Electricity consumption in Australia

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Electricity consumption in Australia: The role of clean energy in reducing CO_2 emissions

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Abstract

Electricity consumption is the primary source of carbon dioxide (CO_2) emissions in Australia. Hence, this research study aims to analyse the role of clean energy consumption on CO_2 emissions and electricity consumption in Australia by making use of yearly data, 1980–2014 and a battery of time series econometric techniques. The autoregressive distributed lag (ARDL) method is employed to investigate the short- and long-run estimates, while the Bayer and Hanck (2013) test is used to examine the cointegration relationship among the variables. The results from the ARDL technique show that a 1% increase in clean energy consumption reduces per capita CO_2 emissions and per capita electricity consumption by 5.50% and 1.19%, respectively in the long-run. The findings also confirm a significant long-run association among the variables. As such, it is emphasised that the government should take further initiatives toward a wider deployment of clean energy use, along with sustainable urbanisation to reduce per capita electricity consumption and CO_2 emissions in Australia.

JEL Classification: Q43, C33, Q40

Keywords: Australia; Electricity; CO_2 emissions; Cointegration and Clean energy

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1. Introduction

In Australia, electricity is the primary source of CO_2 emissions. The Australian CO_2 emissions account for 1.33% (580.1 Mt-CO_2e) of the total global emissions,[1] and 0.97% (422.7 Mt-CO_2e) of the total emissions are from the electricity sector (WRI, 2017). Coal continues to contribute to two-thirds of all electricity generation. Coal, gas, and oil account to approximately 93% of electricity generation with the highest CO_2 emissions per capita concentration (OECD, 2019). There is a growing debate over Australia's existing energy and environmental policy design. Australia is well above (22–25 tons) the OECD average in emissions per capita. Australia needs a comprehensive plan to implement 2030 emission targets. As indicated in a report by the Clean Energy Council (2017):

'…*Australia should be aiming for sustained reduction in electricity sector emissions and lower prices. While we acknowledge the initiatives being pursued by various state governments will mitigate some aspects of a substantial stalling of activity, a strong, national policy framework is likely to be more effective in delivering a transformation in the electricity sector at minimum cost. The clean energy sector's preference remains for a strong, stable and enduring clean energy policy from the federal government*'.

A review paper emphasised the link between climate change policies and investment activities in the electricity sector (Nelson et al., 2012). More specifically, they suggest that future policies should focus more on reducing emissions, particularly in the electricity sector, with non-renewable energy sources (primarily coal) being replaced by renewable ones. Fundamental shifts in the global energy sector open significant opportunities for Australia to move toward innovative energy changes (considering both technological and sectoral changes).

[1] Includes total global greenhouse gas emissions, except land-use, land-use change, and forestry (LULUCF). Mt-CO_2e denotes metric tonnes of CO_2 equivalent.

Recent studies outline various factors that can promote economic growth in Australia at the cost of environmental quality (Leal et al., 2019). For example, one study (Payne, 2010) establishes that Australia's ambitious economic growth targets have been the key driver of increased demand for electricity in the past, thereby, contributing to a large proportion of CO_2 emissions in the country (Payne, 2010). Ertugrul et al. (2016) argue that Australia's policy towards openness has played a key role in achieving the country's economic growth targets during the last two decades. Considering both economic and non-economic factors, Shahbaz et al. (2017) conclude that Australia has been a great beneficiary of globalisation in terms of economic growth, but environmental degradation has increased concomitantly.

There are recent papers in the Australian context that focus on energy consumption/energy production, but not on electricity consumption—the key variable in this study. For example, one study shows that both energy consumption and population growth are the main drivers of CO_2 emissions in Australia (Shahbaz et al., 2017). Another study emphasises the convergence of energy productivity in the case of larger Australian states, viz. Victoria and New South Wales (Bhattacharya et al., 2020). An analysis of the environmental Kuznets Curve (EKC) hypothesis has been conducted for Australia, along with China, Ghana, and the US (Sarkodie and Strezov, 2018). For the developed countries in the sample, such as Australia and the US, the EKC curve eventually plateaued. In another study examining 17 countries, the deployment of renewables is found to be effective in reducing CO_2 emissions (Yao et al., 2019). However, a panel study representing 38 countries reports that the deployment of renewables has been slow in Australia to reduce CO_2 emissions (Bhattacharya et al., 2016).

The empirical literature linking electricity consumption and CO_2 emissions remains undeveloped for the case of Australia.[2] To our knowledge, there is only one academic paper explaining the effects of overall electricity consumption on macroeconomic indicators.[3] Narayan and Smyth (2005) examine short- and long-run relationships across electricity consumption, employment, and real income. It shows that both employment and income have unidirectional causality to electricity consumption in the long-run. This study departs from their research linking CO_2 emissions and electricity consumption by considering variables such as clean energy and innovation. These are the key drivers in reducing CO_2 emissions and meeting the target for 2030. A number of other empirical studies also establish a significant linkage between electricity consumption and CO_2 emissions. For instance, Saint Akadiri et al. (2020) suggest that carbon emissions can be potentially reduced in Turkey by lowering electricity consumption, particularly those from fossil fuel energy sources. In another study, Rahman (2020), in the context of the top 10 electricity-consuming countries, also establishes a significant positive relationship between electricity consumption and CO_2 emissions. Therefore, this evidence confirms that there is a substantial positive association between electricity consumption and CO_2 emissions across country-specific or cross-country studies.

