Sustainable Futures 11 (2026) 101777

Contents lists available at ScienceDirect

Sustainable Futures

journal homepage: www.sciencedirect.com/journal/sustainable-futures

Analysis of persistence in the green GDP. Evidence from 35 OECD countries

Sakiru Adebola Solarin [a], Gloria Claudio-Quiroga [b], Luis Alberiko Gil-Alana [c,*]

[a] Multimedia University, Malaysia
[b] Universidad Francisco de Vitoria, Madrid, Spain
[c] University of Navarra, NCID and DATAI, Pamplona, Spain and Universidad Francisco de Vitoria, Madrid, Spain

A R T I C L E I N F O

JEL classification:
C22
E10
Q56

Keywords:
Persistence
Fractional integration
Green economy
green GDP
Per capita green GDP

A B S T R A C T

This paper deals with the persistence analysis of the real green GDP and real per capita green GDP in a group of 35 countries by using statistical techniques based on fractional integration. Our results indicate that the majority of the series display nonstationary and a high degree of persistence in the two series, implying permanency of shocks. The only exceptions are Australia, that displays a short memory pattern in the two series, Czech Republic that displays an order of integration in the interval (0, 1) and apart from these two countries, Belgium, Israel and New Zealand that also present mean reversion in one of the two series examined. Policy implications are reported at the end of the paper.

1. Introduction

The traditional concept of economic growth is linked to the linear economic model, which involves the extraction of resources to produce goods and services with the primary objective of maximizing production [1]. However, beyond these undeniable achievements in terms of economic growth throughout the 20th century, its sustainability is questionable [2–4]. The pursuit of maximum economic growth has been based on the overconsumption of resources and has resulted in significant environmental damage, with the emission of CO_2 as one of the most important causes on the global warming.

Economic growth, as measured by Gross Domestic Product (GDP), is prioritized as the central goal in economic policy-making, and GDP emerges as the preeminent indicator, playing a critical role in shaping such economic decisions. This indicator was created by Simon Kutznets in 1934 and is defined as the value of goods and services produced in a country in a given period. Since then, it has been considered a measure of economic success and a way to assess the outcome of economic policies. GDP is a good indicator to measure economic growth, but it does not always lead to improved quality of life. The GDP cannot be used as an indicator of overall wellbeing [5]. Many studies claim that GDP is associated with serious environmental problems and that countries not only need to produce more and more, but also demand environmental protection and social sustainability ([6,7]; etc.).

The GDP has several limitations: it is not useful for measuring social welfare; it does not provide information about what is wrong in the economy, and it does not serve for the international comparison of the standard of living countries. In a model in which the priority objective has been to produce as much as possible, we have forgotten the impact that this growth had in terms of resource depletion, environmental damage or inequality in economic growth. Therefore, GDP may not be the most suitable indicator for measuring human well-being that should be sustainable, and thus, we should take into account other aspects beyond economic growth [8].

Over time, the government and policy makers become conscious of the need to measure not only the economic growth, but all the dimensions of sustainability [9]. The relatively novel concept of the green economy was coined at the Rio+20 conference and has since attracted increasing attention in political discourse [10]. Its primary aim is to address and mitigate the ecological degradation resulting from prevalent patterns of economic growth. Many nations and global economic and development institutions believe that green growth is the main

Prof. Luis A. Gil-Alana gratefully acknowledges financial support from the project from 'Ministerium de Economía, Industria y Competitividad' (MINEIC), `Agencia Estatal de Investigación' (AEI) Spain and `Fondo Europeo de Desarrollo Regional' (FEDER), Grant D2023–149516NB-I00 funded by MCIN/AEI/ 10.13039/501100011033. He also acknowledges support from an internal Project of the Universidad Francisco de Vitoria.

* Corresponding author at: University of Navarra, Faculty of Economics and ICS, E-31080, Pamplona, Spain.
E-mail address: alana@unav.es (L.A. Gil-Alana).

https://doi.org/10.1016/j.sftr.2026.101777
Received 25 June 2025; Received in revised form 13 October 2025; Accepted 27 February 2026
Available online 13 March 2026

opportunity for economic transformation, and it is critical to take steps to support it [11]. But in order to make decisions and adopt effective policies, it is necessary to measure and evaluate the strategies adopted in different countries and regions to increase the GDP including environmental protection. To do this, we need to know the size of green growth and some recognized methodological principles. Green GDP first emerged in the early 1990s because of the need to incorporate environmental costs into the traditional GDP measurement. There are different definitions of green GDP but all of them include environmental protection to the traditional GDP.

Stjepanović et al. [8,12] built a new green GDP indicator, incorporating a measure that encompasses the cost of pollution and the level of natural resource utilization into traditional GDP and recently, they offered a database on green GDP from 1970 to 2019, contributing to evaluate and measure the progress towards the Green Economy [13]. The authors argue that the traditional measurement of Gross Domestic Product (GDP) is insufficient to assess sustainable development, as it fails to account for the costs of environmental degradation. The main objective of their work is to provide a standardized methodology for estimating green GDP, incorporating both quantitative and qualitative dimensions, such as the cost of CO_2 emissions, waste management, and the depletion of natural resources. Although there are several approaches and indicators related to the measurement of green Gross Domestic Product (green GDP), they are not without limitations such as lack of consensus, subjectivity, and challenges in estimating depreciation, among others [14]. However, the approach proposed by Stjepanovic et al. [13] stands out for its balanced integration of two key aspects of the green economy: a quantitative component, based on a standardized methodological algorithm, and a qualitative component, which incorporates opportunity cost assessments.

The incidence of green GDP persistence indicates that the current pattern being witnessed in several countries around the globe is likely to persist. Therefore, persistence indicates that long term blueprints are needed to promote green GDP. In this case, active governments interventions are needed as governments often possess the financial capacity to ensure that the desired green GDP is achieved. The absence of green GDP persistence (or mean reversion of green GDP) is a suggestion that short interventions on the part of the governments are adequate to improve green GDP. Moreover, the presence of green GDP persistence indicates predicting future values of the green GDP accurately by merely relying on green GDP past realizations is not feasible [15]. In this case, there is a need to consider the past trends of the factors that affect green GDP to have an accurate forecast of green GDP.

The main objective of this paper is to examine green GDP persistence. We have used the green GDP data provided in Stjepanović et al. [13], which is for the 1970–2019 period. We have used both real green GDP and real per capita green GDP in the analysis. The empirical results indicate that the majority of the series display a high degree of persistence in the two cases. Australia and Czech Republic are the two countries without persistence for both variables. Belgium, Israel and New Zealand are the countries with mean reversion in one of the two variables examined.

