The impact of population ageing on the environmental quality in late-demographic dividend countries

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Abstract

Purpose – The current study examined the impact of population ageing on environmental quality in 17 late-demographic dividend (LDD) countries.

Design/methodology/approach – The panel autoregressive distributed lag (ARDL) model using pooled mean group (PMG) estimator based on the environmental Kuznets curve (EKC) hypothesis was used to analyse data for the period 1990–2018.

Findings – The empirical results demonstrated that in the long run, carbon dioxide (CO_2) emissions decrease with population ageing. The prevailing findings also indicated no sufficient evidence of EKC hypothesis validity and electricity consumption, which is the primary driving force of CO_2 emissions in LDD countries.

Originality/value – Unlike prior works, this paper is among the first to discuss environmental quality due to the current demographic transition towards ageing among LDD countries. Based on the results, population ageing reduces the environmental deterioration. The identification of possible ageing impact is vital to combat the climate change in order for countries to achieve sustainability, better economy and quality environment.

Keywords Climate change, Dynamic panel data, EKC, Elderly, Sustainability

Paper type Research paper

1. Introduction

The world's population is ageing, and the elderly group is estimated to grow to more than 1.4 billion people in 2050 compared to 0.4 billion in the year 2000 (United Nations, 2019). Elderly is defined as those aged 60 and above (Scherbov and Sanderson, 2019); however, most studies have agreed to use 65 as the reference point of age to define elderly (National Research Council, 2012). The rising number of elderly in the population carries a significant impact over economic and social development (Estiri and Zagheni, 2019). Coulmas (2007) posited three stages of population ageing, i.e. ageing, aged and hyper-aged; "ageing society" is when the total of elderly in a society between 7 and 14%, while "aged society" and "hyper-aged society" are when the total of elderly is between 14 and 20% and above 21%, respectively. Most late-demographic dividend (LDD) countries have already been described as an "ageing nation", a mixture of high- and middle-income countries. World Bank (2015) classified demographic dividend status according to the fertility rate, and LDD country has the fertility rate of less or equal to the replacement level of 2.1.

Population ageing has become significantly greater than in the past, and this rate is expected to accelerate in developing countries (Yaziz and Azlina, 2020). Meanwhile, nations

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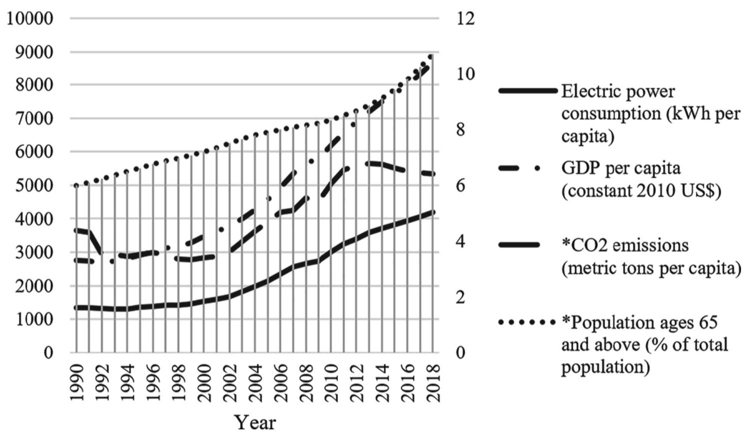
around the world are facing substantial challenges to ensure sustainability for future development. Achieving decent living is one of the pillars in the sustainable development goals (SDGs), which include energy element, responsible consumption and climate action. Previous studies stated that greenhouse gas (GHG) emissions are rising dramatically, which affects environmental quality (Acheampong, 2018; Churchill *et al.*, 2018; Bekun *et al.*, 2019). Meanwhile, population ageing is one of the natural phenomena that happens concurrently with climate change; this was overlooked in past research. Next, International Energy Agency (2019) reported that global energy-related carbon dioxide (CO_2) emissions peaked in 2017. In addition, most regions showed an increasing trend in the total CO_2 emission, analogous to higher energy demand and consumption (BP Statistical Review of World Energy, 2018). Unsustainable energy consumption causes the deterioration of environmental quality. The increase of CO_2 emissions from energy consumption has raised concern such that investigating the nexus between environmental quality and its related determinants is crucial.

Salahuddin *et al.* (2018) argued that electricity consumption is critical for emission level; hence, neglecting this factor is likely to produce bias and misleading results. The environmental Kuznets curve (EKC) is a prominent theory that discusses the impact of economic growth and environmental quality, which has been used by many studies (Alam *et al.*, 2016; Ganda, 2018; Ulucak and Bilgili, 2018). The idea explains that the environmental degradation could worsen as modern economic growth persists until average income is achieved in the course of development, in which this turns to the phase of better environmental quality. This is also perceived simply because of the utilisation of resources despite the country's income level. Auci and Trovato (2018) stated that the overuse of resources is placing pressure on the ecosystem in the population change. Figure 1 represents the overview of time series plot for per capita CO_2 emission, per capita gross domestic product (GDP), per capita electricity consumption and percentage of elderly from 1990 to 2018 in LDD countries. The plot of electric power consumption and per capita GDP is based on the left vertical axis while per capita CO_2 emissions and percentage of elderly is on the right vertical axis. From the year 2014 onwards, all series showed an increasing trend except per capita CO_2 emissions, which, in the beginning, demonstrated a rising trend before falling.

