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Asymmetric inference of carbon neutrality and energy transition policy in Australia: The (de)merit of foreign direct investment

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ABSTRACT

The current study examines the effect caused by potential shock arising from the Australia's 'Direct Action' policy in renewable energy, fossil fuel energy, and foreign direct investment (FDI). Considering the Australia's stake in the energy industrial chain system (production, distribution and marketing) that is majorly fossil fuel-based (coal and gas), it can be said that Australia is occupying a strategic position in the global climate development. For effective investigation and discussion of the findings from this study, we utilized the country's national data of 1996Q1-2018Q4 with different scientific approaches (such as structural break test and short- and long run asymmetric relationships). Emphasis on the findings and discussions is based on both the short run and long inferences arising from positive and negative shocks. The result informed that economic growth and FDI are found to negatively affect environmental quality in Australia by increasing the country's carbon emissions. This observation is inherent when there are positive and negative shocks on economic growth while only a positive shock on FDI creates an environmental effect. Further into the findings is the mitigating power of Australian renewable energy sources in its economic and environmental development. This is confirmed with positive shocks to renewable energy reducing carbon emission at the level of 23 percent while the negative shock increases carbon emissions by 16 percent. The findings imply that the economic activities and FDI penetration in Australia are done in energy cum carbon intensive ground. Additionally, evidence shows that energy transition policy is vital towards the achievement of Australian climate goal of 2030 as such a negative shock on alternative energy development such as limited energy financing and reduction or discontinued clean technology subsidies should be discouraged.

1. Introduction

As the largest Oceania and the world's sixth-largest country, Australia's energy profile remained a source of importance to the world energy market. As reported by International Energy Agency (IEA), Australia's prominence in the energy sector is associated with the country's profile as the leading exporter in uranium and especially coal and liquefied natural gas (LNG) (IEA, 2018). Evidently, by exporting about 85 percent of the country's energy resources, the country has remained one of the main energy markets for the Asian nations. However, the country's energy consumption profile which comprises of about 95% of Australia's primary energy mix is largely from the fossil fuel (the trio of oil, coal, and natural gas). Specifically, oil, coal (Australia's largest energy source), and natural gas energy utilization in Australia as at 2019 accounted for about 39%, 29%, and 26% of primary energy mix respectively (Department of Industry, Science, and Energy Resources, 2021). As such, the Department of Industry, Science, and Energy Resources further implied that Australia has continued to experience growth in domestic energy demand, thus leading to growth in energy consumption by 0.6% in 2019 as compared with a 10-year average growth of 0.7%.

Meanwhile, compared with the fossil fuel sources (see Fig. 1), the share of alternative (renewable) energy utilization in Australia's primary energy mix (standing at 6% in 2019) is reasonably low. For instance, Australian renewable energy production by share of total primary energy production is 1.7% in 2019 while the country's energy

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sources from hydro, solar, and wind (renewables) constitutes 21% of the country's electricity supply (Department of Industry, Science, and Energy Resources, 2021). In pursuit of carbon neutrality agenda, the government has continued to expand its low carbon policy on alternative energy and clean energy technologies development (Effendi and Courvisanos, 2012). Evidently, as at the last day of April 2021, the Department of Industry, Science, and Energy Resources reported that the small-scale renewable installations across Australia have increased to over 4.1 million. On one hand, this evident suggests that Australia is on track in its energy transition policy. On the other hand, the evidence is a demonstration of the Australian commitment to reduce carbon emission by 26–28 per cent below 2005 levels in the next decade (by 2030). While the country's carbon neutrality agenda is yielding an impressive result as witnessed by the decline in its carbon intensity, Australia still has the highest carbon intensity profile among IEA countries (IEA, 2018). Thus, researchers are posed to further query the Australia's carbon neutrality driver amidst the energy transition policy.

Following the aforementioned motivation, this study considers the examination of the Australia's carbon zero (2030) target. Importantly, the objective of the study is directed at (i) investigating the role of renewable energy utilization in attaining a carbon neutral country, (ii) examining the contribution of conventional energy use to the carbon emission trend, and (iii) to evaluate the importance or establish whether foreign direct investment (FDI) in Australia plays a (de)merit role in the country's quest for environmental sustainability. Importantly, the role of FDI in Australia's environmental sustainability drive is considered because of the increasingly investment attractiveness to the European and North American partners in the last two decades (Australian Trade and Investment Commission, 2021). However, because the aforementioned objectives could have been explored in related cases such as the United States, Europe, Asia, and others (Sarkodie and Strezov, 2018; Alola, 2019a; Udemba, 2019 et al., 2019; Adedoyin et al., 2020; Munir and Riaz, 2020; Udemba and Yalçıntaş, 2021), the current approach presents a potentially novel perspective. Considering that the Australia's 'Direct Action' approaches toward reducing carbon emission and environmental hazards entail long- and short-run strategic policies, the current study examines the effect caused by potential shock arising from the 'Direct Action' in renewable and fossil fuel energy and FDI. Arising from the impact of the potential shock, the non-linear autoregressive distributed lag (NARDL) empirical approach is employed to reveal the short- and long-run symmetric and asymmetric inferences. Thus, the revelation from this study is expected to provide useful policy dimension to the Australian government and the stakeholders to the country's 2030 emissions reduction goal.

Proceeding in the study, the structure of the presentations is outlined as follows. A synopsis of the related study is presented in the next section (2) while variables under consideration with related approaches are described and relevant analysis illustrated in section 3. The results with discussion and conclusion with related policy insights are offered in section 4 and 5 respectively.

2. Review of existing studies: A synopsis

Systems of low-emissions and energy transition strategies are increasingly been adopted to confront the danger of climate change. Within this framework, Fragkos et al. (2021) adopted a country-level approach examination to offer relevant perspectives of low-emission pathway for 2050 on emissions, economic, and energy systems. For most of the examined countries (Australia, Brazil, Canada, China, European Union-28, India, Indonesia, Japan, Republic of Korea, Russia and the USA), the study revealed that renewable energy development, along with energy services electrification, and improvement in energy efficiency are the significant low-emission pathways strategies of many of the aforementioned economies. Furthermore, the study revealed that countries specificities, priorities, and resource endowments are the key determinants that favors each country's low-emission technological developments for nuclear, carbon capture and storage (CCS) and advanced biofuels. Similarly, Munir and Riaz (2020) examined the short- and long-run environmental effects arising from the asymmetric trends of the energy forms (oil, gas, coal, and electricity consumption) n Australia, China, and USA. By employing the NARDL, and expectedly, Munir and Riaz (2020) established that increased oil and coal utilization are main significant drivers that worsen carbon emission in Australia in the long-run. Additionally, in the United States, increased oil, coal, and gas utilization worsen environmental degradation in the long-run while oil, gas, and electricity are responsible for intense environmental degradation in China. However, a negative shock in the Australia's electricity, oil, and gas energy usage are significantly desirable to achieving carbon emission reduction. While a shock in electricity, gas, and oil energy consumption causes a carbon emission reduction in China, a shock in only coal, electricity, and gas consumption are enough to cause a significant reduction in carbon emission in the United States.