Reforms in the Australian electricity sector have resulted in increasing prices, higher costs, and expensive investments in the distribution process (Quiggin, 2014). In 2013–2014, the overall demand declined in the national energy market (NEM), which covers all states except Western Australia, as reported by the Australian Electricity Market Operator (AEMO). Australia needs to align its electricity usage to work towards the country's CO_2 emission goals.

[2] There is a vast body of literature on energy-growth and the CO_2 emissions-growth nexus. This is beyond the scope of this review and is thus not included.
[3] Using the three-regime hidden semi-Markov model, a recent study by Apergis et. al. (2019) finds different regimes for different Australian states. This and other studies on the electricity market do not consider the macroeconomic indicators relating CO_2 emissions and electricity consumption. As such, they do not suggest economy-wide policy prescriptions for electricity demand.

Therefore, there is a need for detailed empirical research in analysing electricity consumption and linking it with the drivers of CO_2 emissions.

The primary objective of this study is to investigate the role of clean energy consumption on CO_2 emissions and electricity consumption in Australia. In doing so, the study also incorporates a number of potential drivers of CO_2 emissions and electricity consumption. It narrows a gap in the literature by covering three aspects. First, it analyses a CO_2 emissions model, including demographic factors, such as urbanisation, along with research and development and clean energy consumption. This has resulted in higher levels of private sector investments in clean energy as clean energy innovation is expected to play a major role in Australia's reduction of CO_2 emissions.

Second, it utilises a simple model linking sectoral composition, globalisation, and clean energy consumption in explaining electricity demand in Australia using time series methods. High electricity consumption is the primary source of CO_2 emissions in Australia and clean energy plays a greater role in shifting this trajectory. Therefore, the role of clean energy (which combines improving energy technology and replacement of coal and other non-renewables to renewables) is significant in the case of the Australian electricity sector.

The main advantage of the time series analysis is that it allows an assessment focusing on an individual country, as well as being suitable for prediction purposes. Recently, there has been a significant emphasis on integrating clean energy policies to combat CO_2 emissions.[4] Gradual transitions to clean energy are predicted to have negative effects on CO_2 emissions and positive effects on overall electricity demand.

[4] A number of previous studies (e.g. Paramati et al., 2016; 2017) emphasised the role of clean energy consumption in reducing CO_2 emissions in emerging and major economies around the world.

Third, it establishes the significance of clean energy, innovation, and the presence of the services sector in reducing CO_2 emissions and electricity consumption in the long-run.[5] It also provides policy suggestions based on the findings obtained.

The rest of the paper proceeds as follows. Section 2 describes the empirical models tested and the data employed. Section 3 presents the empirical findings and relates them to the Australian electricity consumption and CO_2 emissions. Finally, Section 4 discusses the major findings and outlines the policy implications.

2. Empirical model, variables, and data

Considering the above background, this paper aims to investigate the role of clean energy consumption on CO_2 emissions and the drivers of electricity consumption by accounting for several factors in the models.

2.1. Model 1: Drivers of per capita CO_2 emissions

The first empirical model examines the determinants of CO_2 emissions. It considers per capita CO_2 emissions instead of carbon intensity. Considering that per capita CO_2 emissions are very high in Australia, it employs CO_2 emissions per capita as the dependent variable.[6] Following the relevant literature, CO_2 emissions are related to *scale, technological, and composition effects*. Scale effects are normally measured by both population (POP) and income (PI), while technological effects are based on technology improvements (Martinez-Zorzoso and Maruotti, 2011), and changes in the input or output mix are captured through composition effects. Patent applications (PA; an indicator of technology/innovation) and clean energy consumption (CEC) capture the technological changes and composition of energy-mix into our model. Moreover,

[5] 'Research and development' and 'innovation' are used interchangeably.
[6] Being a coal-dependent country, Australia's carbon intensity is expected to be higher in comparison to countries with a low carbon fuel-mix. Both the relative contribution of energy intensity and fuel-mix determine the overall carbon intensity changes.

the literature has emphasised other factors that could drive changes in CO_2 emissions, such as internationalisation (measured through the globalisation index G) and urbanisation (UR), which are considered as additional drivers.[7]