Needs and preferences change according to the population structure, which probably causes the electricity consumption and environmental quality to get affected by population ageing. To the best of author's knowledge, there has been little to no empirical research done



Note(s): * series plotted on the right vertical axis

Figure 1.
Late demographic dividend (LDD) countries

to analyse the impacts of population ageing within the environmental quality framework. Thus, this study investigated the direct impact of population ageing on CO_2 emission, representing the environmental quality in the short and long run. In addition, economic growth and electricity consumption, which was one of the most important variables in previous studies, have also been included. This study fulfils the gap, and primarily contributes in examining the impact of population ageing on environmental quality based on the EKC framework. Sampled countries with LDD status were studied in the analysis, owing to the rapid acceleration of older adults in this group. The remainder of this paper is arranged as follows: Section 2 reviews the related literature, Section 3 describes the methodology used in this study, Section 4 presents and discusses the empirical results and finally Section 5 concludes the study.

2. Literature review

This section reviews the theoretical and empirical literature related to environmental quality.

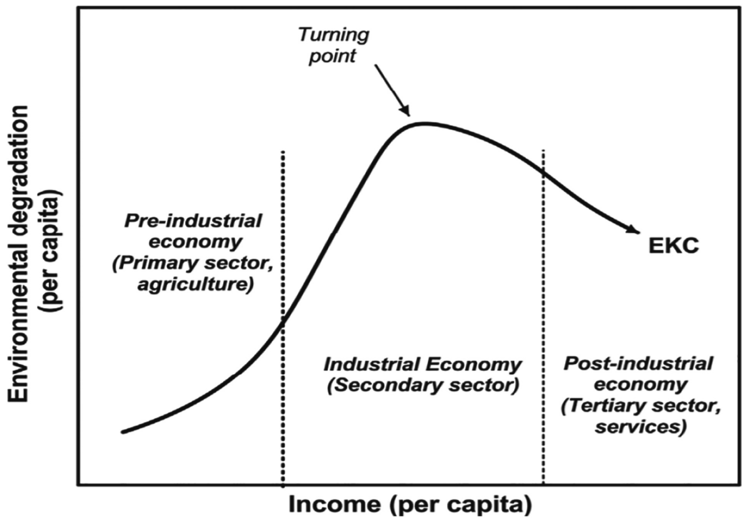
2.1 Theoretical literature

The concern on the relationship between population and environment at global level has stimulated the theoretical discussion among past researchers. The first approach related to population element and environmental issues was IPAT model originated from Ehrlich and Holdren (1971) where I = impact of environment, P = population, A = affluence (consumption per capita) and T = technology (pollution per unit of consumption). However, Cole and Neumayer (2004) posited that the IPAT model is not useful for empirical estimation of the relative change in environment or emissions given proportional changes in population.

Thus, the stochastic version of IPAT known as stochastic impacts by regression on population, affluence and technology (STIRPAT) introduced by Dietz and Rosa (1997) was utilised by the study. Zagheni (2011) stated that STIRPAT model has extensively been used to investigate the role related to demographic component on CO_2 emissions as it makes the IPAT equation operational for statistical analysis. Next, the energy component is linked through the second approach known as population-environment-technology (PET) model, which is integrated according to energy-economic growth model. The PET model is calibrated with household demographic projections, estimates of consumption expenses, savings and labour market input–output table (Dalton *et al.*, 2008). It is a global-scale dynamic computable general equilibrium model designed for the simulation analysis. Another theoretical construct related to the environment is the EKC model. The basic EKC model was originated from Kuznets (1955) and later extended by Grossman and Krueger (1994).

Meanwhile, Ang (2007) in related study stated that there is a significant increase in environmental degradation when income per capita increases before it stabilises and eventually declines. Figure 2 explains at the stage of initial economic development, i.e. pre-industrial economy, environmental degradation increases steadily with income, while at the second stage of the industrial economy, the degradation increases sharply with income until it reaches a certain threshold level or turning point where it begins to decrease. The degradation level continues to reduce in the post-industrial economy with better environmental quality (Kaika and Zervas, 2013).

Although the EKC framework has proven useful to explain the effects of energy consumption on the environment, the particular factors underlying these impacts on the population ageing are still not well understood. Most viewpoints have only shown how population growth has had an effect on the environment but have not resolved the conflicts concerning the ageing situation. Almost everyone has made no progress with the exact relationship between ageing and environmental effects using EKC theory.



Source(s): Kaika and Zervas (2013)

Figure 2.
An environmental Kuznets curve (EKC)

2.2 Empirical literature

The existing literature have synthesised and investigated the relationship between emissions level, economic growth and energy consumption under the EKC framework, which initially coined by Grossman and Krueger in 1994 (Ang, 2007; Apergis and Payne, 2009; Alkhathlan and Javid, 2013; Ozcan, 2013; Wang *et al.*, 2016; Antonakakis *et al.*, 2017). Past studies found mixed results related to the EKC; for instance, Ozcan (2013) found a U-shaped EKC curve for the majority of the sample countries while inverted U-shaped curve and no significant relationship for several other countries under the study. Antonakakis *et al.* (2017) highlighted that different classes of countries mix the impacts of energy on economic growth and the environment. Furthermore, many studies take into account various indicators in the EKC framework to investigate the relationship with environmental quality instead of just energy and economic growth.

