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Does tourism contribute towards zero-carbon in Australia? Evidence from ARDL modelling approach

Avishek Khanal [*,1], Mohammad Mafizur Rahman, Rasheda Khanam, Eswaran Velayutham

School of Business, Faculty of Business, Education, Law and Arts, University of Southern Queensland, Toowoomba, Australia

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ABSTRACT

Climate change is an increasingly serious problem, resulting in significant environmental degradation, and various policies and regulations have been adopted to achieve zero-carbon with the goal of ameliorating this issue. To end this, along with economic growth, governments should consider human activities such as tourism and energy consumption, which are responsible for raising CO_2 emissions, a proxy for environmental degradation, in the atmosphere. Tourism may contribute to climate change through various adverse activities such as transportation and hotel stays. Thus, this study investigates the long-run cointegrating relationship between tourism and environmental degradation, focusing on some other specific factors. Using data from 1976 to 2019, the autoregressive distributed lag bounds test approach is applied to obtain both long-run and short-run coefficients. The estimated results indicate that tourism obstructs the achievement of zero-carbon in Australia. Along with tourist arrivals, energy consumption and gross domestic product are also significant contributors which have a positive and statistically significant long-run relationship with carbon emissions. This study provides policy implications for zero-carbon and sustainable tourism growth in Australia.

Author contribution

Methodology, Software, Writing – review & editing. Avishek Khanal: Conceptualization, Writing – original draft, Data curation. Mohammad Mafizur Rahman: Conceptualization, Supervision, Validation. Rasheda Khanam: Conceptualization, Supervision, Validation.Eswaran Velayutham: Methodology, Software, Writing – review & editing.

1. Introduction

Climate change is one of the most serious problems currently facing the world, with significant environmental degradation resulting from greenhouse gas (GHG) emissions, such as carbon dioxide (CO_2) [1]. Among the various GHGs such as nitrous oxide, methane and chlorofluorocarbons; CO_2 emissions alone contribute 74.4% to the total [2] and have thus emerged as the most significant contributor to global warming and subsequent environmental degradation. To prevent such damage, every country has pledged to limit carbon emissions. While considerable progress has been made towards shorter-term emission reduction objectives, the longer-term emissions trend continues to cause concern.

After dragging its feet on climate change, the Australian Federal Government, like much of the rest of the world, has now committed to achieving zero-carbon by 2050 [3]. Almost all industrialised economies have tightened their 2030 objectives and pledged to reduce emissions by about half this decade [4]. Achieving a zero-carbon or low-emissions goal requires considerable reductions in energy consumption [5] across a variety of contexts because all human activities—including transport, housing, industrial production and tourism—are responsible for raising CO_2 emissions in the atmosphere [5–9]. Tourism is the largest industry in the services sector in Australia and in many other countries, including developing countries with often-fragile economies [10]. According to the World Travel and Tourism Council (WTTC), in 2019 (before COVID19), travel and tourism accounted for US$8.9 trillion (10.3%) of global gross domestic product (GDP) [11]. Tourism contributes to the economy of both developed countries, such as Australia, and developing countries, with businesses associated with tourism creating employment opportunities in a range of ways (including hospitality, accommodation, and catering), which helps to alleviate unemployment and advance manufacturing and service sectors [12]. In 2019, tourism created 330 million jobs, or one job in 10, around the

* Corresponding author.
E-mail addresses: avishek_khanal@yahoo.com, avishek.khanal@usq.edu.au (Avishek Khanal).
[1] Current address: School of Business, Faculty of Business, Education, Law and Arts, University of Southern Queensland, Toowoomba, Australia.

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world [11]. Thus, tourism contributes significantly to economic growth and resumption will be necessary to recover from the economic crises caused by the COVID19.

Tourist arrivals—an essential component of tourism—positively boost the economy and thus play a vital role in a nation's economic growth and development [13]. However, although it brings economic benefits, a high level of tourism is likely to exert negative environmental effects, such as larger CO_2 emissions from using the maximum energy resources available during transportation, hotel stays, theme park attendance and other activities [14]. Given that energy consumption is directly linked with carbon emissions [15,16], tourism activities directly affect the environment in developed nations [17]. In comparison to other economic sectors, tourism consumes a lot of energy [18].

Policymakers in Australia have proposed a path to net zero-carbon, motivated by the need to minimise local contributions to global GHG emissions. The Morrison government took what it described as 'practical and reasonable steps to achieve zero emissions by 2050', while safeguarding Australian employment and creating new possibilities for industry and regional Australia. To achieve zero-carbon overall, zero-carbon energy, has shown promising results, with an 80% reduction in carbon emissions [19]. In addition, decarbonisation policies such as the climate solutions fund, national energy efficiency measures, national energy production plan, energy performance, and refrigeration and air conditioning measures are in effect in Australia [20]. Direct electrification is used to decarbonise electricity generation for residential and commercial buildings, industry, mining, and land transportation [19]. Australia can quickly adopt zero-emissions technologies, such as renewable energy and electric cars, in sectors including power, transportation, and buildings [21]. However, as per our knowledge, tourism has been omitted when considering how to achieve zero-carbon in Australia.

This study investigates the long-run cointegrating relationship between international tourist arrivals and environmental degradation in Australia. In addition, the effects of energy consumption, GDP, financial development, gross fixed capital formation (GFCF) and total population on environmental degradation are analysed using annual data from 1976 to 2019. The novel contribution of this study is that it combines tourism growth and pollution into a single framework, allowing for consideration of tourism's negative impacts (pollution) against its positive influence (economic growth) in a single framework, while also accounting for other factors such as energy, financial development, capital and population. This research also adds to the growing body of knowledge about the possibility for decarbonisation to aid in emission reductions and to achieve zero-carbon by using the autoregressive distributed lag (ARDL) methodology. Because ARDLs are utilised to simulate the environmental degradation function regardless of the series' mixed integration (i.e. I (0)/I (1)) in modelling a long-run connection, this ARDL model outperforms other standard cointegration approaches [22]. Last, to avoid bias in our results, we have added energy consumption to allow for more conclusive findings. The results of our study confirm the presence of cointegration between the variables of the study. Furthermore, the ARDL results also suggest that tourism has a positive and significant impact on carbon emissions. The paper concludes by indicating policy implications of the findings; in particular, that environmentally friendly transportation (e.g. push bikes) and adventure-based tourism such as trekking and scuba diving should be promoted to reduce energy consumption and achieve zero-carbon.

1.1. Trends in CO_2 emissions, tourist arrivals, and energy consumption in Australia

Both as a measure of economic and social growth and as a fundamental humanitarian necessity, energy plays a crucial role in everyday life and economic activity. For instance, Magazzino [23] claimed that energy consumption is important for all industries across the globe, and aids in development of a country. However, it is generally accepted that energy consumption is responsible for environment degradation with tourism also exerting negative impacts. Thus, this section assesses trends in CO_2 emissions, tourism and energy consumption to examine the relationships between them. The volume of CO_2 emissions in Australia has increased over the last four decades (see Table 1). In 1976, carbon emissions were 14.14 per capita. This increased over the three decades until 2010, before declining, perhaps in line with the introduction of solar energy and a reduction in the use of fossil fuels in Australia [24]. The country is responsible for one of the highest CO_2 emissions in the world, accounting for 16.88 per capita carbon emissions in 2019 [25].