Moreover, Shahbaz et al. (2017), Rahman and Vu (2020), and Ahmed et al. (2021) are among the studies that are centered on establishing the linkage of carbon emission with energy, economic, and non-economic factors in Australia. By employing the ARDL approach, Shahbaz et al. (2017) found that Australia's impressive economic growth is not emission-intensive but the reverse is the case of energy

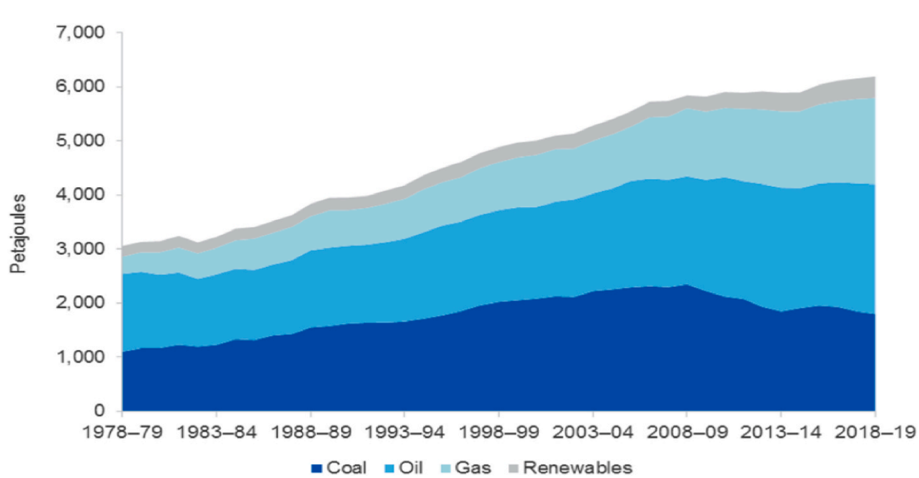

Fig. 1. Share of main fuel utilization in Australia.
Note: This information is sourced from the Department of Industry, Science, and Energy Resources. Is available here https://www.energy.gov.au/data/energy-consumption.

utilization in the country. Additionally, the study revealed that increase in the country's population and the adoption of open border policy have potential of exerting negative impact on environmental quality. Thus, as a policy, Shahbaz et al. (2017) supports sustainable increase in population through the use of efficient energy infrastructure. Meanwhile, Ahmed et al. (2021), employed the dataset over the period 1980–2014 to examine the (short- and long-run) role of electricity and renewable energy utilization in the carbon emission mitigation for Australia. Their finding revealed that carbon emission is reduced by about 1.2% and 5.5% in the long-run whenever there is a percent increase in electricity utilization per person and clean energy utilization per person respectively. Additionally, Rahman and Vu (2020) employed a comparative approach for the case of Australia and Canada with both the ARDL bound and Granger causality approaches to examine the determinants of carbon emission. Accordingly, the study revealed that economic growth in Australia is carbon emission intensive in both short- and long-run while renewable energy utilization and trade acted in the contrary only in the short-run. For Canada, Rahman and Vu (2020) found that trade escalates carbon emission in both terms while carbon emission intensity is also triggered by economic growth and increase in population only in the short term. Moreover, the Granger causality evidence revealed for Canada (Australia) shows a long-term two-way Granger causality economic output, carbon emission, and renewable energy in the long (a short-term one-way Granger causality from economic output, renewable energy utilization, and trade to carbo emission while also validating a long-run causal association among these variables).

As noted from the aforementioned studies and other related literature, economic output, energy mix, population, trade, household composition/behavior and other (non)economic factors have been linked with environmental quality in Australia. Moreover, several studies (Bekun et al., 2019; ; Saint Akadiri et al., 2019a; Ibrahim and Alola, 2020; Ike et al., 2020; Usman et al., 2020) have also illustrated the same perspectives for different countries and/or cases. Although the role of foreign direct investment in the mitigation carbon emission or environmental quality is well-documented in the literature especially for many cases (Salahuddin et al., 2018; Joshua et al., 2020; Ahmad et al., 2019; Udemba, 2019; 2020, 2021; Udemba et al., 2020; Ekwueme et al., 2021), this has sparsely been considered for the specific case of Australia.

2.1. Theoretical framework

Increasing evidence has continued to show that human existence is largely dependent on the richness of the earth's components, especially the environmental endowment. This is because the stock of the natural capital such as comprising of several natural resources (i.e., Land, water, energy sources, etc.) among other earth's components are central to the economy. By economic intuition, there are handful of benefits associated with the humans' desirability for economic advancement, but that has proven to be significantly linked with environmental consequence(s). Following the studies of Ehrlich and Holdren (1971) and later Grossman and Krueger (1991) that opined the trend of environmental quality from the perspectives of population, technological, and economic growth, several other aspects of economic activities are now increasingly linked with environmental quality. Following this revelation, economic expansion alongside socioeconomic aspects such as population and technological advancement are being associated with environmental condition (evidence from later studies of Dietz and Rosa, 1997; York et al., 2003, 2002). Theoretically, it translates that environmental modeling (IPAT) from the impact of human activities has been extended beyond population (P), affluence (A), and technology (T).

Moreover, the novelty in the work of Grossman and Krueger (1991) provides one of the earliest knowledges of the importance of the interaction between economic activities and environmental parameters. While exploring the environmental effects of the trade liberation in Mexico via the policy of North American Free Trade Agreement, Grossman and Krueger (1991) established that the concentration of certain pollutants increases with income per capita. Thus, increasing evidence from the literature has shown that the dimensions of environmental sustainability are now widely entrenched on the role of energy transition (Alola et al., 2019; Adedoyin et al., 2020; Alola and Joshua, 2020; Umar et al., 2021), foreign direct investment (Udemba, 2019, 2020, 2021; Udemba and Yalçıntaş, 2021), financial development (Omri et al., 2015; Shahbaz et al., 2016), tourism (Saint Akadiri et al., 2019a; 2019b; Eluwole et al., 2020), and other non-economic related aspects (Alola et al., 2019a&b).

2.1.1. Specific contribution to the literature

Importantly, beside the aforementioned studies, there are specific studies in the context of environmental-related aspects as summarized in Table A of the appendix. Given the information in Table A, evidence showed that there exists a limited literature on the environmental aspects of socioeconomic and related factors for the case of Australia. Additionally, these aspects of environmental quality have only been limited to economic growth, financial development, trade openness, energy sources (fossil fuel sources and renewable energy), health-related factors, and the environmental Kuznets curve (EKC). Thus, the current study offers more insight from the contributory role of FDI in Australia given that the country's economy is increasingly dependent on investments from the European Union (EU) member states and the North American countries (Australian Trade and Investment Commission, 2021). Furthermore, while also examining the role of conventional and non-conventional energy sources in environmental quality, the current study also offers useful information about the Australia environmental sustainability drive especially when there is a shock in the aforementioned factors (FDI and (non)conventional energy sources) i.e a non-linear relationship.