In a different perspective, the ongoing demographic transition entailing changes in the regional distribution, household composition and population age structure also raise concerns when projecting future CO_2 emission. Yu *et al.* (2018) mentioned that a demographic shift towards small and ageing households boost the energy consumption and emissions driven by the joint variations in the consumption pattern and time use. This study applied the extended snapshot (ExSS) tool, which is a bottom-up engineering model in Chinese household, to investigate the relationship between economic growth, technological change, population dynamics and lifestyle. In Barnicoat and Danson (2015), it was found that the population ageing has high electricity consumption to fulfil their needs with a lack of knowledge of energy saving. The study focused on the awareness and views of elderly about energy usage, routine and habit. Higher consumption will place pressure on the emission level. On the other hand, Wang *et al.* (2021) posited that older people are more likely to be involved in environmental behaviour that promotes lower level of emissions and sustainable consumption. This implies that population ageing probably offers a better opportunity to improve the environmental quality.

A closer look on CO_2 emissions found several studies on the demographic strand although some attempts in this area are still limited. Cole and Neumayer (2004) contributed to the debate on the link between population growth and the environment, including arguments on urbanisation, household size and age structure (excluding 65 and above), hence indicating no discussion related to ageing. Dalton *et al.* (2008) incorporated population ageing into the PET framework using simulation technique of dynamic computable general equilibrium model. It was concluded that population ageing reduces long-term emissions by almost 40% in a low population scenario. Similarly, O'Neill *et al.* (2010) examined the impact of demographic transition on CO_2 emissions based on PET model using simulation technique. The study found that urbanisation, population size and age structure (population ageing) will reduce long-term CO_2 emissions by up to 20%, especially in developed regions.

In contrast, Kronenberg (2009) concluded that demographic change tends to raise GHG emissions via the application of input–output model in the analysis using data from Germany. The study utilised microdata from a household survey and did not deal with population ageing directly in the model estimation. Magnani and Tubb (2008) found similar result that population ageing contributes positively to the emission level. The study mainly focused on explaining about the EKC via willingness to pay. The government could have also limited the budget on environmental conservation and rather focused on other aspects, like healthcare and social security. Zagheni (2011) stated that although several demographic quantities are potentially important determinants of GHG emission, most studies explicitly consider only population size or some measures of age structure. The main contribution of this study is on the methodology part using data from the USA. However, the analysis shows that population ageing reduces long-term emissions based on the IPAT framework and input–output model.

Next, O'Neill *et al.* (2012) investigated the impact on CO_2 emissions from fossil fuels using demographic factors, such as population growth, ageing, urbanisation and changes in household size. However, a modified form of the IPAT equation known as STIRPAT was applied. The result indicated that ageing reduces the emission level, and the decrease in the population growth rate leads to a substantial reduction in global emissions, particularly in the long run. Alternative approaches by Menz and Welsch (2012) are based on the lifecycle and cohort effect, which concluded different results. Demographic transition boosts the emissions level via the increase of population ageing in the OECD (Organisation for Economic Co-operation and Development) countries.

Similar work was also done by Hassan and Salim (2015), which explored the relationship between population ageing, economic growth and CO_2 emissions in high-income OECD countries using the annual time series data for the period between 1980 and 2009. The study employed fully modified ordinary least square (FMOLS) in a panel data based on EKC model and posited that the increase of population ageing reduces the CO_2 emissions level in the long run. However, this study did not include energy or electricity consumption in the model framework. In other words, the study leaves the impact of electricity consumption unexplored with economic growth and population ageing on CO_2 emissions simultaneously.

In summary, based on the literature review, it was found that earlier research produced mixed findings on the relationship of population ageing with CO_2 emissions and most past studies demonstrated that population ageing on emissions was mostly explored from the contexts of household and simulation technique which are not based on the real data. Related studies were also mostly done in the developed countries and less focus on the developing countries. Next, PET and IPAT models serve as a basic framework when discussing the impacts of demographic transition on emissions level, and only Hassan and Salim (2015) utilised the EKC, but they did not explore the impacts of population ageing on electricity consumption. In this case, there is still a lack of clarity on the relationship between population ageing and CO_2 emissions based on the EKC framework. Other than that, several researchers have used the EKC to explore the population aspect of the environment in their more recent works, but the studies did not counter the population ageing effects with energy element.

Therefore, this study fills the research gap in the existing literature. Therefore, in-depth analysis and investigation are crucial, and the contributions of this study will help to formulate specific population, energy or emissions mitigation strategies that provide a more practical approach for future sustainable development.

2.3 The research questions

Due to rapid accelerating of older people in the current population structure worldwide and issue on high level of CO_2 emissions, no specific studies have been conducted focusing on the effects of population ageing when electricity consumption and economic growth are the most prominent drivers of environmental quality. The current study therefore focuses to answer the research questions on whether and to what extent the population ageing of 17 LDD countries influences the environmental quality when electricity consumption and income become the most prominent variables in the EKC framework. The impacts of population ageing on environmental quality are a matter of dispute since previous researchers found ageing will reduce the CO_2 emissions while some concluded that population ageing will increase the CO_2 emissions.

