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RESEARCH ARTICLE

Mitigating environmental degradation with institutional quality and foreign direct investment (FDI): new evidence from asymmetric approach

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Abstract

Chile is currently rated among the performing countries towards the achievement of the global goals of reducing carbon emission. It is on recorded that Chile as a country has moved from highly insufficient to insufficient and still working towards conforming to recommend the region of 2°C in quest of controlling climate change through carbon emission reduction. From this development, it is essential to investigate on the country's strategies in achieving this success and equally make recommendation for other countries to adopt Chile's strategy as a blue print in controlling carbon emission. To effectively do this and achieve the objective of this study, I adopt nonlinear and asymmetric approaches to have a combined (positive and negative) view of the reactions of the selected variable towards determining the impact of each variable towards curbing emission in Chile. Also, a careful selection of variable which includes economic growth (GDP per capita-Y), institutional quality, foreign direct investment (FDI), fossil fuels, and renewable energy consumption was undertaken in this study. The focus was on the interaction of institutional quality and FDI towards ascertainment of environment performance. Chile's quarterly data of 1996Q1 to 2018Q4 was utilized, and the following findings were made: positive and negative shocks to the economic growth, institutional quality, and renewable energy impacted favorably and negatively on Chile's environment through reduction and promotion of emission, respectively. In contrast, positive and negative shocks to FDI and fossil fuels impact both negatively on the Chile's environment through increase in carbon emission. So institutional quality is vital in controlling the negative impact from FDI and fossil fuels.

Keywords Economic growth · Institutional quality · FDI · Sustainable study · Nonlinear study · Chile

Introduction

Climate change is a threat to the entire Earth as it affects the existence of living and non-living things. The dangers associated with climate change cut across the entirety of human race and wild and aquatic lives. Global warming is associated with climate change and detrimental to the continuous existence of the occupants of the Earth. Ugly incidences such as natural disasters, rising of sea level, attack on Antarctic region, strange diseases in form of pandemics and epidemics, and extinction of wild and aquatic lives that are rooted in climate change are in steady occurrence because emissions and climate change. This has led to several summits targeting the control of climate change by the world leaders ranging from Kyoto summit/protocol (1997 and 2005) under the United National Framework Convention on Climate Change (UNFCCC) to Paris Agreement of 2015 with its ratification in 2016. Conventional approaches and scholarly research on how to mitigate climate change are on the increase with

Highlights of Chile's ESPR

1. This is a nonlinear study of Chile's environmental performance.
2. Institutional quality and foreign direct investment (FDI) were used to assess Chile's environment performance.
3. Chile's ambition towards mitigating carbon emission is confirmed with institutional quality.
4. Chile's economic growth and renewable energy are positively impacting the environment.
5. Conclusion is based on policy inferences from Chile's ability to curb emission to other non-performing countries.

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majority focus on strategies to lower carbon emissions. Carbon footprint as it concerns the increase emitting of carbon into surroundings has been studied by different scholars (Alola and Kirikkaleli 2019; Zhang et al. 2021; Chang et al. 2021.; Xu et al. 2021) with different variables and indexes with motive of exposing the real causes and ways of controlling it for effective mitigation of climate change.

Many studies with different instruments and variables such as economic growth (Adebayo and Akinsola 2021; Aslan et al. 2021; Ahmad et al. 2021), economic liberalization policies (trade, globalization, finance, and FDI) (Yu et al. 2021; Gleditsch 2021; Tan et al. 2021), energy consumption policies (renewable and non-renewable sources), electricity (Benitez et al. 2021; Xue et al. 2021), and natural resources (Sarkodie 2021; Zheng et al. 2021) have been utilized in researching climate change, but little has been done with respect to institutional quality. Institutional quality depends largely on the effectiveness and efficient implementing and monitoring of established rules and policies towards moderating any phenomenon. Policies in the areas of environment and economic performance are made, strengthen, and executed through the institutions of any given country. The direction of policies is always determined by the intended goals of enacting such policies. The policies could be in form of discouraging the phenomenon which are inimical to the positive development of the country or encouraging the phenomenon that enhances the positive development of the country. As remarked, climate change is a global phenomenon that is inimical to the existence of life (both humans and other living things including non-living things) and has drawn a global attention that cuts across nations and regions. The causes and effects of climate change have been greatly researched and discussed among scholars in different literature both at national and international levels. Different measures have been agreed under recognized bodies like Kyoto and Paris Agreement such as nations taking responsibility of emissions generation and working towards curbing of climate change through reducing of carbon emission to a globally accepted standard (i.e., between 2°C and 1.5°C) and working towards achieving Sustainable Development Goals (SDGs 6→15). Affairs of nations with regard to sustainable development are determined by its authorities through good initiatives and policies meted out for either short-, medium-, or long-term goals. The authorities of each country are expected to come up with deliberated policies as the effective and efficient way of achieving goals set before them. The effectiveness of the policies is largely dependent on the quality and effectiveness of institutions saddled with the responsibilities of executing and monitoring the policies (Acemoglu et al. 2001; Easterly and Levine 2003; Hall and Jones 1999; Rodrik et al. 2004). The effectiveness of the institutions in delivering their assignments largely depends on the freedom of the institutions from undue interference and corruption (Vogel 1997). Any country that has its institutions heavily controlled by any elected or appointed political officer or infiltrated by the corrupt elements will likely perform low in policy executions. Scenarios such as tax evasion, rules bending and subversion, jumping of processes, and free from penalty are corrupt practices encouraged by corrupt and weak institutions.

One striking area of economic operation that has great impacts on both economic and environmental performances which is likely to be influenced by the institutional quality and corruption is foreign direct investment (FDI). FDI is perceived as among the ways of transferring pollution-intensive economic activities from one nation to another, mostly from developed to developing nations. Studies (Anyanwu 2012; Udemba 2020b) have remarked the direction of FDI towards the resources endowed nations and places where there is laxity in their laws for free ride in operations. Most developing countries including Chile are known with accepting great influx of FDI because of the above cited factors (resources based, serenity of environment, and laxity in their laws). Foreign investors are informed of these factors and always work towards exploiting them for their profiting through production activities. Often times, environmental quality is neglected in the process of carrying out their (foreign investors) production activities through collaboration with corrupt officials in charge of environment regulations.

