleum products consumed by 2030; Eliminate the use of thermal coal by 2030; Increase by 25% overall renewable energy output by 2030; Increase by 50% bio-energy production by 2030.	2016
Saskatchewan	Made-in-Saskatchewan Climate Change Strategy	Outline actions to build resilience to climate change.	2017
Yukon	Our Clean Future Strategy	Reduce emissions by 30% below 2010 levels by 2030	2020

[a] Please see references for individual provinces sources (Government of Alberta, n.d.; Government of British Columbia, n.d.; Government of Canada, n.d.; Government of Manitoba, n.d.; Government of New Brunswick, n.d.; Government of Newfoundland and Labrador, n.d.; Government of Northwest Territories, n.d.; Government of Nova Scotia, n.d.; Government of Nunavut, n.d.; Government of Ontario, n.d.; Government of Prince Edward Island, n.d.; Government of Quebec, n.d.; Government of Saskatchewan, n.d.; Government of Yukon, n.d.).

between economic growth and RE as described in Equation (2). One useful feature of our ARDL approach is its flexibility to the order of integration of the variables under investigation. The variables are first tested to identify their order of integration. This will be done through the Levin-Liu-Chu (LLC) (Levin et al., 2002) and the Im-Pesaran-Shin (IPS) testing procedure (Im et al., 2003) before moving to the cointegration analysis. For this purpose, consider the panel data autoregressive model

$$y_{i,t} = \rho_i y_{i,t-1} + \delta_i X_{i,t} + \epsilon_{i,t} \tag{3}$$

with $t = 1, 2, \ldots, T$ and $i = 1, 2, \ldots, N$ denoting the time and the cross-section dimensions, respectively. The vector $X_{i,t}$ includes exogenous variables such as fixed effects or individual trends; $\epsilon_{i,t}$ are the error terms; and ρ_i are the autoregressive coefficients, which imply that when $\rho_i < 1$, $y_{i,t}$ is a stationary series, whereas if $\rho_i = 1$, $y_{i,t}$ is nonstationary. The difference between the LLC and IPS test is the assumption made on the autoregressive coefficient ρ_i: while the LLC test assumes that there is an identical ρ_i across all groups (i.e., $\rho_i = \rho$), the IPS test allows for the ρ_is to differ freely across all groups. Finally, for both testing procedures, the null hypothesis implies that the series are nonstationary; that is, the panel contains unit roots.[3]

When nonstationary series are identified, testing for the presence of a long-run relationships will be based on the regression equation

$$y_{i,t} = \alpha_i + \beta_i X_{i,t} + \epsilon_{i,t}, \tag{4}$$

where $i = 1,2,\ldots, N$ denotes the cross-section groups; $t = 1,2,\ldots,T$ represents time; the vector $X_{i,t}$ includes a set of independent variables; and $\epsilon_{i,t}$ is the error term. Using the Pedroni (2004) testing methodology, which involves seven tests for cointegration based on two types of residual-based tests under the null hypothesis, the residuals $\epsilon_{i,t}$ will be integrated of order one, $I(1)$, implying no cointegration among the variables. On the other hand, the existence of cointegration, under the alternative hypothesis, implies that there is a long-run equilibrium (i.e., the residual $\epsilon_{i,t}$ will be $I(0)$).

3.2.2 | ARDL and extended ARDL models

Once the order of integration of the individual variables, and the cointegration relationship among the variables have been analyzed, an ARDL error-correction model (ECM) can be used to estimate the neoclassical production function of Equation (2). This will take the form[4]:

$$\begin{aligned}\Delta \ln Y_{i,t} = \alpha_i + \sum_{k=1}^{p} \beta_{k,i} \Delta \ln Y_{i,t-k} + \sum_{k=0}^{q} \gamma_{k,i} \Delta \ln RE_{i,t-k} + \sum_{k=0}^{q} \delta_{k,i} \Delta \ln K_{i,t-k} \\ + \sum_{k=0}^{q} \omega_{k,i} \Delta \ln LF_{i,t-k} + \lambda_{,i} ECT_{i,t-k} + \epsilon_{i,t}.\end{aligned} \tag{5}$$

where Δ is the first-difference operator; i represents the cross-section groups; p and q refer to the lag lengths, which will be determined by the Akaike information criterion (AIC); $\mathrm{ECT}_{i,t-1} = \ln Y_{i,t-1} - \mu_i - \nu_i \ln \mathrm{RE}_{i,t-1} - \kappa_i \ln K_{i,t-1} - \zeta_i \ln \mathrm{LF}_{i,t-1}$ is the error-correction term; λ_i is the adjustment coefficient; and $\epsilon_{i,t}$ is the serially uncorrelated error term. Note that the above ECM contains information on the short-run and long-run relationships between the variables. With regard to the short-run causal link going from RE to Y (or GDP) in Equation (5), the causality is established if at least one of $\gamma_{k,i} \neq 0$ for $k = 0,\ldots,q$. For the long-run relationship, if the λ_i is statistically different from zero, then there exists a long-run relationship between the economic growth and RE.

A possible presence of nonlinearity in the long- and short-run dynamics of the model, during periods of economic peaks and troughs, will also be investigated. For this purpose, a dummy variable (D_t) will be added to the parameters of interest in Equation (5), which result in the extended ARDL representation:

$$\begin{aligned}\Delta \ln Y_{i,t} = \alpha_i + \sum_{k=1}^{p} \beta_{k,i} \Delta \ln Y_{i,t-k} + \sum_{k=0}^{q} (\gamma_{k,i} + \tau_{k,i} D_{i,t-k}) \Delta \ln RE_{i,t-k} \\ + \sum_{k=0}^{q} \delta_{k,i} \Delta \ln K_{i,t-k} + \sum_{k=0}^{q} \omega_{k,i} \Delta \ln LF_{i,t-k} + \lambda_{1,i} ECT_{i,t-k} + \epsilon_{i,t}.\end{aligned} \tag{6}$$

In Equation (6), the series $D_{i,t} = 1$ represent periods of high economic growth and $D_{i,t} = 0$ periods of low economic growth. The extended error-correction term has the following form: $\mathrm{ECT}_{i,t-1} = \ln Y_{i,t-1} - \mu_i - \nu_i \ln \mathrm{RE}_{i,t-1} - \varphi_i D_{i,t-1} \ln \mathrm{RE}_{i,t-1} - \kappa_i \ln K_{i,t-1} - \zeta_i \ln \mathrm{LB}_{i,t-1}$. The coefficients $\gamma_{k,i}$ and $\tau_{k,i}$ in Equation (6) measure the short-run dynamics from RE to GDP during different periods of economic growth; v_i and φ_i in the ECM representation can be interpreted in a similar way, albeit in the long-run. Lastly, short-run causality effects going from RE to GDP, in Equation (6), can also be established for periods associated with economic peaks and troughs.

