RESEARCH ARTICLE

Macroeconomic Determinants of CO_2 Emissions in Australia: Evidence From ARDL Bound Testing Approach

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Abstract: This paper examines the macroeconomic determinants of CO_2 emissions in Australia by applying the autoregressive distributed lag bound testing approach to cointegration. Findings reveal that CO_2 emissions, energy consumption, financial development, and trade openness are cointegrated only when CO_2 emissions are considered as the dependent variable. Under this situation, energy consumption and economic development lead to environmental degradation, whereas financial development improves the environment quality in Australia in the long run. The impact of trade openness on CO_2 emissions is positive. However, this impact is lower than that of economic development and energy consumption. Moreover, bidirectional causality is found between CO_2 emissions and economic development in the short run.

Keywords: CO_2 emissions, economic activities, financial development, trade openness, ARDL Bound Testing

CO_2 emission is the leading cause of environmental degradation throughout the world. The past decades have seen the rapid increase in CO_2 emissions in developed countries. According to World Bank statistics, the growth rate of total CO_2 emissions in Australia was more than 350% during the last half century, rising from 88,202 kilotons (kt) in 1960 to 398,550 kt in 2016. The economy and the environment have a close relationship, and macroeconomic variables are related to CO_2 emissions as linear, quadratic, or cubic forms in a static or dynamic fashion.

A considerable amount of literature has been published on CO_2 emission determinants in different countries and regions. Income and energy consumption are two factors that have been investigated the most by previous studies. Many studies emphasized the linear relationship between income, energy consumption, and CO_2 emissions (Omri, 2013; Menyah & Wolde-Rufael, 2010a; Soytas & Sari, 2009; Ang, 2007; Zhang & Cheng, 2009). On the other hand, other studies focused on the nonlinear relationship between income and emissions either as an environmental Kuznets curve (Vo et al., 2019; Soytas et al., 2007; Agbanike et al., 2019; Choi et al., 2010; Holtz-Eakin & Selden, 1995; Sherafatian-Jahromi et al., 2017; Lean & Smyth, 2010; Apergis & Payne, 2009; Narayan & Narayan, 2010) or a cubic form of the income and emissions relationship (Friedl & Getzner, 2003; Akbostancı et al., 2009; He & Richard, 2010; Galeotti et al., 2006). These studies did not provide conclusive and unanimous results. The summary of mentioned studies is reported in Table 1.

Despite the high economic growth rate in Australia, few studies have investigated the relationship between emissions and income in this country. Although Salahuddin and Khan (2013) found no cointegration evidence between emissions, economic growth, and

Table 1

Previous Studies Considering the Impact of Energy Consumption and Income on CO_2 Emissions

Author(s)	Country(ies)	Time Period	Method(s)	Results
		Linear Relationship		
Omri (2013)	14 MENA countries	1990–2011	GMM	EC→CO_2 Y↔CO_2
Menyah & Wolde-Rufael (2010a)	United States	1960–2007	Granger Causality	CO_2↔Y Nuclear EC→CO_2
Soytas & Sari (2009)	Turkey	1960–2000	Granger Causality	CO_2→EC
Zhang & Cheng (2009)	China	1960–2007	Granger Causality	EC→CO_2
		Nonlinear Relationship		
Vo et al. (2019)	5 ASEAN Countries	1971–2014	FMOLS/DOLS	Miscellaneous
Agbanike et al. (2019)	Venezuela	1971–2013	ARDL	EC→CO_2 CO_2→Y
Sherafatian-Jahromi et al. (2017)	5 Southeast Asian Countries	1979–2010	Pooled Mean Group/ FMOLS	EKC supported
Holtz-Eakin & Selden (1995)	130 Countries	1951–1986	Panel Estimation	Monotonic rising curve
Lean & Smyth (2010)	5 ASEAN Countries	1980–2006	DOLS/Panel Granger Causality	CO_2→Y EKC supported
Narayan & Narayan (2010)	43 Developing Countries	1980–2004	Panel/Individual Cointegration	Miscellaneous
Ang (2007)	France	1960-2000	VECM, ARDL	Y→CO_2 EKC supported
Soytas et al. (2007)	United States	1960-2004	Causality	EC→CO_2 EKC not supported
Apergis & Payne (2009)	6 Countries in Central America	1971-2004	Panel VECM	CO_2↔EC EKC supported
		Cubic Relationship		
Friedl & Getzner (2003)	Austria	1960-1999	Cointegration Method	N shaped relationship supported
Galeotti et al. (2006)	OECD/Non-OECD Countries	1950-1997	Panel Estimation	Miscellaneous
He & Richard (2010)	Canada	1948-2004	Semiparametric and Flexible Nonlinear parametric Modeling methods	EKC supported
Akbostancı et al. (2009)	Turkey/Turkish Provinces	1968-2003/ 1992-2001	Pooled EGLS	EKC not supported