3. Methodology, modeling and data

3.1. Data and variables

Australian data covering the period 1996Q1 2018Q4 are employed in this present study for in depth and explicit analysis of the study. Due to the Australian strategic position in the world as one of the largest (6th) countries of the world and its uniqueness in fossil fuel energy resource with economic complexity, we apply a single country analysis for insightful and clear outcome. Not only that the country is occupying strategic position in the world map, its impact in fossil fuel energy resource (both marketing and consumption) placed Australia as a country of importance in determining the climate condition.

Following the objective of this study which is exploring the effect of expanding renewable energy sector amidst Australian strategic position in global fossil fuel and foreign direct investment, we apply renewable energy policy, economic growth and foreign direct investment as among the variables to test the ability of the country to achieve its carbon neutrality. For direct insight on the carbon emission and its interaction with the selected variables (economic growth, renewable energy and FDI) in determining the atmospheric condition of Australia, we utilized carbon dioxide emissions as the environment indicator. Carbon emission is considered appropriate indicator because of its amount in the components of greenhouse gas emissions which is about 75 percent (International Energy Agency, 2018). Energy policy (renewable energy development) is among the policies adopted in our study through selection of renewable energy consumption as one of the variables to test the possibility of achieving carbon neutrality in Australia. Energy policies that will enhance energy transition such as deregulation and expansion of renewable energy sector are considered as among the effective and potent solutions in mitigating carbon emissions. For this reason, the present study adopts renewable energy as among the selected variables to test the carbon management in Australia. Authors expectation is that renewable energy will mitigate carbon emissions, hence, maintaining a negative relationship with carbon emissions (i.e. $\varnothing_1 = \frac{\partial CO_{2t}}{\partial REN} < 0$). Previous studies (Ahmed et al., 2021; Sarkodie and Strezov, 2018) have utilized renewable energy as a mitigating force towards carbon emissions. Also, FDI is very strategic in determining the Australian carbon management due to the high concentration of foreign investors (mostly from Asia) in the country's energy sector. The dominance of FDI in the hinterland of Australia amounts to a dual growth of energy (fossil fuels) consumption and exports which has implications to the carbon emissions in the economy. This exposes the determining role of FDI in determining the Australian economic and environmental performance. It is believed that FDI leads to technological transfer and innovations (Shahbaz and Rahman, 2012) which can aid in transforming and shaping the energy sector into a less carbon intensive and expands alternative energy resources. For this, FDI is considered important and selected as among the variables in investigation the Australian climate goals. The impact of FDI on the Australian environmental performance through its relationship with carbon emissions can either be positive (when its relationship with CO_2 is $\varnothing_1 = \frac{\partial CO_{2t}}{\partial FDI} < 0$) or negative (when its relationship with CO_2 is $\varnothing_1 = \frac{\partial CO_{2t}}{\partial FDI} > 0$). Literature (Sarkodie and Strezov, 2018; Alola, 2019b; Udemba, 2019 et al., 2019; Adedoyin et al., 2020; Munir and Riaz, 2020; Udemba and Yalçıntaş, 2021) have assessed the possibility of mitigating carbon emissions for different countries. Economic growth as measured with GDP per capita (constant, 2010) is also applied in this study for better exposition on the impact of economic activities on the Australian environmental performance. Most of the economic activities demand excessive utilization of fossil fuel energy because of the current technological formation fashioned to use non-renewable energy sources. The energy mix of any given country tends to impact the economic growth - carbon emission nexus. The situation where the energy sector is more of fossil fuels, economic growth will tend to increase carbon emission and the relationship will look like $\varnothing_1 = \frac{\partial CO_{2t}}{\partial GDP} > 0$ but where the renewable energy is dominating, economic growth will tend to mitigate carbon emissions with relationship like $\varnothing_1 = \frac{\partial CO_{2t}}{\partial GDP} < 0$. The energy and economic data are sourced from British Petroleum (BP) review and World Bank Development Indicator (WDI). Summary of data and variables are shown in Table 1. Also, graphical representation of the series are shown in Fig. 2 below Table 1.

3.2. Methodology and modeling

The non-linear autoregressive distributive lag (NARDL) method is applied in this study for clear and in-depth analysis through its ability to decompose the relationships that exist among the variables of interest. NARDL has a way of exposing the relationship among the variables in a break down process that involves displaying of both positive and negative shocks of the explanatory variables on the dependent variable. Unlike linear approach, asymmetric (NARDL) approaches accounts for both positive and negative impacts of the explanatory variables on dependent variables. Also, NARDL approach does not require any special condition (such as large sample size or special order of integration) in testing for cointegration like other approaches. Another advantage of NARDL is the ability to avoid collinearity problem because of its sensitivity in lag selection. Apart from NARDL method, other methodologies (structural break with traditional unit root tests, diagnostic tests and asymmetric tests for long run relationship among the variables) were also applied.

The model specification is based on nonlinear and asymmetric cointegration as proposed by Shin et al. (2014). The fundamental environmental equation is expressed as follows:

$$CO_{2t} = f(GDP_t,\ REN_t, FDI_t) \tag{1}$$

From Equation (1), the variables as they appeared in the equation are carbon dioxide emissions (CO_2), economic growth (GDP), renewable energy (REN) and foreign direct investment (FDI). Going further, the equation (1) is expressed in a nonlinear and asymmetric model according to Shin et al. (2014). The nonlinear and asymmetric model comprises the decomposed form of relationship (positive$^+$ and negative$^-$ shocks) that exist between the selected explanatory (GDP_t, REN_t, FDI_t) variables and the dependent variables (CO_2). The nonlinear and asymmetric model is expressed as follows:

$$CO_{2t} = f(GDP_t{}^+, GDP_t{}^-, REN_t{}^+, REN_t{}^-, FDI_t{}^+, FDI_t{}^-) \tag{2}$$

For purpose of scientific analysis, equation (2) is further expressed in econometric model as follows:

$$CO_{2t} = \beta_0 + \beta_1^+ GDP_t{}^+ + \beta_2^- GDP_t{}^- + \beta_3^+ REN_t{}^+ + \beta_4^- REN_t{}^- + \beta_5^+ FDI_t{}^+ + \beta_6^- FDI_t{}^- + \mu_t \tag{3}$$

For the purpose of cointegration, equation (3) is further modelled with error correction model (ECM) which contains both the short run and long run asymmetric association between the explanatory and dependent variable. Thus, the cointegration modeling of nonlinear and asymmetric analysis is as follows:

$$\begin{aligned}\Delta CO_{2t} = &+ \beta_0 + \beta_1 CO_{2t-1} + \beta_2^+ GDP_{t-1}^+ + \beta_3^- GDP_{t-1}^- + \beta_4^+ REN_{t-1}^+ + \beta_5^- REN_{t-1}^- + \beta_6^+ FDI_{t-1}^+ + \beta_7^- FDI_{t-1}^- + \sum_{i=0}^{\rho} \delta_1 \Delta CO_{2t-i} + \sum_{i=0}^{\rho} \delta_2^+ \Delta GDP_{t-i}^+ + \sum_{i=0}^{\rho} \delta_3^- \Delta GDP_{t-i}^- \\ &+ \sum_{i=0}^{\rho} \delta_4^+ \Delta REN_{t-i}^+ + \sum_{i=0}^{\rho} \delta_5^- \Delta REN_{t-i}^- + \sum_{i=0}^{\rho} \delta_6^+ \Delta FDI_{t-i}^+ + \sum_{i=0}^{\rho} \delta_7^- \Delta FDI_{t-i}^- + ECM_t + \varepsilon_t\end{aligned} \tag{4}$$