To this end, this study wishes to investigate the sustainable trajectory of Chile with institutional quality and FDI. Chile has been recognized as a country that is ambitious in delivering towards the Paris Agreement of keeping climate condition at 2°C or below. Chile had moved from the state of highly insufficient to insufficient and even to sufficient range of maintaining 2020 national determined contribution (NDC). For accurate investigation of this topic, a shift from single perspective to a more comprehensive approach is utilized by author. Nonlinear-autoregressive distribution lag (NARDL) with structural break is adopted for effective and insightful estimation and discussion of this topic. The novel of this study is on the multifaceted approaches adopted for accurate finding and its justification. Specifically, asymmetric (NARDL) analysis will aid in exposing the two-way impact of institution on Chile's carbon mitigation. NARDL will aid in determining both the increase and decrease shock of institution to the carbon emission control. Again, NARDL distinguishes between the short path and long path effects of the independent variables on the dependent variable. Also, a combination of institutional quality and FDI is perceived by the author as a possible way of exposing the impact of institutional quality on Chile's environment performance. This will equally give insight on the impact of FDI on Chile's environment and how institutional quality is moderating both FDI and environment. Chile is ranked third (3rd) in the attraction and retaining FDI in the Latin America after Mexico and Brazil. This is depicted with the current resurgence of FDI in Chile after the setback of the country's FDI in 2014–2016 periods (Commissioners, 2019). FDI has been identified as a channel to enhance economic growth through projection of new ideas and technologies (Aizenman et al. 2013; Blonigen and Piger 2014), and economic growth by extension impacts the environmental performance through various economic activities. These economic activities ranges from manufacturing, industrial, and agricultural activities which utilize excessive energy in executing them, and this sometimes leads to injection of carbon emission because of over utilization of fossil fuels. It has been argued that FDI constitutes harm on any economy with lax and non-stringent laws towards regulating the excesses of the foreign investors (Udemba 2019 for China). Also, NARDL is considered good for direct insight into the interaction of institutional quality and FDI towards the ascertainment of the environment quality. For the effectiveness of this finding, granger causality is adopted especially for the purpose of exposing direct effect and for forecasting purpose. This will give insight on how Chile has been able to mitigate carbon emission and equally become a model for other developing nations especially within the Latin American countries for effective control and mitigation of climate change. This might not be the only work to have dealt with emission control with institutional quality, but the uniqueness of this work is on the interaction of institutional quality with FDI in determining the strength of Chile in controlling the excesses of foreign investors.

The rest of this study is structured as “Data and variables” section for data and variables, “Methodology and modelling” section for methodology and modelling, “Empirical results and discussions” section for empirical results and discussions, and “Concluding remark and policy recommendation” section for concluding summary and policy implication.

Data and variables

The present work applied Chile’s annual data of 1996 to 2018 which is converted to quarterly data of 1996Q1 to 2018Q4 for the accommodation of greater sample size of 89 instead of 25 as in the case of annual data. Chile is chosen because of its antecedent in curbing the environmental degradation and its prospects and likelihood of peaking emissions (carbon neutrality goal) in 2023 which is 2 years earlier than proposed peak year of 2025 (Climate Action Tracker 2020). Following the record of its performance, Chile is identified as among the first countries to officially tender an updated Paris Agreement target to the UNFCCC in the early 2020. The progressive achievement of Chile towards carbon neutrality (through its national determined contribution) within the periods of 2019 and 2020 has moved the country from the position of highly insufficient to insufficient. Considering the energy mix of Chile with fossil fuels (coal, oil, and gas) amounting up to 73.4 percent of its total primary energy (International Energy Agency, 2017), it is expected that the country will be locked up in carbon emission; instead Chile as a country has defiled this expectation and put itself forward for emulation. This has posited Chile as a frontrunner on climate action which is worth researching for policy recommendation on how to achieve the same fit.

The data used in this work are sourced from three (3) renowned and trusted sources, namely, Worldwide Governance Indicator (WGI), 2018 updated World Development Indicator (WDI), and British Petroleum (BP) Statistical Review of World Energy. With emphasis on the aim of this study which is the efficiency and effectiveness of mitigating carbon emission for carbon neutrality with institution of Chile, this study adopts institutional quality as explanatory variable to measure the efficiency of Chile in handling the emission level of the country through its regulatory bodies (institutions). Institutional quality is an indexed variable that consist of six indicators (voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption), and it is sourced from Worldwide Governance Indicators (WGI). This is considered as the most popular indicators in measuring governance through its institutions (Arndt 2008). Real per capita gross domestic product measured as GDP per capita (constant 2010 US$) is among the explanatory variables in determining the environmental performance of Chile, and it is sourced from 2018 updated World Development Indicators (WDI). The interconnection between the economic growth and the environment performance has been discussed in many literatures (Ekins 1993; Illge and Schwarze 2009; Arrow et al. 1995; Cole 1999; United Nations World Commission on Environment and Development (WCED) 1987; Dergiades et al. 2016). Environmental Kuznets Curve (EKC) theory has been utilized by many scholars to demonstrate the interconnections between economic growth and environment quality through its inverted U-shape (Vehmas et al. 2007; Chen 2008; Stern 2004). FDI is among the explanatory variables adopted in this study to investigate the trend and credible management of carbon emission in Chile, and it is sourced from the 2018 updated World Development Indicators (WDI). FDI is applied in this study and is measured as a foreign direct investment, net outflows (% of GDP). Chile is ranked third (3rd) in the attraction and retaining FDI in the Latin America after Mexico and Brazil. This is depicted with the current resurgence of FDI in Chile after the setback of the country’s FDI in 2014–2016 periods (Commissioners, 2019). FDI has been identified as a channel to enhance economic growth through projection of new ideas and technologies (Aizenman et al. 2013; Blonigen and Piger 2014), and economic growth by extension impacts the environmental performance through various economic activities. These economic activities range from manufacturing, industrial, and agricultural activities which utilize excessive energy in executing them, and this sometimes leads to injection of carbon emission because of over utilization of fossil fuels. Another strong factor that affects the movement of FDI aside from the resources-based (primary resources and human labor) is the institutional-shaped policy of the any given country. The effect could be from the certainty or the uncertainty of the policy which could have two expected effects, positive or negative. Some of these policies shape the political environment with regard to rules and orders (Arellano et al. 2019; Choi et al. 2018; Christiano et al. 2014; Dixit 2011; Aizenman and Spiegel 2006). Carbon emission and renewable and non-renewable energy consumption are all part of the variables (explained and explanatory) utilized in this study. The energy consumption (renewable and non-renewable) is important to this study for the exposition of their impacts towards the injection of emission and controlling of emission by the non-renewable and renewable energies, respectively. Some other studies (Ali et al. 2020; Emir and Bekun 2019; Baloch et al. 2021; Adedoyin et al. 2020a; Adedoyin et al. 2020b) have utilized electricity, economic growth, financial development, and urbanization in studying the environment of other countries. They are all measured in million tonnes of carbon dioxide and million tonnes oil equivalent for carbon dioxide emissions and the energy (renewable and non-renewable) consumption, respectively, and they are sourced from the British Petroleum (BP) Statistical Review of World Energy. The summary of the selected variables with respect to their measurements and time trend of the variables are displayed in Table 1 and Fig. 1 as follows:

Methodology and modelling

Author applied different methods to ascertain the correctness of the data with regard to normality, stability, and fitness of good and for the avoidance of misleading findings and conclusion. The major methodology adopted in this study is nonlinear and asymmetric cointegration. The nonlinear ARDL (NARDL) captures the nonlinear and asymmetric cointegration between the variables and distinguishes between the short-term and long-term impacts of the independent variables (in a decomposed manner of positive and negative impacts) on the dependent variables. NARDL is chosen over other nonlinear approaches such as nonlinear threshold Vector Error Correction Model (VECM) or a smooth transition model and error correction models because of its advantage over them. The likelihood of the model to suffer from convergence problem due to proliferation of number of parameters is minimized in the case of NARDL; also NARDL unlike other approaches ignores the mandatory criteria of integrating in a certain specified order, i.e., I(1), rather it accommodates any order of integration that ranges from integrating at level I(0), integrating at 1st difference I(1) to mixed order of levels and 1st difference. Also, multicollinearity problem is avoided by choosing appropriate lag order for the selected variables (Shin et al. 2014). Other methods adopted in this study ranges from descriptive statistics and unit root tests with structural break tests.

Modelling

The empirical modelling of this study follows the form of multivariate nonlinear autoregressive distributed lag (NARDL) bounds testing method as proposed by Shin et al. (2014). Following Shin et al. (2014), the NARDL model with the asymmetric error correction model is as follows:

$$\begin{aligned}\Delta CO_{2t} = &+\beta_0 + \rho CO_{2t-1} + \alpha_1^+ Y_{t-1}^+ + \alpha_2^- Y_{t-1}^- \\ &+ \alpha_3^+ IQ_{t-1}^+ + \alpha_4^- IQ_{t-1}^- + \alpha_5^+ FDI_{t-1}^+ \\ &+ \alpha_6^- FDI_{t-1}^- + \alpha_7^+ FF_{t-1}^+ + \alpha_8^- FF_{t-1}^- \\ &+ \alpha_9^+ RE_{t-1}^+ + \alpha_{10}^- RE_{t-1}^- + \sum_{i=0}^{\rho} \beta_1 \Delta CO_{2t-i} \\ &+ \sum_{i=0}^{\rho} \beta_2 \Delta Y_{t-i}^+ + \sum_{i=0}^{\rho} \beta_3 \Delta Y_{t-i}^- + \sum_{i=0}^{\rho} \beta_4 \Delta IQ_{t-i}^+ \\ &+ \sum_{i=0}^{\rho} \beta_5 \Delta IQ_{t-i}^- + \sum_{i=0}^{\rho} \beta_6 \Delta FDI_{t-i}^+ \\ &+ \sum_{i=0}^{\rho} \beta_7 \Delta FDI_{t-i}^- + \sum_{i=0}^{\rho} \beta_8 \Delta FF_{t-i}^+ \\ &+ \sum_{i=0}^{\rho} \beta_9 \Delta FF_{t-i}^- + \sum_{i=0}^{\rho} \beta_{10} \Delta RE_{t-i}^+ \\ &+ \sum_{i=0}^{\rho} \beta_{11} \Delta RE_{t-i}^- + \mu_t \end{aligned} \quad (1)$$

From Eq. (1), β_i and $\alpha_i$denote short-run and long-run coefficients with *i=1.....10.* A short-run estimation and analysis is the assessment of the immediate impact of explanatory variable change on the explained (dependent) variable, while the long-run estimation and analysis is the assessment and measurement of the reaction and speed of adjustment from short-run disequilibrium towards equilibrium level in the long run. In furtherance of this study, Wald test is applied to check the long-term asymmetry ($\alpha = \alpha^+ = \alpha^-$) and short-term asymmetry ($\beta = \beta^+ = \beta^-$) for all the variables. CO_{2t} represents carbon emission which is the dependent variable, Y_t represents GDP per capita, and IQ_t, FDI_t, $FF_t\ andRE_t$ represent institutional quality, foreign direct investment, inflow, and renewable energy consumption, respectively. p and q represent the optimal lags for the dependent variable (CO_{2t}) and independent variable (IQ_t, FDI_t, $FF_t\ andRE_t$) which are ascertained by Akaike information criterion (AIC). The effects of independent variables are decomposed into positive and negative effects giving a two-way implication of the changes of the independent variables on the dependent variable. The decomposition of the independent variables in their positive and negative partial sums for increases and decreases is represented as follows:

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} \max\left(\Delta x_j, 0\right) \text{ and } x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j=1}^{t} \max\left(\Delta x_j, 0\right)$$

From the above expression, x_t denotes the independent variables (IQ_t, FDI_t, $FF_t\ andRE_t$) (Birgisdóttir et al. 2017; Hatemi-j 2012; Pesaran and Shin 1998).

Table 1 Summary of the selected variables with their measurements

Variables	Short form	Measurements	Sources
Economic growth	GDP (Y)	GDP per capita (constant 2010 US$)	2018 updated World Development Indicator (WDI)
Institutional quality	I.Q	Rank of the six indicators (voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption)	Worldwide Governance Indicator (WGI)
Foreign direct investment	FDI	Foreign direct investment, net outflows (% of GDP)	2018 updated World Development Indicator (WDI)
Carbon emission	CO_2	Million tonnes of carbon dioxide	2019 British Petroleum (BP) Statistical Review of World Energy
Renewable energy consumption	R.E	Million tonnes oil equivalent	2019 British Petroleum (BP) Statistical Review of World Energy
Non-renewable energy consumption	Fossil fuels (FF)	Million tonnes oil equivalent	2019 British Petroleum (BP) Statistical Review of World Energy

Source: Author's compilation

Shin et al. (2014) proposed bound test (a joint test of all the lagged levels of the explanatory variables) for the symmetric long-run cointegration. *F*-statistics and *t*-statistics of Pesaran et al. (2001) and Banerjee et al. (1998) are considered for the cointegration in this study. For the *F*-statistics test, null hypothesis is expressed as $\alpha = \alpha^{+} = \alpha^{-} = 0$ against the alternative hypothesis $\alpha = \alpha^{+} = \alpha^{-} \neq 0$, while for *t*-statistics, the null hypothesis is expressed as $\alpha = 0$ against alternative hypothesis $\alpha \neq 0$. The decision to reject either of the hypotheses is dependent on the evidence of the bound test subject to comparing the *F*- and *t*-statistics with the critical values of upper and lower bounds. When *F*-stats is greater or less than the upper bound, the decision is there is or no