Note: → and ↔ show the direction of causality energy consumption in Australia, Shahiduzzaman and Alam (2012) illustrated that emissions and income are non-monotonically related, controlling the impact of technological state and black coal export. Notably, black coal and iron are among the main exports of Australia, with black coal being the second-highest export commodity. In 2016, approximately 30% of Australian exports were accounted for by iron ore (16.3%) and coal (12.8%). The production of these commodities is not clean, and it degrades air quality. Controlling the coal export may not be enough to capture the international trade and might lead to unreliable results. For this purpose, the trade openness of Australia is considered in this study.

Previous studies considered the relationship between trade and the environment. Preliminary work on trade liberalization and CO_2 emissions was undertaken by Grossman and Krueger (1991). Trade liberalization and environment relationship were also investigated by Antweiler et al. (2001), Khan et al. (2019), Zhang et al. (2017), Lopez (1994), Ang (2009), Farhani and Ozturk (2015), Jalil and Feridun (2011), Zhang et al. (2018), Ahmed et al. (2017), Farhani et al. (2014), Ali et al. (2016), Choi et al. (2010), Jalil and Mahmud (2009), Jayanthakumaran et al. (2012) and Ozturk and Acaravci, (2013). Trade openness is a good proxy for trade liberalization. The present study considers this variable to find the inward and outward orientation of the Australian economy. However, the geographical isolation of Australia caused low trade with respect to other Organization for Economic Co-operation and Development countries during the last half-century. The ratio of export and import to GDP increased from 27% in 1960 to 41% in 2011. Previous studies also highlighted the important role of trade openness in degrading the environment. Hossain (2011) illustrated that trade openness and economic growth cause CO_2 emissions only in the short run in newly industrialized countries. Halicioglu (2009) and Ozturk and Acavarci (2013) found that foreign trade is an important element in determining CO_2 emissions in Turkey. Jalil and Feridun (2011) indicated the

Table 2

Previous Studies Considering the Impact of Trade on CO_2 Emissions

Author(s)	Country(ies)	Time Period	Method of Estimation	Results
Khan et al. (2019)	Pakistan	1972-2017	ARDL	Bi-directional causality between trade and emissions
Antweiler et al. (2001)	44 Countries	1971-1996	Fixed and Random Effects Models	Free trade is good for the environment
Ali et al. (2016)	Nigeria	1971-2011	ARDL	Trade openness reduces emissions
Jalil & Mahmud (2009)	China	1975-2005	ARDL	Trade positively affects emissions but it is insignificant
Halicioglu (2009)	Turkey	1960-2005	ARDL, VECM	Trade causes emissions
Ang (2009)	China	1953-2006	ARDL, SUR, FIML	More trade, more emissions
Farhani & Ozturk (2015)	Tunisia	1971-2012	ARDL	Emissions cause trade openness
Zhang et al. (2017)	10 newly industrialized countries	1971-2013	OLS, FMOLS, DOLS	Trade openness negatively affects emissions
Zhang et al. (2018)	Pakistan	1970-2011	ARDL	Trade is environmentally friendly
Ahmed et al. (2017)	5 countries in South Asia	1971-2013	FMOLS	Trade openness cause emissions
Jalil & Feridun (2011)	China	1953-2006	ARDL	Trade openness leads to environmental pollution
Jayanthakumaran et al. (2012)	China and India	1971-2007	ARDL	Trade reduces emissions for China in the short run

positive relationship between CO_2 emissions and trade openness in China. More recently, Farhani and Ozturk (2015) concluded that trade openness has a positive effect on emissions. Table 2 represents a summary of studies that examined the impact of income and energy consumption on CO_2 emissions.