The graphs below present the trends in CO_2 emissions and tourist arrivals in Australia from 1974 to 2019. Fig. 1 demonstrates that carbon emissions followed an increasing trend until 2008, and then declined until 2019. In contrast, tourist arrivals have gradually increased over time.

In 1976, Australia welcomed more than half a million international tourists. The 1980s and 1990s saw a significant rise in numbers, which was most evident in the 1990s, where the number of tourists increased from 2,214,900 in 1990 to 3,725,900 in 1995 (see Fig. 2). A marked increase in visitor numbers was observed during the 2000 Sydney Olympics, with arrivals skyrocketing to nearly five million. This number steadily gained momentum until 2019, when Australia greeted 9.4 million international tourists. Similarly, Fig. 3 shows that there was a gradual rise in primary energy consumption throughout the four decades from 1976 to 2019.

2. Literature review

Climate change and the resulting environmental degradation are serious global issues. To overcome further degradation, many researchers have examined different contributors to carbon emissions. While the consumption – carbon emissions – economic growth nexus is examined extensively by extant literature, the impact of economic policy uncertainty and human activities such as tourism on a carbon function has yet to be explored, particularly in Australia. Among a variety of causes, analysts have found that tourism contributes significantly to environmental pollution. Thus, policymakers and researchers have recently displayed interest in investigating the effect of tourism on the environment. For example, Pigram [26] examined the tourism–environment relationship and found that tourism may influence environmental quality in three ways: significantly negatively, moderately negatively, and positively [26]. Numerous studies have found a positive and significant effects of tourism on CO_2 emissions (i.e. tourism increases CO_2 emissions) [6,7,10,17,27–32]; in contrast, some have argued that tourism does not harm the environment [13,33–35].

Tourism has been found to be degrade the environment in countries such as Malaysia as confirmed by Solarin [32], who studied the determinants of CO_2 emissions with a particular emphasis on tourism development. The findings from cointegration and causality tests indicated that a 1% increase in financial development leads to a 0.19% increase in CO_2 emissions, and a 1% increase in arrivals lead to a 0.22%

Table 1
Trends in tourist arrivals, carbon emissions and GDP in Australia.

Year	CO_2 per capita	International tourist arrivals	Energy consumption
1976	14.14	531,900	192.8
1980	15.24	904,700	207.7
1985	15.07	1,142,700	201.1
1990	16.53	2,214,900	218.6
1995	17.24	3,725,900	230.3
2000	18.70	4,931,300	246.9
2005	18.78	5,463,000	250.6
2010	18.28	5,871,600	240.5
2015	17.27	7,449,900	237.0
2019	16.88	9,465,800	233.2

Note: Data for a select number of years are presented to avoid a large table size.

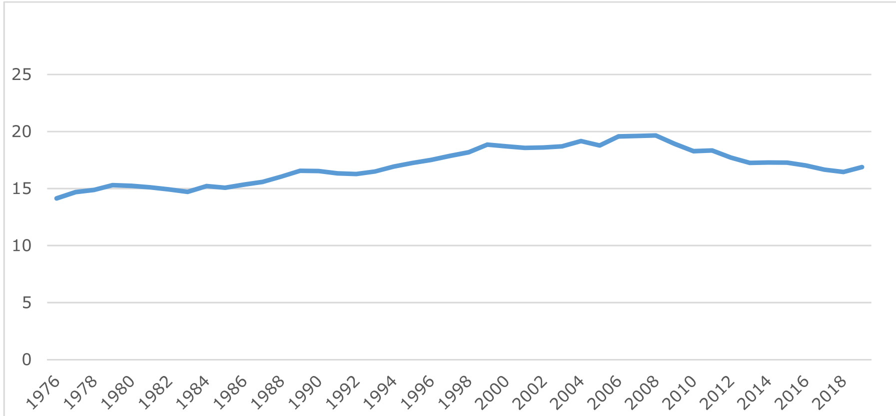

Fig. 1. Trends in CO_2 emissions in Australia.

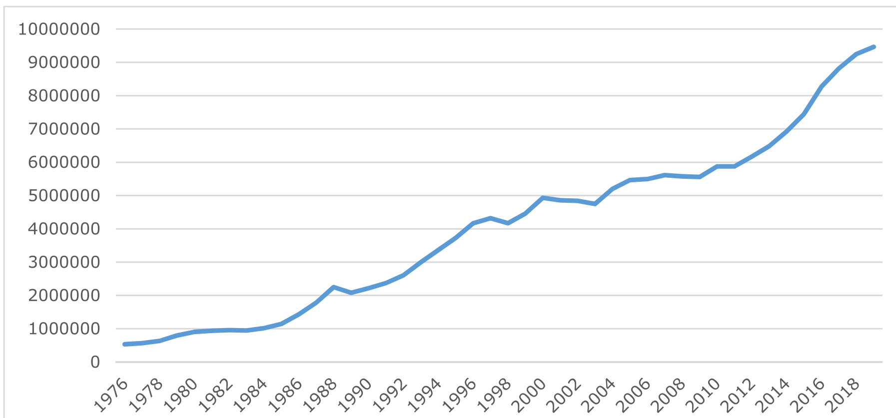

Fig. 2. Trends in tourist arrivals in Australia.

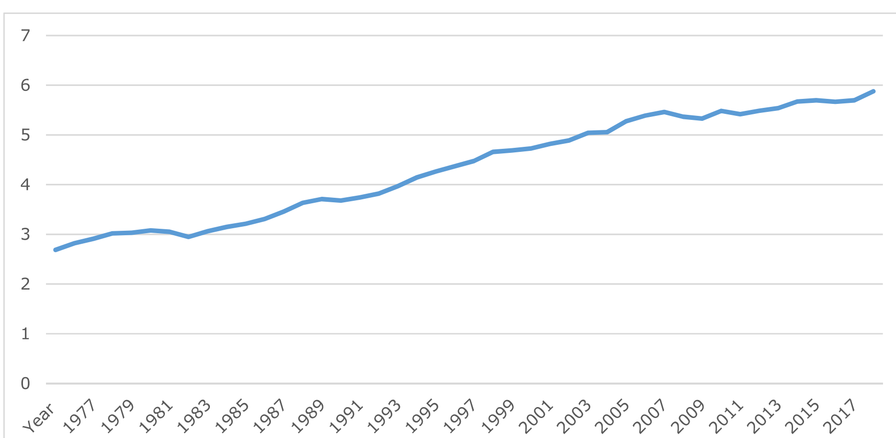

Fig. 3. Trends in energy consumption in Australia.

increase in air pollution in the long run. Similarly, Katircioglu [29] investigated the long-run equilibrium relationship between tourism, energy consumption and CO_2 emissions using ARDL, variance decomposition and impulse responses. The variance decomposition analysis and impulse responses confirmed that tourism development leads to significant variations in CO_2 emissions in both the short and long run. This was further supported by Katircioglu et al. [30], who studied the long-run equilibrium relationship between tourism and CO_2 emissions in Cyprus. They used bounds tests, conditional error correction models and conditional Granger causality tests from 1970 to 2009, and found that tourist arrivals and carbon emissions were cointegrated, suggesting that tourism affects CO_2 emissions in the long run. They concluded that tourist arrivals have a positive and statistically significant effect on CO_2 emissions.

