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RESEARCH ARTICLE

The productive capacity and environment: evidence from OECD countries

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Abstract
Environmental degradation is one of the most important and vital issues of today. In this context, many researchers are testing the environmental impact of different indicators. Many economic parameters affect environmental degradation. At the forefront of these parameters is the *productive economic structures* of the countries. For the first time in the literature, the present paper discusses the dynamic relationship between carbon dioxide (CO_2) emissions, economic growth, and the productive capacity index (PCI) for a panel of 38 organization for economic co-operation and development (OECD) countries spanning the period 2000–2018. In this context, the PCI serves as a measure of the productive economic structure of a country. This empirical study applies panel cointegration techniques to reveal that the series are cointegrated in the long-run. In addition, the pooled mean group-panel autoregressive distributive lag (PMG-ARDL) approach is employed to estimate long-run coefficients. These coefficients confirm the environmental Kuznets curve hypothesis. Finally, the empirical findings confirm that improved productive capacity decreases environmental degradation. This results in important policy recommendations for involved governmental and private stakeholders.

Keywords Economic complexity · Productive capacity · Greenhouse gasses · OECD economies · Knowledge economy · Environmental degradation

JEL Classification O11 · O31 · Q56

Introduction

Economic growth is a critical element in reducing poverty in all its dimensions and achieving decent living standards (Buysse et al. 2018). In addition, continuous growth appears necessary to ensure increased employment rates, higher income levels, and lead to a hopeful life (UN 2021). Policies prioritizing human welfare and enrichment resulted in unprecedented expansions in economic activities, which started in the twentieth century and continued until today (Malik 2012). However, this economic expansion also led to considerable environmental costs as all economic activities

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(including for example agriculture, transportation, manufacturing, and energy consumption) lead to environmental degradation (Hoffmann 2013).

The world's population has increased from 1.65 to 7.71 billion since the 1900s. Simultaneously, the world's gross domestic product (GDP) increased 33 times, from USD 3.41 trillion (constant 2011, USD) to USD 113.63 trillion. As a consequence, primary energy consumption increased from 12,128 to 173,340 TWh in the same period (Vaclav 2017; Roser et al. 2013; Bolt and Luiten Van Zanden 2020).

On the downside, the increased demand for energy and expanding economic activities contributed to a 1 °C rise in the average temperature since 1900. Similarly, CO_2 emissions rose from 1.95 to 36.44 billion tons (Jensen et al. 2012; Friedlingstein et al. 2020). The increase in CO_2 emissions and the rise in the global average temperature are almost entirely man-made. This situation can cause the melting of glaciers, sea-level rise, deforestation, desertification, drought, serious risks in food production, and irreversible negative effects on nature (IPCC 2018).

To halt these unfavorable trends, the Paris Agreement sets the objective of limiting the global average temperature increase to 1.5 °C compared to pre-industrial levels. This agreement explicitly defined climate change as an "urgent and potentially irreversible threat" and formally identified the problem of global warming as one of the most pressing challenges to be addressed through a concerted global effort (Martimort and Sand-Zantman 2013; Suki et al. 2020). This has attracted the attention of many economists, who have attempted to find a solution by creating both theoretical and empirical models (Koc and Bulus 2020).

Many economic parameters affect environmental degradation. At the forefront of these parameters is the *productive economic structures* of the countries (Apergis et al. 2018; Can et al. 2021). The productive economic structure is defined as the orientation of production factors to productive areas thanks to the realization of structural transformation. The realization of this situation is closely related to individual and social skills, product knowledge, and experience (Can and Doğan 2020; Khan and Hou 2021b).

This study further investigates the pivotal impact of productive capacity on CO_2 emissions during the period 2000–2018 for 38 OECD countries. The reason to focus on the OECD countries is twofold. First, the OECD countries represent a large population and significant production capacity. For this reason, they are a major player in world trade and represent the most developed industrial countries (Ahmad et al. 2021). Second, the OECD countries account for most of the world's energy consumption and use large quantities of traditional fossil fuels such as natural gas, oil, and coal. This leads to large amounts of CO_2 emissions (Saidi and Omri 2020). As the OECD countries are increasingly aware of their responsibility, they urgently seek for the most optimal solution to reduce CO_2 emissions (Wang and Wei 2020). Much emphasis is put on increased energy efficiency, also preventing waste of resources. As this topic is high on the policy agenda, this paper's topic is highly relevant in the concerned region. For this reason, it is crucial to investigate the effects of a country's *productive economic structures* on CO_2 emissions in OECD countries. The productive economic structures are measured using the productive capacity index (PCI), which is a quantitative measure for a country's level of productive capacity.