3.3 | Data

The dataset covers nine (out of 13) Canadian provinces and territories[5] namely: Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, Ontario, Quebec and Saskatchewan. Annual data, from 1981 to 2015, for real GDP, capital formation (K), labor force (LF) as well as RE are obtained from Statistics Canada[6] Furthermore, we calculate the share of renewable in total electricity generation (SRE) dividing RE by the total amount of electricity generation. The use of SRE will provide an insight into the extent to which the percentage of renewable energy, over the total, affects the economy. The dataset is composed of 455 observations. The annual real GDP, capital formation, labor force, and RE are expressed in logarithmic form. Furthermore, the annual OECD-based indicator for economic contraction and expansion periods is gathered from the Federal Reserve Economic Data (FRED). Descriptive statistics are reported in Table 2. To match the length of SRE, all other variables in the dataset span from 1981 to 2015. The plots of the original series, that is, RE, GDP, LF, K, and SRE for Canada's nine provinces are shown in Figures 1–5 The shaded areas highlight periods of economic expansion according to OECD's indicator that identifies economic peaks and troughs.

Alberta, British Columbia, Ontario and Quebec are the four largest economies in terms of GDP, labor force, and capital formation, whereas the remaining six provinces (Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, PEI and Saskatchewan) are substantially smaller. A similar pattern can be observed in terms

TABLE 2 Descriptive statistics.

	Mean	SD	Min	Max	Median
GDP (billion dollars)					
Alberta	158 (15%)	99	55	377	109
British Columbia	133 (12%)	63	47	251	120
Manitoba	35 (3%)	15	14	66	32
New Brunswick	20 (2%)	8	7	33	18
Newfoundland and Labrador	17 (2%)	10	5	34	11
Nova Scotia	25 (2%)	10	8	41	22
Ontario	420 (39%)	184	133	760	390
Quebec	221 (21%)	90	83	388	201
Saskatchewan	38 (4%)	22	15	83	30
RE (thousand megawatt hours)					
Alberta	2253 (1%)	1046	1392	5052	1898
British Columbia	56,356 (17%)	5380	44,911	67,329	57,245
Manitoba	27,879 (8%)	6164	15,379	36,440	28,821
New Brunswick	3064 (1%)	543	2028	4410	3090
Newfoundland and Labrador	39,450 (12%)	2772	32,832	44,753	39,633
Nova Scotia	1081 (1%)	191	740	1565	1041
Ontario	38,330 (12%)	2112	33,846	41,269	38,314
Quebec	159,284 (48%)	27,063	99,824	205,649	164,196
Saskatchewan	3672 (1%)	993	1705	5404	3668
LF (thousand persons)					
Alberta	1590 (11%)	379	1134	2301	1509
British Columbia	1818 (13%)	352	1245	2306	1860
Manitoba	544 (4%)	51	460	636	535
New Brunswick	316 (2%)	36	248	361	316
Newfoundland and Labrador	205 (1%)	18	179	243	204
Nova Scotia	400 (3%)	43	321	458	396
Ontario	5618 (39%)	848	4199	6923	5454
Quebec	3377 (24%)	440	2640	4097	3258
Saskatchewan	480 (3%)	40	430	574	464
K (million dollars)					
Alberta	58,278 (21%)	32,823	23,603	130,401	47,195
British Columbia	35,048 (13%)	12,958	17,093	56,695	31,456
Manitoba	8150 (3%)	3113	3880	14,306	7336
New Brunswick	4493 (2%)	1496	2470	7347	4068
Newfoundland and Labrador	4924 (2%)	2496	2450	11,527	4090
Nova Scotia	5923 (2%)	1436	3492	8709	5734
Ontario	94,434 (35%)	31,035	42,427	145,616	88,687
Quebec	51,011 (19%)	16,960	23,886	79,305	45,325
Saskatchewan	11,568 (4%)	5850	6439	26,038	9787
SRE (percentage)					
Alberta	4.49	1.59	2.46	8.31	3.94
British Columbia	91.57	3.34	84.31	96.86	90.51
Manitoba	98.39	1.14	94.30	99.63	98.57
New Brunswick	21.66	7.53	10.05	42.87	20.01
Newfoundland and Labrador	96.28	1.25	93.84	98.99	96.24

TABLE 2 (Continued)

	Mean	SD	Min	Max	Median
Nova Scotia	11.13	2.73	6.26	17.77	10.25
Ontario	27.36	3.48	22.23	34.45	26.60
Quebec	97.04	1.21	95.30	99.83	96.77
Saskatchewan	22.29	4.75	13.67	32.05	22.56

Note: Raw data are reported. GDP is expressed in billion dollars; Renewable Energy (RE) is expressed in thousand megawatt hours; Labor Force (LF) is expressed as number of people in thousands; Capital (*K*) is expressed in million dollars; Share of Renewable Energy (SRE) is expressed in percentage.