Financial development is another factor that influences CO_2 emissions. Previous studies used different proxies to show the important role of this factor. Financial development might help countries use more environmentally friendly technology by attracting foreign direct investment and enhancing economic growth (Tamazian & Rao 2010). On the other hand, financial development might deteriorate the environment by affecting economic growth (Thangavelu & Jiunn 2004) and producing more pollution through growth. Tamazian et al. (2009) reported that financial development improves the air quality in Brazil, Russia, India, and China (the BRIC countries). Another major study by Tamazian and Rao (2010) revealed that environmental degradation is negatively related to financial development. Jalil and Feridun (2011) illustrated that financial development reduces CO_2 emissions in China. In addition, Farhani and Ozturk (2015) reported that financial development negatively affects the environment in Tunisia. Interestingly, Ozturk and Acaravci (2013) found that the impact of financial development on CO_2 emissions is not statistically significant in Turkey. Abbasi and Riaz (2016) found the footprint of financial variables in emission mitigating in Pakistan during 1988–2011. More recently, Charfeddine and Kahia (2019) illustrated that financial development modestly affects CO_2 emissions. The causal relationship between financial development and CO_2 emissions analyzed in Shahbaz et al. (2013), Charfeddine and Khediri (2016), Ozturk and Acaravci (2013), Al-Mulali and Sab (2012), Zhang (2011), Salahuddin et al. (2015), Bekhet et al. (2017) and Solarin (2014) studies with no consensus. Al-Mulali and Sab (2012) and Shahbaz et al. (2013) found bi-directional causality between CO_2 emissions and financial development in Sub Saharan African countries and Malaysia, respectively. On the other hand, Charfeddine and Khediri (2016), Salahuddin et al. (2015) and Ozturk and Acaravci (2013) implied that financial development granger causes CO_2 emissions in the UAE, Gulf Cooperation Council (GCC) countries, and Turkey, respectively. Bekhet et al. (2017) investigated that CO_2 causes financial development in Qatar and Saudi Arabia, and financial development causes CO_2 emissions in Oman, UAE, and Kuwait. Table 3 reports the scholars who investigated how financial development affects emissions.

In spite of the remarkable increase in CO_2 emissions in Australia, not enough studies have examined this important issue. Although Salahuddin and Khan (2013), Shahbaz et al. (2017), and Shahiduzzaman and Alam (2012) investigated the determinant of emissions, the question of whether financial development and trade openness influence the emissions in Australia needs to be addressed. The present study contributes to the literature by answering this question through the inclusion of a proxy for financial development and trade openness, along with economic growth and energy consumption in the case of Australia.

Methods

Model Specification and Methodology

To examine the impact of economic growth, energy consumption, trade openness, and financial development on CO_2 emissions in Australia, the following model is considered:

$$CO_{2t} = A.GDP_t^{\beta_1}.EC_t^{\beta_2}.TO_t^{\beta_3}.FD_t^{\beta_4}.e^{\varepsilon_t} \quad (1)$$

To consider the model as an open economy, we include trade openness following Halicioglu (2009), Jalil and Feridun (2011), and Farhani and Ozturk (2015). A recent study by Farhani and Ozturk (2015) and Ozturk and Acaravci (2013) considered financial development and trade openness in the model. The logarithmic transformation of Equation (1), similar to the model by Jalil and Feridun (2011), is

$$LCO_{2t} = \alpha + \beta_1 LGDP_t + \beta_2 LEC_t + \beta_3 LTO_t + \beta_4 LFD_t + \varepsilon_t \quad (2)$$

The subscript t illustrates the year, LCO_2 denotes the logarithmic form of per capita CO_2 emissions, $LGDP$ denotes the logarithmic form of real per capita gross domestic product, LEC stands for the logarithmic form of energy consumption, LTO indicates the logarithmic form of trade openness, LFD shows the logarithmic form of financial development, and ε is the error term.