This study contributes to the current literature in different aspects. Firstly, to our best knowledge, this is the first attempt that introduces the PCI in the environmental economics literature. PCI is an holistic way to assess economic productivity. Previously, only specific elements were analyzed. Secondly, we test the impact of the PCI on environmental degradation for a panel of 38 OECD countries spanning the period 2000 to 2018. Thirdly, we employed different panel estimation techniques, which are appropriate for the cross-sectional dependent (CD) panel of OECD countries to obtain robust findings.

The remainder of the study is structured as follows. "Theoretical background" provides the theoretical framework and presents an extensive literature review in support of that theoretical framework; "Data and empirical methodology" presents the data and develops the methodological approach. "Empirical results" presents the research results. "Discussion and policy directions" discusses the results and provides policy recommendations. "Conclusion" concludes the research.

Theoretical background

Productive capacity index

Many environmental economists tried to determine the factors affecting the environment for a long time. One of the most frequently used frameworks in these studies is the environmental Kuznets curve (EKC) hypothesis by Grossman and Krueger (1991). The EKC hypothesis became one of the major theories explaining the relationship between economic growth and environmental degradation since the early 1990s (Demissew Beyene and Kotosz 2020). According to the EKC hypothesis, in the first stage of economic development, environmental degradation increases as per capita income increases. However, this trend will reach a tipping point, and environmental degradation will become inversely correlated to per capita income from that moment onwards. This changing relation results in an inverted U-shaped relationship between income and environmental degradation, as presented in Fig. 1.

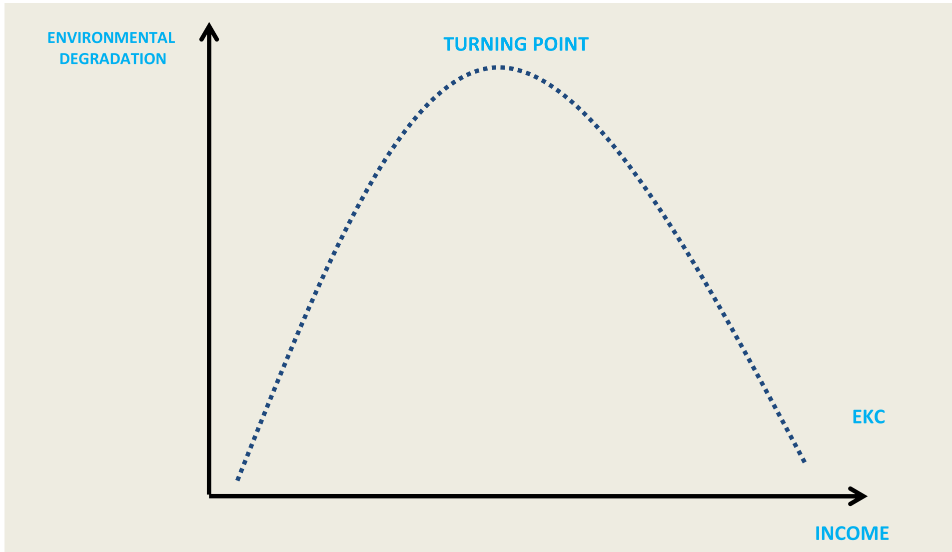

Fig. 1 Traditional U-inverted EKC. Source: prepared by authors

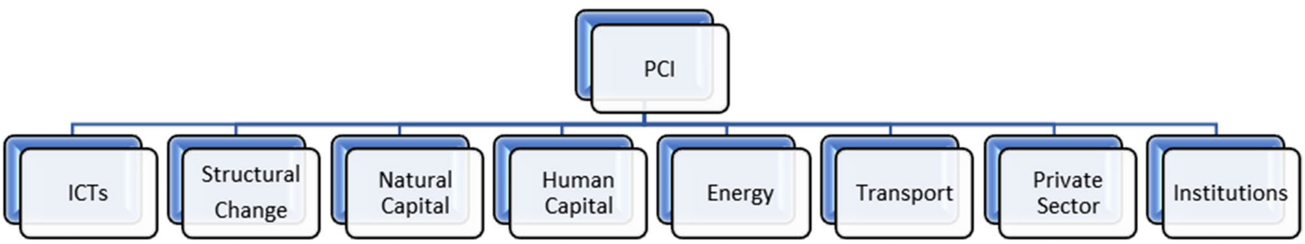

Fig. 2 Productive capacity index and components. Source: UNCTADSTAT (2021)

Studies on this topic started to integrate additional explanatory variables of environmental degradation such as energy consumption. These studies are labeled as second-generation studies. More recent empirical studies also integrated variables such as globalization, foreign direct investments, institutional quality, innovation (Islam et al. 2021), population and urbanization (Chekouri et al. 2020), tourism (Ren et al. 2019), and industrial structure (Guo and Guo 2016).