Besides that, the common impacts of economic growth on environmental quality assert an inverted U-shaped curve following the EKC, which means that environmental degradation tends to reduce when per capita income increases up to a certain level. Nevertheless, there is also a possibility to have non-inverted U-shaped or inverted U-shaped curve among countries regardless of their income status (high- or middle-income countries). For instance, Charfeddine and Mrabet (2017) found the inverted U-shaped relationship in oil-exporting countries and U-shaped among non-oil exporting countries. Following the EKC, this study answered the research question on whether there is an inverted U-shaped curve among the sample countries. It should be noted that electricity consumption naturally increases with CO_2 emissions level (Salahuddin *et al.*, 2018).

3. Research methodology

3.1 Data and sample period

LDD countries, according to the classification of World Bank (see Appendix), were examined to analyse the possible effects of population ageing on environmental quality using the EKC framework. The fertility rate in LDD countries is less or equal to the replacement level of 2.1, causing the population ageing to rise at high level. Thus, using LDD as sample countries is appropriate to achieve the objectives of this study. The research has been conducted in a total of 17 nations. The sample selected was dictated by the data series' availability for all variables. The annual data cover the period from 1990 to 2018 for per capita CO_2 emissions, per capita GDP, per capita electricity consumption and share of elderly in the total population. Per capita CO_2 emissions is expressed in terms of metric tonnes (mt) representing pollution stemming majorly from the burning of fossil fuels and the manufacture of cement. Per capita GDP measured in constant 2010 United States dollars (USD) portrays the countries' income level of economic growth. Per capita electricity consumption is in kilowatt-hour (kWh) while the share of the elderly (people aged 65 and above) is presented in the form percentage of the total population. Data for all sampled countries were obtained from the World Development Indicator (WDI) of the World Bank and Enerdata database. The primary causes of global climate change are due to the emission of the several types of GHGs with CO_2 being the most prominent, thus prompting many researchers to explore more about it (Abeydeera *et al.*, 2019). In addition, the burning of fossil fuels for electricity generation is the largest contributor for global CO_2 emission (US Energy Information Administration, 2021). Therefore, this study used the per capita CO_2 emissions as a dependent variable, which represents the environmental quality indicator and other variables as determinants in the model framework (see Table 1).

3.2 Model specification

The basic framework used is based on the EKC for the empirical estimation of this study. Although most of the past studies related to ageing were based on the IPAT model as introduced by Ehrlich and Holdren (1971), this approach has been criticised for its inability and limitations compared to the EKC framework (Hassan and Salim, 2015). The EKC is used to investigate the impact of various factors besides IPAT while Carson (2010) noted that the IPAT model is a restricted EKC version. Supported by the latest study, Liddle (2015) bridged the STIRPAT and EKC model and stipulated that the transformed model is equivalent to the EKC when translating the dependent variable into per capita terms. Thus, this study adopted the EKC. The inclusion of the energy element in the EKC framework explored by Ang (2007), Ozcan (2013) and Kasman and Duman (2015) is given by the following function:

$$CO_{2it} = f\left(GDP_{it}, GDP_{it}^2, EC_{it}\right) \quad (1)$$

where CO_2 represents per capita carbon dioxide emission, GDP is per capita real gross domestic product, GDP^2 is squared per capita real gross domestic product and EC is per capita energy consumption. The subscript of i and t is country and time dimension in the panel setting. Besides energy consumption as the most prominent variable related to environmental quality, this study fills the gap by focusing on examining the connection between population ageing and CO_2 emissions without disregarding the vitality of income and energy aspect on environmental quality as what Hassan and Salim (2015) have applied in their research. Energy is essentially the major contributor of economic prosperity while electricity acts as a measure of modern economic stage and better living standards. The increase of per capita income has spurred the demand for energy, especially electricity consumption due to changes in lifestyle. Shifting preferences in consumption are crucial characteristics during demographic transition towards ageing society (Yaziz and Azlina, 2020). Thus, population ageing is undoubtedly impactful on electricity consumption, especially via residential sector (Pais-Magalhaes *et al.*, 2020). Structural changes in electricity consumption are followed by the alteration of fossil fuel consumption. Commonly, higher fuel demand for electricity generation leads to increased GHG emissions, predominantly CO_2, which contributes to global warming. Therefore, the proposed framework can be modelled as specified in the natural log-linear form:

$$\ln CO_{2it} = \alpha + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{it}^2 + \beta_3 \ln ELC_{it} + \beta_4 \ln PA_{it} + \varepsilon_{it} \quad (2)$$

where CO_{2it} is per capita CO_2 emission, GDP_{it} is per capita GDP, $GDP_{it}{}^2$ is squared per capita GDP, ELC_{it} is per capita electricity consumption and PA_{it} is share of the population aged 65 years and above in the total population. α and β correspond to the constant and elasticity