Table 3

Previous Studies Considering the Impact of Financial Development (FD) on CO_2 Emissions

Author(s)	Country(ies)	Time Period	Method(s)	Results
Tamazian & Rao (2010)	24 transition economies	1993-2004	GMM	Higher FDI, lower emissions
Tamazian et al. (2009)	BRIC Countries, U.S., and Japan	1992-2004	Standard reduced-form modeling	FD decreases environmental degradation
Jalil & Feridun (2011)	China	1953-2006	ARDL	FD reduces emissions
Farhani & Ozturk (2015)	Tunisia	1971-2012	ARDL	FD deteriorate the environment
Ozturk & Acaravci (2013)	Turkey	1960-2007	ARDL	Impact of FD on emissions is not statistically significant
Abbasi & Riaz (2016)	Pakistan	1988-2011	Augmented VAR, VECM	FDI causes emissions
Charfeddine & Khediri (2016)	The UAE	1975-2011	VECM	Inverted U-shaped relationship between FD and emissions
Charfeddine & Kahia (2019)	MENA	1980-2015	Panel VAR	FD slightly affects emissions
Shahbaz et al. (2013)	Malaysia	1971-2011	ARDL, VECM	Bi-directional causality between financial development and emissions
Al-Mulali & Sab (2012)	Sub Saharan African Countries	1980-2008	Panel Granger Causality	Bi-directional causality between FD and emissions
Salahuddin et al. (2015)	Gulf Cooperation Council	1980-2012	DOLS, FMOLS, DFE	FD reduces emissions
Bekhet et al. (2017)	Gulf Cooperation Council	1980-2011	ARDL	Miscellaneous

The best method to adopt for this investigation is autoregressive distributed lag (ARDL) bound testing by Pesaran et al. (2001), which provides long-term relationships and dynamic interaction among a series of interests. Bound testing has a number of attractive features:

(1) This approach provides reliable results whenever a series of interests are purely integrated in level *I(0)*, in their first difference *I(1)*, or mutually cointegrated. In other words, the series should not be integrated in order 2 *I(2)* or higher.
(2) On the basis of this approach, the empirical evidence is efficient and consistent in the small sample.

The unrestricted error correction models for CO_2 emissions, income, energy consumption, financial development, and trade openness based on the ARDL model are as follows:

$$\Delta LCO_{2t} = \alpha_{10} + \sum_{i=1}^{p} \beta_{11} \Delta LCO_{2t-i} + \sum_{i=0}^{r} \beta_{12} \Delta LGDP_{t-i} + \sum_{i=0}^{s} \beta_{13} \Delta LEC_{t-i} + \sum_{i=0}^{u} \beta_{14} \Delta LTO_{t-i} + \sum_{i=0}^{v} \beta_{15} \Delta LFD_{t-i} + \lambda_1 LCO_{2t-1} + \lambda_2 LGDP_{t-1} + \lambda_3 LEC_{t-1} + \lambda_4 LTO_{t-1} + \lambda_5 LFD_{t-1} + \varepsilon \quad (3)$$

$$\Delta LGDP_t = \alpha_{20} + \sum_{i=1}^{p} \beta_{21} \Delta LGDP_{t-i} + \sum_{i=0}^{r} \beta_{22} \Delta LCO_{2t-i} + \sum_{i=0}^{s} \beta_{23} \Delta LEC_{t-i} + \sum_{i=0}^{u} \beta_{24} \Delta LTO_{t-i} + \sum_{i=0}^{v} \beta_{25} \Delta LFD_{t-i} + \lambda_1 LCO_{2t-1} + \lambda_2 LGDP_{t-1} + \lambda_3 LEC_{t-1} + \lambda_4 LTO_{t-1} + \lambda_5 LFD_{t-1} + \varepsilon \quad (4)$$