Features in equation (4) have been explained in the previous equation (1) → 3, only a few attributes of equation (4) needed to be mentioned here. Hence, short run and long run coefficients, 1st differenced operator, error correction model, and positive and negative shocks are $\delta_{1\to7}$ and $\beta_{1\to7}$, Δ , ECM_t , β_1^+ and β_1^- respectively. ρ and i denote the optimal lag selection for both the explanatory and dependent variables selected. Furthermore, Wald test for asymmetries is conducted in our study for both periods (short run $\delta = \delta^+ = \delta^-$ and long run $\beta = \beta^+ = \beta^-$) for all the variables. The shocks (positive and negative) from the explanatory variables determines the impact of economic growth,

Table 1
Summary of Data and variable.

Variables	Short Forms	Measurements	Sources
Economic growth	GDP (y)	GDP per capita (constant, 2010 US$)	World Bank Data
Carbon dioxide emissions	CO_2	Million tonnes of CO_2	2019 British Petroleum (BP) Review
Renewable energy	REN	Million tonnes oil equivalent	2019 British Petroleum (BP) Review
Foreign Direct Investment, Inflow	FDI	Ratio of GDP	World Bank Data

Source: Authors Compilation.

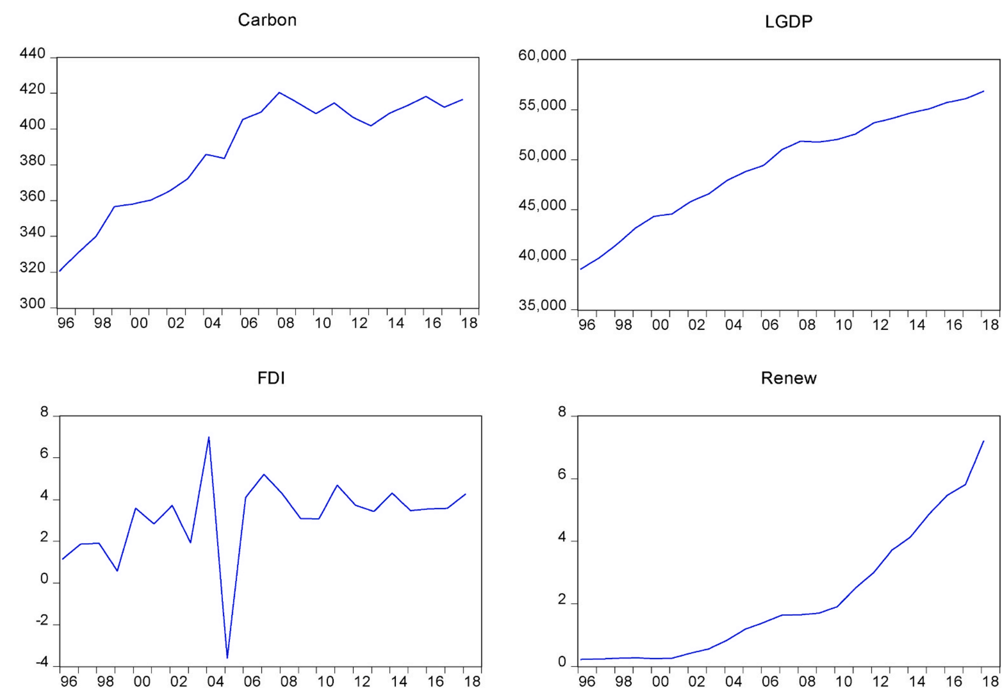

Fig. 2. Graphical representation of the trends in series (Economic growth, Renewable energy, and FDI and carbon dioxide emissions) in Australia for the period of 1996Q1 2018Q4.
Source: Authors Compilation.

renewable energy and FDI on carbon dioxide emissions in a decomposed (both positive and negative impacts) manner. This can be displayed with a partial sums for the variations (increase and decrease) in the explanatory that determines the responsiveness of the dependent variables. Thus, it can be expressed as:

$$\varnothing_t^+ = \sum_{\gamma=1}^{t} \Delta\varnothing_\gamma^+ = \sum_{\gamma=1}^{t} max(\Delta\varnothing_\gamma, 0) \ and$$

$$\varnothing_t^- = \sum_{\gamma=1}^{t} \Delta\varnothing_\gamma^- = \sum_{\gamma=1}^{t} max(\Delta\varnothing_\gamma, 0)$$

From the expression above, the partial sum displays the individual impacts of the selected explanatory variables on the dependent variable. $\varnothing_t$ denotes the explanatory variables (*GDP, REN and FDI*) that impact the dependent variables in positive and negative shocks. Further, long run asymmetric coefficients also measures the connection between explanatory variables and dependent variables within the model of positive and negative shocks in the long run. It is calculated as $L_{mi} = \beta^+/\rho$ and $L_{mi} = \beta^-/\rho$. The asymmetric response of the dependent variable to the shocks (positive and negative) of the explanatory variables can as well be expressed with asymmetric dynamic multiplier which can be shown as follows:

$$\varnothing_j^+ = \sum_{\gamma=0}^{j} \frac{\partial CO_{2t+\gamma}}{Y_t^+}, \varnothing_j^- = \sum_{\gamma=0}^{j} \frac{\partial CO_{2t+\gamma}}{Y_t^-}, \varnothing_j^+ = \sum_{\gamma=0}^{j} \frac{\partial CO_{2t+\gamma}}{REN_t^+}, \varnothing_j^- = \sum_{\gamma=0}^{j} \frac{\partial CO_{2t+\gamma}}{REN_t^-}, z_j^+ = \sum_{\gamma=0}^{j} \frac{\partial CO_{2t+\gamma}}{FDI_t^+}, \varnothing_j^- = \sum_{\gamma=0}^{j} \frac{\partial CO_{2t+j}}{FDI_t^-}, \ For\ j = 0,\ 1,\ 2$$

From the dynamic multiplier, if j→∞, then $\varnothing_j^+ \rightarrow L_{\varnothing_j^+}$ and $\varnothing_j^- \rightarrow L_{\varnothing_j^-}$. Adjustment of short run equilibrium is identified between the initial and new convergence among the explanatory variables following the changes that affect the framework.

Asymmetric cointegration is among the approaches adopted in this study, and to test the existence of cointegration, we utilized bound test following Shin et al. (2014). We applied both F and T statistics of Pesaran et al. (2001) for the identification of the existence of

Table 2
Descriptive statistics.