Indicator name	Abbreviation	Measurement scale	Source
Per capita carbon dioxide emission	CO_2	Metric tonnes	Enerdata
Per capita real Gross Domestic Product	GDP	Constant 2010 US$	WDI
Per capita electricity consumption	ELC	Kilo-watt hours	Enerdata
Share of the population aged 65 years and above	PA	% Of the total population	WDI

Note(s): WDI represents World Development Indicator (https://data.worldbank.org/) while Enerdata denotes global energy data (https://www.enerdata.net)

Table 1. Data description and measurement units

values, respectively. ε_{it} is the error term with the assumption of identically and independently distributed with zero mean and constant variance. The coefficients of β_1, β_2, β_3 and β_4 are the parameter to be estimated, which was hypothesised that the sign for β_1 and β_3 is positive while β_2 and β_4 is negative. Initially, economic growth is harmful to the environment, $\beta_1 > 0$ but after a certain level, the relationship between economic growth and emissions improves the environmental quality through emissions reduction, $\beta_2 < 0$. The rise of electricity consumption is expected to increase the CO_2 emissions level, $\beta_3 > 0$, and this can be reduced when the economy moves towards an ageing nation as implied by $\beta_4 < 0$.

3.3 Econometric methodology

This study employed the pooled mean group (PMG) estimator proposed by Pesaran *et al.* (1999) who integrated the dynamic heterogeneous panel into the error-correction model using the autoregressive distributed lag (ARDL) technique, ARDL*(p, q)* where p is the lag dependent, and q is the lag independent variables. The basic model is given as follows:

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} x_{i,t-j} + \mu_i + \varepsilon_{it} \tag{3}$$

where $i = 1, 2, \ldots, N$ refers to each group and $t = 1, 2, \ldots, T$ for time period. In order to estimate an ARDL*(p, q)* model, x_{it} $(k \times l)$ is the vector of explanatory variables for group i. μ_i represents the fixed effects; λ_{ij} is the coefficients of the lagged dependent variables, δ_{ij} are $k \times 1$ coefficient vectors and j is the number of time lag. According to this study, y_{it} per capita CO_2 emission and x are vector of per capita GDP, squared per capita GDP, per capita electricity consumption and share of the population aged 65 years and above in the total population.

Following the panel ARDL pathway, equation (3) is expressed with inclusion of an error-correction term (ECT), $ECT_{it} = y_{it-1} - \theta_i X_{it}$ rewritten as follows:

$$\Delta \ln y_{it} = \mu_i + \varphi_i (y_{it-1} - \theta_i X_{it}) + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta \ln y_{it-j} + \sum_{j=0}^{q-1} \delta^*_{ij} \Delta \ln X_{it-j} + \varepsilon_{it} \tag{4}$$

where

$$\theta_i = -(\beta_i / \varphi_i);$$

$$\varphi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij} \beta = \sum_{j}) = \delta_{ij};$$

$$\lambda^*_{ij} = -\sum_{m=j+1}^{p} \lambda_{im}, j = 1, 2, \ldots, p-1;$$

$$\delta^*_{ij} = -\sum_{m=j+1}^{q} \delta_{im}, j = 0, 1, 2, \ldots, q-1.$$

The long-run equilibrium relationship between y_{it} and X_{it} is defined by the θ_i, the long-run coefficients. Meanwhile, λ^*_{ij} they are the short-run coefficient of lagged dependent and independent variables. The error-correction coefficient φ_i measures the adjustment speed of y_{it} towards its long-run equilibrium due to a change in X_{it} and $\varphi_i < 0$, which confirms the existence of a long-run relationship. The cointegration between y_{it} and X_{it} ascertains with the significant negative value of φ_i in the estimation. The lag length is chosen by minimising the Akaike information criterion (AIC).

The main reason of choosing this estimator is because it can be used with variables of various integration orders regardless of *I(0), I(1)* or a mixture between the integration order of variables under analysis. This represents the significant benefit of the ARDL as it makes checking for the unit root test unnecessary and not vital. Moreover, both the short- and long-run effects can be estimated simultaneously in the analysis. The potential existence of endogeneity and ARDL model, particularly PMG estimators, provides robust coefficient since the model includes lags of dependent and independent variables. In this process, all the estimators consider the long-run equilibrium, and the heterogeneity of the dynamic adjustment process is computed by the maximum likelihood. The ARDL model in error-correction form is a relatively new cointegration test; however, it is crucial to have consistent and efficient estimates of the parameters for the long-run relationship.

3.4 Estimation strategies

The first stage involved a stationarity test to identify the integration order of the series. The panel ARDL model provides consistent estimates irrespective of the integration order either $I(0)$ or $I(1)$ among the variables. However, the estimation was not applicable with variables of $I(2)$ and above, leading to the spurious result. Thus, the panel unit root tests used Levin–Lin–Chu (LLC) as proposed by Levin *et al.* (2002), Im–Pesaran–Shin (IPS) by Im *et al.* (2003) and Fisher augmented Dickey–Fuller (ADF) tests by Maddala and Wu (1999) were being used extensively in this study. The null hypothesis can be constructed as H_0: $\rho = 1$ means that all series in the panel have a unit root or not stationary, while the alternative $H1$: $\rho < 1$ indicates that all series have no unit root or stationary. LLC allows intercept heterogeneity and IPS enables heterogeneity both for cross-sectional unit intercept and slope. IPS suggests an alternate method of testing that is based on the average of individual unit root test statistics. In addition, Fisher ADF test ultimately allows for heterogeneous specification and can be used on individual unit root test.