A link between clean energy (proxied by renewables) and carbon emissions is established for 15 European countries by Ucan et al. (2014) using the data between 1990 and 2011. Their results indicate that an increase in renewable energy consumption leads to increases in real GDP, which in turn has a negative impact on greenhouse gas emissions. Similarly, Farhani (2015) reports unidirectional causality running from renewable energy consumption to CO_2 emissions. Several empirical studies (Kasman and Duman, 2015; Halicioglu, 2009; Acaravci and Ozturk, 2010; Saboori and Sulaiman, 2012; Sadorsky, 2014) employ the variable of urbanisation as the main determinant of environmental pollution (e.g. CO_2 emissions). Rapid urbanisation can affect economic growth, energy consumption, and environmental degradation in developing countries, as well as in the developed world, albeit to a lesser extent. For EU member countries, trade is a significant determinant in increasing CO_2 emissions (Kasman and Duman, 2015). In Sadorsky's (2014) study, ecological modernisation, urban environmental transition, and compact city theories are considered in relating urbanisation to the natural environment. These theories suggest that urbanisation may have either positive or negative effects on the natural environment. A long-run, unidirectional, causal relationship is established between urbanisation and CO_2 emissions (Sadorsky, 2014).[8] Therefore, the following model is tested for CO_2 emissions:

$$CO_{2t} = f\,(POP_t, PI_t, PA_t, CEC_t, G_t, UR_t) \quad (1)$$

[7] Australia is investing heavily in clean energy innovations.
[8] The findings of Ahmad et al. (2020) indicate that fossil fuel consumption positively contributes to carbon emissions in the OECD economies.

where CO_2 denotes per capita carbon emissions. Real per capita income has been considered with a quadratic relationship with CO_2 emissions within the EKC hypothesis. Therefore, following the literature of Martinez-Zorzoso and Maruotti (2011), Arouri et al. (2012), and Jebli and Youssef (2015), an alternative (non-linear) version of model (1) is considered by adding a square term to account for the non-linear role of per capita income. Per capita CO_2 emissions are measured in metric tons; GDP per capita (PI) is measured in 2010 U.S. dollars; PA includes patent applications filed each year (a proxy for R&D)[9]; and CEC includes consumption of hydropower, nuclear, geothermal, and solar power as a percentage of total energy use.[10] An overall globalisation (G) index is used, which includes economic, political, and social globalisation. UR is the total urban population. To validate the EKC hypothesis, the following version of Model (1) is considered:

$$CO_{2t} = f\,(POP_t, PI_t, PI^2_t, PA_t, CEC_t, G_t, UR_t) \qquad (1')$$

2.2. Model 2: Drivers of per capita electricity consumption

In Model (2), the drivers of per capita electricity consumption (ELC) are examined. Electricity consumption is linked to a CO_2 emissions model as electricity is the primary source of CO_2 emissions. This is primarily due to the presence of the coal-driven electricity sector in Australia. Changes in sectoral shares of agriculture (AGR), industry (IND), and services (SER) are considered in the model to observe their separate role on electricity demand in Australia, as suggested by Tang and Shahbaz (2013) and Zhang et.al.(2017). Globalisation (G) and clean energy consumption (CEC) are added as additional factors that may affect the demand for electricity in Australia. As suggested by Weller (2018), globalisation created an oligopolistic market structure that increased the overall demand for per capita electricity. The availability of

[9] We use the sum of the number of patent applications to the European patent office and patent applications filed under the Patent Cooperation Treaty (PA; OECD, 2018). In the absence of patent and R&D data only for the energy sector, we have used the data at the national levels.
[10] Following Paramati et al. (2016, 2017), we use this measure.

clean energy provides an opportunity for consumers to choose renewable (clean) energy over non-renewable energy (electricity). This transition might be a result of wider awareness programmes to improve environmental sustainability by reducing the use of non-renewable energy sources to protect the planet and climate. This has been emphasised in Azad et al. (2014). Following one report, sectoral shares from CO_2 emissions and electricity consumption have changed over the last two decades.[11] Export sectors are energy-intensive and require more electricity relative to imported goods.

Recent initiatives of clean energy consumption have reduced energy intensity and this will have a direct effect on electricity prices and the overall electricity demand in the economy.[12] Except for the SER and CEC variables, a positive sign for the remaining variables is expected in the following empirical model:

$$ELC_t = f\,(AGR_t, IND_t, SER_t, G_t, CEC_t) \qquad (2)$$

where per capita electricity consumption (ELC) is in kilowatt-hours. To include sectoral shares in GDP, the total value added from the AGR, IND, and SER sectors are considered, while all the sectors are measured in constant 2010 US dollars. Except for the globalisation index, all the other variables are obtained from the World Development Indicators (WDI) online database maintained by the World Bank, while the data on the globalisation index is obtained from the KOF globalisation index database.[13] The series is on an annual basis, spanning the period 1980 to 2014, capturing both the pre- and post-reform periods. Following several recent studies

[11] https://www.energy.gov.au/government-priorities/energy-supply/renewable-energy-and-technology (accessed 23 December 2019).
[12] Commonwealth of Australia. National Inventory by Economic Sector 2014; 2016.
[13] To capture individual effects of globalisation from economic, social, and political aspects, the analysis uses the Swiss Economic Institute's KOF index (2013). This index combines three aspects of globalisation: economic globalisation, which includes economic flows in relevance to restrictions in trade and capital; social globalisation, which accounts for the spread of ideas, information, images, and people; and political globalisation that considers the diffusion of government policies (Dreher, 2006).