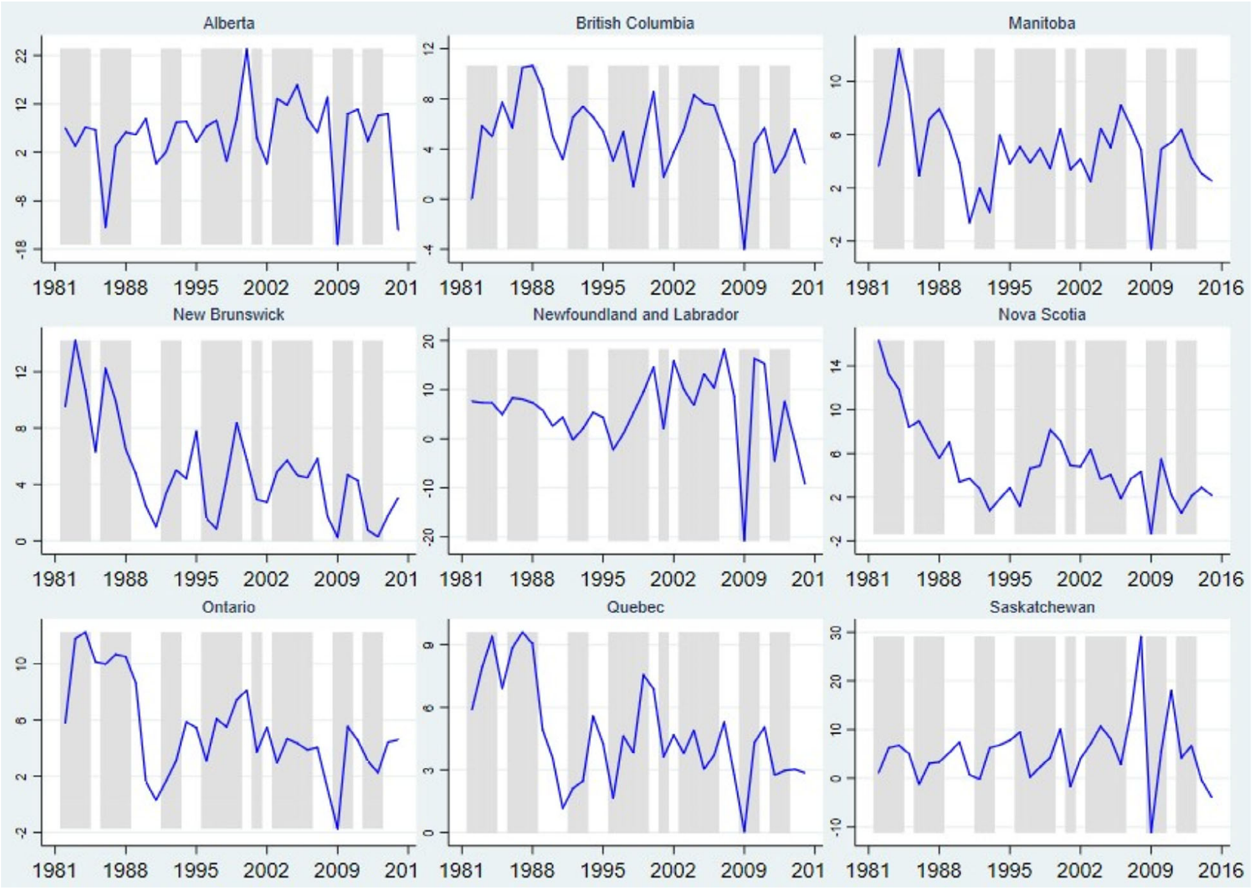

FIGURE 1 GDP percentage change over the period 1981–2015. Shaded areas denote periods of high economic growth. [Colour figure can be viewed at wileyonlinelibrary.com]

of renewable and nonrenewable electricity generations for all largest provinces but Alberta. The province of Alberta has abundant fossil fuels and it has proved to be more cost-effective to use nonrenewable-energy sources compared to renewable energy sources. On the contrary, Quebec, Manitoba, Newfoundland Labrador, and British Columbia show the largest share of renewable, all consistently over 90%. It is worth noting that Quebec and Manitoba have almost achieved the status of 100% green electricity generation.

In Figure 1, periods of GDP economic growth expansion are defined by the shaded areas. During early 1990, the GDP growth rates in most provinces fell sharply. The same trend is observed following the 2008 financial crisis and the 2014 economic downturn. Figure 2 shows the percentage change of electricity generation by renewable sources. There is no obvious trend for the nine provinces. The respective labor force and capital formation for each province are displayed in Figures 3 and 4. Lastly, Figure 5 depicts the share of renewable in electricity generation. British Columbia, Manitoba,