Our work offers two contributions to existing literature. We construct two new measures of green GDP- real green GDP or RGGDP and real green GDP per capita or RGGDP per capita, based on the current green GDP figures of Stjepanovic et al. [13]. Therefore, the data used in this paper contains all the virtues associated with the green GDP figures provided by Stjepanovic et al. [13] plus being data expressed in real terms. Nominal figures cannot completely capture changes in quantities because nominal terms are also affected by the changes in prices. The second contribution is the examination of persistence of both RGGDP and per capita RGGDP. This is the first study to undertake such exercise: the use of fractional integration to examine the persistence of green production. The benefit of this approach is its suppleness in the dynamic dimension of the models with allows us consider cases of nonstationary data with mean reverting behaviour.

The data of Organisation for Economic Co-operation and Development (OECD) countries have been used in this study because of several reasons. The total real GDP in the OECD countries in 2022 was 53.69 trillion (US$ 2015 prices), which represented about 60 % of the global real GDP during the same period [16]. The OECD countries have better capacity to expand green production, relative to the developing countries. Several OECD countries have been implementing policies to ensure smooth transition to green production over the years [17]. Lastly, some of the OECD countries have been experiencing decline in emissions [16], due to the several policies introduced to transitioned towards green production.

The remaining sections of the paper are structured as follows. First, we review the extant literature in Section 2. Section 3 is dedicated to the data description. Section 4 illustrates the methodology. Section 5 exhibits the empirical findings while Section 6 involves the conclusion of the paper.

2. Contextual setting

The belief that economic growth alone led to well-being led for decades to neglect the environmental damage that this economic growth produced. Nations and regions not only need to advance economically but also insist on environmental protection and social sustainability [7]. Many international institutions, governments and policymakers began to look for tools to enable the transition to a more sustainable green economy. This is how the concept of green growth has emerged in international policy discourse as a response to the need to integrate sustainability into economic growth. Its goal is to achieve economic progress without harming natural resources [11]. Thus, some researchers have initiated discussions about the need to emphasize the importance of green economic growth beyond traditional economic expansion [18,19]. Some of these studies show that it is possible to achieve economic growth by decoupling it from the massive use of resources and carbon emissions through technology [20,21], while others consider that this is not yet possible and that alternative strategies to green growth are needed [22].

The outcomes of the green economy will primarily hinge on its definition. There is no unanimity in the definition, but the concept of green growth is defined in different ways. For example, the Badjeena et al. [23] affirms that green growth, a vital tool for achieving sustainable development, is efficient, clean, and resilient economic growth because it does not waste natural resources, minimizes pollution, and reduces environmental impact. The OECD [20] asserts that green growth is essential for promoting economic growth while guaranteeing that natural assets persist. The definition of green economy of UNEP (United Nations Environment Programme) is '*one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities*' [21]. Despite the different definitions of green growth, all of them include environmental protection to the concept of traditional economic growth.

The need to measure the progress towards green growth and evaluate the effectiveness of the measures adopted has been analysed through different indicators and associated measurement methods. Several organizations and research groups have put forward indicators of green growth. For example, the Green Growth Knowledge Platform (GGKP), collaborative forum for organizations such as OECD, UNEP and the World Bank, developed a framework to monitor progress on green growth. The OECD introduced a standardized set of indicators to assess green growth and to facilitate cross-country comparisons of progress [17]. From then on, several alternative well-being indicators began to appear, all of them useful for policy analysis and the measuring countries' performance in progress towards green growth [13].

In 1993, the United Nations Statistical Institute first introduced the concept of GGDP in its System of Integrated Environmental and Economic Accounting (SEEA). This system aimed to integrate resources and environmental costs into national economic production, thereby accounting for the economic production costs necessary to adjust the original GDP. Boyd [24] argued that GGDP could and should be built. The GGDP has not been precisely defined, although there are two definitions commonly cited. Firstly, the GGDP is the traditional GDP corrected with the inclusion of depreciation of natural resources reserves and secondly, the GGDP, included the ecosystem services value [18].

There are different approaches in environmental accounting that are appropriate for calculating GGDP coverage [25]. One of the most important involves adjusting existing accounting techniques to incorporate natural capital degradation. This entails quantifying the costs connected to natural resources depletion and environmental damage, as well as identifying defensive expenditures aimed at mitigating or preventing environmental damage. The GGDP has limitations because it cannot estimate all the environmental damage in monetary terms. The difficulties in calculating the green GDP have been analyzed by several authors ([26];).

Many papers have analyzed the green GDP in different countries or regions, like OECD countries [27], Thailand [28], India [29] and specially China ([30–32]; Cai et al., 2024; etc.). Most of these studies have the limitation that they focus on a single country or a few years. Stjepanović et al. [12] provided a new method of measuring the cost of ecological and environmental degradation that could be utilized to compare sustainable economic growth across countries. They presented a new GGDP measure, initially introduced as a growth rate, which greatly simplifies its comparison with traditional indicators. These authors created an alternative classification scheme considering the characteristics of green growth, both quantitatively trough common methodological algorithms and qualitatively trough opportunity costs. They calculated GGDP for a total of 44 countries for the year 2014.

Two years later and expanding on this research, these authors extended their calculations to cover the period from 2008 to 2016 for the same 44 countries [8]. A new database on GGDP is presented by Stjepanović et al. [13] for the set of 160 countries from 1970 to 2019. This new database enables academics, governments, and policymakers to analyze and monitor environmental policies. This study should be completed with the study of the long-term behavior of GGDP because it can have important economic and politic implications. To our knowledge, there are no studies that analyze the persistence of GGDP, and this is the objective of this work.

3. Computation of GGDP and data description

The computation of the GGDP is based on removing the expenses involving the use of natural resources and environmental depletion from the conventional GDP. This is because natural resources use, waste, and the emission of CO_2 are regarded as the most important factors of green sustainable development and global climate [13]. According to Stjepanović et al. [13], the factors of green GDP can be expressed as:

$$\text{GreenGDP} = \text{GDP} - (\text{PCDM} * \text{KtCO}_2) - (\text{Twatse} * 74KWh * Pelect) - \left(\frac{GNI}{100} * \%NRD\right) \quad (1)$$

where green GDP is the green version of the conventional GDP (current US$) in Eq. (1). GDP on the right side of the equation is the aggregate of the gross value added of all producers that are resident within a country. The first subtraction from GDP is the CO_2 pollution cost (which has been computed as the market price of carbon (or *PCDM*) multiplied by CO_2 emissions in kilotonnes (or $KtCO_2$)). The second subtraction captures the opportunity cost of waste which can be transformed into electricity. The second subtraction is based on total commercial and industrial waste in tonnes (or *Twatse*) multiplied by 74 kW-hours of electricity (or *74KWh*), and price of electricity per KWh (or *Pelect*). The final subtraction involves gross national income (or GNI) and natural resource depletion adjusted savings (or NRD). It relates the depletion of different natural resources and gross national income. The details and sources of data for the variables can be found in Stjepanović et al. [13].