Tourism like other economic activities, has a close relationship with environmental quality, as it increases CO_2 emissions by increasing energy consumption. León et al. [17] investigated the link between tourism and carbon emissions in 14 developed countries and 31 less-developed countries from 1998 to 2006. The results showed that a 1% increase in tourist arrivals raised CO_2 emissions by 0.13% and 0.04% in developed and less-developed countries, respectively. The results also demonstrated that population growth increased carbon emissions in developed and developing countries, with a 1% rise in the population resulting in a 0.87% rise in CO_2 emissions in developed countries and a 0.49% rise in less-developed countries [17]. Likewise, Durbarry and Seetanah [7] reviewed the effect of tourism and travel on climate change in Mauritius, and found that a 1% increase in tourist arrivals was associated with a 0.08% increase in CO_2 emissions in the long run. The ARDL model long- and short-run results showed that an increase in tourist arrivals significantly and positively affected CO_2 emissions.

A study conducted in Southeast Asia by Sherafatian-Jahromi et al. [31] analysed a linear and nonlinear nexus between tourism and CO_2 emissions, using the panel cointegration and pooled mean group techniques, and found that tourist arrivals and carbon emissions are cointegrated, suggesting that tourism increases CO_2 emissions in the long run. Additionally, in Pakistan, tourist arrivals significantly affect carbon emissions, with a 1% increase in tourist arrivals increasing carbon emissions by 0.14% in the long run [10]. Turkey has been a popular location for which to investigate the relationship between CO_2 emissions and tourist arrivals. In a study using three cointegration tests (Bayer--Hanck, Fourier ADL and ARDL), Eyuboglu and Uzar [28] found that a 1% increase in tourism and GDP caused a 0.099% and 0.766% increase in carbon emissions, respectively. For the Brazil, Russia, India, China and South Africa (BRICS) economies, the tourism sector has been found to significantly encourage economic growth, but also degrade environmental quality [27]. The above studies each demonstrated that tourist arrivals are a source of environmental degradation.

A recent study by Koçak et al. [8] using an advanced panel data estimation that focused primarily on how CO_2 emissions reacted to tourism developments found that tourism arrivals have an increasing effect on CO_2 emissions, while tourism receipts have a reducing effect on the environment. Using data from 31 selected OECD countries from 1995 to 2016 and a panel quantile approach, Alola et al. [6], revealed that the effect of international tourism arrivals is significant and damaging to environmental quality.

In contrast to the above research demonstrating that tourism leads to environmental degradation, other research has found that tourism decreases CO_2 emissions. A study by Lee and Brahmasrene [13] using cointegration tests examined the influence of tourism on economic growth and CO_2 emissions, using panel data from European Union (EU) countries from 1988 to 2009, and found that a 1% increase in tourism arrivals reduced CO_2 emissions by 0.105%. The findings argued that tourism directly affects economic growth and reduces CO_2 emissions in the EU. This was further supported by Shakouri et al. [35] for 12 Asia-Pacific countries from 1995 to 2013. Using a panel generalised method of moments (GMM) and panel Granger causality test, the findings revealed that tourism arrivals resulted in a decrease in CO_2 emissions in these Asia-Pacific countries. Further, Dogan and Aslan [34] explored the relationship between CO_2 emissions, real GDP, energy consumption and tourism in the EU and candidate countries, using panel models robust to heterogeneity and cross-sectional dependence. The results from ordinary least squares (OLS) with fixed effects, fully modified OLS (FMOLS), dynamic OLS (DOLS) and the group-mean estimator indicated that tourism lessens CO_2 emissions. Balsalobre-Lorente et al. [33] inspected the long-run relationship between economic growth, international tourism, globalisation, energy consumption and CO_2 emissions in developed countries, and concluded that international tourism leads to environmental improvements once economies have reached a specific improvement phase in their tourism industry.

Modelling the transition to a decarbonised environment or to achieve zero-carbon is crucial. Several studies have been conducted regarding renewable energy policies at the national and regional levels in Australia, including those examining zero-carbon housing in Victoria [5], contributions to regional decarbonisation [36], a zero-carbon, reliable and affordable energy future [19], and zero-emission housing policy development [37]. However, though tourism is a significant contributor to carbon emissions, it was ignored in all these studies.

The increased use of renewable energies has contributed to a decrease in worldwide emissions growth [38]. According Magazzino et al. [38] empirical research suggests that renewable energy consumption is an effective policy tool for reducing CO_2 emissions without hurting GDP growth. Financial development can also significantly negatively affect the environment. Rjoub et al. [39] investigated the effects of financial development, political institutions, urbanisation and trade openness on CO_2. Using FMOLS, DOLS and canonical cointegrating regression, they found that financial development significantly increases CO_2. In a cross-sectional weighted estimated generalised least squares methodology, Arellano-Bond GMM and orthogonal-deviation GMM, Yasin et al. [40] found that a 1% rise in financial development increases CO_2 by 0.82%. In accordance, GFCF is among the main contributors to CO_2 emissions, with a 1% increase in GFCF causing an 8.5% increase in CO_2 [41]. Thus, GFCF has a positive long-run effect on CO_2 emissions [42]. Tourism and GFCF homogeneously cause CO_2 emissions [43]. Generally, total population increases carbon emissions [44]; however, Shi et al. [45] found that an increase in total population leads to decreased carbon emissions in upper-middle-income and high-income countries, and this was supported by Khanal [46] in the Australian context.

Although various studies have explored the energy--growth–environment relationship [34,41,42,47], few have investigated the effect of tourism on the carbon emissions growth nexus [10,28]. As noted earlier (see Table 1), Australia welcomes a high number of tourists, and also discharges a high level of CO_2. Thus, an assessment of the connection between international tourist arrivals and environmental degradation is crucial. A large body of literature has investigated the effect of tourism on carbon emissions in various including Mauritius [7], Cyprus [30], Malaysia [32], Pakistan [10] and Turkey [28,29,48].

This research differs from earlier effort in two ways, allowing us to address gaps in the existing literature. To our knowledge, this is the first study to use the recently established ARDL technique to examine the factors driving CO_2 emissions to achieve zero-carbon in Australia. Moreover, the Zivot-Andrews unit root test approach is used to account for the break in the time series, offering a novel component of the research as previous studies have ignored such a possibility in zero-carbon analysis. The innovation and scientific contribution of this study lies in examining the nexus between carbon emissions, tourism, energy, economic growth, financial development, capital and total population using the ARDL modelling approach. The findings of this paper will help policymakers to analyse tourism and energy policies from a broader environmental perspective.

3. Empirical model and econometric methods

Following previous studies, this study estimates the nexus between tourist arrivals and the environment, while controlling energy consumption, GDP, financial development, GFCF and total population. The linkages between these variables are tested from yearly time-series data for 1976 to 2019. GDP data were available only from 1976, and tourism data only until 2019; thus, the selection of the sample period was based on the availability of annual data before the COVID-19 pandemic to analyse the long-run relationship between the variables. We used the dependent variable of CO_2 emissions per capita [10,28] as a proxy for environmental pollution, and the main independent variable of tourist arrivals (TA) as a proxy for tourism. The control variables are energy consumption (primary energy consumption), GDP per capita (constant 2010 US$) [29,32] for economic growth, financial development (FD) (% of GDP) [39,40], GFCF (constant 2010 US$) [41–43] and total population (*TP*) [15,44–46].