In addition to the variables mentioned in the paragraph above, also the concept of "productive economic structure" has gained interest as a potential driver of environmental impact (Can and Gozgor 2017; Doğan et al. 2019). Increasing the productive capacity of countries requires more efficient use of the available resources. Keeping input levels equal, this should enable higher output levels. Increased productive capacity also creates possibilities to increase overall well-being. At present, no country is fully efficient, and resources are lost in all economies. This situation inevitably causes significant environmental problems at micro and macro level.

Many parameters measure or represent a country's productive economic structure. Some examples of such parameters are economic complexity, export concentration, trade diversification, or industrial structure. These parameters are often falsly used as a comprehensive measure for the entire productive structure of an economy. In reality, they only cover a limited and specific part of an economy and its productive structure. For that reason, they should be used more carefully. To tackle this issue, the UN presented the Product Capacity Index last year. That proposed index does manage to capture an economy's entire productive economic structure (UNCTADSTAT 2021).

In this context, the productive capacity of a country determines its economic development trajectory and the transformation of its production systems and abilities (Thirlwall 2007; Kurniawan and Managi 2019). The PCI index, prepared by the UN, is a composite index composed of 46 indicators, including eight main components (UNCTAD 2021). Figure 2 presents those eight components. PCI is calculated as a geometric average of these domains or categories. The categories were chosen based on their relevance to conceptual and analytical frameworks for building productive capacity. PCI can be represented algebraically as follows:

$$PCI = \sqrt[N]{\prod_{i=1}^{N} X_i^{PCA}} \tag{1}$$

where N is the total number of categories and X_i^{PCA} is the weighted category score extracted using the principal component analysis (PCA) of category i. Where X_i^{PCA} is PCI category scores extracted using PCA (UNCTAD 2021).

As can be seen in Fig. 2, there are a variety of factors that can influence the process of boosting productive capacity.

Each of the sub-parameters that make up the PCI has a relationship with the environment:

– "ICT" (internet, mobile phones, and telephone penetration levels) affects economic growth and productivity (Qureshi and Najjar 2017) but also potentially affects the environment as it can optimize resource use in many sectors (e.g., transport and logistics, energy) thereby reducing energy consumption levels and related CO_2 emissions (Chatti 2021; Wang et al. 2015).
– "Structural change" significantly determines environmental quality. Changing from agricultural production systems to the energy-intensive heavy industry will for example increase that country's energy demand, hurting environmental quality. However, further developing into high technology production structures might lead to reduced energy consumption levels (Yuan et al. 2009).
– "Natural capital" is an important element of sustainable economic development and economic productivity growth (Brandt et al. 2017). As such, the presence of natural capital potentially affects environmental quality.
– "Human capital" determines a country's productivity and hence, directly and indirectly, affects that country's economic growth rates (Can and Can 2022; Fafchamps and Quisumbing 1999). In the first stage, human capital increases the use of non-renewable resources and pollution levels. However, passing a threshold, further development of human capital increases environmental awareness and the use of environmentally friendly technology which reduces CO_2 emissions and stimulates the efficient use of resources (Khan 2020).
– "Energy" is not used intensively for productive purposes in structurally weak economies. Inadequate access to energy limits a country's export capacity, competitiveness, and production capacities (UNCTAD 2021). Therefore, energy performance is one of the key elements of inclusive and sustainable economic growth (Ahmad and Zhang 2020; Sharif et al. 2017). Increased energy efficiency will lead to less energy consumption and reduce environmental degradation.
– Transport activities result in emissions as it accounts for 18% of global CO_2 emissions (International Energy Agency 2022). Because of its dependence on fossil fuels, the transport sector also has the potential to considerably increase environmental pollution (Santos 2017). In addition, transport activities drive economic growth and increase regional productivity (Alotaibi et al. 2021) resulting in more emissions. Nevertheless, increasing the transport sector's efficiency can also increase a region's energy efficiency and hence reduces the region's environmental impact.
– "The private sector" significantly determines the creation and expansion of a country's productive capacity (Hancock et al. 2011). In this context, some authors claim that the private sector makes more efficient makes use of resources compared to the public sector. However, this view is challenged by other authors who stress some environmental concerns (Talukdar and Meisner 2001) as the private sector faces problems in matching the interest of its (private) stakeholders and protecting (public) environmental quality (Rashed and Shah 2021).
– "Institutions" are defined as a set of formal and informal rules and regulations. Poor institutional quality impedes the development of the least developed countries, limits the productive capacity of these countries, and prevents the emergence of their economic potential (Casson et al. 2010). Strong institutional quality can increase the efficiency, enforceability of environmental regulation and hence reduce CO_2 emissions (Bhattacharya et al. 2017).