The green GDP figures provided in Stjepanović et al. [13] are in nominal figures. However, what matters most to the economy is the increase or decrease in quantities. Nominal figures cannot completely capture changes in quantities because nominal terms are also affected by the changes in prices. Hence, green GDP (current US$) cannot be reasonably compared overtime. In order to estimate the real green GDP or RGGDP, the following expression has been utilised:

$$\text{RGGDP}_t = \left(\text{Green GDP}_t * \frac{CPI_b}{CPI_t}\right) \quad (2)$$

where CPI_b is the consumer price index in the base year (which is 2015) and CPI_t is the consumer price index in the current year in Eq. (2). There is also the need to measure how much RGGDP value can be attributed to each individual citizen. Such figure provides insights on economies that are growing alongside with their populations. Per capita GGDP can be calculated using the following expression:

$$\text{Per capita RGGDP}_t = \frac{\text{RGGDP}_t}{Population_t} \quad (3)$$

where per capita RGGDP is defined as RGGDP divided by population in Eq. (3).

The GGDP dataset has been generated from the work of Stjepanović et al. [13], while the consumer price index and population figures have been obtained from World Bank [16]. Supplementary Figure 1 displays the time series plots and Table 1 gives the descriptive statistics for RGGDP and per capita RGGDP for the 38 OECD countries from 1970 to 2019.

US, Japan, Germany, UK, France, Italy and Canada are the countries with the largest RGGDP. These countries are coincidentally G7 members. Luxembourg, Switzerland, Norway, Denmark, US, Sweden, and Australia are the countries with the largest per capita RGGDP. The trends in these two variables are shown in Figs. 1 and 2, which depict that the countries witnessed growth in both RGGDP and per capita RGGDP in most of the periods under consideration.

4. Method

The methodology used in the paper is fractional integration. This is a modelization that implies that fractional degrees of differentiation can be used to render a time series stationary I(0). We first define integration of order 0. This refers to a second order stationary process where the infinite sum of the autocovariances is finite.

Fractional integration is sometimes denoted as I(d) or integration of order d where d can be any real value. A process x(t), $t = 0, \pm 1, \ldots$ is integrated of order d if after its D-differentiation, the process becomes I (0), i.e.,

$$(1 - L)^d x(t) = u(t) t = 0, \pm 1, \ldots. \quad (4)$$

where L refers to lag, such that $L^k x(t) = x(t\text{-}k)$.

The estimation of d is crucial from several viewpoints. Thus, if $d = 0$, clearly x(t) = u(t) and the process is short memory, in constrast with the long memory feature that takes place if $d > 0$. Values of d below 0.5 still display the property of stationarity while this property is lost if $d \geq 0.5$; another interesting point is 1, since $d < 1$ indicates mean reversion, with shocks possessing transitory impacts and waning in the long run, while $d \geq 1$ shows lack of this property. The estimation in this paper is conducted using the likelihood function in the frequency domain as provided in Robinson [33].

5. Empirical results

Following the literature on unit roots, we allow for deterministic components like an intercept and a time trend, such that x(t) in (1) are

Table 1
Descriptive statistics GGDP and per capita GGDP.

Panel A: GGDP			Panel B: per capita GGDP		
COUNTRY	MEAN	STANDARD DEVIATION	COUNTRY	MEAN	STANDARD DEVIATION
AUSTRALIA	666,373.39	317,515.13	AUSTRALIA	34,640.06	10,100.60
AUSTRIA	270,268.37	84,827.02	AUSTRIA	33,507.71	8919.77
BELGIUM	324,085.68	97,031.37	BELGIUM	31,115.09	7802.58
CANADA	994,845.24	370,683.98	CANADA	33,011.52	7438.70
CHILE	110,762.53	69,844.44	CHILE	7181.35	3390.60
COLOMBIA	135,558.06	84,046.60	COLOMBIA	3495.99	1416.30
COSTA RICA	26,479.79	17,380.34	COSTA RICA	6786.21	2784.58
CZECH REPUBLIC	144,512.57	39,305.06	CZECH REPUBLIC	13,893.97	3641.83
DENMARK	224,406.46	59,595.67	DENMARK	41,980.87	9429.83
ESTONIA	16,610.31	5835.68	ESTONIA	12,227.10	4706.72
FINLAND	166,374.33	56,844.53	FINLAND	32,303.31	9515.99
FRANCE	1778,769.70	513,142.90	FRANCE	29,317.83	6372.41
GERMANY	2472,551.71	655,396.74	GERMANY	30,623.51	7574.36
GREECE	175,482.85	44,765.93	GREECE	16,880.39	3291.41
HUNGARY	96,478.95	19,640.09	HUNGARY	9426.29	2164.48
IRELAND	135,110.70	91,464.70	IRELAND	32,831.80	17,839.05
ISRAEL	154,238.28	89,165.94	ISRAEL	25,165.49	6787.08
ITALY	1545,138.94	360,513.25	ITALY	26,830.93	5735.58
JAPAN	3323,486.30	981,044.46	JAPAN	26,845.29	6879.99
KOREA	668,949.60	508,723.98	KOREA	14,063.47	9677.99
LITHUANIA	30,260.30	9533.60	LITHUANIA	9525.17	3871.51
LUXEMBOURG	33,420.97	17,156.79	LUXEMBOURG	73,333.14	26,462.34
NETHERLANDS	534,975.83	177,655.19	NETHERLANDS	34,193.13	8861.94
NEW ZEALAND	110,636.25	41,430.18	NEW ZEALAND	28,842.37	6078.99
NORWAY	242,547.01	86,906.96	NORWAY	53,239.45	14,773.07
POLAND	258,093.30	134,247.02	POLAND	6866.67	3437.06
PORTUGAL	152,212.18	49,035.40	PORTUGAL	15,045.31	4284.43
SLOVAK REP.	70,694.31	17,545.41	SLOVAK REP.	13,113.31	3185.08
SLOVENIA	35,932.07	8016.22	SLOVENIA	17,739.72	3714.76
SPAIN	838,971.62	295,696.11	SPAIN	20,125.45	5322.96
SWEDEN	335,701.45	106,291.01	SWEDEN	37,444.45	9365.42
SWITZERLAND	484,881.18	122,834.02	SWITZERLAND	67,537.12	10,228.09
TURKEY	366,478.31	274,987.21	TURKEY	5579.66	3052.42
UK	1989,766.96	647,412.37	UK	33,175.48	9098.62
US	11,503,300.61	4599,420.03	US	41,652.64	11,172.04

GGDP is in US$ million.