(Alam et al., 2016; Bhattacharya et al., 2015), the data series has been converted into natural logarithmic values.

The above models are investigated using time series econometric methods. Equations 1 and 1' are versions of the CO_2 emissions model, whereas Equation 2 is derived from the ELC model. In particular, the analysis applies the unit root test to examine the order of integration of the variables, and then an autoregressive distributed lag (ARDL) bounds testing approach is employed to investigate the long-run equilibrium relationship across these variables. The bounds testing procedure is a powerful methodological approach for estimating level relationships when the underlying property of time series is I(0) or I(1), or jointly cointegrated. The long-run elasticities are also explored using the ARDL approach. Endogeneity is less of a problem in the ARDL technique as this is free of residual correlation (i.e. all variables are assumed to be endogenous). Finally, the Fully Modified Ordinary Least Square (FMOLS) method is also applied for a robustness check and the validation of long-run estimates.

For robustness checks, the long-run equilibrium relationship is investigated among the variables in Equations (1) and (2) using the cointegration test recommended by Bayer and Hanck (2013). The major advantage of this new cointegration test is that it allows one to combine various individual cointegration tests developed previously to provide a more conclusive finding and to avoid potential conflicting results provided before. This test is based on four individual cointegration tests, including those outlined in previous studies (Engle and Granger, 1987; Johansen, 1991; Boswijk, 1994; Banerjee et al., 1998). Hence, the findings derived from this test are more informative and reliable.[14]

[14] The descriptive statistics using log data on the selected variables are provided in the Appendix-I. The main conclusion from these statistics is that the standard deviation is significantly higher for the patent applications; while the lowest standard deviation is found for CO_2 emissions. The evidences from Jarque-Bera test confirm that the null hypothesis of data is normally distributed is rejected only for the patent applications; while the null hypothesis is accepted for all the other variables. Therefore, these evidences imply that the data is normally distributed with the exception of patent applications.

3. Empirical Results and Discussion

3.1. Order of integration and structural breaks

To begin the empirical analysis, the Augmented Dickey-Fuller test (ADF; Dickey and Fuller, 1979) is applied. The results of the ADF test with structural breaks are displayed in Table 1. They highlight that none of the variables considered reject the null hypothesis of a unit root at the 5% level of significance. However, the null hypothesis could be rejected when the ADF test was applied to the first-order differences of the data series. The findings imply that all of the considered variables have the same order of integration. Furthermore, the ADF test also provides structural breaks in each of the series. These results indicate that the structural breaks prevail across the sample period and not in specific periods. Considering these findings, it is argued that there can be cointegration relationships among the variables in models (1) and (2).

[Insert Table 1 here]

3.2. Long-run equilibrium relationship

The long-run equilibrium association was explored among the variables in models (1) and (2) using the ARDL Bounds testing approach. The results are reported in Table 2. The ARDL Bounds cointegration test results for Equation (1), where the per capita CO_2 emissions are a function of the total population, per capita income, patent applications, clean energy consumption, globalisation, and urbanisation, indicate the rejection of the null hypothesis of no cointegration at the 1% significance level. Similar results were also obtained for Equation (1'), where the per capita income was squared in the model. Likewise, the results for Equation (2), where the per capita electricity consumption is a function of the GDP shares of agriculture, industries, service sector, globalisation, and clean energy consumption, imply a considerable long-run association among these variables. Finally, the ARDL Bounds test was applied to investigate the long-run relationship among variables in Equations (1), (1'), and (2), by excluding the global financial crisis (GFC) period (i.e. 2007–2009).[15] Overall, the findings from the ARDL Bounds testing approach indicate that all of the considered models document a substantial long-run equilibrium relationship.

[Insert Table 2 here]

Unstable parameters can result in model misspecifications and may yield biased estimates. The stability of the parameters of the ARDL models were examined, following others who emphasised that the estimated parameters may vary over time (Hansen, 1992). To confirm the stability of the parameters, the analysis makes use of the CUSUM test, which is based on the cumulative sum of the recursive residuals, as well as the CUSUM of squares test (Brown et al., 1975). If the estimated parameters show instability, both the CUSUM sum and CUSUM squares lie outside the area between the two critical boundaries. The findings of these tests on (1), (1'), and (2) are presented in Figure 1, which illustrates that the estimated statistics are within the 5% critical values, implying that the structure of the parameters has not diverged abnormally, and therefore, these estimates are stable over the period under examination.

[Insert Figure 1 here]

3.3. Short- and long-run estimates

The cointegration test results do not imply whether the right-hand side variables have a positive or negative impact on the left-hand side variables. Hence, the ARDL method is applied on

[15] The previous literature (e.g. Paramati, Gupta, and Roca, 2015) clearly highlighted that the GFC period for Australia is from mid of 2007 to the end of 2009. Therefore, in this paper, we excluded the data for 3 years (i.e. from 2007 to 2009) and then re-estimated the models to observe whether the GFC had any influence on our estimations.

Equations (1), (1'), and (2) to investigate the short- and long-run estimates using the full sample data. The results are presented in Table 3.