Literature review

In the current environmental economics literature, researchers explore the environmental impact of some of the individual components of PCI (e.g., economic complexity, transportation, export diversification, renewable energy, human capital). Table 1 provides an overview of the main studies found in this context. However, no study provided a holistic exploration of the environmental impact of the entire productive structure (simultaneously including all components). In this context, this study fills an important gap in the literature.

Data and empirical methodology

Data and descriptive statistics

This research aims to investigate the dynamic short and long-run interdependence between environmental indicators (CO_2 emissions), economic growth, and the PCI. This is achieved using various panel cointegration techniques of estimations for a panel of 38 OECD countries[1] over the

[1] Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, South Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, UK, USA.

Table 1 The effect of PCI indicators on environmental degradation literature (summarized results)

Authors	Period	Country/country group	PCI indicators	Environmental degradation indicator	Method	Result
Can and Gozgor (2017)	1964–2014	France	Economic complexity	CO_2	DOLS	(-)
Neagu and Teodoru (2019)	1995–2016	25 EU countries	Economic complexity	GHG emissions	FMOLS, DOLS	(+)
Ahmed et al. (2022)	1985–2017	G7 countries	Economic complexity	EF	CUP-FM	(-)
Ahmad et al. (2021a, b)	1984–2017	Emerging countries	Economic complexity	EF	CS-ARDL	(+)
Peng et al. (2022)	1992–2018	BRICS	Economic complexity	CO_2	CUP-FM	(-)
He et al. (2021)	1990–2018	Top 10 energy transition economies	Economic complexity	CO_2	CS-ARDL	(-)
Martins et al. (2021)	1993–2018	Top 7 complex economies	Economic complexity	CO_2	CS-ARDL	(+)
Liu et al.(2018)	1990–2013	Japan, Korea, China	Export concentration	EF	VECM	Inverted U-shaped for Japan and Korea but (+) for China
Adebayo et al. (2022)	1965–2019	Turkey	Structural change	CO_2	NARDL	(-)
Sharma et al. (2021)	1990–2015	8 developing countries of Asia	Renewable energy consumption	EF	CS-ARDL	(-)
Charfeddine (2017)	1970–2015	Qatar	Energy consumption	EF, CO_2	Markov switching equilibrium correction model	Inverted U-shaped
Khan and Hou (2021a, b)	1995–2018	38 International Energy Agency (IEA) countries	Energy consumption	EF	FMOLS	(+)
Sharif et al. (2019)	1990–2015	74 nations	Renewable energy consumption	CO_2	FMOLS	(-)
Sharif et al. (2020)	1965–2017	Turkey	Renewable energy consumption	EF	QARDL	(-)
Godil et al. (2021)	1990–2018	China	Renewable energy consumption	CO_2	QARDL	(-)
Christoforidis and Katrakilidis (2021)	1984–2016	29 OECD countries	Institutional quality	EF	CS-DL, DOLS-MG	(-)
Abid (2016)	1996–2010	25 SSA countries (Sub-Saharan Africa)	Institutional quality	CO_2	GMM-DIFF, GMM-SYST	(-)
Hosseini and Kaneko (2013)	1980–2007	129 countries	Institutional quality	CO_2	Period SUR	(-)
Bano et al. (2018)	1971–2014	Pakistan	Human capital	CO2	ARDL	(-)
Ahmed and Wang (2019)	1970–2014	India	Human capital	EF	ARDL, DOLSFMOLS, CCR	(-)
Nathaniel (2021)	1980–2016	G7	Human capital	EF	GMM, ARDL, FGLS,	(-)
Sahoo and Sethi (2021)	1990–2016	36 developing countries	Natural resource	EF	MG, AMG, DCCE, FMOLS, DOLS	(-)
Ahmad et al. (2020)	1984–2016	22 emerging economics	Natural resource	EF	CS-ARDL,AMG	(+)

Table 1 (continued)

Authors	Period	Country/country group	PCI indicators	Environmental degradation indicator	Method	Result
Danish et al. (2019)	1990–2015	BRICS countries	Natural resource	CO_2	AMG	(X)
Haseeb et al. (2019)	1994–2014	BRICS countries	ICTs	CO_2	DSUR	(-)
Zhang and Liu (2015)	2000–2010	China	ICTs	CO_2	FGLS	(-)
Danish et al. (2018)	1990–2015	N-11 countries	ICTs	CO_2	AMG	(+)
Godil et al. (2020)	2000M1–2019M8	USA	Transportation services	CO_2	QARDL	(-)
Saboori et al. (2014)	1960–2008	27 OECD countries	Road transport sector	CO_2	FM-OLS	(+)
Ben Jebli and Hadhri, (2018)	1995–2013	The top ten international tourism countries	Transportation	CO_2	FMOLS, DOLS	(-)
Khan et al. (2019)	2001–2017	Asian emerging economies	Transportation	CO_2	FMOLS, DOLS	(+)
Sharif et al. (2020)	1995–2018	Malaysia	Transportation	CO_2	QARDL	(+)