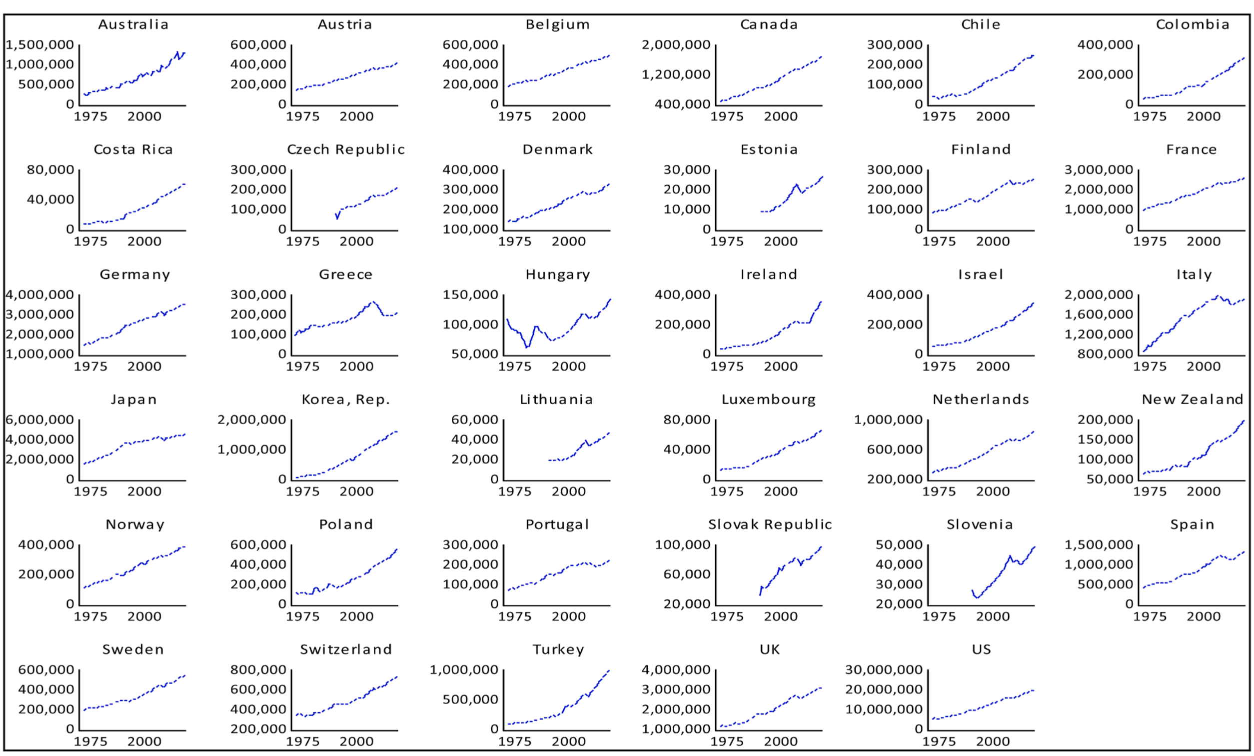

Fig. 1. GGDP (US$ million) in OECD countries, 1970–2019.

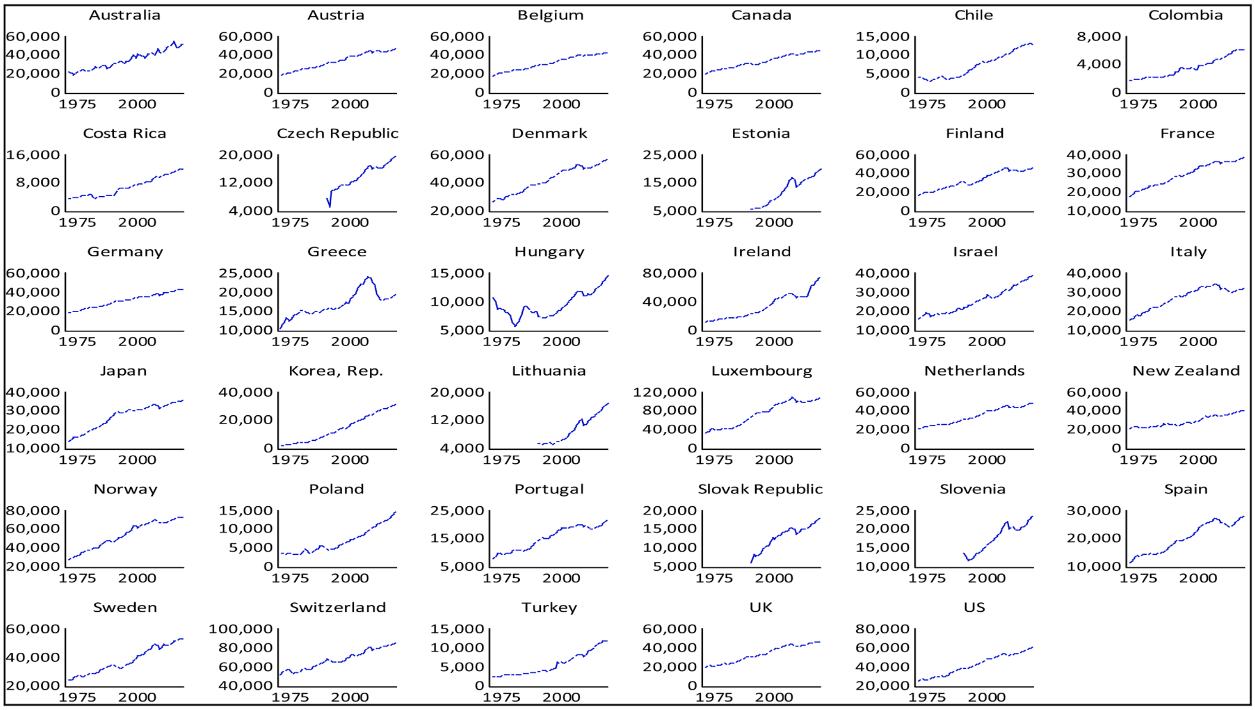

Fig. 2. per capita GGDP in OECD countries, 1970–2019.

the errors in a regression specification of the following form,

$$y(t) = \beta_0 + \beta_1 t + x(t), \; t = 1, 2, \ldots, \tag{5}$$

where β_0 and β_1 are coefficients to be computed, in addition to d.

Table 2 displays the estimates of the differencing parameter d for RGGDP, for three different specifications: 1) we consider the case of no deterministic terms (column 2), 2) we allow for an intercept only (which is available in column 3), and 3) allowing for an intercept as well as a linear time trend (which is available in column 4). We have marked in bold those cases corresponding to the selected models based on statistical significance. Tables 3 reproduces the estimated coefficients for the selected models in Table 2.