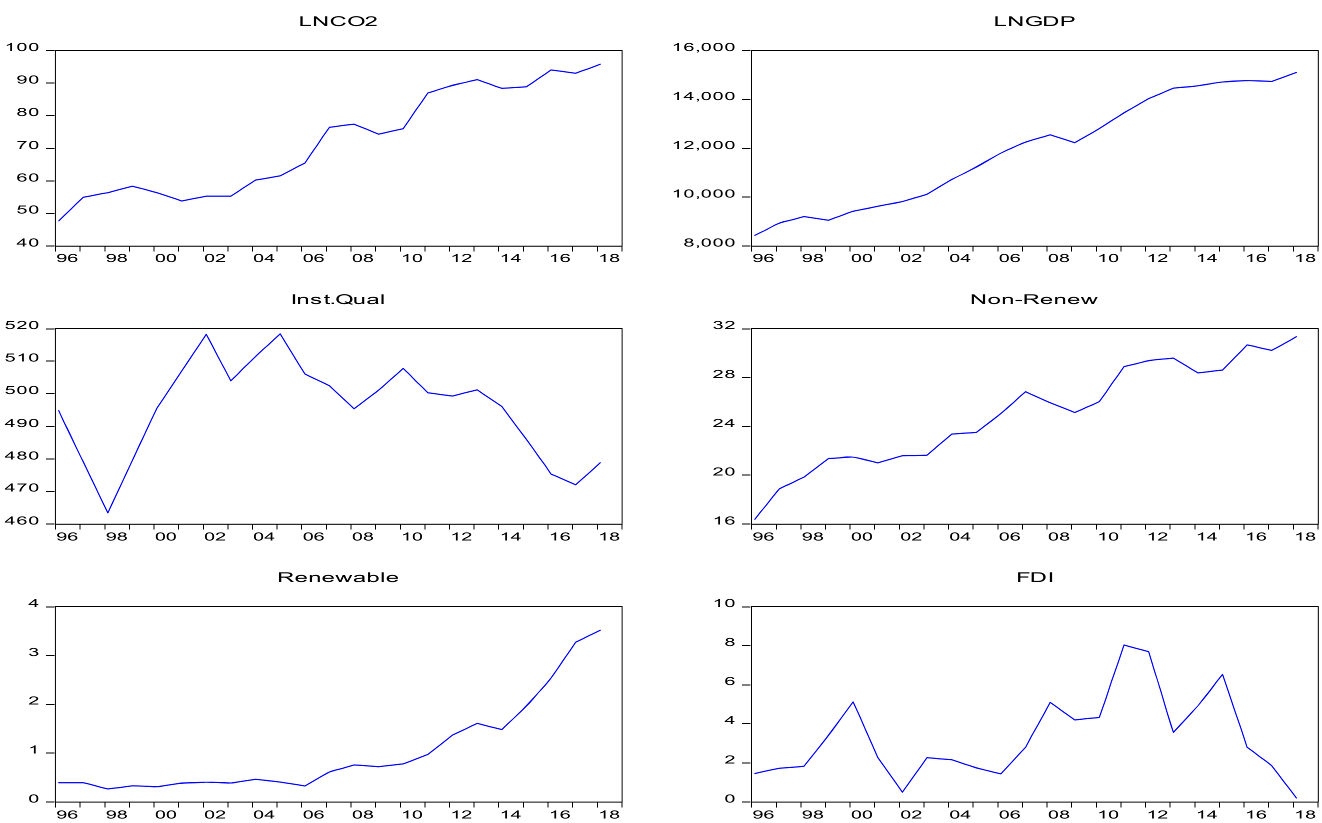

Fig. 1 Trends in GDP per capita, institutional quality, FDI, carbon emission, fossil fuels, and renewable energy consumption in Chile from 1996Q1 to 2018q4

cointegration. If the F-stats fall in between the upper a -nd lower bounds, the outcome is inconclusive.

Moreover, the long-term asymmetric coefficients are calculated based on $L_{mi} = \alpha^{+}/\rho$ and $L_{mi} = \alpha^{-}/\rho$. The long-run coefficients measure the relationship between the variables (dependent and independent) w.r.t positive and negative changes of the independent variables in the long-run equilibrium. The estimation of asymmetric dynamic multiplier effects is expressed in equation as follows: $m_h^{+} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{Y_t^{+}}, m_h^{-} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{Y_t^{-}}, m_h^{+} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{IQ_t^{+}}, m_h^{-} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{IQ_t^{-}}, m_h^{+} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{FDI_t^{+}}, m_h^{-} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{FDI_t^{-}}, m_h^{+} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{FF_t^{+}}, m_h^{-} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{FF_t^{-}}, m_h^{+} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{RE_t^{+}}, m_h^{-} = \sum_{j=0}^{h} \frac{\partial CO_{2t+j}}{RE_t^{-}}$, for h = 0,1,2……….where if h →∞, then $m_h^{+} \rightarrow L_{mi^{+}}$ *and* $m_h^{-} \rightarrow L_{mi^{-}}$.

The asymmetric responses of the dependent variable to positive and negative changes in the independent variables are depicted with dynamic multipliers. From the estimated multipliers, the dynamic adjustment is identified from the initial equilibrium to the new equilibrium between the system variables following the changes that affect the system.

Empirical results and discussions

The results gotten from the approaches adopted in this study are presented in this section with interpretations and discussions following the movement and directions of the findings. The discussions will be based on the findings from descriptive statistics and unit root tests with structural break version of the unit root. Also, large part of the discussion of the empirical findings will be based on results of the asymmetric cointegration test (long-run relationship between the variables in a decomposed manner) and a detailed presentation of the asymmetric causalities between the variables.

Descriptive statistics and unit root tests

The outcomes of the descriptive statistics and unit root tests with structural break version of unit root tests are shown in the Tables 2, 3, and 4. Table 2 specifically presents the outcome of descriptive statistics. The result shows that renewable energy consumption is less volatile to compare with other variables followed by foreign direct investment (FDI), fossil fuel, and carbon emission, institutional quality, and economic growth. Economic growth proves to be the variable with the highest volatility followed by institutional quality. Also, the data displayed an asymmetric distribution with the outcomes from skewness. The Jarque-Bera shows outcome with all the outcomes showing significant which means that the series are not normally distributed and do not show a bell shape. This paves way for author to rely on asymmetric analysis in this study.

Unit root tests

Tables 3 and 4 display the results of unit root tests (conventional and structural break).

Table 3 shows the outcome of three traditional (basic) unit root tests applied in this study to ascertain the stationarity and order of integration of the series. The three approaches utilized in this study are Dickey and Fuller (1979), Perron (1990), and Kwiatkowski et al. (1992). Most times, time series data tend towards volatility because of some structural occurrences.