Note: (+), (-), and (X) signs indicate the effect of PCI indicators on environmental degradations. While the (+) sign presents a positive effect, (-) and (X) represent negative and statistically insignificant impacts, respectively. EF, OLS, ARDL, NARDL, DOLS, FMOLS, AMG, DSUR, GMM, VECM, AGE, PMG,CS-ARDL, CS-DL, FGLS, DOLS-MG, DCCE, QARDL, and CUP-FM stand for ecological footprint, ordinary least squares, autoregressive distributed lag, nonlinear autoregressive distributed lag method, dynamic ordinary least squares, fully modified ordinary least squares, augmented mean group, iterative seemingly unrelated regression, generalized methods of moments, vector error correction model, applied general equilibrium, and pooled mean group, cross-sectional autoregressive distributed lag approach, cross-sectional augmented distributed lag, feasible generalized least squares, dynamic ordinary least squares-group-mean, dynamic common correlated effect, quantile autoregressive lagged, and continuously updated fully modified method respectively

period 2000–2018. It is impossible to compose more extensive time periods because of data availability, i.e., the PCI is only calculated for these years. In addition, the study tries to evaluate the validity of the environmental Kuznets curve (EKC) hypothesis. The data on CO_2 emissions and real GDP are obtained from The World Bank World Development Indicator (WDI 2021). The data on the PCI are obtained from UNCTADSTAT (2021).

Our empirical study first provides some descriptive statistics on the main variables of the selected sample of OECD countries. The first leg of Table 2 reports on the sample's average CO_2 emission, real GDP, and PCI.

Table 2 demonstrates that the highest volume of CO_2 emissions is recorded in the USA (5,776,410 ktonnes in 2000) while the smallest volume of CO_2 emissions is recorded in Iceland (1860 ktonnes in 2012). This suggests close correlation between emissions and economic activities as the USA also reported the highest real GDP value (1.50e + 18 USD in 2018) while Iceland accounts for the smallest real GDP (1.06e + 10 USD in 2000). Finally, the USA has the highest index of productive capacity (52.63663 in 2016), while the lowest index was calculated for Colombia (24.70107 in 2000). The pairwise correlation between the analysis variables revealed no problem with correlation.

Model construction, and econometric methodology

The present research applies the approach by Apergis et al. (2018), which is based on the EKC frameworks. That approach explains the evolution of the environmental impact (CO_2 emissions) using GDP and the GDP's square. In addition, the empirical model considers the PCI as an explanatory variable representing the productive economic structure. This empirical study does not integrate energy

Table 2 Descriptive statistics

Variable	Obs	Mean	Std. dev	Min	Max
CO2	722	331,412.5	866,300.9	1860	5,776,410
GDP	722	3.70e + 15	6.10e + 16	1.06e + 10	1.50e + 18
PCI	722	39.71749	4.846304	24.70107	52.63663
Pairwise correlation		CO2	GDP	PCI	
	CO2	1.0000			
	GDP	0.2160	1.0000		
	PCI	0.3444	0.0832	1.0000	

Notes: *CO2*, carbon dioxide emissions; *GDP*, gross domestic product; *PCI*, productive capacity index variables (e.g., energy use) into the empirical model since the PCI index includes different energy indicators such as GDP per kilogram of oil consumption, total energy consumption per capita, and renewable energy consumption as a share of total final energy consumption. Including other energy variables would lead to multicollinearity problems.

The empirical model is defined as follows:

$$CO_2 = f\left(GDP, GDP^2, PCI\right) \tag{2}$$

The natural logarithmic form of Eq. (1) is defined as follows:

$$LnCO_{2,it} = \beta_0 + \beta_1 LnGDP_{it} + \beta_2 LnGDP_{it}^2 + \beta_3 LnPCI_{it} + \varepsilon_{it} \tag{3}$$

where i=1,…,38 and t = 2000,…,2018; CO_2, GDP, GDP^2, and PCI represent CO_2 emissions per capita, income per capita, the square value of income per capita, and productive capacity index respectively. *Ln* denotes the natural logarithmic form of each variable.

The study explores the role of the PCI and economic growth on the propagation of the environmental indicators (CO_2 emissions). To this end, the empirical analysis applies various econometric tests. In addition, the EKC hypothesis is verified in the long-run and the directions of causalities among the variables are assessed in both the short- and long-run. The analyses apply the following step-wise approach: (i) examining the degree of cross-sectional dependence in residuals using Pesaran (2004) test; (ii) testing the integration order of the variables using either the first or the second generation panel unit root tests (PURT) depending on the cross-sectional dependence results; (iii) checking if variables are cointegrated using Pedroni (2001) and Westerlund (2007) tests; and finally (v) estimating the long-run coefficients using the PMG-ARDL approach.