We observe in Tables 2 and 3 that of the 35 countries examined, a time trend is required in 30. Thus, only Estonia, Greece, Hungary, Israel and Slovenia display insignificant trends. For the 30 countries requiring a time trend, all of them show a positive coefficient, and the highest values are observed in the cases of Korea (0.070), Turkey (0.052), Ireland (0.048), Costa Rica (0.048) and Spain and Colombia (0.045). In relation with the differencing parameter d, we see that the results are very heterogeneous across countries. Thus, evidence of short memory or I(0) behaviour is found in the cases of Australia and Belgium, with estimated values of d equal to 0.11 and −0.10 respectively; Czech Republic is the only country that displays an estimate of d in the interval (0, 1), while for the rest of the countries, d is equal to or higher than 1. In particular, looking at the confidence bands, the unit root null hypothesis, i.e., $d = 1$ cannot be rejected for 20 countries (Turkey, New Zealand, Colombia, Slovakia, Israel, Poland, Germany, Sweden, Lithuania, Switzerland, Costa Rica, Denmark, US, Canada, Luxembourg, Austria, Netherlands, UK, Estonia and Slovenia), while this hypothesis is rejected in favour of $d > 1$ for the remaining twelve countries (Norway, Italy, Ireland, Korea, Chile, France, Japan, Finland, Portugal, Hungary, Greece and Spain). Thus, according to this specification based on white noise errors, only three countries (Belgium, Australia and Czech Republic) display transitory shocks, disappearing by themselves in the long run.

Tables 4 focusses on the per capita GGDP series, reporting only the values of the selected specifications. Once again, the time trend is required in the majority of the countries. In fact, the time trend coefficient is found to be statistically insignificant only for the cases of Greece, Hungary and Slovenia. The highest coefficients for the time trend are found in Korea (0.058) and Estonia (0.041). Looking at the degree of persistence, the results are again very heterogeneous across countries: Australia is the only country displaying a short memory pattern, with an estimate of d equal to 0.12; Three countries show evidence of fractional integration with mean reversion: Czech Republic (with $d = 0.33$) and Israel and New Zealand (0.63); fifteen countries encounter values of d around 1 (Colombia, Turkey, Slovakia, Switzerland, Germany, Poland, Costa Rica, Lithuania, US, Denmark, Canada, Netherlands, Sweden, Estonia and Slovenia), while sixteen display values of d significantly above 1 (Belgium, Austria, Luxembourg, Korea, Japan, Chile, Italy, Ireland, UK, France, Norway, Portugal, Finland, Greece, Hungary and Spain).

Table 5 summarizes the results reported above for the two series under examination. It is observed that only Australia display short memory in the two cases, while Czech Republic is the only one showing a value of d in the interval (0, 1) for the two series. Apart from these two countries, only Belgium (for RGGDP) and Israel and New Zealand (with per capita RGGDP) display some evidence of reversion to the mean.

The foregoing results suggest evidence for the persistence of both RGGDP and per capita RGGDP in the majority of the OECD countries. As the extant papers on the persistence of RGGDP are not available in the literature, it is not ideal to directly compare the empirical findings of the current studies with the extant papers on GGDP. However, some rationales for the results can be provided. One of the plausible reasons for persistence of RGGDP and per capita RGGDP is the persistence of the components of GGDP and per capita GGDP, which includes GDP, CO_2 emissions, inflation, and population size. According to Gil-Alana et al. [15], a series that is dependent on other series that are persistent will absorb the persistence from the other series. It has been shown that both GDP and population series are highly persistent [15]. Erdogan et al. [34] has shown that CO_2 emissions is a persistent series, while Caporin and Gupta [35] has proved that inflation is persistent.

Another possible reason for the persistence in the series is that the mean of the RGGDP and per capita RGGDP have changed across time. A persistent variable is characterised by a stochastic process and as such

Table 2
Estimates of d based on GGDP data (in logs).

Country	No regressors	With a constant	With a linear time trend
AUSTRALIA	0.92 (0.74, 1.19)	0.72 (0.65, 0.83)	**0.11 (−0.12, 0.53)**
AUSTRIA	0.93 (0.75, 1.19)	1.29 (0.70, 1.61)	**1.16 (0.98, 1.40)**
BELGIUM	0.92 (0.74, 1.18)	0.25 (0.12, 0.42)	**−0.10 (−0.34, 0.25)**
CANADA	0.93 (0.75, 1.19)	1.31 (0.74, 1.63)	**1.15 (0.96, 1.43)**
CHILE	0.92 (0.74, 1.19)	1.25 (1.02, 1.67)	**1.28 (1.02, 1.72)**
COLOMBIA	0.93 (0.74, 1.20)	0.85 (0.77, 1.12)	**0.79 (0.56, 1.08)**
COSTA RICA	0.93 (0.74, 1.19)	1.08 (0.86, 1.49)	**1.07 (0.82, 1.43)**
CZECH REPUBLIC	0.86 (0.61, 1.22)	0.49 (0.36, 0.66)	**0.28 (0.03, 0.61)**
DENMARK	0.93 (0.75, 1.19)	1.16 (0.72, 1.56)	**1.10 (0.87, 1.45)**
ESTONIA	0.87 (0.57, 1.23)	**1.30 (0.92, 1.93)**	1.27 (0.90, 1.93)
FINLAND	0.93 (0.75, 1.19)	1.48 (1.15, 1.95)	**1.38 (1.10, 1.87)**
FRANCE	0.92 (0.75, 1.19)	1.48 (1.25, 1.80)	**1.31 (1.13, 1.59)**
GERMANY	0.93 (0.75, 1.20)	1.08 (0.74, 1.50)	**1.04 (0.86, 1.37)**
GREECE	0.93 (0.75, 1.20)	**1.45 (1.24, 1.73)**	1.41 (1.22, 1.68)
HUNGARY	0.92 (0.74, 1.19)	**1.42 (1.15, 1.82)**	1.43 (1.15, 1.81)
IRELAND	0.92 (0.77, 1.19)	1.29 (1.04, 1.58)	**1.27 (1.05, 1.56)**
ISRAEL	0.94 (0.77, 1.19)	**0.91 (0.73, 1.18)**	0.91 (0.72, 1.18)
ITALY	0.93 (0.75, 1.19)	1.34 (1.18, 1.57)	**1.26 (1.13, 1.45)**
JAPAN	0.93 (0.74, 1.19)	1.43 (1.26, 1.67)	**1.31 (1.19, 1.50)**
KOREA	0.92 (0.73, 1.24)	1.42 (1.27, 1.64)	**1.27 (1.15, 1.44)**
LITHUANIA	0.87 (0.60, 1.24)	1.06 (0.86, 1.49)	**1.06 (0.75, 1.49)**
LUXEMBOURG	0.93 (0.74, 1.19)	1.20 (0.90, 1.59)	**1.16 (0.94, 1.49)**
NETHERLANDS	0.92 (0.73, 1.19)	1.27 (0.95, 1.56)	**1.19 (1.01, 1.45)**
NEW ZEALAND	0.93 (0.73, 1.20)	0.82 (0.72, 1.00)	**0.75 (0.57, 1.02)**
NORWAY	0.93 (0.75, 1.19)	1.40 (1.11, 1.79)	**1.25 (1.05, 1.62)**
POLAND	0.93 (0.74, 1.19)	0.96 (0.80, 1.52)	**0.91 (0.52, 1.52)**
PORTUGAL	0.93 (0.74, 1.19)	1.50 (1.24, 1.89)	**1.38 (1.17, 1.76)**
SLOVAK REP.	0.88 (0.62, 1.25)	0.54 (0.41, 0.88)	**0.86 (0.63, 1.19)**
SLOVENIA	0.87 (0.60, 1.23)	**1.42 (0.99, 1.84)**	1.42 (0.91, 1.85)
SPAIN	0.93 (0.75, 1.19)	1.84 (1.56, 2.24)	**1.71 (1.45, 2.11)**
SWEDEN	0.93 (0.74, 1.19)	1.04 (0.85, 1.55)	**1.04 (0.74, 1.50)**
SWITZERLAND	0.93 (0.75, 1.19)	1.02 (0.83, 1.62)	**1.06 (0.72, 1.63)**
TURKEY	0.93 (0.73, 1.19)	0.86 (0.78, 1.03)	**0.67 (0.45, 1.02)**
UK	0.93 (0.73, 1.19)	1.32 (0.87, 1.84)	**1.25 (0.91, 1.79)**
US	0.93 (0.73, 1.19)	1.22 (0.85, 1.62)	**1.11 (0.91, 1.47)**