The findings in Equation (1) illustrate that a 1% increase in clean energy consumption reduces CO_2 emissions in the short- and long-run by 0.70% and 5.49%, respectively. It indicates that higher levels of clean energy consumption help to reduce CO_2 emissions in the short- and long-run. Income and urbanisation also have a significant positive effect on CO_2 emissions. In contrast, patent applications have a reduction effect on CO_2 emissions in the short- and long-run, whereas globalisation has a significant negative effect only in the long-run.

The per capita income is squared and included explicitly in the modelling approach to explore whether doubling per capita income reduces the growth of CO_2 emissions. The results from Equation (1') indicate that the squared per capita income (PI^2) has a substantial negative impact on CO_2 emissions. This finding implies that once Australia reaches a threshold in per capita income, economic activities will reduce growth in CO_2 emissions. These findings are consistent with the EKC hypothesis in Australia. Therefore, energy policies should be directed toward investing in research and development of clean energy for sustainable growth.

Moreover, the results from Equation (2) indicate that a 1% growth in the industrial sector increases electricity consumption in both the short- and long-run by 8.74% and 1.74% respectively, while a 1% growth in the service sector reduces electricity consumption in the short- and long-run by 6.41% and 4.97%, respectively.

[Insert Table 3 here]

An empirical investigation was carried out in both the short- and long-run using the ARDL method by excluding the global financial crisis (GFC) period from the analysis. The findings are reported in the last two columns of Table 3 and suggest that they are mostly similar when the GFC period is excluded. However, in most cases, the nature of impact remains the same, albeit statistically insignificant in some cases.

3.4. Robustness checks

For robustness checks, the long-run equilibrium relationship among the variables in Equations (1) and (2) are investigated using the cointegration test recommended by Bayer and Hanck (2013). The findings of these models in the full sample as well as those excluding the GFC period are reported in Table 4. The test results of EG-JOH and EG-JOH-BAN-BOS on all equations confirm the long-run equilibrium relationship for both the full sample and that excluding the GFC period. All the findings are statistically significant at the 1% or 5% level. Considering these findings, it can be argued that there is a considerable long-run association among the variables in Equations (1) and (2).

[Insert Table 4 here]

Moreover, the analysis investigates the long-run estimates in Equations (1') and (2) by using the Fully Modified Ordinary Least Squares (FMOLS) method (Hansen and Phillips, 1990) for both the full sample and the one excluding the GFC period. This methodological approach uses a semi-parametric method to address the issue caused by the long-run correlation between the cointegrating equation and stochastic regressor innovations. This method provides more reliable findings concerning long-run estimates (in the presence of cointegration association). The new findings are presented in Table 5.

Based on Equation (1') across the full sample and excluding the GFC period, a 1% increase in clean energy uses decreases CO_2 emissions by 0.10% and 1.07% in the full sample and excluding the GFC period, respectively. However, population, per capita income, globalisation, and urbanisation have a significant positive effect on CO_2 emissions. Similarly, the results suggest that a 1% growth in squared per capita income, as expected, decreases CO_2 emissions by 2.09% and 0.94% in the full sample and excluding the GFC period, respectively. A similar impact was also found on innovations (PA). Finally, the results from Equation (2) document that industrialisation and globalisation have a positive contribution to electricity consumption, whereas the services sector has a significant negative impact in the full sample period. The evidence from excluding the GFC period shows that clean energy consumption has a substantial negative impact on electricity consumption, along with the service sector; whereas agriculture, industrialisation, and globalisation continue to drive electricity demand in Australia. Therefore, future globalisation strategies and domestic production need to maintain a balance between low-carbon intensive service sector and investing in carbon-intensive industries to use clean energy to reduce overall electricity consumption. The overall findings from the FMOLS analysis are similar to those from the ARDL approach, suggesting that the findings of this study are robust.

[Insert Table 5 here]

The results for Australia are consistent with other studies. In particular, one study also provides statistical support to the EKC using time series data (Ang, 2007). It makes use of the ARDL bounds test and data for France, spanning the period 1960–2000. Others employ a dataset for Turkey over the period 1968–2003, using the cointegration method to arrive at an inverted-shaped form of the EKC (Akbostanci et al., 2009). Another study provides solid evidence of an inverted U-shaped EKC in the case of Nigeria over the period 1960–2008 (Chuku, 2011). One of the most recent EKC estimation studies uses a Turkish data sample, spanning the period 1960–2013 (Oztac et al., 2017); it reports the presence of an inverted U-shaped EKC for CO_2 emissions.