Empirical results

Cross-sectional dependence

The first step of the empirical analysis tests for the degree of Cross-sectional dependence (CD) in residuals. The test is developed by Pesaran (2004) and produces a widely accepted test statistic for the selection of other econometric procedure tests applied in the analysis such as the panel unit roots and the cointegration tests. The test developed by Pesaran (2004) is applied to check which kind of PURT is required. The null hypothesis assumes the non-existence of CD in residuals, which enables the use of the first-generation PURT.

The alternative assumption suggests the existence of CD in residuals, requiring the second-generation PURT to identify stationary characteristics. Pesaran (2004) has advanced this test to examine the degree of CD in data. Detecting cross-sectional dependence can decrease the data's efficiency and result in spurious outcomes (Phillips and Sul 2003). Pesaran (2004)'s statistics use a simple average of all pairwise correlation coefficients of OLS residuals obtained from the regression of the augmented Dickey-Fuller (Dickey and Fuller 1979) for each series.

Table 3 Pesaran (2004)'s cross-sectional dependence test result

Variable	CD-test	*p*-value	corr	abs(corr)
$LnCO_2$	21.03	0.000***	0.182	0.577
LnGDP	94.03	0.000***	0.814	0.814
LnPIC	108.94	0.000***	0.943	0.943

Notes: "***" indicates statistical significance at the 1% level. All statistics are computed under the null hypothesis of cross‾section independence

The outcomes of the CD test are reported in Table 3. These results reject cross-sectional independence in residuals of all underlining variables at the 1% significance level. This requires the second generation PURT.

Panel unit root test

In a subsequent step, the study applies the cross-sectional augmented IPS (CIPS) PURT developed by Pesaran (2007) to check for the integration order of variables. The null hypothesis assumes that the variable is not stationary, while the alternative hypothesis assumes the stationary of series. The Pesaran test (2007) does not require the calculation of a factor allowing the removal of CD. An advanced ADF regression captures the CD that arises with a single-factor model. Table 4 reports the CIPS PURT results. These results show that, at level, all variables contain a unit root. However, after the first difference, they become stationary, proving that all variables are integrated of order one, I(1) at the 1% significance level.

Panel cointegration

The stationary tests proved that all variables are I(1) and the long-run cointegration can be checked using numerous cointegration techniques such as Pedroni (2007) and Westerlund (2007). Pedroni (2007) developed two sets of cointegration statistics (within and between dimensions). For the common process (within dimension), Pedroni (2007) has developed four statistics: v, rho, PP, and ADF statistics. For the individual process (between dimension), the test comprises three statistics: rho, PP and ADF statistics. Westerlund (2007) has advanced four cointegration tests which are based on the CD

Table 4 CIPS PURT results

	CIPS unit root test (Pesaran 2007)			
At Level	t-Statistic	−1.191	−1.786	−1.309
	Prob	-	-	-
At first difference	*t*-Statistic	−4.188***	−2.962***	−4.483***
	Prob	-	-	-

Notes: "***" indicates statistical significance at the 1% level. Pesaran panel unit root test (CIPS) with cross−sectional and first difference means included for each variable. The deterministic chosen is constant. Critical value are −2.03 (10%), −2.11 (5%), and −2.25 (1%)

Table 5 Panel Cointegration Tests Results

Westerlund cointegration tests				
Statistic	Value	*Z*-value	*P*-value	Robust *P*-value
Gt	−3.052	−2.466	0.007***	0.063*
Ga	−7.336	6.283	1.000	0.397
Pt	−17.931	−2.918	0.002***	0.040**
Pa	−7.311	3.930	1.000	0.247
Pedroni cointegration tests				
Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob	Statistic	Prob
Panel v-statistic	0.086119	0.4657	0.123294	0.4509
Panel rho-statistic	0.368554	0.6438	−0.855053	0.1963
Panel PP-statistic	−2.140036	0.0162**	−4.395778	0.0000***
Panel ADF-statistic	−2.282922	0.0112**	−4.709156	0.0000***
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob		
Group rho-statistic	1.380753	0.9163		
Group PP-statistic	−3.800751	0.0001***		
Group ADF-statistic	−3.935883	0.0000***		

Notes: "***," "**," and "*" indicate statistical significance at the 1%, 5%, and 10% levels, respectively

statistic of residuals. The statistics inspired by Westerlund produce an efficient outcome given the presence of CD in residuals.