The data for tourism are collected from the Australian Bureau of

Statistics [49]; GDP, GFCF and TP are obtained from the World Development Indicators [50] and data on CO_2 emissions and energy consumption are acquired from BP Statistical Review [51]. CO_2 is multiplied by one million to attain million tons, which we then divide by total population to attain per capita figures. Table 2 presents the variable descriptions and data sources.

3.1. Theory and model

The theoretical background for this study begins with the hypothesis that tourist arrivals may be a significant contributor to carbon emissions. Many studies have highlighted GDP as a key contributor to climate change, in addition to energy usage. Several papers have attempted to establish a relationship between energy, the environment and economic growth [52–54], with Katircioglu [29] and Eyuboglu and Uzar [28] also adding tourist arrivals to this. We follow Katircioglu [29] and Eyuboglu and Uzar [28] to generalise an empirical model to examine the effect of tourism on the environment. Their specified time series model states that CO_2 emissions are affected by international tourist arrivals, economic growth, and energy consumption. Therefore, the estimated model of our study is justified in light of the literature by following the study of Katircioglu [29] and Eyuboglu and Uzar [28]. The general form of tourism-energy-growth-environment equation is modelled as follows:

$$CO_2 = f\ (TA,\ EC,\ GDPpc,\ FD,\ GFCF,\ TP) \tag{1}$$

where CO_2 is carbon emissions per capita, *TA* is tourist arrivals, EC is energy consumption, *GDPpc* is gross domestic product per capita, *FD* is financial development, *GFCF* is gross fixed capital formation, and *TP* is total population. All variables are used in their logarithm form in the above econometric analysis to gain the growth effects of the regressors on the dependent variable:

$$logCO_2 = f\ (logTA,\ log\ EC,\ logGDPpc,\ logFD,\ logGFCF,\ logTP) \tag{2}$$

To investigate the long-run relationship between CO_2, *TA*, *EC*, *GDP*, *FD*, *GFCF* and *TP*, we employ the following equation derived from Equation (1):

$$CO_{2t} = \beta_0 + \beta_1 TA_t + \beta_2 EC_t + \beta_3 GDP_t + \beta_4 FD_t + \beta_5 GFCF_t + \beta_6 TP_t + \varepsilon_t \tag{3}$$

Table 2
Variable description and data source.

Symbol	Variable	Definition	Source	Article source
CO₂	CO_2 emissions	CO_2 emissions per capita	BP Stats	[10,28]
TA	Tourist arrivals	International tourism, number of arrivals. Number of movements; short-term visitors arrivals	ABS	[10,28]
EC	Energy consumption	Primary energy comprises commercially traded fuels, including modern renewables used to generate electricity	BP Stats	[14]
GDPpc	GDP per capita	GDP per capita (constant 2010 US$)	WDI	[29,32]
FD	Financial development	Financial development (% of GDP)	WDI	[39,40]
GFCF	Gross fixed capital formation	GFCF (constant 2010 US$)	WDI	[41–43]
TP	Total population	Total population-based on de facto definition of the population with mid-year estimates	WDI	[15, 44–46]

Note: ABS = Australian Bureau of Statistics, WDI = World Development Indicators, BP Stats = BP Statistical Review.

To obtain the direct elasticities of coefficients and make the estimation process smooth, we take the logarithm of the variables, which helps select suitable time series models derived from Equation (2):

$$logCO_{2t} = \beta_0 + \beta_1 logTA_t + \beta_2 logEC_t + \beta_3 logGDP_t + \beta_4 logFD_t + \beta_5 logGFCF_t + \beta_6 logTP_t + \varepsilon_t \tag{4}$$

where $\beta_0,\ \beta_1,\ \beta_2,\ \beta_3,\ \beta_4,\ \beta_5\ and\ \beta_6$ are the slope coefficients, ε_t is the error term, t is the time period, and log is the logarithm function.

3.2. Stationarity and unit root test

Before analysing the given data, the stationarity properties should be assessed to meet the requirements of an appropriate model for the analysis. To check the stationarity of the data, we employ Augmented Dickey-Fuller (ADF) [55] and Phillips-Perron (PP) [56] unit root tests. The null hypothesis is that a series has a unit root (non-stationarity), while the alternative is that there is stationarity. We apply the ADF unit root test to determine the maximum number of integrations. However, as this test may be a non-robust test for the unit root to ensure certainty regarding stationarity among the variables, an additional test for the unit root, the PP test, is implemented. As a non-parametric statistical method, the PP test considers serial correlation without using the lagged differences of the dependent variable [57]. In time series, the PP test allows for milder assumptions on the distribution of errors, with an opportunity to control for higher-order serial correlation, as well as being robust against heteroscedasticity [58]. Hence, we apply both ADF and PP tests to check the stationarity of our variables. The ADF model tests the unit root as follows:

$$\Delta y_t = \mu + \delta y_{t-1} + \beta_t + \sum_{i=1}^{k} d_i \Delta y_{t-i} + e_t \tag{5}$$

where k = number of lags, $t - i = 1 \ldots k$, $\delta = \alpha - 1$, α = coefficient of y_{t-1}, Δy_t = first difference of y_t and e_t = white noise disturbance. The null hypothesis for ADF is that $\delta = 0$, against the alternative hypothesis of $\delta < 0$. If we do not reject the null, the series is non-stationary, whereas rejection means the series is stationary. The PP model tests the unit root as follows:

$$\Delta y_t = \mu + \delta y_{t-1} + \beta_t + e_t \tag{6}$$

3.3. ZA unit root test

The ADF test and PP test can sometimes provide biased and spurious results in the presence of unaccounted for structural breakpoints in the series [59]. Thus, we apply the ZA structural break unit root test before cointegration [60]. Zivot and Andrew's technique is performed by running the following equation, adapted from Ertugrul et al. [61]:

$$\Delta y_t = c + cY_{t-1} + \beta t + dDU_t + dDT_t + \sum_{j=1}^{k} d_j \Delta Y_{t-j} + \varepsilon_t \tag{7}$$

where DU_t is the shift dummy variable showing the shift that occurs at each point break date, and DT_t is the trend of the shift dummy variables [61], which may be identified as:

$$DU_t = \begin{cases} 1\ if\ t > TB \\ 0\ if\ t < TB \end{cases} \quad \text{and} \quad DT_t = \begin{cases} t - TB\ if\ t > TB \\ 0\quad if\ t < TB \end{cases}$$

The null hypothesis of the unit root break date is $c = 0$, which suggests that the series is not stationary with a drift not containing information regarding the structural breakpoint, while the $c < 0$ hypothesis implies that the variable is trend-stationary, with one unknown time break.

3.4. Cointegration analyses

The long-term relationship between tourism and the environment in this study is investigated by using three cointegration approaches: the ARDL bounds test and the Johansen-Juselius test.