We report the estimates of d for each seires and each specification of the deterministic terms. In parenthesis, the 95 % confidence bands. In bold, the most appropriate specification for each series.

Table 3
Estimated coefficients in the selected model for each series. GGDP data.

Country	No regressors	With a constant	With a linear time trend
AUSTRALIA	0.11 (−0.12, 0.53)^{SM}	26.229 (1005.49)	0.034 (39.61)
AUSTRIA	1.16 (0.98, 1.40)^{UR}	25.556 (1472.82)	0.024 (5.70)
BELGIUM	−0.10 (−0.34, 0.25)^{SM}	25.933 (368.23)	0.018 (7.45)
CANADA	1.15 (0.96, 1.43)^{UR}	26.743 (490.00)	0.028 (6.59)
CHILE	1.28 (1.02, 1.72)^{EXP}	24.273 (444.50)	0.036 (1.73)
COLOMBIA	0.79 (0.56, 1.08)^{UR}	24.207 (573.43)	0.045 (15.15)
COSTA RICA	1.07 (0.82, 1.43)^{UR}	22.477 (457.09)	0.047 (5.27)
CZECH REPUBLIC	0.28 (0.03, 0.61)^{FR}	25.097 (339.63)	0.034 (8.59)
DENMARK	1.10 (0.87, 1.45)^{UR}	25.545 (1350.53)	0.019 (5.23)
ESTONIA	1.30 (0.92, 1.93)^{UR}	22.900 (448.55)	—
FINLAND	1.38 (1.10, 1.87)^{EXP}	24.990 (24.990)	0.030 (2.08)
FRANCE	1.31 (1.13, 1.59)^{EXP}	25.165 (919.20)	0.026 (4.24)
GERMANY	1.04 (0.86, 1.37)^{UR}	27.920 (1427.23)	0.019 (6.14)
GREECE	1.45 (1.24, 1.73)^{EXP}	25.215 (774.80)	—
HUNGARY	1.42 (1.15, 1.82)^{EXP}	25.447 (511.32)	—
IRELAND	1.27 (1.05, 1.56)^{EXP}	24.198 (633.64)	0.048 (3.44)
ISRAEL	0.91 (0.73, 1.18)^{UR}	24.601 (77.91)	—
ITALY	1.26 (1.13, 1.45)^{EXP}	27.411 (1378.11)	0.012 (2.67)
JAPAN	1.31 (1.19, 1.50)^{EXP}	27.928 (1288.80)	0.028 (3.13)
KOREA	1.27 (1.15, 1.44)^{EXP}	24.727 (719.26)	0.070 (5.53)
LITHUANIA	1.06 (0.75, 1.49)^{UR}	23.700 (424.23)	0.029 (2.35)
LUXEMBOURG	1.16 (0.94, 1.49)^{UR}	23.081 (699.77)	0.037 (4.53)
NETHERLANDS	1.19 (1.01, 1.45)^{EXP}	26.265 (1430.59)	0.024 (4.77)
NEW ZEALAND	0.75 (0.57, 1.02)^{UR}	24.742 (666.12)	0.025 (10.66)
NORWAY	1.25 (1.05, 1.62)^{EXP}	25.977 (1264.77)	0.029 (4.31)
POLAND	0.91 (0.52, 1.52)^{UR}	25.458 (378.71)	0.032 (4.58)
PORTUGAL	1.38 (1.17, 1.76)^{EXP}	24.841 (930.73)	0.034 (2.40)
SLOVAK REP.	0.86 (0.63, 1.19)^{UR}	24.196 (357.29)	0.037 (4.44)
SLOVENIA	1.42 (0.99, 1.84)^{UR}	24.046 (739.16)	—
SPAIN	1.71 (1.45, 2.11)^{EXP}	26.600 (1588.11)	0.045 (4.44)
SWEDEN	1.04 (0.74, 1.50)^{UR}	25.949 (1326.85)	0.021 (2.40)
SWITZERLAND	1.06 (0.72, 1.63)^{UR}	24.163 (1184.33)	0.017 (4.79)
TURKEY	0.67 (0.45, 1.02)^{UR}	25.012 (481.88)	0.052 (19.60)
UK	1.25 (0.91, 1.79)^{UR}	29.963 (1467.66)	0.023 (3.33)
US	1.11 (0.91, 1.47)^{UR}	29.193 (1540.07)	0.028 (7.23)

SM shows short memory or I(0) behavior; MR indicates mean reversion; UR evidence of unit roots; and EXP, explosive patterns or values of d significantly above 1.

Table 4
Estimated coefficients in the selected model for each series. Per capita GGDP data.