The findings on the role of R&D in mitigating the impact of CO_2 emissions are related to the fact that firms attempt to develop green products or production supported by increased operational and energy efficiencies (Dangelico and Pujari, 2010). As a result, environmental innovation (i.e. eco-innovation) is a popular environmental strategy that many firms adopt to achieve superior environmental and economic performance (Triguero et al., 2013). More specifically, a positive relationship between environmental investment and operational performance has been identified (Gonzalez-Benito and Gonzalez-Benito, 2005). However, in other cases, studies have documented a positive link between R&D expenditures and environmental management systems (Arora and Cason, 1996), but a negative link between R&D expenditures and pollution (Cole et al., 2005). Similarly, a recent study by Alam et al. (2020) suggests that R&D plays an important role in promoting clean energy consumption and reducing the growth of CO_2 emissions in a sample of OECD economies in which Australia is part of the sample countries. Similarly, Paramati et al. (2020) also confirm that the growth in R&D activities not only increases renewable energy consumption, but also reduces CO_2 emissions in a sample of EU member countries. Researchers have also found a positive link between proactive environmental management and environmental performance (López-Gamero et al., 2009). Overall, the link between R&D investments and environmental performance appears to be rather varied (Etzion, 2007).

4. Conclusion and Policy Implications

At the United Nations Framework Convention Conference of the Parties (COP) in Paris, Australia ratified in reducing greenhouse gas emissions by 26–28% by 2030 in comparison to the 2005 levels. The Australian government is continuously reviewing its climate policies to meet the 2030 targets. Australia has a good potential to reduce emissions at a relatively low cost in which the electricity sector plays a major role. The findings of this study reveal that the growth of per capita income adds to environmental degradation; however, once it reaches a threshold point, then it will assist in improving environmental sustainability. In this regard, policymakers need to initiate environmental awareness programmes among citizens and should focus on actions relating to electricity consumption and the degradation of the environment. Further, the government needs to be proactive in funding and encouraging R&D activities in energy and environment-related to achieve sustainable economic growth in the country.

This study established that growth in clean energy consumption significantly reduces CO_2 emissions and electricity consumption both in the short- and long-run. Therefore, the need for continuous clean energy deployment in reducing emissions and electricity consumption is emphasised. By investing in clean energy resources, the country will reduce the burdens of fossil fuel consumption, and simultaneously reduce emissions. Policy advisers and the government think-tank should promote effective policies for the growth of clean energy generation and with specific applications in the real economy. This has been occurring in recent years as reported by Clean Energy Australia (2021).[16] Renewable energy sources generated 2.7% of the total electricity. Moreover, the findings indicate that both population and urbanisation exert significant effects on increasing CO_2 emissions. The impact of globalisation on electricity consumption was positive and statistically significant. Based on these findings, it is argued that greater engagement of the Australian economy with global markets is increasing the demand for electricity use by increasing economic activities, while emitting more CO_2. Therefore, policy advisers need to work with alternative energy supply sources to meet the increasing demand for energy. For example, more emphasis should be placed on increasing clean and renewable energy sources to improve energy supply conditions. This will eventually improve the environmental quality and decrease the dependence on non-renewable

[16] https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2021.pdf

energy sources. Focusing on the service sector for export purposes and importing industrial output will reduce emission-intensive trade transactions and the overall electricity consumption. Among the sectors, namely agriculture, industry, and services, the industrial sector is found to be carbon-intensive, while the service sector is associated with lower CO_2 emissions in the case of Australia. Investing in clean energy and reducing coal exports should be prioritised.

While it is beyond the scope of this research to determine the overall policy aspects in designing the electricity market in Australia, the findings emphasise the following policy suggestions which need to be prioritised by Australia to meet specific CO_2 emission targets.

Considering that the electricity sector is the major polluter in Australia, investments in coal technology and clean energy resources (e.g. renewables, battery storage) need to be prioritised. This sector is in a good position to reduce emissions at a relatively low cost. In this context, research, development, and innovation will play major roles in supporting various schemes in a cost-effective manner in reducing emissions.

Increasing energy efficiency in the urban sector will enhance affordability. Federal and state governments should further promote urbanisation, enhance renewable energy resources, and provide incentives for developing clean energy consumption and a low-emission urbanisation programme.

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Table 1: Unit root test results with structural breaks.

Variable	t-Statistic	Prob.	Break date	t-Statistic	Prob.	Break date
	Level			First difference		
CO_2	-3.353	0.471	1995	-6.759***	0.000	2009
POP	-2.785	0.794	2007	-6.061***	0.000	2007
PI	-2.549	0.888	1993	-4.996***	0.000	1992
PA	-3.794	0.239	1999	-4.531**	0.040	1997
G	-2.879	0.749	1991	-6.378***	0.000	2002
UR	-0.336	0.990	2008	-8.537***	0.000	2007
ELC	-3.735	0.265	1985	-5.874***	0.000	2002
AGR	-3.107	0.623	1995	-9.708***	0.000	2009
IND	-0.760	0.990	1998	-6.329***	0.000	2003
SER	-2.336	0.940	1993	-5.031***	0.000	1992
CEC	-1.978	0.984	2012	-8.211***	0.000	2009

Notes: The unit root test results were estimated using the constant in the models following Perron and Vogelsang (1993); ** and *** indicate the rejection of the null hypothesis of a unit root at the 5% and 1% significance levels, respectively.

Table 2: The ARDL Bounds test for the cointegration analysis.