Table 2 Descriptive statistics

	CO_2	GDP(Y)	IQ	Fossil fuel	R. energy	FDI
Mean	72.06506	11920.01	495.6476	25.03927	0.996039	3.380622
Median	74.34149	12227.21	499.6729	25.48706	0.612572	2.794579
Maximum	95.80449	15111.70	518.4195	31.34284	3.517400	8.028459
Minimum	47.64945	8427.822	463.3548	16.37165	0.262705	0.194500
Std. Dev.	15.45950	2182.778	14.06412	3.956083	0.891835	1.943206
Skewness	0.123907	−0.021613	−0.507611	−0.168749	1.488826	0.677839
Kurtosis	1.416927	1.535331	2.218909	1.875767	4.185897	2.639614
Jarque-Bera	9.521260	7.962254	6.084561	5.109362	38.09481	7.297029
Probability	0.008560	0.018665	0.047726	0.077717	0.000000	0.026030
Sum	6413.790	1060881.	44112.64	2228.495	88.64751	300.8754
Sum Sq. Dev.	21031.67	4.19E+08	17406.36	1377.252	69.99253	332.2923
Observations	89	89	89	89	89	89

CO_2 denotes carbon emission, GDP(Y), denotes economic growth, FDI denotes foreign direct investment, fossil fuels (FF) denotes non-renewable energy consumption, and RE denotes renewable energy consumption. Sources: Computed by author

Table 3 Conventional (ADF, PP, and KPSS) unit root test

Variables	Level		1st Diff		
	Intercept	Intercept and trend	Intercept	Intercept and trend	Order
			ADF		
LCO_2	−0.4615	−3.2403*	−3.4636**	−3.4391*	MIXED
LGDP	−0.3998	−3.1073	−3.0890**	−3.0537	I (1)
LIQ	−2.7466*	−2.8044	−3.1158**	−3.1852*	MIXED
FDI	−1.5819	−0.9997	−1.00668	−1.3905	MIXED
LFF	−0.9280	−4.4573***	−3.6149***	−3.5449**	MIXED
LRE	1.0582	−0.6868	−2.4257	−3.3049*	I (1)
			PP		
LCO_2	−0.5988	−1.9884	−3.6604***	−3.6317**	I (1)
LGDP	−0.6678	−1.6629	−3.3403**	−3.3107*	I (1)
LIQ	−1.4518	−1.4624	−3.2720**	−3.3358*	I (1)
FDI	−1.8259	−1.3841	−3.8258***	−3.9331**	I (1)
LFF	−1.6026	−3.2646*	−3.8064***	−3.7510**	MIXED
LRE	4.8410	−1.1247	−2.5412	−3.6129**	I (1)
			KPSS		
LCO_2	1.1774***	0.1386*	0.0648	0.0659	I (1)
LGDP	1.2058***	0.1082	0.1103	0.0959	I (1)
LIQ	0.2452	0.22297***	0.1313	0.0630	I (1)
FDI	0.4167*	0.1332*	0.1812	0.0814	I (1)
LFF	1.2067***	0.0741	0.1150	0.0495	I (1)
LRE	0.9757***	0.2814***	0.8319***	0.1071	MIXED

Null hypothesis is non-stationary for ADF and PP and stationary for KPSS

The signs depict (*) significant at the 10%; (**) significant at the 5%; (***) significant at the 1%, and (no) not significant

*MacKinnon (1996) one-sided *p*-values

These occurrences could be in form of natural disasters like earthquake, macroeconomic problems such as recession or depression like 2008/2009 financial meltdown, or outbreak of diseases such as pandemic or epidemic like the case of

Table 4 Zivot-Andrew break test

Variables	Ziv-A	Prob	Lg	Break period	CV@ (1%)	CV@ (5%)
LCO_2	−3.74868	0.3632	4	2003Q2	−5.57	−5.08
LGDP	−4.07140	0.0018***	4	2009Q2	−5.57	−5.08
LIQ	−4.87723	0.03958**	4	2003Q2	−5.57	−5.08
FDI	−5.3099	0.0010***	4	2010Q2	−5.57	−5.08
LFF	−5.08214	0.0674*	4	2010Q2	−5.57	−5.08
LRE	−2.1459	0.00016***	4	2014Q2	−5.57	−5.08
D LCO_2	−3.74868	0.3632	4	2003Q2	−5.57	−5.08
DLGDP	−3.42126	0.4019	4	2003Q2	−5.57	−5.08
DLIQ	−3.78407	0.37841	4	2000Q2	−5.57	−5.08
DFDI	−5.4905	0.0104*	4	2010Q2	−5.57	−5.08
DFF	−3.5537	0.0616*	4	2012Q2	−5.57	−5.08
DLRE	−4.8337	0.28315	4	2008Q2	−5.57	−5.08

The signs depict (*) significant at the 10%; (**) significant at the 5%; (***) significant at the 1%, and (no) not significant

*MacKinnon (1996) one-sided *p*-values

Table 5 Nonlinear ARDL long- and short-run results

	Long-run estimation				Short-run estimation				
Variables	Coeff	Std Error	*t*-stat	*P*-value	Variables	Coeff	Std Error	*t*-stat	*P*-value
GDP^+	−0.004***	0.001	−4.975	0.000	GDP^+	−0.004***	0.001	−6.658	0.000
GDP^-	0.009***	0.001	7.254	0.000	GDP^-	0.009***	0.001	9.241	0.000
IQ^+	−0.649***	0.042	−15.64	0.000	IQ^+	−0.649***	0.030	−21.54	0.000
IQ^-	0.524***	0.033	15.83	0.000	IQ^-	0.524***	0.022	23.31	0.000
FDI^+	0.908***	0.081	11.17	0.000	FDI^+	0.908***	0.056	16.31	0.000
FDI^-	−0.034	0.061	−0.550	0.584	FDI^-	−0.034	0.035	−0.955	0.343
FF^+	3.323***	0.089	37.27	0.000	FF^+	3.323***	0.062	53.91	0.000
FF^-	4.193***	0.313	13.37	0.000	FF^-	4.193***	0.209	20.00	0.000
RE^+	−2.634***	0.789	−3.337	0.002	RE^+	−2.634***	0.538	−4.892	0.000
RE^-	2.786	2.330	1.196	0.237	RE^-	2.788**	1.351	2.063	0.044
C	1.232***	0.199	6.199	0.000	ECT(-)	−0.004***	0.001	−7.221	0.000
Diagnostic tests									
R^2	0.996								
$AdjR^2$	0.995								
DW statistics	2.18								
F-statistics	825.1 [0.000]								
Bound tests	F=3.99998**	K=10		@ 5%	$I(0)$=2.3	$I(1)$=3.5			
Bound tests	t=−7.22166***	K=10		@ 1%	$I(0)$= −3.9	$I(1)$= −5.9			
χ^2 *LM*	0.111 [0.963]								
χ2 *HET*	31.79 [0.104]								