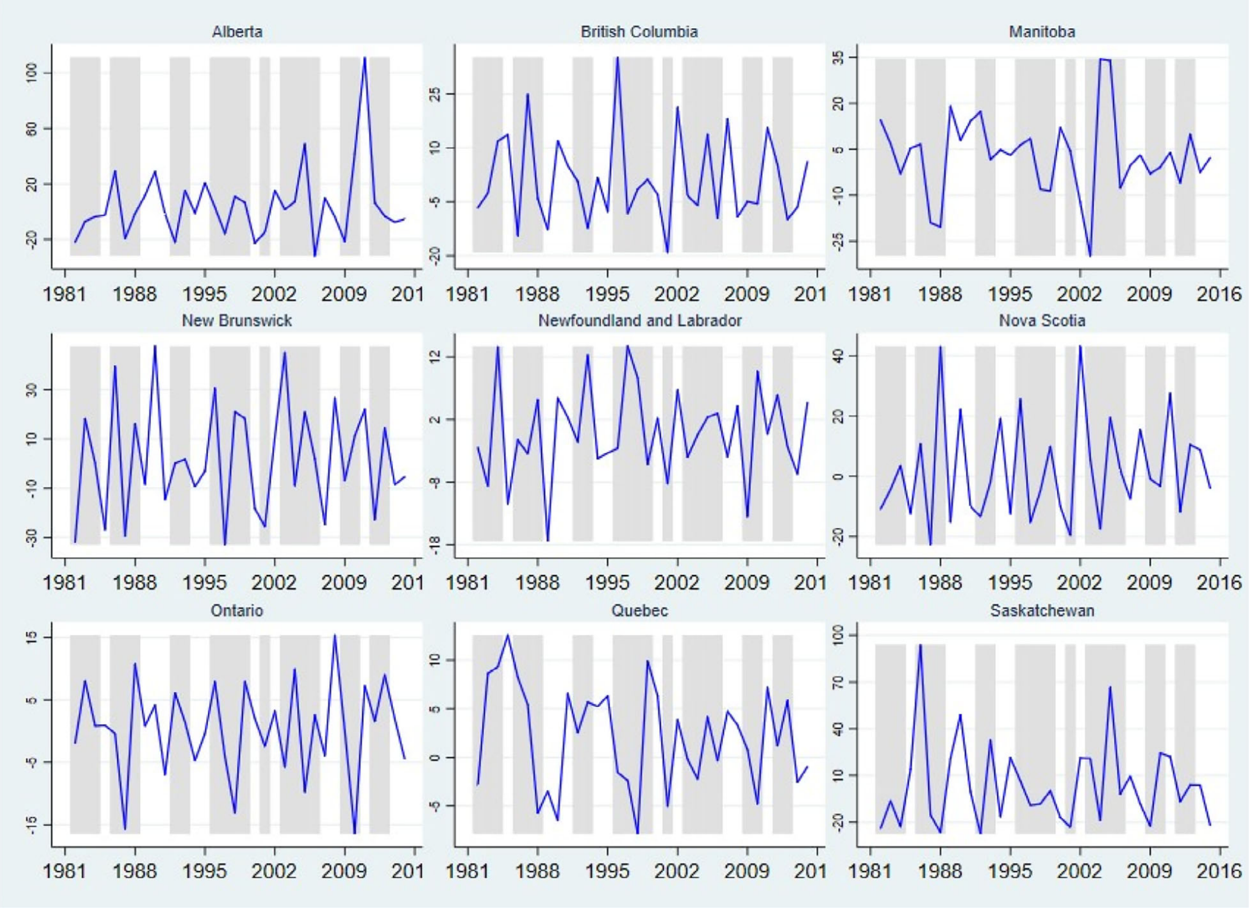

FIGURE 2 Renewable Energy (RE) percentage change over the period 1981–2015. Shaded areas denote periods of high economic growth. [Colour figure can be viewed at wileyonlinelibrary.com]

Newfoundland and Labrador, and Quebec have attained a 90%-share level since 1981. On the other hand, since 1981 as well, Alberta, New Brunswick, Nova Scotia, Ontario, and Saskatchewan have reached only relatively low shares.

4 | EMPIRICAL ANALYSIS

4.1 | Unit-root and cointegration tests

The results of the LLC and IPS unit-root tests are presented in the top part of Table 3. The series lnRE appears to be *I*(0), that is, stationary in levels, whereas the presence of a unit root is found in the cases of ln*Y* and lnLF. All series are found to be *I*(0) after taking the first differences. Finally, the testing results for ln*K* are mixed, with the LLC test indicating the presence of unit roots in levels, which is contradicted by the IPS approach. As mentioned previously, the presence of a mix of *I*(0) and *I*(1) series further motivates the use of our panel ARDL model since the approach allows for the presence of variables with different order of integration.

The results of the Pedroni cointegration tests, presented in Table 3 (bottom), show that five statistics, out of seven, reject the null hypothesis of no cointegration at the 1% level, thereby suggesting that there exists a long-run relationship between ln*Y*, lnRE, ln*K*, and lnLF.

4.2 | Empirical results

Having established the presence of a long-run relationship, the pooled mean group (PMG) estimation, first introduced by Pesaran et al. (1999), will be used to estimate our models. The PMG, which constrains the longrun coefficients to be the same across different groups while allowing for the short-run coefficients to vary across groups is an extension of the mean group (MG) estimator (Pesaran & Smith, 1995), which averages the coefficients within each group. Thus, the PMG estimator assumes a homogeneous relationship in the long run across groups and allows heterogeneity in the short run across sections. The PMG estimator's characteristics suit better the scope of our study since we are primarily interested in examining the nationwide long-run relationship as well as the short-run causality dynamics across the nine provinces considered in this study. Given the annual data frequency of our data, the maximum lag length is set to 2 years and the AIC selects one lag for all variables.

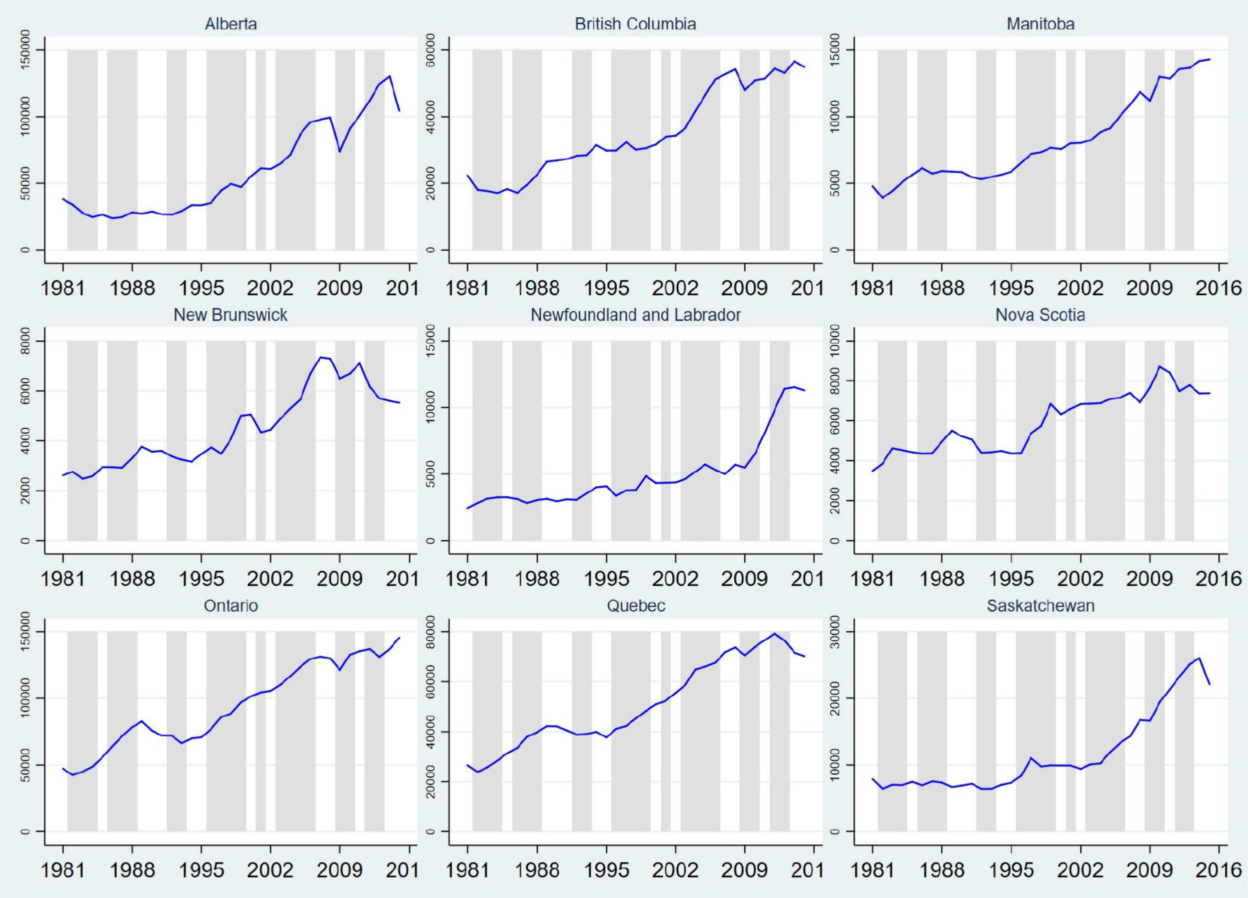

FIGURE 3 Capital (K) over the period 1981–2015. Shaded areas denote periods of high economic growth. [Colour figure can be viewed at wileyonlinelibrary.com]

We first estimate the classical production function models discussed in Section 3.1. Four different models will be estimated, with the different model specifications summarized in Table 4.