$$\Delta LEC_{2t} = \alpha_{30} + \sum_{i=1}^{p} \beta_{31} \Delta LEC_{t-i} + \sum_{i=0}^{r} \beta_{32} \Delta LCO_{2t-i} + \sum_{i=0}^{s} \beta_{33} \Delta LGDP_{t-i} + \sum_{i=0}^{u} \beta_{34} \Delta LTO_{t-i} + \sum_{i=0}^{v} \beta_{35} \Delta LFD_{t-i} + \lambda_1 LCO_{2t-1} + \lambda_2 LGDP_{t-1} + \lambda_3 LEC_{t-1} + \lambda_4 LTO_{t-1} + \lambda_5 LFD_{t-1} + \varepsilon \quad (5)$$

$$\Delta LTO_t = \alpha_{20} + \sum_{i=1}^{p} \beta_{41} \Delta LTO_{t-i} + \sum_{i=0}^{r} \beta_{42} \Delta LCO_{2t-i} + \sum_{i=0}^{s} \beta_{43} \Delta LGDP_{t-i} + \sum_{i=0}^{u} \beta_{44} \Delta LEC_{t-i} + \sum_{i=0}^{v} \beta_{45} \Delta LFD_{t-i} + \lambda_1 LCO_{2t-1} + \lambda_2 LGDP_{t-1} + \lambda_3 LEC_{t-1} + \lambda_4 LTO_{t-1} + \lambda_5 LFD_{t-1} + \varepsilon \quad (6)$$

$$\Delta LFD_t = \alpha_{20} + \sum_{i=1}^{p} \beta_{51} \Delta LFD_{t-i} + \sum_{i=0}^{r} \beta_{52} \Delta LCO_{2t-i} + \sum_{i=0}^{s} \beta_{53} \Delta LGDP_{t-i} + \sum_{i=0}^{u} \beta_{54} \Delta LEC_{t-i} + \sum_{i=0}^{v} \beta_{55} \Delta LTO_{t-i} + \lambda_1 LCO_{2t-1} + \lambda_2 LGDP_{t-1} + \lambda_3 LEC_{t-1} + \lambda_4 LTO_{t-1} + \lambda_5 LFD_{t-1} + \varepsilon \quad (7)$$

To determine whether the series is cointegrated, ordinary least squares (OLS) should be applied to estimate Equations (3)–(7). In the second step, the F-test should be applied for the lagged levels of the variables. The null of no cointegration and the alternative hypothesis of cointegration for Equations (3)–(7) are as follows:

H_0: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5$

H_1: $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5$

Rejecting the null means that the series is cointegrated in the long run.

To establish the direction of the causal relationship between the series, the vector error correction method is employed as follows:

$$(1-L)\begin{bmatrix} LCO_{2t} \\ LGDP_t \\ LEC_t \\ LTO_t \\ LFD_t \end{bmatrix} = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ \beta_5 \end{bmatrix} + \sum_{i=1}^{p} (1-L) \begin{bmatrix} B_{11i} & B_{12i} & B_{13i} & B_{14i} & B_{15i} \\ B_{21i} & B_{22i} & B_{23i} & B_{24i} & B_{25i} \\ B_{31i} & B_{32i} & B_{33i} & B_{34i} & B_{35i} \\ B_{41i} & B_{42i} & B_{43i} & B_{44i} & B_{45i} \\ B_{51i} & B_{52i} & B_{53i} & B_{54i} & B_{55i} \end{bmatrix} \times \begin{bmatrix} LCO_{t-1} \\ LGDP_{t-1} \\ LEC_{t-1} \\ LTO_{t-1} \\ LFD_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} u_{it} \\ u_{2t} \\ u_{3t} \\ u_{4t} \\ u_{5t} \end{bmatrix} \quad (8)$$

In these equations, the lagged error correction term is shown by the ECT_{t-1}, which is derived from the long-run ARDL estimates and illustrates the speed of adjustment. In particular, the optimal lags are selected based on Schwarz's Bayesian criterion (SBC).