*, **, and *** mirror 10%, 5%, and 1% significance level, respectively

COVID-19. This phenomenon which causes structural change is capable of altering the stability of indicators and variables, and for accuracy in any research work, it is essential to accommodate these trends in the variables. For the purpose of clarity and accuracy in the findings of this study, I adopt both the conventional unit root tests such as ADF, PP, and KPSS and the Zivot and Andrews (1992) structural break tests for the unit root tests. Most times, the conventional unit root tests are limited in the total exposition of the stationarity of the variable, and for this, structural break tests will aid in exposing the existence of unit root with emphasis on the year such structural break which is capable of registering a lasting or permanent shock in the economy occurred. From the result of the conventional unit roots in Table 3, a mixed order of integration, i.e., I(0) and I(1), is established showing the existence of unit root. Furthermore, from the result of Zivot Andrew test, the variables are found to be non-stationary in the presence of structural breaks that occurred in 2003Q2 for CO_2, GDP, and institutional quality, 2009Q2 for GDP, 2010Q2 for FDI and fossil fuels, 2014Q2 for renewable energy consumption, 2000Q2 for institutional quality, 2012Q2 for fossil fuels, and 2008Q2 for renewable energy consumption. These findings on the structural break dates give credence to the graphical representation of the data in Fig. 1. From the identified dates, especially 2003 and 2008/2009, strategic global oil and financial shocks took place which affects the world economy, and these shocks are capable of transcending to individual countries such as Chile. Specifically, 2008/2009 affected the utilization of renewable energy source and economic growth of Chile as seen from the break dates of 2008/2009 which reflected on renewable energy and GDP. Also, oil shock of 2003 which affected oil price and market has shown tendency of impacting Chile economy which is reflected in the case of GDP, CO_2, and institutional quality. It is vital for the exposition of the trends of the variables adopted in any research work which might form the basis of the choice of the approach to adopt in the entire study; however, the current study has adopted nonlinear NARD and asymmetric approach, and this does not need any special criteria for adoption.

Nonlinear ARDL and cointegration

The nonlinear ARDL (NARDL) results are shown in Table 5 with the following findings derived from the result: first, goodness of fit is established from the estimation with 0.996 and 0.995 representing the values of R^2 and adjusted R^2 which shows that carbon emission (CO_2) injected in Chile is explained by economic growth (GDP), institutional quality (IQ), foreign direct investment, inflows (FDI), fossil fuels (FF), and renewable energy consumption (RE) at 99.6 percent, while the remaining variation is explained by the error term in the model. The absence of autocorrelation and serial correlation is established with both Durbin Watson (DW) and LM tests at 2.18 and 0.111 [0.963], respectively. Heteroscedasticity is tested, and the normal distribution of error term is confirmed at 31.79 [0.104]. The ability of the short-term disequilibrium to return back to equilibrium in the long run is ascertained with highly significant error correction term (ECT) at −0.004 which means that the disequilibrium will be adjusted at 0.004 percent in the long run which also points to the presence of long-run relationship between the variables (dependent and independent). Second, the non-linear interactions and shocks of the explanatory variables with and to the dependent variable in a decomposed (positive and negative) process both in the short run and long run are presented as follows: a positive shock to economic growth has a positive and significant effect on environment (a coefficient of −0.004 at 1 percent significant level), which indicates a reduction of carbon emission. This shows that a positive shock to economic growth promotes positive environment performance in Chile. This points towards the reduction in dilapidation of the environment quality due to the positive performance of economic growth. In contrast, a negative shock to the economic growth of Chile is positively linked to carbon emission which shows a negative environment performance. This means that the slow in economic growth portrays a dampen of the environmental quality by 0.009 at 1 percent significant level. This exposition of the growth pattern in Chile clearly shows the sensitive nature of economic activities in determining the environmental performance of Chile, and it calls for government attention and proactive actions through its environment regulatory institutions and agencies. The same asymmetric pattern is established between economic growth and environment in the short run. This finding is consistent with the findings from the past literature (Doda 2014) and largely contradicts the findings by Eng and Wong (2015) for the USA, Burke et al. (2015) and York (2012). As revealed by York (2012), economic expansions increase environmental degradation, while economic slowdown is accompanied by reduction in environmental degradation. Nevertheless, York (2012) advocated the symmetric reaction of CO_2 emissions to economic change. A positive shock to institutional quality impacts positively on the environment performance of Chile by reducing the carbon emission, while a negative shock to the institutional quality is expected to impact negatively on Chile's environment performance by increasing carbon emission. This asymmetric pattern of interaction between institutional quality and environment is established in both periods (long run and short run) with varying degrees in their coefficients. Hence, a positive shock to institutional quality of Chile will impact significantly (at 1 percent) and positively on the quality of Chile's environment by reducing the emission by 0.0649 (−0.649) both in long run and short run, respectively. A negative shock to the institutional quality will cause a significant (at 1 percent) and negative change on Chile's environment quality by increasing the carbon emission by 0.524. This is a success story for Chile which revealed that positive and negative performance of Chile's environment depends largely on the positive and negative changes on the institutions of the country. This finding revolves around the quality of Chilean institutions. This finding is pointing towards the needs for effective and efficient management of Chile by the government officials through its regulatory institutions and agencies. For this scenario to be maintained, there is a need for determined and corruption-free institutions in the country for effective and efficient delivery in execution and monitoring of policies. Occasions may demand the implementation of regulatory policies to checkmate the excesses of economic agents on energy, land, and other pollution-intensive utilization; this could only be achieved if the regulatory policies of the country are placed above individual needs and pursued without favor or on a selective (discriminative) manner. This finding is in line with the author's expectation on the control of carbon emission in achieving carbon neutrality and enhances environment quality with institutional quality. This equally supports the findings from Vogel (1997), Panayotou (1997), Gagliardi (2008), Aron (2000), Subramanian (2007), Lee and Kim (2009), Abid (2016), and Uzar (2020) who are of opinion that institutional quality is an effective tool for correcting environmental degradation. However, study from Wawrzyniak and Doryń (2020) distinguishes the impact of institutional quality on carbon emission between government effectiveness and control corruption. They found government effectiveness positively impacting the environment, while corruption control is doing otherwise. A positive shock to the foreign direct investment (FDI) which depicts increase in FDI will impact negatively on Chilean environmental performance by increasing the carbon emission at 0.908 and at 1 percent significant level. On the contrary, a negative shock to the foreign direct investment (FDI) which portrays reduction in FDI will impact positive but not significant on Chilean environmental performance by reducing the carbon emission by 0.034 (−0.034). The same asymmetric pattern of interaction between the FDI and environment is established both in long run and short run. This shows that FDI has the potential to dampen the Chilean environmental performance if not controlled, but thanks to the potential mitigating force of Chile's institutions. A careful look at the FDI trend on the graphical presentation of the data gives insight to the movement of FDI into Chile which is not stable. This is a sign that a force is always trying to control the infiltration of FDI and its menace in Chilean economy. This finding supports the theory of pollution haven hypothesis (PHH) for the case of Chile and inconsistent with the findings by Acharyya (2009), Zhang (2011), Lau et al. (2014), and Pao and Tsai (2010). Again, a positive shock to the fossil fuels will impact significant (at 1 percent level) and negatively on Chile's environmental performance by increasing the carbon emission by 3.323, while a negative shock to the fossil fuel will have a significant (at 1 percent level) and positive effect on Chile's environmental performance by reducing carbon emission by 4.193. The asymmetric pattern found between fossil fuels and the environmental performance are in line with the expectations of the author; hence, as remarked above from Chile's energy mix, 79 percent of Chile's energy consumption is derived from fossil fuel, and this is emission driven capable of increasing the emission if not regulated or controlled. The same asymmetric pattern of interaction is established both in long run and short run. The finding supports the findings from Udemba et al. (2019) for China, Udemba et al. (2019) for Indonesia, and Udemba (2020a) for Turkey. However, a departure from the findings of impacts of fossil fuels on environment shows that a positive shock to the renewable energy consumption will impact positively and significantly (at 1 percent level) on Chile's environment by reducing the carbon emission by 2.634 (−2.634). In contrast, a negative shock to the renewable energy consumption portraying a reduction in renewable energy will significantly impact negative on environment performance by increasing the emission level by 2.786. This pattern is repeated in both long term and short term, and it portrays renewable energy consumption as a good measure to mitigate the environmental performance. This finding is in consonance with the findings from studies of Kirikkaleli et al. (2020), Shafiei and Salim (2014), Wang et al. (2021), and Khan et al. (2020).