Models A1 and A3 are used as baseline models and include Renewable Energy (RE) and Share of Renewable Energy (SRE), respectively. Models A2 and A4 include the dummy variable indicating economic expansion, which is interacted with RE and SRE, respectively.[7] The estimated models with associated robust t-statistics and maximized log-likelihoods values are presented in Table 5 (left panel for Model A1, right panel for Model A2). Results of Models A3 and A4 are provided in Table 6.

From Table 5, while the estimated speed of adjustment coefficient of the error-correction term ECT_{t-1} in the baseline Model A1 is negative and significant (thus corroborating the existence of a long-run relationship between the economic growth and RE), no short-run Granger-causality is observed from RE to GDP. When the dummy variable is included (Model A2) the null hypothesis of no Granger-causality running from RE to GDP is strongly rejected by the data during high-economic-growth periods. Note that on the basis of the estimated maximized loglikelihoods presented in Table 5 (709.953 for Model A1 and 732.296 for Model A2), the resulting likelihood ratio test (asymptotically distributed as $\chi^2_{(2)}$) indicates that Model A1 is rejected in favor of Model A2 at any significance level.[8] Turning to Table 6, the baseline estimated Model A3 (left panel) only show a causality running from SRE to GDP in the long run. Results with dummy variable (Model A4), presented in the right panel, is qualitatively similar: when the share of renewable energy is considered, statistically significant evidence of Granger-causality running from SRE to GDP only emerges in the long run while no short-run causality is found during periods of both low-and high-economic growth.[9]

The above results suggest that investing in renewable energy has a sizeable and positive effect on economic growth. Those are in line with efforts made by politicians at provincial and federal levels to increase the amount and percentage of Canada's electricity generated by renewable sources. Such support has been in the form of subsidizing projects and initiatives for renewable energy production using tax dollars. Furthermore, it seems that undertakings that strengthen the generation of renewable energy, being a driver of GDP, are particularly worthwhile in high economic growth periods.

4.3 | Reverse causality

As a robustness check, we also test for the presence of reverse causality, therefore looking at the effect of Y (GDP) on RE (Model B1). For consistency with the previous findings, in this section, we only

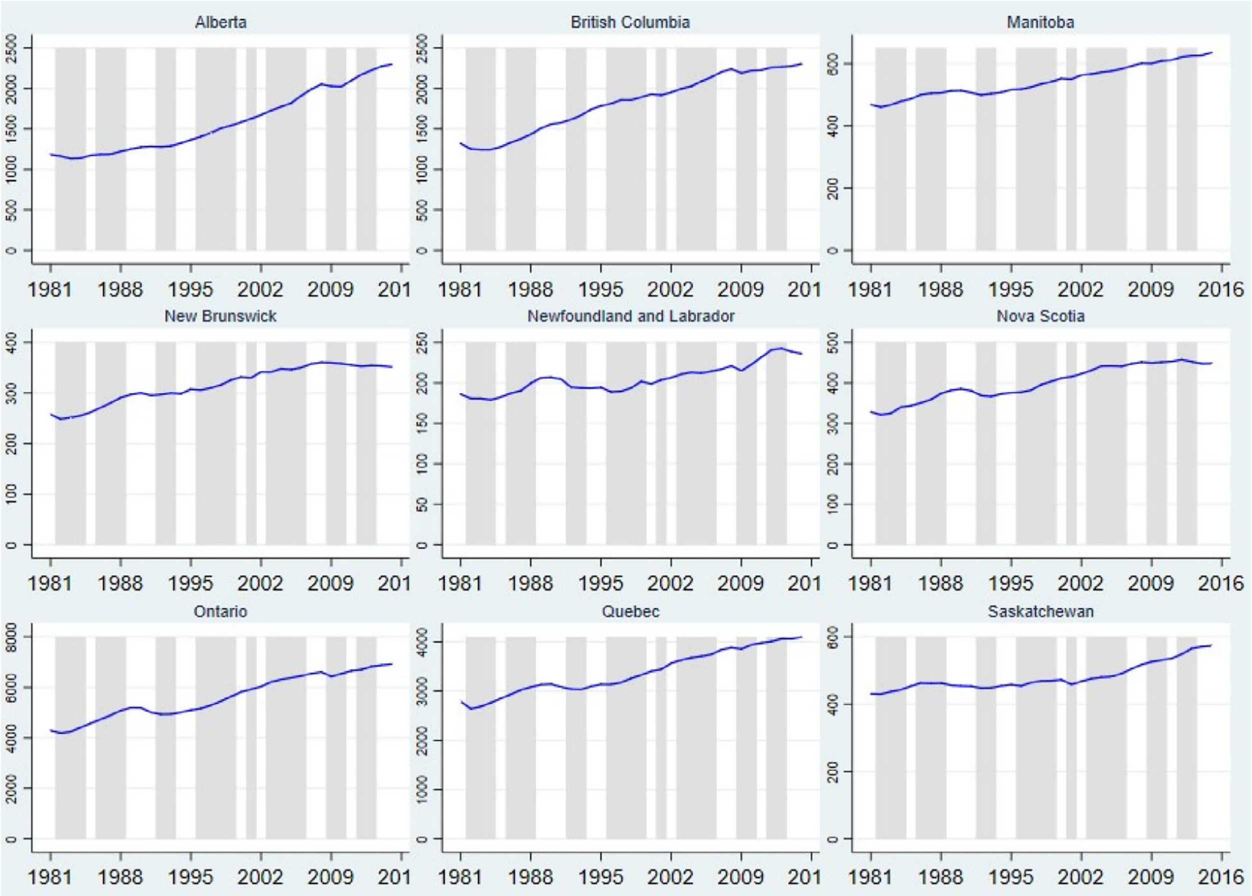

FIGURE 4 Labor Force (LF) over the period 1981–2015. Shaded areas denote periods of high economic growth. [Colour figure can be viewed at wileyonlinelibrary.com]