Data

The dependent variable in this study is per capita CO_2 emissions (CO_2) measured by metric tons per capita. The explanatory series consists of economic development (GDP) as measured by per capita gross domestic product (constant: US$2,010); per capita energy consumption (EC), which refers to energy use (kilogram of oil equivalent per capita); trade openness (TO), which is the proportion of exports plus imports of goods and services (% of GDP); and the ratio of broad money to GDP, which is the proxy for financial development (FD). The data covered are from 1960 to 2016 and obtained from the World Development Indicator (WDI) database, World Bank.

Results

As previously mentioned, this study employs an ARDL estimator to investigate the macroeconomic determinant of CO_2 emissions in Australia. In the first step, we have to prove that the series is stationary in level *I(0)* or in the first difference *I(1)*. For this purpose, the augmented Dickey–Fuller (ADF), Phillips–Perron (PP), and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) stationary tests are employed. The null hypothesis in the ADF and PP stationary tests indicates that the series is not stationary. However, the null hypothesis in KPSS shows that the series is stationary. In the case of the immensely persistent series, the high power of the KPSS unit root test is an advantage over the ADF unit root test. Results for each series are shown in Table 4 in three conditions, namely, with intercept, with intercept and trend, and without intercept and trend. Accordingly, the null of having a unit root is rejected in all cases based on the ADF and PP tests, and the series is first-order integrated, *I(1)*. The KPSS test also reveals that the series is stationary in its first differences.

In the second step, as shown in Table 5, the ARDL cointegration bound test is applied for Equations (3)–(7). The optimal lag length is found based on SBC. Pesaran et al. (2001) preferred the critical value in Narayan (2005) because the sample is relatively small (below 100). Consequently, the obtained statistics for each model is compared with the critical value in Narayan (2005). Accordingly, whenever CO_2 emission is considered a dependent variable, the calculated F-statistic is higher than the *I(1)* critical value in Narayan (2005). As a result, the null hypothesis of no cointegration among the series is rejected. In other words, co-movement exists between emissions, economic growth, energy consumption, financial development, and trade openness in the long run. When economic growth, energy consumption, financial development, and trade openness are considered dependent variables, the calculated F-statistics are below the *I(0)* critical value. Consequently, when other series are used as a dependent variable, no evidence of cointegration is found among the series.

To ensure the reliability of results, multiple diagnostic tests are conducted, as shown in Table 2. Accordingly, no serial correlation and heteroscedasticity are found. Moreover, the normality test based on the skewness and kurtosis of the sample data illustrates that the data are distributed normally. Finally, the Ramsey RESET specification approved the correct functional form of the model.

The long-run coefficients are estimated considering the CO_2 emissions as a dependent variable. Table 6 presents the results of the estimation based on three different estimators in three columns. The first column shows the ARDL estimator, which is the main estimator considered in this study. The second and third columns present the results of dynamic ordinary least square (DOLS) and fully modified ordinary least square (FMOLS), which are conducted to check the robustness.

The long-run coefficients suggest that with a 1% increase in economic growth, the CO_2 emissions in Australia rise by 0.81%. Furthermore, the findings show that economic activities deteriorate air quality, and this impact is higher than that of energy consumption and trade openness. The findings also show that the elasticity of emissions with respect to economic activities is lower than 1.

Energy consumption is also positively related to CO_2 emissions in Australia. Fossil fuel consumption is a possible explanation for this result. According to the WDI database, fossil fuel energy consumption (% of total) in Australia increased from 86% in 1960 to 94% in 2016. Moreover, coal consumption in Australia approximately doubled from 1980 to 2012. The U.S. Energy Information Administration reported that emissions from the consumption of coal in Australia increased from 98 million metric tons in 1980 to 212 million metric tons in 2012.