3.4.1. ARDL bounds test approach

After testing the stationarity properties of the series, the ARDL bounds test approach is applied to test the existence of cointegration between the variables for long-run relationships between the variables. The ARDL bounds test, developed by Pesaran et al. [62] provides two asymptotic critical value bounds when the independent variables are either I (0) or I (1). We accept that the test statistics surpass the upper critical bound (UCB) and thus conclude that a long-run relationship among the variables exists. The following equation is used to estimate cointegration relationships among variables:

$$\begin{aligned}\Delta logCO_{2t} = {} & \beta_0 + \beta_1 logCO_{2t-i} + \beta_2 logTA_{t-i} + \beta_3 logEC_{t-i} + \beta_4 logGDP_{t-i} \\ & + \beta_5 logFD_{t-i} + \beta_6 logGFCF_{t-i} + \beta_7 logTP_{t-i} + \sum_{i=1}^{p} \beta_8 logCO_{2t-i} + \sum_{i=1}^{p} \beta_9 \Delta logTA_{t-i} \\ & + \sum_{i=1}^{p} \beta_{10} \Delta logEC_{t-i} + \sum_{i=1}^{p} \beta_{11} \Delta logGDP_{t-i} + \sum_{i=1}^{p} \beta_{12}\, \Delta logFD_{t-i} + \sum_{i=1}^{p} \beta_{13}\, \Delta logGFCF_{t-i} \\ & + \sum_{i=1}^{p} \beta_{14}\, \Delta logTP_{t-i} + \varepsilon_t \end{aligned} \tag{8}$$

where ε_t is white noise, Δ denotes the first difference and $t-i$ indicates the optimal lags chosen by the Akaike information criterion (AIC). The bounds test procedure is based on the joint F-statistic to determine the joint significance of the coefficient of the lagged variables. In this regard, the null hypothesis is $H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = 0$, which implies that a cointegrating relationship does not exist among the regressors, against the alternative of H_1: $\beta_r \neq 0$, where $r = 1, 2, 3, 4, 5, 6{,}7$.

3.4.2. Johansen-Juselius cointegration testing approach

The second approach of cointegration test is the Johansen and Juselius [63] cointegration method, which also estimates the long-run relationship among the series. The Johansen and Juselius cointegration technique is based on trace statistics (λ_{trace}) and maximum eigenvalue (λ_{max}) statistics. Trace statistics examine the null hypothesis of r cointegrating relations against the alternative of N cointegrating relations, and are computed as:

$$\lambda_{trace} = -N \sum_{i=r+1}^{n} log(1-\lambda_i) \tag{9}$$

where N is the number of observations and λ is the ordered eigenvalue of matrices. The maximum eigenvalue statistics tests the null hypothesis of r cointegrating relations against the alternative:

$$\lambda_{max} = -N \;\log\; (1-\lambda_r + 1) \tag{10}$$

where N is the number of observations and λ is the ordered eigenvalue of matrices.

3.5. Lag length test

We employ AIC lag order selection to determine the best model to select, as the AIC criteria were deemed suitable for lag length selection given the nature of this study [64].

3.6. Long- and short-run dynamics

After testing the stationarity properties of the series and the three different cointegration approaches, we apply ARDL testing to examine the long- and short-run coefficients. The ARDL approach to cointegration helps to identify cointegrating vector(s). That is, each of the underlying variables stands as a single long-run relationship equation. If one cointegrating vector (the underlying equation) is identified, the ARDL model of the cointegrating vector is reparametrised into an error correction model (ECM). The reparametrised result gives long-run relationships and short-run dynamics (traditional ARDL) among the variables of a single model [65]. After the cointegration is confirmed among the variables, the long-run and short-run elasticity according to the ARDL specification are determined via the equations below.

3.6.1. Long-run

$$\begin{aligned} logCO_2 = {} & \beta_0 + \sum_{i=1}^{q} \beta_1 logCO_{2t-i} + \sum_{i=1}^{q} \beta_2 logTA_{t-i} + + \sum_{i=1}^{q} \beta_3 logEC_{t-i} \\ & + \sum_{i=1}^{q} \beta_4 logGDP_{t-i} + \sum_{i=1}^{q} \beta_5\, logFD_{t-i} + \sum_{i=1}^{q} \beta_6 logGFCF_{t-i} + \sum_{i=1}^{q} \beta_7 logTP_{t-i} + \varepsilon_t \end{aligned} \tag{11}$$

Here, β reflects the variance in the long-run variables, while $t-i$ indicates the optimal lags chosen by AIC for the long-run estimates. The following ECM is used for the short-run ARDL model.

3.6.2. Short-run

$$\begin{aligned} logCO_2 = {} & \alpha_0 + \sum_{i=1}^{q} \alpha_1 \Delta logCO_{2t-i} + \sum_{i=1}^{q} \alpha_2 \Delta logTA_{t-i} + \sum_{i=1}^{q} \alpha_3 \Delta logEC_{t-i} \\ & + \sum_{i=1}^{q} \alpha_4 \Delta logGDP_{t-i} + \sum_{i=1}^{q} \alpha_5 \Delta logFD_{t-i} + \sum_{i=1}^{q} \alpha_6 \Delta logGFCF_{t-i} + \sum_{i=1}^{q} \alpha_7 \Delta logTP_{t-i} \\ & + \mu ECT_{t-i} + \varepsilon_t \end{aligned} \tag{12}$$

Table 3
Descriptive statistics.

	$logCO_2$	logTA	logEC	logGDPpc	logFD	logGFCF	logTP
Mean	1.23	6.48	0.62	4.61	1.84	11.22	7.27
Median	1.23	6.63	0.65	4.61	1.89	11.20	7.27
Maximum	1.29	6.98	0.77	4.76	2.15	11.57	7.40
Minimum	1.15	5.73	0.43	4.45	1.43	10.81	7.15
Std deviation	0.04	0.37	0.11	0.10	0.25	0.24	0.08
Skewness	−0.12	−0.64	−0.28	−0.08	−0.45	0.02	0.06
Kurtosis	1.89	2.14	1.59	1.55	1.78	1.64	1.91
Jarque-Bera (chi^2)	2.38(0.30)	4.41(0.11)	4.18(0.12)	3.90(0.14)	4.20(0.12)	3.39(0.18)	2.22(0.33)
Observations	44	44	44	44	44	44	44

Here, α reflects the variance in the short-run variables and the coefficient of the ECT is denoted by μ, which shows the speed of adjustment of the variables towards long-run convergence. Further, $t-i$ represents the optimal lag lengths using the AIC criteria for short-run dynamics.

3.7. Robustness check

We also used the FMOLS (fully modified OLS)and canonical cointegrating regression (CCR) on the provided model as a sensitivity check to examine the long-run influence of explanatory factors on the dependent variables.

4. Empirical results and analysis

Given the timeframe of 1976–2019 with annual observations, there were 44 observations for each variable selected in this study. The descriptive statistics for the variables (measured in natural logarithms) were found to be normally distributed within a reasonable range (see Table 3). Thus, the data are unlikely to provide spurious findings. The Jarque-Bera statistics indicate that all series have zero mean and finite covariance. All variables were transformed to logarithms before estimation to avoid heteroscedasticity and calculate elasticities.

This study applies three unit root test (ADF, PP and ZA) and two cointegration tests (ARDL bounds test and Johansen-Juselius test), as discussed below.

4.1. ADF and PP unit root and ZA structural break test

We examined three different kinds of unit root tests—ADF, PP and ZA—to avoid any spurious relationship. The results of the unit root tests are reported in Table 4. The ADF and PP tests indicate that the variables are stationary at first differences, I (1). The AIC and Newey-West lags were used to determine the lag length for the ADF and PP.

We also apply the Zivot and Andrews [60] structural break unit root test (see Table 5) to examine the status of the unit root test and the presence of a structural break in our series.

These results suggest that we can reject the null of unit root at a 1% significance level. Given that the calculated *t*-statistics value at the level is below the critical values, the variable is non-stationary. The null hypothesis can be rejected when the critical value (1%, 5% and 10%) is greater than the test statistic value. After first difference, all *t*-statistics values, which are above the critical values, show evidence of

Table 5
ZA structural break trended unit root test.