discuss the results of the extended models (i.e., with dummy variables interacted with Y).[10] Thus, estimated model for RE takes the form:

$$\Delta \ln RE_{i,t} = \alpha_i + \sum_{k=1}^{p} \beta_{k,i}\Delta \ln RE_{i,t-k} + \sum_{k=0}^{q}\left(\gamma_{k,i}+\tau_{k,i}D_{i,t-k}\right)\Delta \ln Y_{i,t-k} + \sum_{k=0}^{q}\delta_{k,i}\Delta \ln K_{i,t-k} + \sum_{k=0}^{q}\omega_{k,i}\Delta \ln LF_{i,t-k} + \lambda_i ECT_{i,t-1} + \epsilon_{i,t}. \quad (7)$$

with

$$ECT_{i,t-1} = \ln RE_{i,t-1} - \mu_i - \nu_i \ln Y_{i,t-1} - \varphi_i D_{i,t-1}\ln Y_{i,t-1} - \kappa_i \ln K_{i,t-1} - \zeta_i \ln LF_{i,t-1}. \quad (8)$$

We will refer to this as Model B1. Replacing RE in Equations (7) and (8) with SRE will result in Model B2. Estimation to the above specification as parameters point estimates for Model B1 (Table 7, left panel) clearly shows no evidence of Granger-causality running from Y (GDP) to RE in the short run; a similar result is also observed for Model B2 (Table 7, right panel). Overall, our results suggest a strong long-run relationship between the economic growth and renewable-energy with evidence of unidirectional causality going from renewable energy to economic growth.

Our results, indicating no causality from GDP to renewable and share of renewable energy generation, are incentives for governments/policymakers neither to make acts nor regulations in order to promote renewable energy. Economy growth does not necessarily attract investments in green energy technology. As a result, economic growth may not facilitate the growth of renewable energy. For the governments seeking to expand renewable energy, it is important to make strategic plans to attract R&D investments.

5 | CONCLUSION AND POLICY IMPLICATIONS

This study examined the dynamic linkages between renewable energy and economic growth for the case of Canada. Our country of interest is particularly relevant as it represents an example of an economy that is at the forefront of the transition towards a green economy but at the same time an economy with very high level of CO_2 emissions. Our approach considered an extended neoclassical production technology framework as the theoretical background, which has then been estimated and tested empirically by means of autoregressive distributed lag models. Potential nonlinearity in the dynamic nexus between

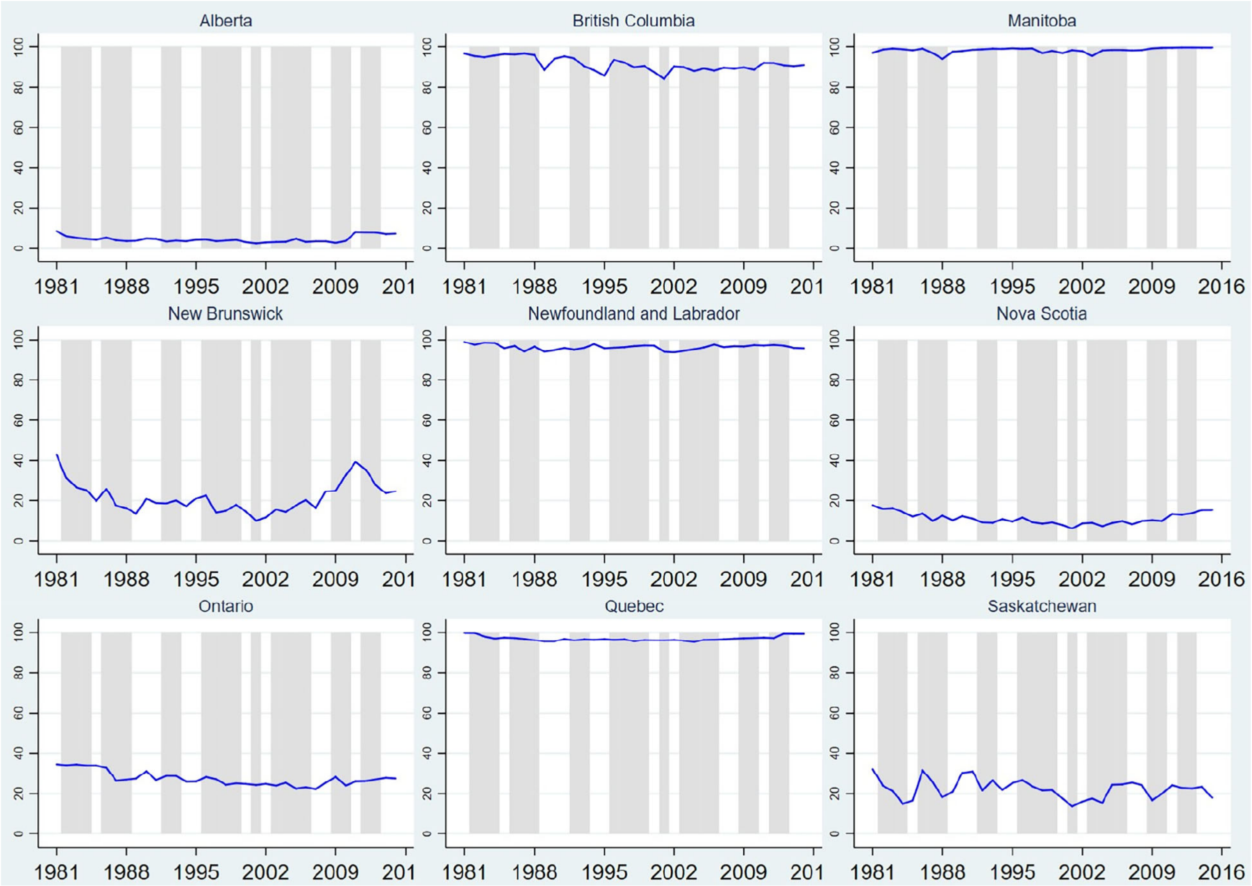

FIGURE 5 Share of renewables in electricity generation (SRE) over the period 1981–2015. Shaded areas denote periods of high economic growth. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Results of the LLC and IPS unit-root tests.