Furthermore, our findings show that trade openness is positively related to CO_2 emissions. More specifically,

Table 4

Stationary Tests

	ADF		PP		KPSS	
	Level	1 Diff.	Level	1 Diff.	Level	1 Diff.
LCO_2						
Intercept	-3.31**	-6.88***	-3.57***	-6.91***	0.79***	0.66**
Intercept and Trend	-1.27	-8.12***	-1.09	-8.32***	0.24***	0.07
None	2.23	-6.30***	1.96	-6.39***		
LGDP						
Intercept	-1.34	-6.27***	-1.31	-6.24***	0.96***	0.15
Intercept and Trend	-1.80	-6.41***	-1.96	-6.37***	0.09	0.06
None	8.27	-3.48***	8.27	-3.27***		
LEC						
Intercept	0.69	-8.31***	0.93	-8.26***	0.78**	0.39*
Intercept and Trend	-1.33	-9.02***	-1.24	-9.02***	0.18**	0.05
None	1.39	-8.07***	1.37	-8.06***		
LFD						
Intercept	1.61	-6.99***	1.59	-6.05***	0.76***	0.58**
Intercept and Trend	-0.99	-7.70***	-0.99	-7.70***	0.22***	0.07
None	3.01	-6.17***	2.73	-6.41***		
LTO						
Intercept	-0.96	-8.29***	-0.74	-8.80***	0.86***	0.11
Intercept and Trend	-2.96	-8.21***	-2.96	-8.70***	0.11*	0.11
None	1.08	-8.16***	1.58	-8.37***		

Note: *, **, *** imply 10%, 5%, 1% level of significance

Table 5

The ARDL Cointegration Bound Test and Diagnostic Tests

	Bound Testing to Cointegration		Diagnostic Tests			
Estimated Model	Lag Length	F-Stat.	$\chi2$ Serial	$\chi2$Heteroscedasticity	Normality Test	Ramsey Test
F(LCO_2/LGDP,LEC,LFD,LTO)	(1,0,1,1,0)	4.67**	0.97(0.31)	1.08 (0.72)	0.59(0.74)	1.16(0.28)
F(LGDP/LCO_2,LEC,LFD,LTO)	(2,0,1,3,0)	2.90	0.67(0.71)	1.48(0.48)	1.54(0.46)	0.83(0.44)
F(LEC/LCO_2,LGDP,LFD,LTO)	(1,1,1,0,3)	1.90	2.00(0.36)	0.96 (0.89)	0.40(0.81)	1.58(0.21)
F(LFD/LCO_2,LGDP,LEC,LTO)	(1,0,0,1,0)	2.72	0.39(0.62)	3.58(0.05)	0.37(0.83)	2.10(0.15)
F(LTO/LCO_2,LGDP,LEC,LFD)	(1,0,3,0,3)	1.64	0.22(0.74)	1.22(0.61)	0.23(0.88)	2.63(0.11)

Note: Critical values are in Narayan (2005)
** imply 5% level of significance

a 1% increase in foreign trade boosts emissions by 0.25%. The positive sign of trade openness is in line with Grossman and Krueger (1995), Halicioglu (2009), and Jalil and Feridun (2011). Although trade openness deteriorates air quality, this impact is lower than that of economic development and energy consumption.

Interestingly, the findings in Table 6 show that financial development improves air quality in the long run. Accordingly, a 1% increase in financial development reduces CO_2 emissions by 0.34%. Our findings support the positive influence of financial development on the environment in Tamazian and Rao (2010) and Tamazian et al. (2009). Although the positive impact of financial development could veil the negative effects of trade openness, the negative influences of economic development and energy consumption could not be covered through financial development.

As mentioned before, DOLS and FMOLS estimators are also applied to investigate the long-run relationships among the series. Our findings based on the ARDL estimator are supported by the DOLS and FMOLS results. All coefficients are statistically significant. In addition, the sign of coefficients is consistent with previous findings. Any increase in GDP per capita, per capita energy consumption, and trade openness degrades the environment, whereas financial development promotes clean air quality.