Variable	At level		At first difference	
	t-statistics	Time break	t-statistics	Time break
$logCO_2$	−3.28(0)	2009	−6.32(0)*	2009
logTA	−4.34(1)	1986	−5.51(2)*	1997
logEC	−2.66(0)	2009	−5.932(0)*	1984
logGDPpc	−2.63(0)	1997	−6.59(0)*	1993
logFD	−3.33(1)	1985	−6.23(0)*	1983
logGFCF	−2.42(0)	2002	−6.04(0)*	1993
logTP	−2.16(1)	2012	−6.53(0)*	2008

Note: Lag order shown in parentheses. Critical values: 1%: −5.34, 5%: −4.80, 10%: −4.58, where * is 1% level of significance.

Table 6
Results of lag order selection criteria.

Lag	LL	LR	AIC	HQIC	SBIC
0	682.58	NA	−33.78	−33.67	−33.48
1	1035.80	565.14**	−48.99	−48.14	−46.63**
2	1087.67	64.84	−49.13	−47.53	−44.70
3	1145.80	52.29	−49.59	−47.24	−43.09
4	1256.78	61.05	−52.69**	−49.59**	−44.12

Note:* Indicates lag order selected at 5% level of significance. LL: likelihood, LR: likelihood ratio, HQIC: Hannan and Quinn information criterion and SBIC: Schwarz Bayesian information criterion.

Table 7
Bounds test for cointegration.

Model	F-statistics	LCB [I_0]	UCB [I_1]
$logCO_2 = f$ (*logTA, logEC,logGDPpc, logFD, logGFCF, logTP*)	6.25*	2.88	3.99

Note: * 1% critical value for the bounds test. LCB = lower critical bound.

Table 4
Unit root tests.

Tests	$logCO_2$	logTA	logEC	logGDPpc	logFD	logGFCF	logTP
ADF							
At level I (0) Constant	−1.57 (−2.93)	−2.82*** (−2.93)	−1.81 (−2.93)	−0.92 (−2.93)	−1.33 (−2.93)	−1.17 (−2.93)	1.16 (−2.93)
At level I (0) Constant & Trend	−0.42 (−3.52)	−1.46 (−3.52)	−0.88 (−3.52)	−1.08 (−3.52)	−0.29 (−3.52)	−2.01 (−3.52)	−0.86 (−3.52)
At first difference I (1)	−5.00* (−2.93)	−3.99* (−2.93)	−5.09* (−2.93)	−5.61* (−2.93)	−4.48* (−2.93)	−5.30* (−2.93)	−4.26* (−2.93)
PP							
At level I (0)	−2.02 (−2.93)	−2.70*** (−2.93)	−1.81 (−2.93)	−0.91 (−2.93)	−1.19 (−2.93)	−1.18 (−2.93)	1.58 (−2.93)
At level I (0) Constant & Trend	−0.53 (−3.52)	−1.49 (−3.52)	−1.08 (−3.52)	−1.08 (−3.52)	−1.08 (−3.52)	−1.74 (−3.52)	−0.66 (−3.52)
At first difference I (1)	−4.97* (−2.93)	−3.80* (−2.93)	−5.07* (−2.93)	−5.57* (−2.93)	−4.47* (−2.93)	−5.18* (−2.93)	−4.26* (−2.93)

Note: * is 1% and *** is 10% significance level. AIC criteria are selected to find optimal lags. 5% critical values (CV) are given in parentheses.

Table 8
Johansen-Juselius cointegration test.

Rank	Trace statistic	5% critical value	Max. eigen. statistic	5% critical value
0	158.14	124.24	54.44	45.28
1	103.70	94.15	41.99	39.37
2	66.58**	68.52	31.53**	33.46
3	40.93	47.21	17.84	27.07
4	22.15	29.68	8.56	20.97
5	9.41	15.41	6.10	14.07
6	2.66	3.76	2.34	3.76

Note: ** the number of cointegration at 5% critical value.

stationarity. The results of the ZA reveal that all series are first difference stationary—I (1)—in the presence of a single structural break in the series. Carbon emissions in Australia declined in 2009, reflecting the impact of the 2008 recession on industrial production and overall energy use.

4.2. ARDL bounds test results and lag order selection

The ARDL bounds test of cointegration examines the cointegration between variables. To obtain the bounds tests, we select AIC to estimate the lag length of the considered variables to examine the long-run relationship between the series (see Table 6).

After selecting lag (4), in line with the AIC criterion, we use this to determine the cointegration among the variables using the ARDL bounds test (see Table 7).

The empirical results for the bounds test for cointegration are shown in Table 7. The null hypothesis is that if the *F*-statistics are lower than the lower critical bound series, there is no cointegration; if the *F*-statistics are higher than the UCB series, there is cointegration. In our case, there exists a long-run nexus between the variables because the calculated *F*-statistic (6.25) is higher than the UCB [I_1] (3.99) at 1% critical value.

4.3. Johansen-Juselius cointegration test

After the ARDL bounds test for cointegration, we further check for cointegration using the Johansen and Juselius [63] test to determine whether this shows that any combination of the variables are cointegrated. The results are presented in Table 8.

Here, the trace statistics are less than the 5% critical value; thus, we accept the null hypothesis, implying that there is one cointegration in both the trace and maximum eigenvalue statistic, and this guides a substantial long-run relationship among the series of variables. The Johansen-Juselius cointegration test has a null hypothesis that if the trace and maximum value is greater than the 5% critical value, we reject the null hypothesis of no cointegration. The results from the Johansen-Juselius cointegration test reveal t a minimum of one cointegration among the variables.

Table 9
Long-run dynamics using ARDL (1, 3, 1, 2, 0, 0, 0) model coefficients.

Variables	Coeff.	t-stats	Prob.
Constant	9.99	16.70	0.00*
logTA	0.13	3.33	0.00*
logEC	0.46	2.56	0.02**
logGDPpc	0.51	2.01	0.06***
logFD	0.01	0.12	0.91
logGFCF	0.04	0.73	0.47
logTP	−1.74	−11.32	0.00*
Diagnostic test			
Serial correlation (Breusch-Godfrey LM test for autocorrelation)	0.41 (0.67)	Heteroscedasticity (Breusch-Pagan/Cook-Weisberg test for heteroscedasticity)	0.88 (0.58)
Normality Jarque-Bera	0.87	*F*-stat (prob.)	292.26
R^2	0.99	Adjusted R^2	0.99

Note: * is significant at 1% critical level, ** is significant at 5% critical level and ***is significant at 10% critical level.

Table 10
Short-run dynamics using ARDL approach.

Variables	Coeff.	t-stats	Prob.
*ΔlogCO*2	−0.58	−3.44	0.00*
ΔlogTA	0.07	3.22	0.00*
ΔlogEC	0.27	2.04	0.05**
ΔlogGDPpc	0.30	1.91	0.07***
ECM (−1)	−0.58	−7.93	0.00*

Note: * is significant at 1% critical level, ** is significant at 5% critical level and ***is significant at 10% critical level.