Panel unit root test				
Variable	**LLC level**	**Difference**	**IPS level**	**First difference**
lnGDP	−1.5212	−6.5424**	−0.5916**	−8.3662**
lnRE	−4.0527*	−15.6833**	−4.1556**	−17.4057**
ln*K*	−1.4467	−10.6049**	−2.0412**	−12.0417**
lnLF	0.96740	−9.0740**	0.9614	−10.2028**

Pedroni cointegration test					
	Statistic	**Probability**		**Statistic**	**Probability**
Panel *v*-statistic	8.7177	0.0000	Group *ρ*-statistic	0.6439	0.7402
Panel *ρ*-statistic	−0.4601	0.3227	Group PP-statistic	−3.7758	0.0001
Panel PP-statistic	−3.2681	0.0005	Group ADF-statistic	−2.5642	0.0054
Panel ADF-statistic	−2.7621	0.0032			

Note: individual intercept and trend are included for lnGDP, ln*K*, and lnLF in the test regression. Individual fixed effects are included. The symbols * and ** signif GDP the rejection of the null hypothesis of a unit root at the 5% and 1% significant levels, respectively.

economic growth and renewable energy which, surprisingly, has received little attention in the literature, has been controlled for.

The key result of our study is the empirical evidence on the relevant role played by asymmetric effects, which is, renewable energy determines economic growth differently during periods of low economic growth compared to periods of high economic growth. More specifically, it shows that renewable energy and economic growth share a long-run equilibrium and such an effect is strengthened when the economy is in a business expansion. While capital and labor appear to be the most relevant determinants, renewable energy

TABLE 4 Summary of model specifications.

Model	Dependent variable	Explanatory variables
A1	GDP	RE, LF, and *K*
A2	GDP	RE, LF, *K* and economic expansion dummy
A3	GDP	SRE, LF, and *K*
A4	GDP	SRE, LF, *K* and economic expansion dummy

Note: A1: Baseline ARDL Model with Renewable Energy (RE); A2: Extended ARDL Model with Renewable Energy (RE); A3: Baseline ARDL Model with Share of Renewable Energy (SRE); A4: Extended ARDL Model with Share of Renewable Energy (SRE).

plays a significant role. Failing to control for the state of the business cycle would lead to the (wrong) conclusion of no evidence of a growth effect.

The results from the panel autoregressive distributed lag models indicate that long-run causal linkages go from renewable-energy usage, labor force, and capital formula to economic growth. On the contrary, there is no evidence of a significant causal effect running from economic growth, capital and labor force to renewable energy in neither the long run nor the short run. Our results, for Canada, support the growth hypothesis, showing a unidirectional causality going from renewable energy to economic growth. The pattern observed shows that a transition to a greener economy appears to lead to economic growth.

Nonetheless, policy makers should be careful while devising green economy policies, taking into account the business cycles as well as the heterogeneous nature of local economies. Renewable energy for production and consumption impact the local economic development and household income. Deployment of subsidy policies for renewable-energy use and technological innovations supporting its production is of prime consideration in as much as the utility of renewable energy, through economy of scale, and could also potentially facilitate its efficient generation.

In Canada, the power to legislate and implement policies concerning renewable energy rests on three levels of government: federal, provincial, and municipal. The legislative authority in harnessing natural resources is mainly under the purview of each provincial government, which has oversight in the management of natural resources within its territorial jurisdiction. The federal government, however, decides the national priorities and hence indirectly influences provincial legislation through its regulation of the trading of renewable and nonrenewable energy within and outside Canada. To some extent, the municipal government has a certain influence on the crafting of policies enacted by the federal government especially in the process and manner of policy implementation.

For instance, the Green Energy Act (GEA) in Ontario, which was introduced in 2009 but repealed in 2019 in an attempt to build a

TABLE 5 ARDL model results.

Model A1	PMG estimates			Model A2	PMG estimates		
	Coefficient	*t*-statistic	Probability		Coefficient	*t*-statistic	Probability
Long-run estimate				Long-run estimate			
lnRE$_{t-}$1	0.0930	1.3505	0.1780	lnRE$_{t-}$1	0.1586	2.0295	0.0434
ln$K_t - 1$	0.5820	4.5345	0.0000	D* lnRE$_{t-}$1	0.0004	3.2436	0.0013
lnLF$_{t-}$1	1.0322	3.0125	0.0028	ln$K_t - 1$	0.4982	4.1172	0.0001
				lnLF$_{t-}$1	1.1275	3.5321	0.0005
Short-run estimate				Short-run estimate			
ΔlnRE$_t$	0.0243	1.0241	0.3067	ΔlnRE$_t$	0.0191	0.7235	0.4700
ΔlnK_t	0.0998	2.4367	0.0155	DΔ* lnRE$_t$	0.0001	−3.8938	0.0001
ΔlnLF$_t$	0.5192	3.8001	0.0002	ΔlnK_t	0.0982	2.3549	0.0193
ECT$_{t-}$1	−0.1245	−4.1170	0.0001	ΔlnLF$_t$	0.3516	2.8670	0.0045
Intercept	−0.3761	−3.3783	0.0008	ECT$_{t-}$1	−0.1127	−4.9987	0.0000
				Intercept	−0.4392	−4.2921	0.0000
Maximized log-likelihood	709.9530			Maximized log-likelihood	732.2961		
AIC	−1403.9060			AIC	−1444.5922		
SC	−1212.8983			SC	−1211.4495		
HQC	−1327.5911			HQC	−1351.4431		
R^2	0.4785			R^2	0.5444		

Note: GDP is the dependent variable of Models A1 and A2. The explanatory variables of Model A1 are Renewable Energy (RE), Capital (*K*); and Labor Force (LF) while those of Model A2 are RE, economic growth expansion dummy (*D*), *K*; and LF. Log-likelihood value, AIC, Schwarz Criterion (SC), Hannan-Quinn information criterion (HQC), and R^2 of the estimated models are provided.

TABLE 6 ARDL model results.