Table 6

Long Run Estimates

	Dependent Variable LCO_2		
	ARDL	**DOLS**	**FMOLS**
LGDP	0.81***	0.78***	0.87***
LEC	0.59***	0.63***	0.72***
LTO	0.25**	0.30***	0.20**
LFD	-0.34***	-0.33***	-0.31***

Note: **, *** imply 5%, 1% level of significance

The short-run causal relationship between the series is investigated by applying the Wald test. The results in Table 7 show that financial development causes CO_2 emissions in the short run, with no feedback. Furthermore, economic development causes CO_2 emissions. Consequently, to reduce CO_2 emissions in Australia, economic development should be immolated in the short run. The same results were obtained by Menyah and Wolde-Rufael (2010b) and Solarin (2014). Moreover, energy consumption causes economic development in the short term, as found by Asafu-Adjaye (2000), Masih and Masih (1996), and Narayan and Smyth (2008). Finally, unidirectional causality is found from financial development to economic growth, as well as trade openness to energy consumption.

Table 7

Granger Causality Estimates

Dependent Variable	**Direction of Causality**					
	Short run					**Long run**
	ΔLCO_{2t-1}	**$\Delta LGDP_{t-1}$**	**ΔLEC_{t-1}**	**ΔLTO_{t-1}**	**ΔLFD_{t-1}**	**ECT_{t-1}**
ΔLCO_2		10.71***	17.42***	4.40**	5.13**	-0.37***
$\Delta LGDP$	3.60*		4.47**	1.31	3.80***	
ΔLEC	14.79***	5.27***		3.99***	2.31	
ΔLTO	0.56	1.92	0.007		1.79	
ΔLFD	0.0005	0.03	2.61*	0.50		

Note: *, **, *** imply 10%, 5%, 1% level of significance

Discussion

The main purpose of this paper is to investigate the determinants of CO_2 emissions in Australia. For this purpose, the ARDL bound cointegration test is used to examine the relationship between CO_2 emissions, energy consumption, economic development, financial development, and trade openness from 1960 to 2016. Multiple stationary tests are applied to prove that the series is integrated in level or its first difference. According to the cointegration bound test by Pesaran et al. (2001), our series is cointegrated only by considering the CO_2 emissions as a dependent variable. Consequently, economic development, energy consumption, trade openness, and financial development affect the emissions in the long-run. The long-run estimation based on ARDL, DOLS, and FMOLS indicates that only financial development is negatively related to emissions, and expansion in other variables deteriorates air quality. Economic growth has been identified as a major contributing factor for CO_2 emissions in Australia. Consequently, it is highly recommended that policymakers increase their GDP with caution.

Moreover, the finding of the current study is consistent with those of Grossman and Krueger (1995), Ang (2009), and Jalil and Feridun (2011), who found strong evidence of positive relationship between trade and emissions. Accordingly, it is recommended to policymakers to less liberalize the trade sector to improve the air quality. This study confirms that more financial development is associated with less emission, which is in agreement with Tamazian et al. (2009) and Jalil and Feridun (2011). It can be thus suggested that financial development is an essential factor in Australia to have a better environment.

The findings show that the negative impact of energy consumption is higher than that of trade openness. We highly recommend that policymakers reduce the nation's consumption of fossil fuels and substitute them with more environmentally friendly sources of energy, such as solar energy. Australia receives a large amount of solar radiation per year. According to the Australian Government, Geoscience Australia (2008), the receiving solar radiation in this country is around 58 million PJ per year, which is almost 10,000 times higher than total annual energy consumption. Therefore, this substitution is highly recommended. The short-run causal relationship between the series shows that economic development in Australia needs to be better managed to decrease CO_2 emissions.

Declaration of ownership

This report is our original work.

Conflict of interest

None.

Ethical clearance

This study was approved by the institution.

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