Furthermore, Wald test is adopted in this present study for the purpose of unfolding the long-run asymmetric interaction and its significance. The result displayed in Table 6 confirms significant long-run asymmetric relationship between the variables at 1 percent for economic growth (GDP-Y), institutional quality (IQ), foreign direct investment (FDI), and fossil fuels (FF) and at 10 percent for renewable energy (RE). This finding confirms and gives support to the findings from cointegration and error correction term with insight in the long-run (asymmetric) relationship between the variables. The stability of the model is tested and confirmed by the CUSUM and CUSUMSQ in Figs. 2 and 3 below Table 6.

Lastly, the adjustments to new equilibrium equations after the early negative and positive shocks are illustrated with NARDL multipliers for the explanatory (GDP-Y, IQ, FDI, FF, RE) variables. This is shown in Fig. 4. The asymmetry adjustments of CO_2 to negative and positive shocks are shown with black-dotted and solid black lines, while the red-dotted lines are the asymmetric pattern that shows the difference between positive and negative shocks.

Concluding remark and policy recommendation

This study is an investigation into the factors that have assisted Chile as a country to maintain a steady positive improvement on its environmental performance through mitigating carbon emission. Part of the objective is to give insight on Chile's success towards achieving carbon neutrality and to possibly recommend the strategies for other countries to adopt. This will evidently trigger a conscious effort towards reduction in climate change through individual activeness in curtailing the rate of emissions globally. To effectively do this and achieve the objective of this study, I adopt nonlinear and asymmetric approaches to have a combine (positive and negative) view of

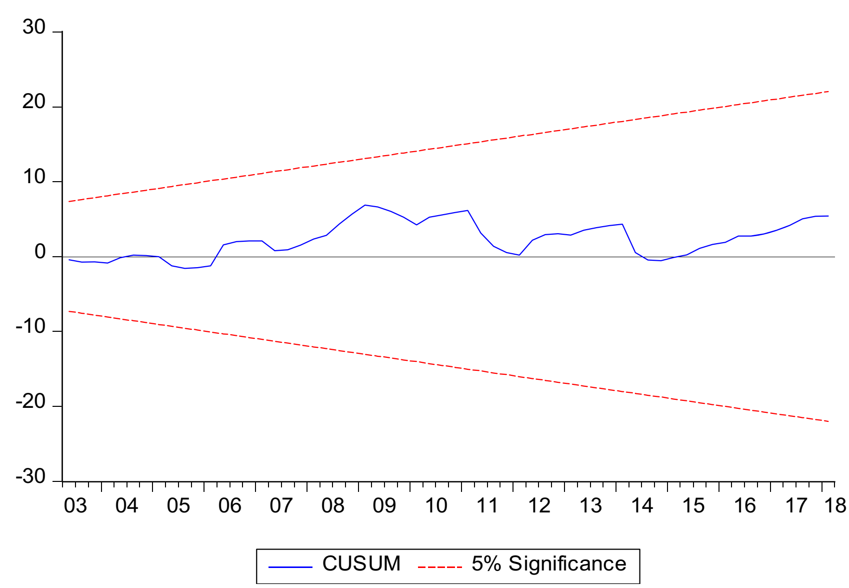

Fig. 2 Plot of cumulative sum of recursive residuals. The blue line is the solid line, while the red lines that bounded the blue line are the critical bounds at 0.5

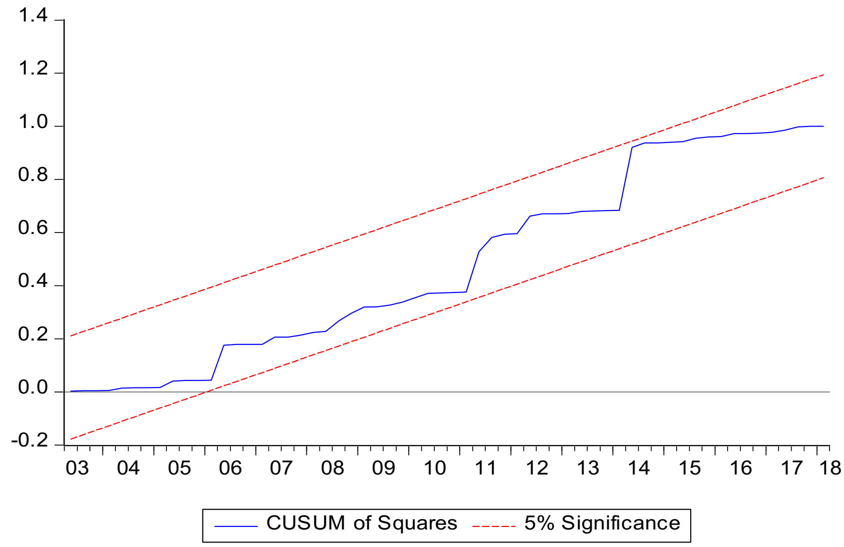

Fig. 3 Plot of cumulative sum square of recursive residuals. The blue line is the solid line, while the red lines that bounded the blue line are the critical bounds at 0.5

the reactions of the selected variable towards determining the impact of each variable towards curbing emission in Chile. Also, a careful selection of variable which includes economic growth (GDP per capita-Y), institutional quality, FDI, fossil fuels, and renewable energy consumption was undertaken in this study. The focus was on the interaction of institutional quality and FDI towards ascertainment of environment performance. The reason is because of the potency of policies in controlling negative phenomenon such as carbon emission. The effectiveness and efficient execution of policies to achieve the intended goals are highly dependent on the quality and functionality of the established institutions saddle with such assignment. Also, FDI has been used in many studies to test the environment performance, and the outcomes are mixed (positive and negative) with majority of FDI impacting negatively on environment of developing countries due to laxity in policies of those countries. It is not enough to generalize that institution's rooted policies are positive in controlling the negative phenomenon without research. Bearing in mind Chile's positive trend of controlling the carbon emission, the present paper hypothesized that institutional quality of Chile's government positively impact the environment quality. From the nonlinear analysis, I find positive shock to the institutional quality aiding environment quality positively through reduction of carbon emission; the same trend is recorded in the case of economic growth and renewable energy. In contrast, FDI and fossil fuels are impacting negatively on Chile's environment when increased, but thanks to the controlling force from institutional quality and economic growth.