Model A3	PMG estimates			Model A4	PMG estimates		
	Coefficient	*t*-statistic	Probability		Coefficient	*t*-statistic	Probability
Long-run estimate				Long-run estimate			
lnSRE$_{t-}$1	0.4883	3.4079	0.0008	lnSRE$_{t-}$1	0.4059	3.1190	0.0020
ln$K_t - 1$	0.5299	4.3701	0.0000	*D** lnSRE$_{t-}$1	0.1316	3.3700	0.0009
lnLF$_{t-}$1	1.2486	3.9751	0.0001	ln$K_t - 1$	0.5005	4.6516	0.0000
				lnLF$_{t-}$1	1.3102	4.7549	0.0000
Short-run estimate				Short-run estimate			
ΔlnSRE$_t$	0.0464	0.6247	0.5327	ΔlnSRE$_t$	0.0657	0.8199	0.4130
ΔlnK_t	0.0982	2.5658	0.0108	*D*Δ* lnSRE$_t$	−0.0844	−1.5466	0.1232
ΔlnLF$_t$	0.5326	3.8556	0.0001	ΔlnK_t	0.0903	2.438	0.0160
ECT$_{t-}$1	−0.1312	−3.6531	0.0003	ΔlnLF$_t$	0.3764	2.9728	0.0032
Intercept	−0.3679	−2.9998	0.0030	ECT$_{t-}$1	−0.1298	−3.6103	0.0004
				Intercept	−0.3799	−2.9875	0.0031
Maximized log-likelihood	715.1561			Maximized log-likelihood	736.4864		
AIC	−1414.3122			AIC	−1452.9728		
SC	−1223.3891			SC	−1219.9258		
HQC	−1338.0312			HQC	−1359.8619		
R^2	0.4772			R^2	0.5478		

Note: GDP is the dependent variable of Models A3 and A4. The explanatory variables of Model A3 are Share of Renewable Energy (SRE), Capital (*K*); and Labor Force (LF) while those of Model A4 are SRE, economic growth expansion dummy (*D*), *K*; and LF. Log-likelihood value, AIC, SC, HQC, and R^2 of the estimated models are provided.

TABLE 7 ARDL models results (Reverse Causality).

Model B1	PMG estimates			Model B2	PMG estimates		
	Coefficient	*t*-statistic	Probability		Coefficient	*t*-statistic	Probability
Long-run estimate				Long-run estimate			
lnGDP$_{t-}$1	0.0133	0.2216	0.8250	lnGDP$_{t-}$1	−0.0047	−0.5200	0.6030
*D** lnGDP$_{t-1}$	−0.0001	−0.0370	0.9700	*D** lnGDP$_{t-1}$	0.0001	0.0200	0.9850
ln$K_t - 1$	0.0918	1.1327	0.2570	ln$K_t - 1$	0.0202	1.5500	0.1200
lnLF$_{t-}$1	−0.0800	−0.4859	0.6270	lnLF$_{t-}$1	−0.0464	−1.3900	0.1650
Short-run estimate				Short-run estimate			
ΔlnGDP$_t$	−0.2978	−1.1830	0.2370	ΔlnGDP$_t$	0.0370	0.4000	0.6900
*D*Δ* lnGDP$_t$	−0.0011	−1.1889	0.2350	*D*Δ* lnGDP$_t$	0.0001	−0.1500	0.8820
ΔlnK_t	0.1818	1.7310	0.0830	ΔlnK_t	−0.0276	−0.9400	0.3470
ΔlnLF$_t$	−0.1906	−0.2818	0.7780	ΔlnLF$_t$	−0.0960	−1.1200	0.2620
ECT$_{t-}$1	−0.5279	−5.1319	0.0000	ECT$_{t-}$1	−0.4207	−5.7200	0.0000
Intercept	8.3866	5.0204	0.0000	Intercept	0.3464	3.5700	0.0000
Maximized log-likelihood	267.8821			Maximized log-likelihood	807.3581		
AIC	−515.7652			AIC	−1594.7162		
SC	−254.1962			SC	−1363.1255		
HQC	−411.2585			HQC	−1502.1868		
R^2	0.3272			R^2	0.2654		

Note: Renewable Energy (RE) and Share of Renewable Energy (SRE) are dependent variables in Models B1 and B2, respectively. The explanatory variables are GDP, economic growth expansion dummy (*D*), Capital (*K*), and Labor Force (LF). Log-likelihood value, AIC, SC, HQC, and R^2 of the estimated models are provided.

renewable-energy economy, entailed the promotion of energy-efficient measures to affect energy conservation and create green-energy jobs. The GEA provided assistance to renewable-energy project developers and established the project standards. At microeconomic level, homeowners are incentivized, for example, by a low or 0% interest-rate loan to produce or to participate in the utility of renewable-energy generating devices or initiatives (e.g., solar panels). Despite its abolition, the GEA is purposeful and our research results are aligned with its principles in the context of economic growth. Therefore, it needs to be revisited, and the lessons from the multifaceted GEA issues must be learned to obtain an improved version of the Act. Such issues (political or otherwise) include the controversy surrounding the feed-in tariff rates, "made in Ontario" clauses to receive the tariff rates, islanding of the power system, meeting targets of job creation, employment effects of green-energy policies, and the management of a renewable-energy programme. Future research may want to investigate the direct and indirect costs associated to the implementation of infrastructures designed at producing green energies.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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ENDNOTES

[1] Other authors, such as Al-Mulali et al. (2013), also pointed out that the assumption of a linear causality in the dynamics of a process can lead to misleading conclusions.

[2] Please note that all policies mentioned in this subsection are sourced from provincial Government websites.

[3] Please note that the alternative hypothesis of the LLC test is no unit roots.

[4] Please note that the ARDL representation can deal with variables showing a mixing order of integration ($I(0)$ vs. $I(1)$); this will be clear in the empirical section.

[5] Prince Edward Island (PEI), Northwest Territories, Nunavut and Yukon are excluded due to data unavailability.

[6] Note that the RE generation data is combined by two series. One series covers 1981–2007, and the other one covers 2008–2015. Statistics Canada changed its sampling design. Prior to January 2008, hydro included wind and tidal generation. From January 2008 onwards, wind and tidal generation are reported separately. Then, the annual RE generation data is estimated by summing up the monthly data. The same transformation was also adopted by Wadstrom et al. (2019).

[7] Please note that since Model A1 (A3) is a restricted version of Models A2 (A4), these restrictions will be tested using likelihood ratio test statistics.

[8] Even though Model A1 is rejected, the restricted estimates are of some interest as they show that failing to take into account for different economic cycles in the model specification may wrongly suggest no causality running from renewable energy to aggregate output.

[9] Please note that the imposed restriction reduces the maximized log-likelihood from 736.486 (Model A4) to 715.156 (Model A3); that leads to Model 3 being rejected by means of the likelihood ratio test at any statistical conventional level.

[10] Please note that, as for the models estimated in Section 4.2, also in this case the extended model with dummy is supported by the data based on likelihood ratio tests (LR).

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