4.4. ARDL (long- and short-run) approach

Table 9 presents the long-run equilibrium relationship among variables estimated using the ARDL (1, 3, 1, 2, 0, 0, 0) approach using ECM. The results for the long-run coefficient estimates show that tourist arrivals have a positive and significant effect on CO_2 emissions with a 1% increase in tourist arrivals, associated with a 0.13% surge in CO_2 emissions in the long run at a 1% significance level. Energy consumption has long been held responsible for environmental degradation. The results from the long-run ARDL model shows that a 1% increase in energy use results in 0.46% rise in CO_2 emissions. Similarly, GDP, FD, and GFCF have a positive effect on carbon emissions, where FD and GFCF have a positive yet non-significant effect. The findings reveal that a 1% increase in GDP leads to a 0.51% surge in carbon emissions implying that economic activity plays an important role in generating CO_2 emissions in Australia. Moreover, the total population has a negative coefficient −1.74, with 0.00 probability (*p*) value.

An ECM, which measures the speed of adjustment, is required to obtain the short-run dynamics of the series and its coefficient given the existence of a cointegrating nexus between the variables [66]. The estimated ECM adjustment term, ECM (−1), is negative (−0.58) and statistically significant at a 1% critical level. Table 10 presents the short-run results, and the impact of the independent variable (tourist arrivals) on the dependent variable (CO_2 emissions) in Australia. The results show that tourist arrivals have a significant positive effect (coefficient = 0.07 and *p*-value = 0.00) on the environment in Australia. Likewise, the results reveal that energy consumption and economic growth also affect the environment in the short-run with a 1% increase in energy consumption associated with 0.27% increase in CO_2 emissions

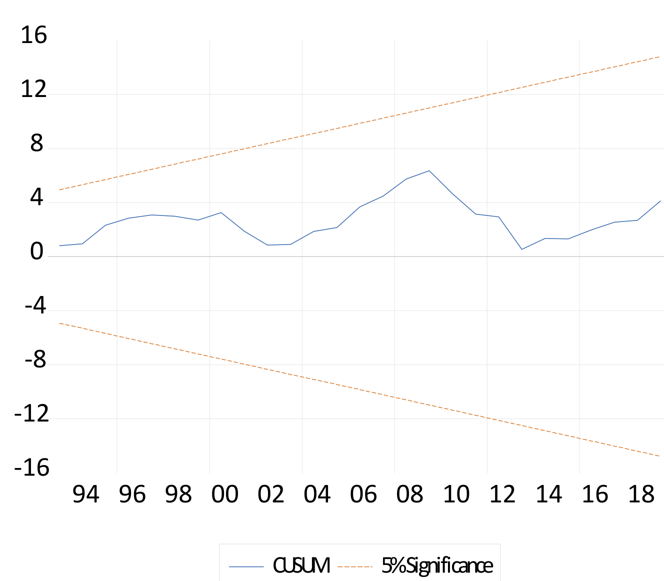

Fig. 4. Plot of CUSUM of recursive residuals.

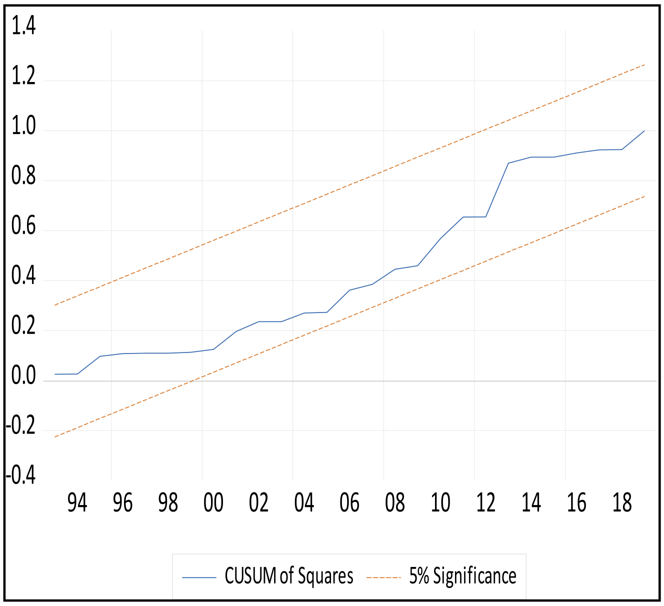

Fig. 5. Plot of CUSUMQ of recursive residuals.

Table 11
Results of the FMOLS and CCR regressions.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Fully Modified Least Squares (FMOLS)				
logTA	0.06	0.02	3.29	0.00*
logEC	0.75	0.14	5.42	0.00*
logGDPpc	0.14	0.19	0.72	0.48
logFD	0.06	0.03	2.01	0.05**
logGFCF	0.05	0.04	1.30	0.20
logTP	−1.52	0.10	−15.58	0.00*
C	10.12	0.44	23.04	0.00*
Canonical Cointegrating Regression (CCR)				
logTA	0.06	0.02	3.34	0.00*
logEC	0.76	0.15	5.12	0.00*
logGDPpc	0.13	0.20	0.64	0.53
logFD	0.06	0.03	2.12	0.04**
logGFCF	0.05	0.04	1.45	0.15
logTP	−1.53	0.11	−13.29	0.00*
C	10.15	0.46	21.91	0.00*

Note: * is significant at 1% critical level, and ** is significant at 5% critical level.

at the 5% critical level, and a 1% increase in GDP associated with 0.30% surge in CO_2 emissions at the 10% significance level.

4.5. Diagnostic test results

Diagnostic tests were undertaken to check serial correlation, heteroscedasticity and normality using the Breusch-Godfrey LM test for autocorrelation, the Breusch-Pagan/Cook-Weisberg test for heteroscedasticity and the Jarque-Bera test for normality. The Breusch-Godfrey LM test shows no serial correlation, the Breusch-Pagan/Cook-Weisberg test indicates no heteroscedasticity in the data, and the Jarque-Bera test reveals that the residuals are normally distributed.

4.6. Stability of the short-run model

The stability of the model is checked using the cumulative sum of recursive residuals (CUSUM) and CUSUM of squares (CUSUMQ) [67]. The results presented in Figs. 4 and 5 indicate the absence of any instability in the coefficients, as the CUSUM and CUSUMQ statistics fall inside the critical bands of the 5% confidence interval of parameter stability.

4.7. Robustness check

To further validate the robustness of the long-run results of the ARDL framework, fully modified least squares (FMOLS) and canonical cointegrating regression (CCR) were applied (see Table 11). The long-run estimations from both the FMOLS and CCR are similar and generate the same sign. The results reveal that the long-run coefficient of TA has the expected positive sign (0.06) in the FMOLS and CCR, with a 1% significance level, the same as those derived from the ARDL estimations.

5. Discussion

Energy saving and emissions reduction initiatives are putting pressure on Australia's economic growth. A feasible roadmap to decarbonisation in Australia is crucial. In the process of decarbonisation, tourism-related environmental consequences are unavoidable, because most tourism-related activities rely on fossil fuels for energy, resulting in considerable CO_2 emissions. Thus, this study investigates whether tourism contributes to zero-carbon emission. To achieve this objective, we employ ADF, PP and ZA unit root tests and long-run and short-run ARDL econometric techniques. According to the results obtained from the ADF, PP and ZA tests, the logarithm forms of the analysed variables of CO_2 emissions, tourist arrivals, energy consumption, GDP per capita, financial development, GFCF and total population were stationary at first difference. Next, the long-run cointegration between variables was examined, with the ARDL bounds test approach and Johansen-Juselius cointegration test indicating at least one cointegrating relationship.