	LCARBON	LGDP	FDI	LRENEW
Mean	388.6736	49481.00	3.130754	2.098300
Median	405.3326	51024.24	3.499911	1.638424
Maximum	420.5070	56864.33	7.005444	7.215217
Minimum	320.5250	39056.18	−3.618815	0.221546
Std. Dev.	29.31655	5105.380	1.538443	1.954503
Skewness	−0.783278	−0.421517	−1.441073	0.946100
Kurtosis	2.272465	1.993476	7.145289	2.731848
Jarque-Bera	11.06346	6.392416	94.52610	13.54404
Probability	0.003959	0.040917	0.000000	0.001145
Sum	34591.95	4403809.	278.6371	186.7487
Sum Sq. Dev.	75632.48	2.29E+09	208.2790	336.1671
Observations	89	89	89	89

Source: Authors computation with Eviews.

cointegration. For this, hypothetical statements are expressed with null and alternative in support or against the existence of cointegration. The null and alternative hypotheses are expressed as follows: H_0: $\beta = \beta^+ = \beta^- = 0$ against the alternative (H_1): $\beta = \beta^+ = \beta^- \neq 0$. Cointegration is determine by comparing the values of F and T stats with the critical values of upper bound. Null hypothesis of no cointegration is rejected if the values of F and T stats are greater than the critical values of upper bound and vice versa.

4. Empirical findings and discussions

Findings and results from different approaches (summary of statistics, unit root test with both structural break and traditional tests, asymmetric cointegration with long run asymmetries among the variables of interest) applied in this study will be discussed in this section.

4.1. Summary of statistics and unit root

We present the results and findings from both descriptive statistics and stationarity in this section. Output from descriptive statistics is presented in Table 2. Features of the variables like volatile level of the variables. Economic growth is highly volatile followed by carbon dioxide emissions, while renewable energy and FDI are less volatile among the variables. Additionally, from the output of Jarque Bera, the series are not normally distributed. This gives us the direction of applying asymmetric analysis in this study.

Table 3
Unit root test with PP, ADF and KPSS.

Variable	Unit root at level		Unit root at 1st Diff		
	Intercept	Intercept and trend	Intercept	Intercept and trend	Remarks
PP					
CO_2	−3.030**	−1.409	−3.835***	−4.130***	MIXED
GDP	−3.761***	−1.728	−3.191**	−3.796**	MIXED
RE	7.409	1.918	−0.786	−2.862	MIXED
FDI	−3.458**	−3.775**	−4.720***	−4.603***	MIXED
ADF					
CO_2	−2.160	−1.665	−2.190	−2.666	MIXED
GDP	−2.164	−2.288	−2.954**	−3.453*	I(1)
RE	2.918	1.289	−0.757	−2.512	MIXED
FDI	−2.850*	−3.903**	−5.447***	−5.589***	MIXED
KPSS					
CO_2	1.055***	0.280***	0.575**	0.069	MIXED
GDP	1.199***	0.292***	0.664**	0.057	MIXED
RE	1.111***	0.294***	1.104***	0.137*	MIXED
FDI	0.577**	0.056	0.024	0.021	I(1)

Note: The signs *, ** and *** represent significant levels at 10, 5 and 1 percent. PP= Philips perron, ADF = Augmented Dickey Fuller, KPSS= Kwiatkwoski Philips-Schmidt-Shin.
Source: Authors' computation with Eviews.

Table 4
Zivot Andrew structural break Test.

Variables	ZA	P-Value	Lag	Break Period	CV@1%	CV@5%
CO_2	−3.286	0.000***	4	2007Q2	−4.80	−4.42
GDP	−5.371	0.000***	4	2006Q2	−5.57	−5.08
RE	−2.548	0.002***	4	2009Q4	−4.80	−4.42
FDI	−3.542	0.009***	4	2004Q2	−5.57	−5.08
			1st Diff			
DCO_2	−2.809	0.463	4	2011Q3	−4.80	−4.42
DGDP	−4.447	0.000***	4	2008Q2	−5.57	−5.08
DRE	−2.862	0.061*	4	2008Q4	−4.80	−4.42
DFDI	−4.340	0.065*	4	2006Q2	−5.57	−5.08

Note: The signs *, ** and *** represent significant levels at 10, 5 and 1 percent. ZA = Zivot Andrews, LG = lag, P-Value = probability value, CV = critical values.
Source: Authors' computation with Eviews.

4.2. Unit root test

Tables 3 and 4 show the outputs of both conventional unit root test and structural break test. Unit root test is good in any time series study like this present study. It gives insight on the stability of the selected/applied series which determines the explanation to the findings. Different conventional approaches (such as augmented Dickey and Fuller, 1979; Phillips and Perron, 1988 and kwiatkwoski Philips-Schmidt-Shin-KPSS, 1992) are applied for the test of stationarity for the series. Zivot- Andrew, 1992 approach is equally applied for structural break test. It is essential to compliment the conventional test with structural test for insight into effects of structural changes such as macroeconomic cum financial and policies issues, natural, and health issues which are capable of creating permanent shocks that affect the movement and stability of any variable utilize in research of any economy. From the outputs of both methods, mixed order of integration is established in the applied series which confirms non-stationarity of some variables. Specifically, structural breaks that occur due to shocks from macroeconomic cum financial policies/issue took place in the following years: 2007Q2 and 2011Q3 for carbon emission (CO_2), 2006Q2 and 2008Q2 for economic growth (GDP), 2008Q4 and 2009Q4 for renewable energy (RE), 2004Q2 and 2006Q2 for foreign direct investments (FDI). The revealed structural break dates are all contained in the sample period of this present study (1996Q1-2018Q4). Events that could possibly permit structural change with shocks are notably oil shocks that was caused by 9/11 terrorists attack, and 2008/9 global financial meltdown.

4.3. Nonlinear ARDL approach

4.3.1. Diagnostic estimates

Findings from nonlinear cointegration and long run asymmetries estimations are presented in Tables 5 and 6 below. Estimations from the nonlinear analysis include both the cointegration and decomposed shocks from both short run and long run dynamics, goodness of fit and other diagnostic tests. The values of R^2 and adjusted R^2 at 0.98 respectively represent the goodness of fit. This means that about 98 percent of carbon dioxide emissions are explained by the explanatory variables (economic growth, renewable energy and FDI), while the remaining part are explained by the error term. Through the diagnostic tests (Durbin Watson-1.99, Breusch-Godfrey serial correlation LM test- 0.0002 [0.9885] for serial correlation and Breusch- Pagan-Godfrey test 1.079 [0.4072] for heteroscedasticity), estimations are satisfied free from econometric cum statistical problems such as auto and serial correlations, heteroscedasticity. The stability of the model is also tested and confirmed with cumulative sum and cumulative sum square (CUSUM

Table 5
Non-linear ARDL (NARDL).