The next stage was the panel cointegration test to confirm the long-run equilibrium relationship between the dependent variable of per capita CO_2 emission and all the explanatory variables. This procedure is vital to ascertain the convergence between the variables investigated. Several testing procedures are available to test for panel cointegration. This study applied the panel cointegration test suggested by Pedroni (1999, 2004). The test is based on the Engle and Granger (1987) cointegration regression residual and has been widely used in the empirical literature. The structure of the estimated residual expressed as $\varepsilon_{it} = \rho_{it}\varepsilon_{it-1} + u_{it}$ derived from the following long-run model:

$$Y_{it} = \alpha_i + \lambda_i t + \sum_{j=1}^{m} \beta_{ji} X_{jit} + \varepsilon_{it}, \qquad (5)$$

where Y and X are assumed to be integrated of order one in levels. The null hypothesis H_0: $\rho_i = 1$ indicates no cointegration among all seven tests (within and between dimension statistics) in the heterogeneous panels, whereas the alternative hypothesis H_a: $\rho_i < 1$ provides different specifications. The first group of test statistics known as "within" dimension comprises panel v statistic, panel rho-statistic, panel *PP*-statistic and panel *ADF*-statistic. The second group of test statistics termed "between" dimension include group rho-statistic, group *PP*-statistic and group *ADF*-statistic. All seven statistics were normally distributed and based on the average of individual autoregressive coefficient associated with the unit root tests of the residuals for every cross-sectional unit. In the next step, the statistics need to be compared with the appropriate critical values. If the critical values are exceeded, the null hypothesis of no cointegration is rejected, and it can be concluded that there is a long-run relationship between the variables.

The last stage was to estimate the long-run relationships among per capita CO_2 emission, per capita real GDP, squared per capita real GDP, per capita electricity consumption and proportion of the population ageing using PMG estimator established as equation (4). The details information on the estimator has been explained in the previous section of (3.3).

The PMG estimator is accurate and consistent only if the long-term coefficients in the model are similar across countries or known as the long-term homogeneity constraints. Mean group (MG) estimator is the alternative estimator also utilised in the study. If the hypothesis of long-term homogeneity is valid, the PMG is the most efficient estimator. However, the suitability of the model is determined by the standard Hausman test, and there is also a possibility of other estimator outperforming the PMG.

4. Empirical findings and discussion

4.1 Descriptive statistics and correlation analysis

First, the descriptive statistics and correlation for the data series are described in Table 2. The per capita CO_2 mean value is 4.5399 metric tonnes (mt), and the average value for population ageing proportion is 8.5895% per total population. The percentage of population ageing is in the range of 7%–14%, which indicates that all listed countries (see Appendix) are relevant and considered in the stage of ageing (Coulmas, 2007). The evidence demonstrates that all variables exhibit long-right tail skewness for all the variables. Additionally, the kurtosis values show that per capita GDP and squared per capita GDP have a leptokurtic curve (>3.0) while other variables have a platykurtic curve (<3.0). It has been verified that almost none of the skewness and kurtosis values for the above variables follow normality conditions. The correlation analysis possesses a positive correlation between CO_2 emissions and all variables under consideration. Among all variables, electricity consumption has the strongest positive correlation with CO_2 emissions. Per capita GDP, squared per capita GDP and share of the population aged 65 years and above have moderate, positive correlation with per capita CO_2 emission. It should be noted that the correlation coefficient test is inadequate to support any findings. Further estimation using econometric approach was required to verify more accurate and coherent viewpoints to answer the research objectives.

4.2 Empirical findings and discussion

Like the traditional ARDL model approach, panel ARDL does not require a unit root test for the variables. However, since PMG is not applicable to the integration order of two *I(2)* or higher, the unit root testing was conducted. The results in Table 3 show that all variables under review confirmed that the series are integrated at order one *I(1)* and zero *I(0)*, which means that all variables were found to be stationary at the level and first differences. All tests are conducted with a trend and constant. Hence, the next procedure is to test for panel cointegration.

	Late-demographic dividend countries (obs = 459)				
Variables	CO_2	GDP	GDP^2	ELC	PA
Mean	4.5399	9813.457	2.13 E+08	2325.947	8.5895
SD	3.7227	10829.36	5.68 E+08	1541.815	3.2751
Min	0.2826	433.2839	187735.0	92.1180	3.6817
Max	15.1629	70298.66	4.94 E+09	6207.629	17.4172
Skewness	0.9000	2.7469	4.6347	0.6887	0.5595
Kurtosis	2.7413	11.2769	27.9529	2.7275	2.1840
CO_2	1.0000				
GDP	0.7068	1.0000			
GDP^2	0.6918	0.9966	1.0000		
ELC	0.9085	0.8411	0.8186	1.0000	
PA	0.4821	0.5088	0.5091	0.5215	1.0000

Table 2.
Descriptive statistics and correlation matrix

Table 4 presents the results on the various tests for cointegration. The null hypothesis indicates no cointegration among all seven tests (within and between dimension statistics) in the heterogeneous panels. From the result in Table 4, panel PP-stat, panel ADF-stat, group PP-stat and group ADF-stat rejecting the null hypothesis at a 1% significance level which indicates the existence of cointegration among the variables. However, since the tests yield mixed results when some series are cointegrated and some are not (panel v-stat, panel rho-stat and group rho-stat), the key criterion to verify the existence of cointegration relationship between these variables is by using the ECT. The good value of ECT must significantly negative and less than unity in absolute value.