	Model	F-statistic	Lag order	Outcome
	Full Sample			
Eq1	$CO_2 = f\,(POP, PI, PA, CEC, G, UR)$	8.249***	6	Long-run relationship exists
Eq2	$ELC = f\,(AGR, IND, SER, G, CEC)$	9.830***	6	Long-run relationship exists
	Excluding the GFC period			
Eq1'	$CO_2 = f\,(POP, PI/PI^2, PA, CEC, G, UR)$	7.017***	4	Long-run relationship exists
Eq2	$ELC = f\,(AGR, IND, SER, G, CEC)$	6.715**	5	Long-run relationship exists

Note: ** and *** indicate the rejection of the null hypothesis of no long-run relationship at the 5% and 1% significance levels, respectively.

Table 3: Short-run and long-run estimates from the ARDL models.

Eq 1': $CO_2 = f\,(POP, PI/ PI^2, PA, CEC, G, UR)$				
	Full sample		*Excluding the GFC period*	
Variable	Short-run estimates	Long-run estimates	Short-run estimates	Long-run estimates
	Coefficient	Coefficient	Coefficient	Coefficient
POP	2.849*** (3.154)	-5.350*** (-4.166)	5.154*** (6.108)	11.417*** (9.730)
PI	0.147** (1.948)	2.647*** (3.402)	0.248*** (2.913)	1.709*** (5.739)
PI^2	-0.0837* (1.900)	-1.165*** (4.196)	-	-
PA	-0.348*** (-2.881)	-4.012*** (-4.973)	-0.016*** (-3.107)	-0.463 (-1.031)
CEC	-0.701*** (-4.544)	-5.497*** (-2.654)	-1.845*** (-3.645)	-4.219*** (-3.404)
G	-0.108 (-0.172)	-1.186*** (-2.705)	-0.248*** (-2.460)	-0.269 (-1.013)
UR	3.937*** (5.154)	5.107*** (3.149)	8.401*** (7.184)	3.172*** (4.051)
CE (-1)	-0.110*** (-3.071)	-	-0.815*** (-2.441)	-
Constant	-	-	-	-
Eq 2: ELC = f (AGR, IND, SER, G, CEC)				
AGR	3.168 (0.137)	1.738 (0.096)	0.491 (0.816)	1.072 (1.013)
IND	8.741*** (6.187)	1.709*** (4.153)	5.219*** (3.754)	2.217*** (3.170)
SER	-6.412*** (-3.901)	-4.972*** (-4.053)	-0.0837* (1.900)	-1.230** (-2.005)
G	0.348*** (2.881)	4.012*** (4.973)	0.016*** (3.107)	0.118*** (3.182)
CEC	-0.108 (-0.172)	-1.186*** (-2.705)	-0.248*** (-2.460)	-2.916*** (-6.104)
CE (-1)	-0.110*** (-3.071)	-	-0.815*** (-2.441)	-
Constant	-	-	-	-

Note: *, **, and *** imply the significance levels at the 10%, 5%, and 1%, respectively.

Table 4: Bayer-Hanck (2013) cointegration test results.

Models	Full sample		Excluding the GFC period	
	EG-JOH	EG-JOH-BAN-BOS	EG-JOH	EG-JOH-BAN-BOS
Eq 1: $CO_2 = f\,(POP, PI, PA, CEC, G, UR)$	98.046***	388.102***	29.229**	245.679***
Eq 2: $ELC = f\,(AGR, IND, SER, G, CEC)$	120.928***	60.497***	163.001***	190.430***