Having ascertained the performance of the variables towards controlling Chile's environment quality through the interactions of the selected variables from the estimation, the following policies are recommended: first, with the findings that affirmed the potency of controlling carbon emission through institutional quality, priority and more attention should be given to the maintenance of institutional quality so as to keep up with the trend of maintaining good environment performance. Economic growth should be encouraged with both short- and long-term policies with rapt attention paid towards energy mix to ensure relaxing of carbon-intensive economic activities; hence, it is effective in controlling carbon emission. This will help in promoting the energy decentralizing and a gradual move away from fossil fuels towards more renewable energy sources such as solar and hydro. Also, considering responsible consumption and production as among the Sustainable Development Goal (SDG-12) targets, a policy that will help to moderate the consumption and production pattern in the country is vital. This could be in form of placing a target on the manufacturing sectors which will be taxable if violated. Further, findings reveal the negative implication of FDI and fossil fuels to the environment performance of Chile, and this suggests a conscious effort towards the moderation of these variables with effective policy. The instrument of institution should be channeled towards regulating the activities of foreign investors and task the investor to adhere to energy transition agenda. This will aid in accessing the positive impact of FDI on Chile's environment

Table 6 Long-run asymmetries (WALD test)

Variables	x^2Chi-square [Prob]	Decision
GDP(Y)	47.83*** [0.000]	Yes
IQ	267.8***[0.000]	Yes
FDI	62.37*** [0.000]	Yes
FF	7.082***[0.008]	Yes
RE	3.661* [0.056]	Yes

*Indicates 1% significance level

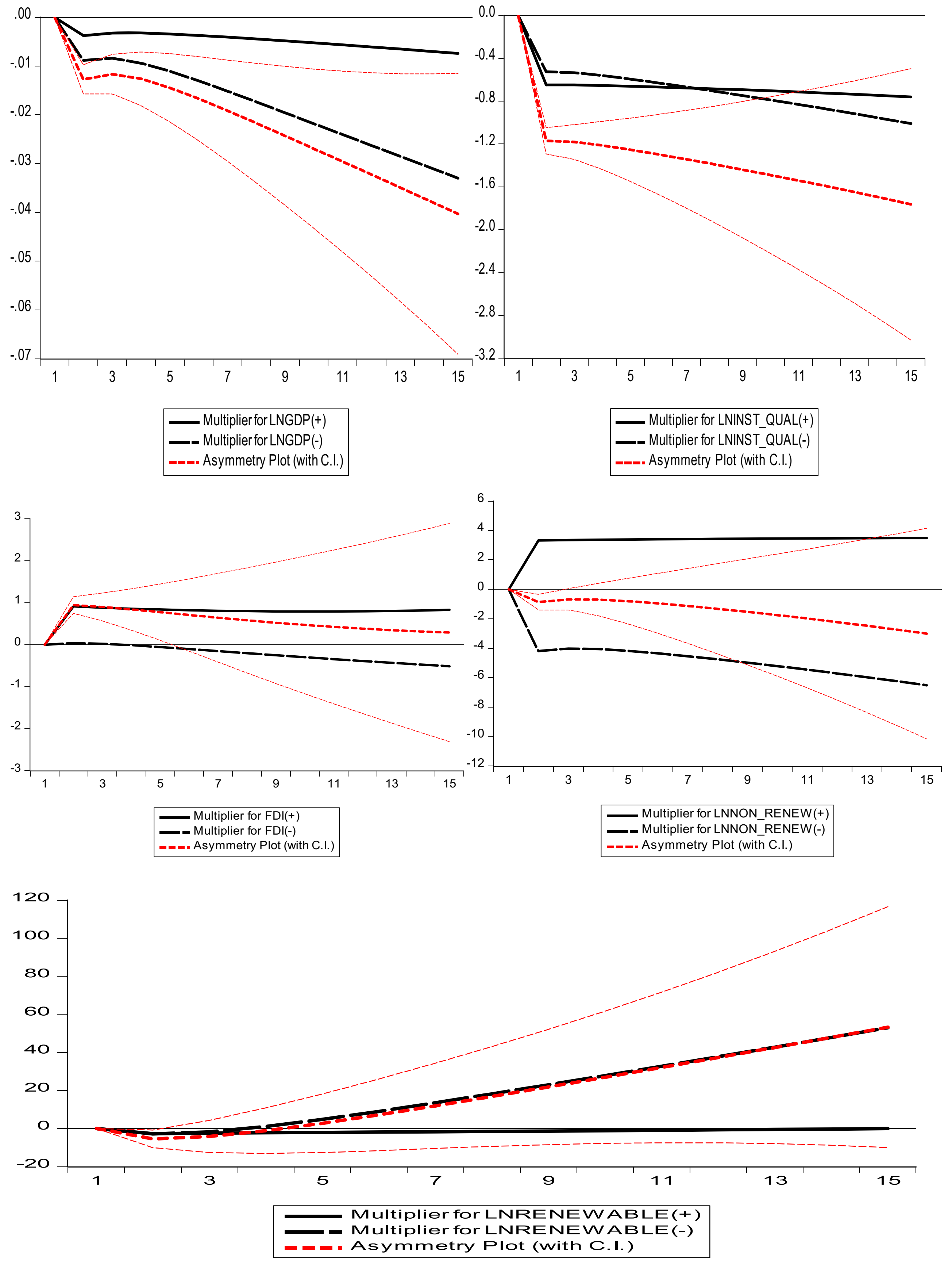

Fig. 4 Multiplier for GDP, institutional quality, FDI, fossil fuels, and renewable energy consumption

and move the economic operation to a more green production economy.

Conclusively, this study has implication to other countries and will likely serve as a blue print to other countries especially countries within the Latin American region towards carbon neutrality.

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Data Availability Data sources are outlined above in Table 1 and will be made available on demand.

Declarations

Ethics approval and consent to participate I, the author, is giving my ethical approval and consent for this paper to be published in ESPR if found publishable.

Consent to participate I, the author, is giving my consent for participation in this paper to be published in ESPR if found publishable.

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