In order to estimate equation (4), there is a need to choose the alternative estimators since the PMG estimator is consistent and efficient only when the long-run coefficient in a model fulfils the homogeneity restrictions or equal across countries. The MG estimator proposed by Pesaran and Smith (1995) was also utilised. MG does not impose any limitations and restrictions. The MG estimator allows variations for all countries in the short and long term by estimating regressions for each group and averaging the coefficients. The Hausman test determines the suitability between PMG or MG; hence, this study is more relevant by the measurement using the PMG estimator as Hausman test results reveal that the null hypothesis of the long-run homogeneity cannot be rejected at 1% significance level ($\chi^{2(4)} = 0.25$, p-value $= 0.993$). Thus, the presentation only focuses on the PMG results as shown in Table 5.

The key estimation results in Table 5 prove that the ECT is significantly negative and less than the point of unity, which indicates there exists a long-run relationship between CO_2 emissions and the determinants. One of the interests in this study is the relationship between income and emissions. The per capita GDP coefficient is positive, while the squared per capita GDP coefficient is negative in the long run as expected. However, both per capita GDP and squared per capita GDP are not statistically significant in the model estimation, which could not support the EKC hypothesis. Although the impact of income is not significant in the long run, the short-run result confirms that the per capita GDP and squared per capita GDP have a significant impact on the CO_2 emission. The result is supported by Ozcan (2013), Ozturk and Al-Mulali (2015) and Aye and Edoja (2017). The majority of the LDD countries consist of middle-income countries as mentioned earlier in this study. Thus, the countries probably have a similar impact among LDD and middle-income in supporting the findings. Additionally, He (2007) concluded that not all developing countries possessed the inverted U-shaped curve, which adequately describes the relationship between growth and CO_2 emissions.

Next, in terms of the impact of electricity consumption on CO_2 emissions, this is positively associated in the short and long run but is more of a significance in the latter. The result suggests that per capita CO_2 emissions increase as electricity consumption increase with income growth. For example, when electricity consumption increases by 1%, the CO_2

	Common unit root		Individual unit root			
	LLC		IPS		ADF	
Variable	Level	Δ	Level	Δ	Level	Δ
CO_2	−1.579*	−10.320***	−2.345**	−10.440***	52.867**	160.441***
GDP	−0.361	−3.708***	−1.354*	−5.740***	45.518	95.610***
GDP^2	0.131	−4.412***	−1.706**	−6.038***	48.478*	96.734***
ELC	−2.978**	−7.987***	−2.065**	−8.900***	61.580**	144.138***
PA	−1.492*	2.211	2.368	−1.718**	84.275***	52.931**

Note(s): ***, ** and * denote significance at 1, 5 and 10% significance level, respectively; LLC is Levin–Lin–Chu test statistics; IPS is Im–Pesaran–Shin test statistics; ADF is augmented Dickey–Fuller test statistics

Table 3. Results of panel unit root tests

Pedroni test	Statistics
Within dimension	
Panel v-stat	−0.879
Panel rho-stat	1.214
Panel PP-stat	−4.144***
Panel ADF-stat	−4.792***
Between dimension	
Group rho-stat	1.855
Group PP-stat	−5.884***
Group ADF-stat	−6.353***

Note(s): ***denote significance at 1% level. The null hypothesis is no cointegration against alternative hypothesis of cointegration existence. Trend assumption: Deterministic intercept and trend

Table 4.
Results of panel cointegration tests

Dependent variable: CO_2 emissions Independent variables *Long-run coefficient*	Coefficient	Standard error
GDP	0.421	0.265
GDP^2	−0.009	0.013
ELC	0.431***	0.049
PA	−0.043***	0.013
Error correction	−0.402***	0.075
Short-run coefficient	Coefficient	Standard error
Δ GDP	−9.473**	4.662
Δ GDP^2	0.611**	0.290
Δ ELC	0.249*	0.138
Δ PA	−0.052	0.117
Intercept	−1.912***	0.348

Note(s): ***, ** and * denote significance at 1, 5 and 10% significance level, respectively. All variables are in natural logarithms and lag structure is ARDL (1,1,1,1,1)

Table 5.
Results of the PMG estimates of the long and short-run elasticities

emissions rise by approximately 0.431%, which is almost half with holding income and population ageing being constant. This result is consistent with Salahuddin *et al.* (2018). Among all, the main interest in this study is the relationship between population ageing and CO_2 emissions. Population ageing significantly affects the emission with a negative relationship in the long term, which suggests that CO_2 emissions will decrease when population ageing proportion increases in the population structure. For instance, a 1% increase in population ageing causes emissions to decrease by 0.043% in the long term. This demonstrates that population ageing has a direct impact on environmental quality from the alteration of demand pattern particularly related to electricity. Population ageing transform the consumption structure and influence the CO_2 emission, which verifies the preceding discussion on the linkage of population ageing and environmental quality. The results provide evidence of better environmental quality in population ageing in line with Hassan and Salim (2015). The impact of ageing on emission will be more significant when income level is greater and countries level up their status to high-income nation.