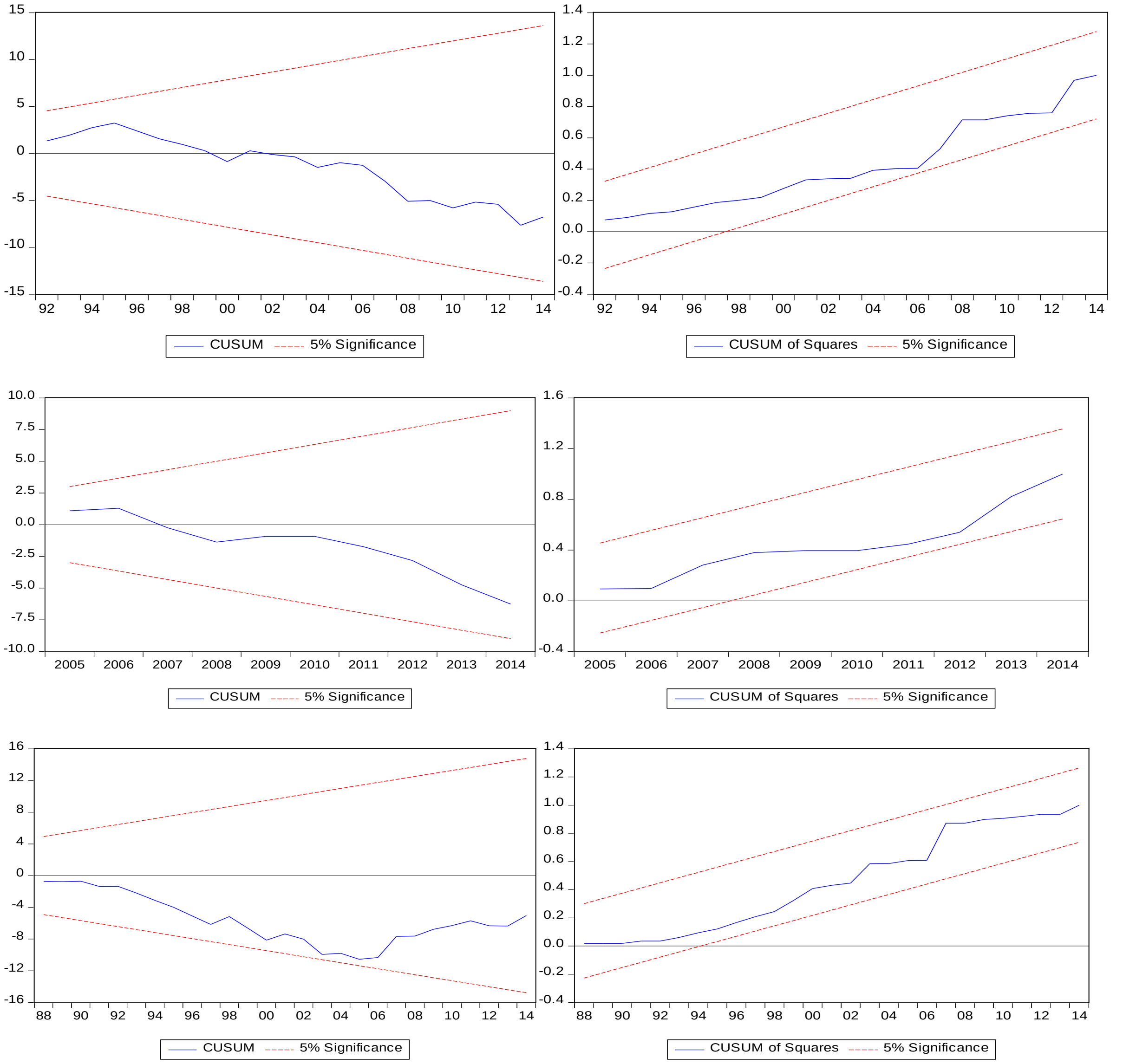
Note: The models were estimated using unrestricted constant; *** and ** indicate the rejection of the null hypothesis of no cointegration at the 1% and 5% significance level.

Table 5: Long-run estimates using the FMOLS estimations.

Eq 1': $CO_2 = f(POP, PI, PI^2, PA, CEC, G, UR)$			*Eq 2:* $ELC = f(AGR, IND, SER, G, CEC)$		
	Full sample	*Excluding the GFC period*		*Full sample*	*Excluding the GFC period*
Variable	Coefficient	Coefficient	Variable	Coefficient	Coefficient
POP	0.539* (1.487)	1.034*** (3.837)	AGR	0.0936 (0.174)	0.0854* (1.130)
PI	2.315*** (5.062)	1.305*** (9.416)	IND	2.015*** (4.055)	3.408*** (3.094)
PI^2	-2.094*** (-3.078)	-0.946* (-1.120)	SER	-3.528*** (-8.741)	-5.701*** (-4.892)
PA	-1.004*** (-2.390)	-8.305*** (-15.487)	G	1.602** (1.372)	2.050*** (2.904)
CEC	-0.108*** (-3.681)	-1.071*** (-7.125)	CEC	-2.314 (-0.031)	-0.039* (-1.831)
G	1.074*** (3.581)	0.917*** (5.015)	-	-	-
UR	4.218*** (5.190)	3.073*** (7.182)	-	-	-
Constant	-13.491***	-19.713***	-	-14.008	-9.947

Note: *, **, and *** imply the significance levels at the 10%, 5%, and 1%, respectively.

Figure 1: Cumulative sum of recursive residual and cumulative sum of the squares of recursive residuals (Model-1, 1' and 2 are displayed below in rows).



Appendix-I: Descriptive statistics

	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability
CO2	2.792	2.901	2.684	0.063	0.112	1.703	2.526	0.283
ELC	9.097	9.303	8.685	0.190	-0.775	2.329	4.160	0.125
POP	16.734	16.971	16.503	0.135	0.021	1.946	1.624	0.444
PI	10.612	10.909	10.304	0.203	-0.015	1.579	2.948	0.229
PA	7.204	9.434	1.386	2.971	-1.091	2.330	7.598	0.022
CEC	2.067	2.228	1.899	0.091	-0.259	2.163	1.414	0.493
G	4.284	4.396	4.135	0.096	-0.354	1.556	3.772	0.152
UR	2.757	3.001	2.531	0.133	0.112	2.027	1.454	0.483
AGR	23.577	23.997	22.991	0.291	-0.068	1.831	2.022	0.364
IND	26.112	26.463	25.713	0.237	-0.290	1.821	2.516	0.284
SER	26.884	27.456	26.250	0.380	-0.100	1.713	2.474	0.290

Note: The descriptive statistics were calculated using log (LN) data.