Table 5 shows the outcomes of cointegration tests and suggests that two statistics out of the four Westerlund cointegration tests confirm the presence of a long-run relationship among the variables. The Pedroni outcomes reveal that four statistics among seven reject the null hypothesis of no cointegration. Thus, these tests confirm the long-run cointegration among the variables.

Long-run estimation

In the next step, the study investigates the structural long-run interdependence between CO_2 emissions, economic growth, and PCI using the PMG ARDL approach. Pesaran et al. (1999) developed a transitional econometric estimator (PMG estimator) which imposes the similarity of long-rum coefficients while allowing the short-run coefficients to vary between country groups using the ARDL approach was further used to estimate long-run coefficients. The PMG estimator investigates whether the long-run coefficients are constant across individual country groups. However, it permits the variation of the short-run coefficients, the residuals variance, and the intercepts. The ARDL model developed by Pesaran et al. (2001) has been applied in numerous empirical studies because of the econometric advantages that allow its use regardless of whether the series is I(1) or I(0). In addition, this technique simultaneously generates the long-term and short-term coefficients in the same model and gives good outcomes with a small sample.

Table 6 presents the outcomes of the PMG-ARDL. The analysis demonstrates that all estimated coefficients are statistically significant at the 1% level. Those coefficients can be interpreted as elasticities given the logarithmic form. A 1% increase in real GDP leads to a 9.49% increase in CO_2 emissions, while a 1% increase in the square of real GDP leads to a 0.17% decrease in CO_2 emissions. These

Table 6 PMG-ARDL Estimates ($LnCO_2$ dependent variable)

Variable	Coefficient	Std. error	*t*-statistic	Prob.*
Long-run equation				
LnGDP	9.493406	1.102707	8.609181	0.0000***
$LnGDP_2$	−0.167496	0.020882	−8.021023	0.0000***
LnPCI	−1.030800	0.123126	−8.371933	0.0000***
Short-run equation				
ECT	−0.344033	0.062134	−5.536951	0.0000***
$D(LnCO_2)$	51.20099	83.60371	0.612425	0.5406
$D(LnCO_2(-1))$	142.8724	65.94581	2.166512	0.0308**
$D(LnGDP^2)$	−0.929726	1.540782	−0.603412	0.5466
$D(LnGDP^2(-1))$	−2.721465	1.200791	−2.266393	0.0239**
D(LnPCI)	1.545381	0.359766	4.295518	0.0000***
D(LnPCI(-1))	1.034886	0.437662	2.364576	0.0185**
C	−40.89130	7.357215	−5.557985	0.0000***

Notes: "***" and "**" indicate statistical significance at 1% and 5%, respectively. ECT denotes the error correction term. D(.) indicates the first difference

findings confirm the EKC's expectations that environmental issues are not the main priority in developing countries. Instead, priority is given to lifting income, economic growth, and employment. However, once development has pushed income above a specific threshold, the environmental awareness of the society starts to increase and gain importance. As a result, environmental degradation will decrease. These findings are in the line with the studies of Khan et al. (2022).

Interestingly, the PCI coefficient is negative and statistically significant. Hence, the PCI does affect the included environmental indicator (CO_2 emissions). A 1% increase in the index of productive capacity will decrease emissions of CO_2 by 1.03%. To the best of our knowledge, this is a new observation that has not been investigated before. The finding somewhat supports the research of Can and Gozgor (2017) who used the economic complexity index as a proxy for productive economic structure. We can conclude that the productive capacity of a country serves as a new potential parameter, considerably impacting environmental quality and an economy's environmental impact. Additionally, the error correction term is statistically significant and negative. The latter indicates that the speed of adjustment towards equilibrium for CO_2 emissions is −0.34 per unit.

Discussion and policy directions

Emissions that lead to climate change are one of the biggest problems of today's world. In addition, environmental problems also pose important obstacles to sustainable development. For this reason, reducing CO_2 emissions has become one of the main priorities in both developed and developing countries, both at the national and international levels. Since environmental pollution is a very comprehensive and almost entirely human-induced problem, there is no easy solution.

Our results are similar to those reported in the studies conducted by Bampatsou and Halkos (2018), Ding et al. (2021), Karaduman (2022), and Amin et al. (2022). According to these studies, rising productivity levels contribute to the mitigation of the negative environmental effects of economic growth. Indirectly, this observation provides arguments in favor of an effective emission monitoring system for different pollutants to minimize the effects of climate change. In contrast, Nathaniel and Adeleye (2021) suggest that increasing productive capacity leads to the generation of harmful industrial pollutants and environmental degradation. As these studies obtain different results, it deems necessary to take into account both the countries' production capacities and productivity levels simultaneously.