4.3 Policy implication and recommendation

This study has proven that electricity consumption positively impacts CO_2 emission in the short and long run, thus deteriorating environmental quality. In the short run, a rise in income will increase environmental degradation among LDD countries but no in the long run. This indicates that conservative energy policies to reduce the CO_2 emissions might be useful because conserving energy does not impede economic growth in the long run. However, conservative policies and limited electricity consumption will delay economic prosperity and slow down the development process towards a high income nation. In the industrial sector, policymakers need to encourage the adoption of green technology and renewable energy in the production process. All countries were urged to invest in renewable resources to generate electricity from solar, wind, hydro, etc. Renewable energy will play a vital role in meeting countries' energy needs in a sustainable manner besides their potential to mitigate emission levels. Moreover, LDD countries can implement carbon capture, utilisation and storage (CCUS) and carbon-free new technologies to enhance environmental quality without jeopardising or delaying economic growth. On top of that, tariff regulation, energy efficiency and energy saving can be implemented to support clean energy transition, especially in the current demographic structure.

Any changes in the demographic composition will continue to be significant in the coming decades among LDD countries while most are in the developing phase. The situation requires many considerations to be made between the aspect of economic growth (i.e. population size, consumption structure and production) and environmental quality. In the long run, population ageing is an additional impacts on reducing CO_2 emissions. Theoretically, the environmental quality is expected to become better with higher income levels among related countries. In other words, appropriate environmental policies can only be enforced as income level increases. Building nuclear energy plant is another viable alternative for low CO_2 emission that need significant investment. In the real situation, it is not easy to formulate environmental policies and promoting economic growth simultaneously. Sustainable population strategies corresponding to the population structure is also vital. The rapid increase in the human population leads towards overconsumption, which presses environmental problems. An additional number of populations means an additional number of new consumers contribute to higher electricity demand, which will deteriorate the environmental quality in the long run. In this sense, adding fewer new consumers reflects sustainable population strategies for consumption sustainability. Besides, the unequal distribution within the human population has also become one of the major concerns in sustainable development as population ageing is dominant in suburban or rural areas. Embracing related policies to stabilise the population distribution will influence electricity consumption and environmental quality.

It is important to note that the low fertility rate mainly drives population ageing. Thus, investment in human capital has been discussed in many studies besides population plan strategies. Population ageing has promoted higher investment in human capital stemming from the quality of education. Education improvement across different age structures is crucial in economic growth. In a different dimension, good quality human capital and education positively impact society and the environment. Therefore, controlling and mitigating the CO_2 emissions level is possible with initiatives supporting the phenomena of ageing. The impacts of electricity consumption, economic development and population ageing are significant to construct effective and relevant policies in the current and future demographic structure. In this case, improving and monitoring the management process is crucial to balance both environmental quality and economic growth. The key elements of mitigation policy, such as technology preference, pollution abatement, usage efficiency and consumption pattern, are important to mitigate environmental degradation. The demographic policy will entail benefits in population ageing for better future policy direction, while education and human capital certainly play essential roles in strengthening society (Lutz *et al.*, 2019).

5. Conclusion

This study investigated the impact of population ageing on environmental quality in 17 LDD countries based on the EKC hypothesis. Using panel data retrieved between the years 1990 and 2018 and PMG estimator, the empirical results showed no evidence of a valid EKC hypothesis for the long term. The significant impact of income on the emissions level in the short run among the countries under study occurs due to the fast and progressive developing process. Meanwhile, electricity consumption has an adverse effect in reducing the emissions either in the long or short run. The findings of the study have significant policy implications. The main contribution is population ageing, which provides evidence that countries with a relatively higher number of senior citizens in the population structure tend to emit fewer emissions and foster better environmental quality. However, this study is limited in scope and only covers the variables stated in model estimation. Within this limitation, countries should focus on earning higher income to mitigate CO_2 emissions while in a state of changing population structure. In this sense, all countries are responsible to decide their direction towards sustainable development as well as better economic and environmental quality. The scope of this study was discussed from the direct impact of population ageing on environmental quality through the utilisation of CO_2 as a proxy. While this study focuses on CO_2 emission among 17 LDD countries by considering electricity consumption structure as well as economic growth, the impact on environmental quality goes beyond this. Population ageing tends to influence the environmental quality indirectly in which the impact of other related variables should be investigated in future studies.

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Appendix

Late-demographic dividend (LDD) countries	
Brazil (BRA)	Poland (POL)
Chile (CHL)	Romania (ROU)
Costa Rica (CRI)	Russian Federation (RUS)
Cyprus (CYP)	Sri Lanka (LKA)
Ireland (IRL)	Thailand (THA)
Kazakhstan (KAZ)	Tunisia (TUN)
Malaysia (MYS)	Uruguay (URY)
Mauritius (MUS)	Vietnam (VNM)
Morocco (MAR)	

Table A1. LDD countries according to the classification of World Bank

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