Instruments	Long-Path Estimation				Short-Path Estimation				
	Coef	S.Error	t-stat	Prob	Instruments	Coef	S. Error	t-stat	Prob
GDP^+	0.004*	0.002	1.832	0.075	GDP^+	0.004***	0.001	3.779	0.001
GDP^-	0.162***	0.046	3.512	0.001	GDP^-	0.162***	0.021	7.609	0.000
FDI^+	3.380***	0.413	8.188	0.000	FDI^+	3.380***	0.259	13.03	0.000
FDI^-	−0.998***	0.240	−4.152	0.000	FDI^-	−0.998***	0.160	−6.252	0.000
RE^+	−23.45***	3.331	−7.038	0.000	RE^+	−23.45***	1.858	−12.61	0.000
RE^-	16.84***	6.998	2.406	0.000	RE^-	16.84***	4.017	4.192	0.000
C	78.52*	45.79	1.715	0.095	ECT(−)	−0.109***	0.009	−12.66	0.000
Diagnostic Tests									
R^2	0.999								
$AdjR^2$	0.989								
DW Statistics	1.994								
F-Statistics	10269.2 [0.000]								
Bound tests	F = 16.91***, T = −12.6***K = 7			,@ 1%	I(0) = 3.72	I(1) = 5.16			
				,@ 5%	I(0) = -2.9	I(1) = -4.1			
χ^2 *LM*	0.0002 [0.9885]								
$\chi 2$ *HET*	1.079 [0.4072]								

Note: *, ** and *** depicts significant at 10, 5 and 1 percent level respectively.
Source: Authors computation with Eviews statistical tool.

Table 6
Long-path asymmetries between the instruments (WALD test).

Instruments	x^2 Chi-Square [P-value]	Conclusion
GDP	10.93*** [0.002]	Yes
FDI	60.90*** [0.000]	Yes
RE	7.80* [0.008]	Yes

Note: * indicates 1% significance level.
Source: Authors computation with Eviews.

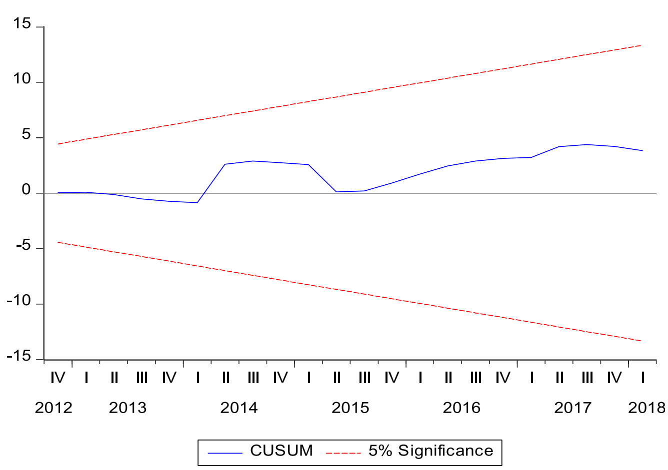

Fig. 3. Plot of Cumulative sum (CUSUM)
Source: Authors computation.

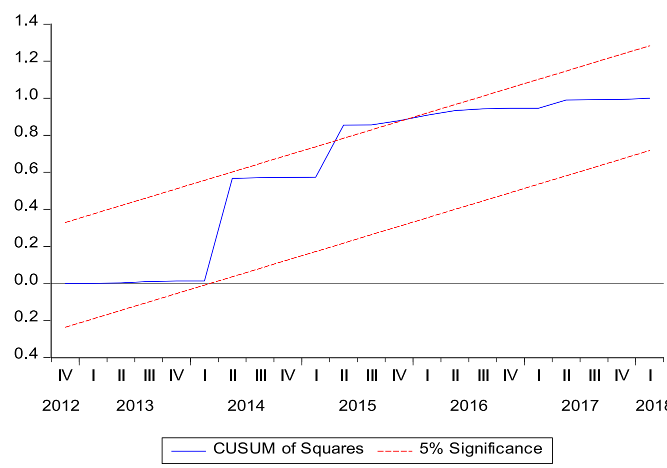

Fig. 4. Plot of Cumulative sum square ($CUSUM^2$)
Source: Authors computation.

and $CUSUM^2$), and the output are shown with Figs. 3 and 4. The speed of adjustment from short run disequilibrium is tested with error correction model (ECM) and the significantly negative output of ECM confirmed the ability of the model to adjust in the long run (say 9 years and some months i.e 1/0.109 = 9.17) at 10.9 percent (−0.109). The optimal lag selection was done with Akaike information criterion (AIC) and the lag is 1. Result will be made available on request. Cointegration is confirmed with the values of F = 16.91 and T = −12.6 greater than the critical values of upper bound at I(1) = 5.16 and I(1) = -4.1 at 5 and 1 percent respectively. This shows the likelihood of long run asymmetric relationship between the variables of interest.

4.3.2. Discussion of long run and short run of the non-linear ARDL

In continuation with the discussion and analysis, the output from the nonlinear dynamics of short run and long run relationships (positive and negative shocks) between the variables are presented in this section. As established from the methodology, NARDL method is applied in this study because of its ability to decompose the association that exist between carbon emission and the explanatory variables. NARDL exposes the relationship among the variables in a break down process that involves displaying of both positive and negative shocks of the explanatory variables on the dependent variable. Unlike linear approach, asymmetric (NARDL) approaches accounts for both positive and negative impacts of the explanatory variables on dependent variables.

The finding of this from both long run and short run are as follows: the positive and negative shocks to the Australian economic growth have negative impacts on its environment through the increase of carbon emissions. This points to the fact that carbon emissions tend to increase in the two scenarios (positive and negative shocks) and for this, the Australian environmental performance is affected. Quantitatively, a percent increase (in the case of positive shock) or decrease (in the case of negative shock) in Australian economic growth will lead to 0.004 and 0.162 percentage increase in carbon emissions (CO_2) at 1 percent significant level respectively. The same magnitude and pattern of response is observed in the long run with variation in t-statistics and level of significance for the case positive shocks. This finding supports the findings from, Rahman and Vu (2020) for Australia but contrast the finding by Shahbaz et al. (2017) for Australia.

For the case of FDI, the positive and negative shocks to FDI increase and reduce carbon emissions in Australia in both periods (short run and long run). This finding comes in different magnitudes of t-stats and significant level in both short run and long run. Hence, the percent increase (positive shock) or decrease (negative shock) of Australia FDI will increase or decrease its carbon emissions at the magnitude of 3.380 and −0.998. Simply put, increase in Australian FDI cause increase in its carbon emissions and vice versa. The same pattern is repeated in both periods (short run and long run) but in different magnitude in t-starts and significant level. This is not surprise considering the history of Australian open and welcoming environmental policy to foreign investors including Chinese investors (Drysdale, 2011). China remains the biggest investor in the Australian mining and resources sector through its state owned enterprises. With the level of openness and welcoming approach of Australian authority towards the foreign investors in a bid to maintain a robust economy, tradeoff is expected on the part of the country's environmental performance. There may be some level of negligence on the impact of the activities of foreign investors on the environment which will eventually impact negatively on the country's environmental performance. This finding supports the findings from Ren et al. (2014); Ding et al. (2018); Udemba et al. (2019); Udemba, (2021).