Country	No regressors	With a constant	With a linear time trend
AUSTRALIA	0.12 (−0.14, 0.54)^{SM}	9.000 (451.00)	0.019 (27.49)
AUSTRIA	1.18 (1.03, 1.40)^{EXP}	9.736 (559.83)	0.021 (4.59)
BELGIUM	1.16 (1.00, 1.36)^{UR}	9.711 (571.15)	0.019 (4.62)
CANADA	1.13 (0.92, 1.44)^{UR}	9.883 (540.86)	0.016 (4.13)
CHILE	1.28 (1.03, 1.72)^{EXP}	8.200 (153.38)	—
COLOMBIA	0.75 (0.49, 1.07)^{UR}	6.365 (178.86)	0.027 (10.56)
COSTA RICA	1.05 (0.78, 1.43)^{UR}	8.065 (164.98)	0.026 (3.21)
CZECH REPUBLIC	0.33 (0.08, 0.63)^{FR}	8.944 (110.83)	0.033 (7.62)
DENMARK	1.12 (0.92, 1.45)^{UR}	10.138 (537.38)	0.016 (4)
ESTONIA	1.27 (0.92, 1.95)^{UR}	8.607 (163.00)	0.041 (1.88)
FINLAND	1.40 (1.11, 1.89)^{EXP}	9.650 (353.53)	0.026 (1.75)
FRANCE	1.30 (1.12, 1.57)^{EXP}	9.713 (676.30)	0.020 (3.41)
GERMANY	0.98 (0.80, 1.32)^{UR}	9.749 (490.55)	0.018 (6.95)
GREECE	1.42 (1.20, 1.72)^{EXP}	4.228 (282.31)	—
HUNGARY	1.43 (1.17, 1.83)^{EXP}	9.297 (186.93)	—
IRELAND	1.29 (1.07, 1.57)^{EXP}	9.310 (244.46)	0.037 (2.49)
ISRAEL	0.63 (0.44, 0.94)^{FR}	9.662 (324.20)	0.017 (14.63)
ITALY	1.28 (1.15, 1.49)^{EXP}	9.613 (478.49)	0.017 (2.21)
JAPAN	1.25 (1.11, 1.46)^{EXP}	9.485 (446.13)	0.021 (2.96)
KOREA	1.23 (1.11, 1.41)^{EXP}	7.453 (219.76)	0.058 (5.41)
LITHUANIA	1.08 (0.78, 1.50)^{UR}	8.578 (150.45)	0.038 (2.85)
LUXEMBOURG	1.20 (1.03, 1.49)^{EXP}	10.358 (309.80)	0.025 (2.62)
NETHERLANDS	1.14 (0.95, 1.42)^{UR}	9.890 (537.91)	0.018 (4.21)
NEW ZEALAND	0.63 (0.43, 0.93)^{FR}	9.906 (290.96)	0.014 (8.53)
NORWAY	1.30 (1.12, 1.64)^{EXP}	10.132 (503.19)	0.024 (2.93)
POLAND	0.98 (0.66, 1.55)^{UR}	8.167 (117.62)	0.028 (5.41)
PORTUGAL	1.37 (1.09, 1.83)^{EXP}	8.867 (304.44)	0.029 (2.85)
SLOVAK REP.	0.85 (0.62, 1.18)^{UR}	8.717 (129.39)	0.036 (4.46)
SLOVENIA	1.42 (0.99, 2.07)^{UR}	9.538 (287.39)	—
SPAIN	1.70 (1.43, 2.12)^{EXP}	9.274 (542.96)	0.035 (1.88)
SWEDEN	1.15 (0.86, 1.41)^{UR}	10.054 (502.35)	0.016 (3.38)
SWITZERLAND	0.97 (0.52, 1.58)^{UR}	10.838 (534.53)	0.010 (3.94)
TURKEY	0.76 (0.57, 1.05)^{UR}	7.636 (137.64)	0.035 (9.71)
UK	1.29 (1.01, 1.77)^{EXP}	9.801 (481.43)	0.020 (1.77)
US	1.08 (0.86, 1.47)^{UR}	10.065 (531.25)	0.019 (5.35)

SM shows short memory or I(0) behavior; MR indicates mean reversion; UR evidence of unit roots; and EXP, explosive patterns or values of d significantly above 1.

does not have a consistent mean or distribution overtime [36]. For instance, the average RGGDP in the US increased from about 5.76 trillion (US$ 2015 prices) in the 1970s to 7.92 trillion (US$ 2015 prices) in the 1980s, 10.99 trillion (US$ 2015 prices) in the 1990s, 14.95 trillion (US$ 2015 prices) in the 2000s, 17.89 trillion (US$ 2015 prices) in the 2010s. The average per capita GGDP in Germany increased from about 20,109 (US$ 2015 prices) in the 1970s to 25,146 (US$ 2015 prices) in the 1980s, 31,379 (US$ 2015 prices) in the 1990s, 35,670 (US$ 2015 prices) in the 2000s, 40,811 (US$ 2015 prices) in the 2010s [16]. Similar scenarios are observed for both variables in the majority of OECD countries.

Table 5
Estimates of d. Summary.

$d = 0$	$0 < d < 1$	$d = 1$	$d > 1$
i) GGDP			
Belgium (−0.10) Australia (0.11)	Czech Republic (0.28)	Turkey (0.67) New Zealand (0.75) Colombia (0.79) Slovak Rep. (0.86) Israel (0.91) Poland (0.91) Germany (1.04) Sweden (1.04) Lithuania (1.06) Switzerland (1.06) Costa Rica (1.07) Denmark (1.10) US (1.11) Canada (1.15) Luxembourg (1.16) Austria (1.16) Netherlands (1.19) UK (1.25) Estonia (1.30) Slovenia (1.42)	Norway (1.25) Italy (1.26) Ireland (1.27) Korea (1.27) Chile (1.28) France (1.31) Japan (1.31) Finland (1.38) Portugal (1.38) Hungary (1.42) Greece (1.45) Spain (1.71)
ii) GGDP per capita			
$d = 0$	$0 < d < 1$	$d = 1$	$d > 1$
Australia (0.12)	Czech Republic (0.33) Israel (0.63) New Zealand (0.63)	Colombia (0.75) Turkey (0.76) Slovak Rep. (0.85) Switzerland (0.97) Poland (0.98) Germany (0.98) Costa Rica (1.05) US (1.08) Lithuania (1.08) Denmark (1.12) Canada (1.13) Netherlands (1.14) Sweden (1.15) Belgium (1.16) Estonia (1.27) Slovenia (1.42)	Austria (1.18) Luxembourg (1.20) Korea (1.23) Japan (1.25) Chile (1.28) Italy (1.28) UK (1.29) Ireland (1.29) Norway (1.30) France (1.30) Portugal (1.37) Finland (1.40) Greece (1.42) Hungary (1.43) Spain (1.70)

The results are not consistent with the hypothesis in Smyth [37]. According to the hypothesis, series with smaller figures are likely to be more mean reverting. However, Australia, which is only country to display short memory in the two cases, is not among the countries with the lowest RGGDP or per capita RGGDP. Australia has the tenth largest RGGDP among the OECD countries, and has the seventh largest per capita RGGDP among the OECD countries. Belgium, which also display some evidence of reversion to the mean with RGGDP, is not among the countries with the lowest RGGDP among the OECD countries. Israel and New Zealand, which display some evidence of reversion to the mean with per capita RGGDP, are not among the countries with the lowest per capita RGGDP among the OECD countries.