This paper's empirical findings indicate that a country's productive capacity significantly determines its CO_2 emissions. Since the PCI index is a composite index consisting of eight main components, governmental policies and non-governmental strategies can target different components to reduce CO_2 emissions in general. This leads to a wide set of possible policy recommendations.

Policy recommendations

First, the uptake of ICT can be stimulated using smart devices and networks, enabling the optimization of management planning and the supply chain of goods and freight transportation. The widespread use of the internet facilitates access to information across the entire value chain and decreases trading costs for manufacturers (Danish et al. 2018). This also increases energy efficiency and limits time loss and environmental pollution. In this respect, it is of great importance for policymakers to support ICT investments.

The Paris Agreement provides the perfect framework to design regulations at the global level aimed at reducing transport-related emissions. Clean technologies need to be supported by taxes and subsidies to become a competitive alternative in the process of decarbonizing the transport sector. To do that, governments share a budget to support the transportation sector (Rayner 2021).

The environmental impact of the transformation of economic structures is also important. To meet energy demand during the transformation process, the use of renewable energy sources should be encouraged. Increasing the quality of regulatory and supervisory institutions and ensuring institutional reliability in these countries will facilitate compliance with environmental regulations to be made in the long-term. That regulation can also target the private sector. The public and private sectors should collaborate to reduce and prevent environmental pollution. A set of reliable indicators must be agreed upon to establish environmental targets, share social responsibility, and conduct monitoring and evaluation by establishing autonomous institutions in public–private partnerships.

To increase the environmental awareness of human capital, the content of education should be updated in a way that will increase environmental awareness. All human activities depend on natural capital. Therefore, rather than seeing sustainability as an ethical problem, awareness campaigns can also stress the strategic importance of the availability of resources. From a risk management perspective, natural capital should be conserved and enhanced, and its productive capacity should be increased.

Finally, from an environmental point of view, it is necessary to drastically reduce the consumption of natural resources. This could imply the reintroduction of idle resources into the economy as well as improving the efficiency of current economic resources. The latter also relates to the increased attention for the circular economy concept. That concept is gaining momentum as a tool to minimize waste production and limit the need for materials (Brusselaers et al. 2022). In this context, a country's productive capacity is likely to closely link to that county's technical capacity to, for example, recycle waste and regain materials (Lin et al. 2019). Also, a country's digital capacity will determine to what extent circular initiatives such as sharing platforms will take off.

Many countries are designing circular economy action plans; this analysis demonstrates that these action plans are likely to benefit from investments and policies in support of the productive capacity of circular sectors especially as those sectors are more future proof than their linear counterparts. Hence, the PCI can be used to identify the areas in which a country may be excelling or lagging, highlighting which policies are effective and which require remedial action.

Highlighting the sectors of the future is also interesting in the light of skills mismatch. Increasing the productive capacity of a country might require new skills and expertise. This might create a situation of so-called skills-mismatch. The latter especially holds in case the productive capacity of innovative or emerging (e.g., circular) sectors is targeted, with other skills being used much less. In this context, McGuinness et al. (2018) observed that the problem of underutilized human capital receives too little policy attention.

Limitations and future research

This study explores the impact of the PCI Capacity Index on environmental on CO_2 emissions in the sample of OECD countries. Future research can expand the geographical focus of this research to crosscheck the findings in different contexts. In addition, future research can also test the impact of PCI on various environmental indicators such as the ecological footprint, carbon footprint, sulfur oxides (SO_X), nitrogen oxides (NOx), carbon monoxide (CO), and non-methane volatile organic compounds (VOC) for these different country groups. Expanding the environmental impact beyond CO_2 emissions might entail new insights. Finally, the sub-components of PCI can be used as an explanatory variable for various country groups.

In this study, we used the EKC hypothesis. For future research, scholars can test the environmental impact of PCI by using stochastic impacts by regression on population, affluence, and technology (STIRPAT) model.

Conclusion

Many economic parameters affect environmental degradation. This research demonstrates that a country's productive economic structure is among the major indicators explaining environmental impact. More particularly, this research attempted to inspect the impact of productive capacity on CO_2 emission based on the EKC frameworks in a sample of 38 OECD countries over the period 2000 to 2018. The empirical findings employed Westerlund and Pedroni cointegration tests and PMG-ARDL approaches. The cointegration analysis revealed that series are cointegrated. The outcomes gained from the PMG-ARDL approach confirmed the validity of the EKC hypothesis. Besides, the empirical findings provide evidence that productive capacity has significant and a negative impact on CO_2 emissions.

Author contribution IO: conceptualization, data curation, writing-original draft. MBJ: formal analysis, data handling, and methodology. MC: conceptualization, data curation, writing—original draft, supervision. IG: writing—original draft. JB: writing—original draft, writing—review and editing.

Data availability All data generated or analyzed during this study are included in this article.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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