However, the findings from the shocks (positive and negative) to renewable energy proved to be a game changer for the Australian climate and sustainability goals. The findings show that renewable energy is effective tool in controlling Australian carbon emission. Hence, a percent increase (positive) or decrease (negative) of Australian renewable energy sources will significantly (at 1 percent) decrease or increase its carbon emissions at −23.45 or 16.84 percentage respectively. It is quite interesting to see that the magnitude (23) of its power to curb carbon emissions during positive shock is higher than its magnitude (16) in increasing emissions during negative shocks for the case of Australia. This is a success story for the Australian authorities and calls for policy pathway towards achieving its climate and sustainable goals. This finding is in support of the findings of Paramati et al. (2017); Ibrahim and Alola (2020); Rahman and Vu (2020) for Australia; Fragkos et al. (2021) and Ahmed et al. (2021).

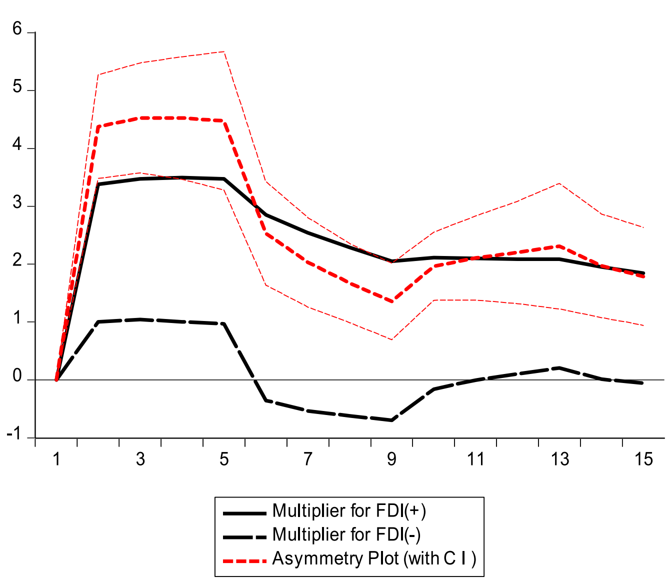

Fig. 5. Multiplier for FDI
Source: Authors computation.

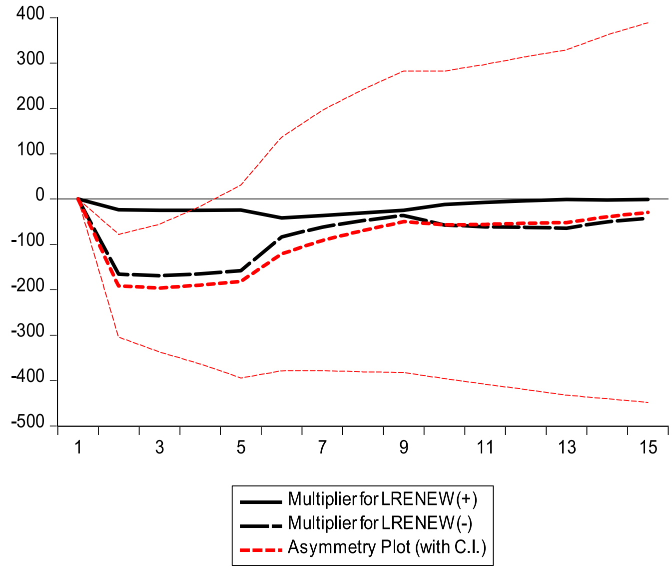

Fig. 6. Multiplier for REN
Source: Authors computation.

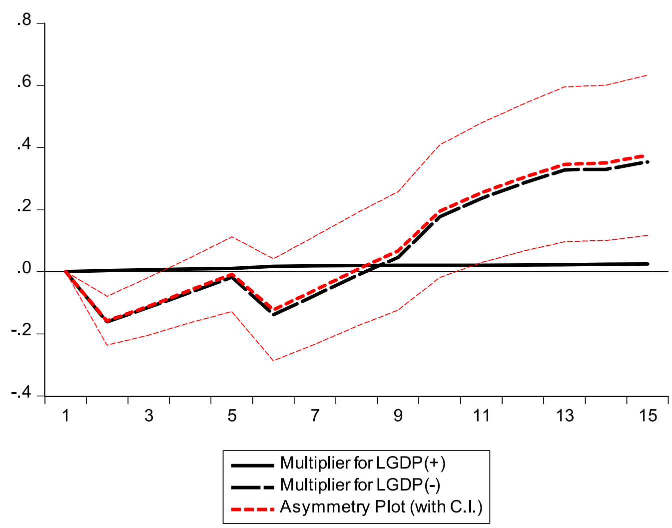

Fig. 7. Multiplier for GDP
Source: Authors computation.

4.4. Diagnostic test

Part of the diagnostic test estimated in our study is the stability test of the model with CUSUM and $CUSUM^2$ tests. The output with the blue lines well bounded inside the two red lines in both recursive tests show that the model is stable.

Wald test is also applied in our studies as a robust check to compliment the non-ARDL findings. The Wald test is the approach of testing the long run asymmetries between the explanatory (economic growth, FDI and renewable energy) variables and the dependent (CO_2) variable. The findings from the Wald test as shown in Table 6 confirm the long run asymmetries between the variables at 1 percent for all the explanatory variables. This findings support the result from error correction model (ECM) which attests to the possibility of long run relationship existing among the variables at 10.9 percent up to duration of 9 years and some months. Furthermore, non-ARDL multiplier is included in the analysis to expose the ability of the dependent variable (CO_2) to adjust and maintain its equilibrium after some level of positive and negative shocks have been witnessed. The multiplier aid in ascertaining the asymmetric adjustment of the emissions to the shocks of the explanatory variables. This is represented with the interaction between the black lines and the red lines as they appeared in Figs. 5–7 below Table 6.

4.5. Implications from the findings and related studies

The following findings are made from our estimations: First, both positive and negative shocks to the Australian economic growth have negative impacts on environment quality through the increase of carbon emissions in the short- and long-run. Although the magnitude of the impact of the positive shock in both long- and short-run is significantly lower compared to the impact of the negative shock during the tow regimes, this points to the fact that carbon emissions in the country declines when there is a sudden surge in economic activity which arises from improvement in economic performance. Moreover, this result portrays economic intuition and expectation for developed economy such as Australia. Furthermore, comparing our findings with other previous studies, our findings on the impact of Australian economic growth on its environmental performance supports findings from Rahman and Vu (2020) for Australia, Mbarek et al. (2018) for Tunisia, Rahman and Velayutham (2020) for South Asia countries, Kashem and Rahman (2019) for Bangladesh, Balsalobre-Lorente et al. (2018) and Ahmed et al. (2017) for four countries, EU-5 countries and ASEAN-8 countries, respectively but contrast the finding by Shahbaz et al. (2017) for Australia.