The long-run ARDL test results show that growth in tourist arrivals significantly affect CO_2 emissions in Australia in the long run. This further suggests that international tourist arrivals are playing a substantial role in degrading the Australian environment. These findings align with those of previous studies [7,8,10,28]. Because of the extensive use of transportation, the tourist industry has a considerable impact on climate change, as a result increased CO_2 emissions driven by energy consumption. The relationship between increased carbon emissions and energy consumption and economic development is one of the most critical aspects of the global warming debate. Economic growth and energy use, as major transmission routes, are the primary causes of environmental degradation. According to our long-run results, EC, GDP, GFCF and FD are also responsible for contributing CO_2 to Australia's environment. These results for Australia might be explained by the country's rapid economic growth in recent years, but are also driven by its high energy consumption, which places it among the top 10 emitters. The Australian energy industry is heavily reliant on fossil fuels, which serve as its primary source of electricity generation. These findings align with those of Khanal [15] and Majeed et al. [68]. Furthermore, Australia faces a trade-off between economic expansion and CO_2 emissions because economic growth currently implies concomitant in CO_2 emissions. Our result that GDP increases carbon emissions aligns with Zmami and Ben-Salha [69] while our result on GFCF align with the results of Rahman and Ahmad [41], Petrović and Lobanov [42], Zaman et al. [43] and financial development with Solarin [32], Rjoub et al. [39], and Yasin et al. [40]. Thus, capital formation and financial development also contribute to the degradation of the Australian environment. Moreover, the coefficient of total population is negative in the long run. This result contradicts Hashmi and Alam [44], yet aligns with Shi et al. [45], who argued that a 1% increase in total population causes a decline of 0.182% and 0.147% in carbon emissions in upper-middle-income and high-income countries, respectively. In addition, our result is consistent with Khanal [46], who revealed that a higher total population decreases carbon emissions in the long run in Australia.

According to our estimated results, tourist arrivals and the other explanatory variables (EC and GDP) also have a positive and significant effect on carbon emissions in the short run in Australia. This is understandable, as the effect of tourism, energy and economic growth on CO_2 emissions and climate change is both a long-term and short-term phenomenon. Hence, this study concludes that tourism, energy and GDP exerts a positive and statistically significant effect on CO_2 emissions in Australia, both in the long run and the short-run. This supports previous studies that also found both a short-run and long-run effect [29,31].

Thus, Australia must make a significant effort to modify its industry/ trade structure, to moderate tourism growth to reduce pressures on the environment arising from that source, and to invest in low-carbon technologies to meet existing emissions objectives and proceed towards decarbonisation or a zero-carbon economy.

6. Conclusion

Climate change has become a major issue affecting people all over the world as a result of rising GHGs in the atmosphere. The research on climate change and tourism has mostly concentrated on the effects of a changing climate on tourist demand. Evaluating tourism industry emissions and measures to decarbonise through international tourist arrivals has received little attention. Thus, this study used time series data of 44 years (1976–2019) to examine the nexus between international tourist arrivals, energy consumption, and CO_2 emissions controlling other variables. To estimate the relationship, this study used the unit root test, ARDL bounds test approach and Johansen-Juselius cointegration test. The results from the unit root tests indicate that all series are integrated at the first difference. The bounds test and the Johansen-Juselius cointegration test revealed that there exists a long-run relationship among the variables. According to the long-run coefficients estimated from the ARDL model, tourism, energy usage and GDP have a positive and significant impact on the environment. Moreover, the FMLOS and CCR results support the ARDL results, revealing that international tourist arrivals, primary energy consumption and economic growth are significant contributors to CO_2 emissions in Australia.

The findings of this study have several policy implications. The first is that policymakers in Australia should focus on building a more sustainable tourism industry, such as by promoting tourism-related infrastructure that uses green energy instead of fossil fuels, and by developing a transport system that uses clean energy through subsidies and other forms of assistance. Thus, supporting the use of environmentally friendly transportation and technologies is crucial, including encouraging the use push bikes for short distances. Policies should be implemented to develop a carbon-neutral tourism sector, which is particularly important for Australia, as it possesses many important natural tourist attractions (such as the Great Barrier Reef). Moreover, the results from this study also suggest implementing more efficient alternatives to attract green tourism including cleaner energy for land transportation, such as hybrid engines or even carbon-neutral transportation solutions, is one of them. The development of a sustainable tourism model would not only assist in preserving the world-renowned natural environment of Australia, but would also ensure continuous international tourist arrivals, as maintaining and improving the environment, biodiversity and ecosystems are key to future tourist arrivals. Adventure-based activities such as scuba diving and hiking should be promoted to minimise energy consumption and lessen environmental degradation. Development in solar, wind, hydrogen, and other technologies would help Australia to achieve zero-carbon, which is increasingly needed, given the country's emission reduction targets. The overall policy implications are a cautionary indicator and should serve as a warning call to the government and officials who are more concerned with changing how policies appear than how they function to achieve zero-carbon. To achieve the sustainable development goals and the zero-carbon mission, resource allocation needs to be enhanced. Tourism growth plans and associated market sectors must be re-assessed in light of the possibility for emission reductions in Australia. Imposing a carbon tax on tourism might help to achieve low-carbon tourism development.

To reduce the effect of tourism on CO_2 emissions, the Australian federal and state governments should focus on converting the carbon-intensive tourism industry into a more sustainable, 'green' industry. For example, strategies should be implemented to promote bicycle-oriented tourism (where possible) to replace motorised and fossil-fuel transport [34]. Further research and funding for the development of environmentally friendly technologies, especially those in relation to the tourism sector, should be provided by Australian governments.

Several factors contribute to the aforementioned long-run relationship between tourist arrivals and CO_2 emissions. Previous empirical studies have indicated that tourism-related transportation services contribute a significant amount of CO_2 emissions [70]. A large portion of tourism-related CO_2 emissions (nearly 95%) is associated with transport services, such as the aviation sector [71]. Further, increasing tourist arrivals contribute to growth in infrastructure development (e.g. accommodation, airports and roads), which contributes to CO_2 emissions [13]. Thus, the air transportation sector's (proxy for tourism) effect on GHGs seems to be neglected, which is an area for future research. Further research is also required to understand which types of tourism affect CO_2 emissions the most, and which tourist destinations in Australia are most affected. Moreover, a study on the impact of COVID-19 on tourism, and the consequences for the environment, could be a good focus for future research. The limitation of this study is that it focused on only one environmental element (carbon emissions) while disregarding other elements that may also be important.

Data availability statement

The data generated during and/or analysed in the current study are available in the ABS, BP Statistical Review of World Energy, and WDI repositories. The tourism data were collected from the ABS (2020) Overseas Arrivals and Departures (Cat. No.3401.0), https://www.abs.gov.au/Ausstats/abs@.nsf/glossary/3401.0. The GDP, GFCF and TP data were obtained from the World Development Indicators (2021) (https://datacatalog.worldbank.org/dataset/world-development-indicators). The data on CO_2 emissions and EC were acquired from BP Statistical Review of World Energy (2022). Retrieved from https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

Author contribution

Methodology, Software, Writing – review & editing. Avishek Khanal: Conceptualization, Writing – original draft, Data curation. Mohammad Mafizur Rahman: Conceptualization, Supervision, Validation. Rasheda Khanam: Conceptualization, Supervision, Validation.Eswaran Velayutham: Methodology, Software, Writing – review & editing.

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.

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