Second, for the case of FDI, the positive and negative shocks to FDI respectively increase and reduce carbon emissions in Australia in both periods (short run and long run). Unlike the impact of economic performance, this finding comes in different magnitudes of t-stats and significant level in both short run and long run as the magnitude of the impacts were significantly larger when there is a positive shock. Interestingly, this result justifies the argument that Australia is a tangibly FDI destination. Thus, while considering the tendency of shifting or offshoring carbon emission through FDI to Australia by trade partners such as the neighboring China, a positive shock to FDI would expectedly trigger more environmental degradation. In comparing our findings with other previous studies, our findings on the impact of FDI into Australian economy on its environmental performance supports findings from (Drysdale, 2011). The work of Drysdale exposed the Australian open and less rigid policy in attracting foreign investors into its mining and resource sector. As remarked in previous section 4.3, most of Australian foreign attracted investments especially from China are domicile in its mining and resources sector through its state-owned enterprises. There might be some level of trade-off on the part of the country's environmental performance due to negligence of foreign investors on the environment and maximum attention and priority given to its economic performance. This finding supports the findings from Ren et al. (2014) for China; Ding et al. (2018); Udemba et al. (2019); Udemba, (2021). Ren et al. (2014) made a discovery on the negative implication of FDI on Chinese environment through inducing of carbon emissions.

Third, the findings from the shocks (positive and negative) to renewable energy proved to be a game changer for the Australian climate and sustainability goals. The findings show that renewable energy is an effective tool in controlling Australia's carbon emission. A considerable attention should be devoted to renewable energy development in Australia given that a positive shock and negative shock to the Australian renewable energy profile significantly triggers a positive and negative change in the country's carbon emissions by 23.45 percent and 16.84 percent respectively. In comparison, our finding aligns with the findings from Paramati et al. (2017); Ibrahim and Alola (2020); Rahman and Vu (2020) for Australia; Fragkos et al. (2021) and Ahmed et al. (2021) that all hinted on the relevance of renewable energy development in mitigating GHG emissions. Specifically, Rahman and Vu (2020) find in their comparative study between Australia and Canada, that renewable aids in mitigating the carbon emission for the case of Australia in the long run. Their finding indicates that renewable energy source decreases Australia carbon emission in the magnitude of 11 percent. This is an indication that Australia is underway to affirm Kyoto's protocols, and points to the fact that it will possibly attain its climate goal via the adaptation of renewable.

5. Conclusion and policy recommendation

This study is the examination of the current state of Australian climate performance and its ability towards achieving sustainability development. The focus of our study is streamed and highlighted with three (3) statements as follows: (i) investigating the role of renewable energy utilization in attaining a carbon neutral country, (ii) examining the contribution of conventional energy use to the carbon emission trend, and (iii) to evaluate the importance or establish whether foreign direct investment (FDI) in Australia plays a (de)merit role in the country's quest for environmental sustainability. Specifically, the current study investigates the effect caused by potential shock arising from the 'Direct Action' in renewable and fossil fuel energy and FDI. For clear and in-depth findings and reports from our study, we apply several approaches ranges from structural break test to non-linear autoregressive distributed lag (NARDL) cointegration and long run asymmetric analysis. Our emphasis and policy recommendation is based on the outcome of both the short run and long run shocks (positive and negative). Arising from the impact of the potential shock, the NARDL empirical approach exposed the short- and long-run symmetric and asymmetric inferences as follows: economic growth and FDI are found to be carbon intensive without mitigating effects towards the country's (Australia) carbon emissions. This is observed in both positive and negative shocks of economic growth but only in positive shock of FDI. This implies that the economic activities FDI inclusive in Australian are done in energy cum carbon intensive ground. The availability of fossil fuels (e.g. coal and gas) in a large quantity could be part of motivation for excessive use of energy which generate massive and intense carbon emissions in the economy. Further into the findings is the mitigating power of Australian renewable energy sources in its economic and environmental development. This is confirmed with positive shocks to renewable energy reducing carbon emission at the level of 23 percent while the negative shock will increase carbon emissions by 16 percent.

5.1. Policy and recommendation

This shows that energy policy (renewable energy) has a lot to contribute towards the achievement of Australian climate goal of 2030 (i.e. carbon zero). Thus, the revelation from this study is expected to provide useful policy dimension to the Australian government and the stakeholders to the country's 2030 emissions reduction goal. Australian authorities are encouraged to look into the following energy policies towards the achievement of the country's climate goal: 1. Energy transition to alternative energy sources (renewables), 2. Partial Privatization of the renewable energy sector to attract and encourage private individuals into the sector. This will boost the sector through the efficiency and effectiveness of the private persons, 3. Introduction of technological innovation programs through research and development (R&D) program to boost and expand the renewable energy sector, 4. Government subsidy policies will assist in attracting more players into the sector. Also, from our finding we established the worsening state of Australian environment through positive shock to FDI on the carbon emission. This can be controlled through strict regulations on the activities of foreign investors to balance both the economic and environmental development of the country. Also, environmental taxation can be used to curb the excesses of the industries and manufacturing firms in the economy. Placing a carbon ceiling at which tax will be introduced if exceeded is a short way of introducing environmental taxation.

Our study is limited by the choice of the variables applied. Other sensitive variables and environment indicators such as trade, globalization, institutions and ecological footprint can be considered in subsequent research as relevant instruments to study Australian climate goal. In conclusion, our study has implication to other large economies such as China and USA, and especially the developing states. For instance, many European countries, India, and several developing economies that are determined in sustaining the current level of economic growth through FDI and other growth indicators can learn from this evidence and add more pressure on the side of the foreign investors for inclusive (economic and environment) growth.

CRediT authorship contribution statement

Edmund Ntom Udemba: Data curation, Writing – review & editing, Supervision, Writing – review & editing, Formal analysis, Investigation, Methodology, Validation, Supervision. **Andrew Adewale Alola:** Writing – review & editing, Visualization, Validation, Corresponding.

Declaration of competing interest

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.

Appendix

Table A
Summary of environmental-related extant studies for Australia.

The authors	Sample period	Empirical approach	Major findings
Nasir et al. (2021)	1980–2014	Granger causality and cointegration estimators for long and short-run effect	Long-run positive impact of financial development, energy consumption, and trade openness on CO_2. EKC was invalid.
Munir and Riaz (2020)	1975 to 2018	Non-ARDL (NARDL) model for Australia, China, and the United States.	Increase in oil and coal consumption in Australia triggers CO_2 emissions.
Sarkodie and Strezov (2018)	1974 to 2013	Estimators of FMOLS, DOLS, and CCR.	Reduction of fossil fuels and increase in renewable energy are critical to environmental sustainability. EKC is invalid.
Speldewinde et al. (2009)	1971–2013	Advanced spatial model by Besag, York and Mollie (Besag et al., 1991).	There is a significant link between dryland salinity and depression.
Moosa (2017)	1960–2014	Empirical methods.	EKC is validated but also environmental degradation and income per capita nexus is time-varying.
Sarkodie and Strezov (2018b)	1971 to 2013	Pooled Mean Group Autoregressive Distributed Lag (PMG/ARDL) method.	A 1% increase in urban population and ecological footprint in Australia decrease energy intensity by 0.10% and 0.11% respectively. EKC was invalid.

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