6. Concluding comments

In this article we have employed a fractionally integrated model in the analysis of real and real per capita green GDP series of 35 countries. The results, though heterogeneous across countries show evidence of high degrees of persistence in the majority of the cases, and the only evidence of mean reversion is found in the cases of Belgium (RGGDP), Israel and New Zealand (per capita RGGDP), and Australia and New Zealand (in the two series). An implication of the presence of persistence in RGGDP or per capita RGGDP in OECD countries is that long-term policies are needed to boost green production in the OECD countries.

Besides, long term policies as against short term interventions are needed to tackle any unexpected changes in persistent series including those triggered by COVID-19 pandemic.

Long run policies or interventions include supporting technology and research projects that facilitate the uptake of more energy-efficient technologies. Another policy is to raise public understanding of approaches to decrease household waste; encouraging product innovations that decrease waste or grow recycling habits; and reducing barriers to the development of markets for recycled goods. The results also signal that it is not practical to predict the subsequent values of RGGDP and per capita RGGDP by merely depending on their past figures in majority of the OECD countries. There is a need to incorporate the role of other possible factors in forecasting future values of GGDP. Hence, the role of demand-side and supply-side factors of GGDP should be considered when using forecasting models such as grey forecasting model and neural network analysis.

The results further suggest that few OECD countries such as Australia and New Zealand can use short term policies to boost green production and short-term interventions can be successfully used to restore green production back to its pre-shock level. The short-term policies or interventions include promoting, tradable permits, environment-related taxes and other market-based methods to managing natural resources. Also fixing fees for waste disposal to reflect the market price is another suitable short-term approach that can be used to boost green production.

There are few limitations that are associated with this paper. We have only considered persistence of RGGDP and per capita RGGDP in the OECD countries. Subsequent studies can also analyse the persistence of RGGDP and per capita RGGDP in other economic blocs including Association of Southeast Asian Nations (ASEAN), South Asian Association for Regional Cooperation (SAARC), and African Union (AU) countries. The convergence of RGGDP and per capita RGGDP can be considered by future papers. Investigating the convergence of the two series would provide insights on whether commodity-specific policy or joint policy is required to ensure the expansion of green production in each economy.

Ethic statement

Not applicable

CRediT authorship contribution statement

Sakiru Adebola Solarin: Writing – original draft, Resources, Methodology, Funding acquisition, Data curation. **Gloria Claudio-Quiroga:** Writing – review & editing, Visualization, Validation, Resources, Formal analysis, Data curation. **Luis Alberiko Gil-Alana:** Software, Investigation, Funding acquisition, Formal analysis, Data curation.

Declaration of competing interest

There is no conflict of interest with the publication of the present manuscript.

Data availability

Data will be made available on request.

References

[1] R. Merli, M. Preziosi, A. Acampora, How do scholars approach the circular economy? A systematic literature review, J. Clean. Prod. 178 (2018) 703–722.

[2] M. Lieder, A. Rashid, Towards circular economy implementation: a comprehensive review in context of manufacturing industry, J. Clean. Prod. 115 (2016) 36–51.

[3] F. Sariatli, Linear economy versus circular economy: a comparative and analyzer study for optimization of economy for sustainability, Visegr. J. Bioeconomy Sustain. Dev. 6 (1) (2017) 31–34.

[4] W. Steffen, K. Richardson, J. Rockström, S.E. Cornell, I. Fetzer, E.M. Bennett, S. Sörlin, Planetary boundaries: guiding human development on a changing planet, Science 347 (6223) (2015) 1259855.

[5] B.F. Giannetti, F. Agostinho, C.M. Almeida, D. Huisingh, A review of limitations of GDP and alternative indices to monitor human wellbeing and to manage eco-system functionality, J. Clean. Prod. 87 (2015) 11–25.

[6] F. Ahmed, S. Kousar, A. Pervaiz, J.E. Trinidad-Segovia, Pilar del, M. Casado-Belmonte, W. Ahmed, Role of green innovation, trade and energy to promote green economic growth: a case of South Asian Nations, Environ. Sci. Pollut. Res. 29 (5) (2022) 6871–6885.

[7] Fleurbaey M., Kartha S., Bolwig S., Chee Y.L., Chen Y., Corbera E., … Sagar A. (2014) Sustainable development and equity. Retrieved from http://centaur.reading.ac.uk/38524/1/ipcc_wg3_ar5_chapter4.pdf (accessed on 28/03/2024).

[8] S. Stjepanović, D. Tomić, M. Škare, Green GDP: an analyses for developing and developed countries, Econ. Manag. 22 (4) (2019) 4–17.

[9] S. Kousar, A.I. Bhutta, M.R. Ullah, A. Shabbir, Impact of economic and green growth on poverty, income inequalities, and environmental degradation: a case of South Asian economies, Environ. Sci. Pollut. Res. 30 (12) (2023) 35200–35213.

[10] E.B. Barbier, The green economy post Rio+ 20, Science 338 (6109) (2012) 887–888.

[11] M. Jacobs, Green growth: Economic theory and Political Discourse, 108, Grantham Research Institute on Climate Change and the Environment, London, 2012.

[12] S. Stjepanović, D. Tomić, M. Škare, A new approach to measuring green GDP: a cross-country analysis, Entrep. Sustain. Issues 4 (4) (2017) 574.

[13] S. Stjepanovic, D. Tomic, M. Skare, A new database on green GDP; 1970-2019: a framework for assessing the green economy, Oecon. Copernic. 13 (4) (2022) 949–975.

[14] J.N. Rauch, Y.F. Chi, The plight of green GDP in China, Cons.: J. Sustain. Dev. 3 (1) (2010) 102–116, https://doi.org/10.7916/consilie nce.v0i3.4498.

[15] L.A. Gil-Alana, S.A. Solarin, M. Balcilar, R. Gupta, Productivity and GDP: international evidence of persistence and trends over 130 years of data, Empir. Econ. 64 (3) (2023) 1219–1246.

[16] World Bank, World Development Indicators, 2024. Retrieved from, https://databank.worldbank.org/reports.aspx?source=world-development-indicators# (accessed on 28/03/2024).

[17] OECD, Green Growth Indicators 2014, OECD Green Growth Studies, OECD, Paris, 2014.

[18] M. Kalantaripor, H. Alamdarlo, Spatial effects of energy consumption and green GDP in regional agreements, Sustainability. 13 (18) (2021) 10078.

[19] K. Kempa, A. Tyagi, Climate and environmental impacts of green recovery: evidence from the financial crisis, World Dev. Sustain. 6 (2025) 100194.

[20] OECD, Towards Green growth. Towards green Growth: Monitoring Progress, OECD, Paris, 2011.

[21] UNEP, Towards a Green economy: Pathways to Sustainable Development and Poverty Eradication, 2011. Retrieved from, www.unep.org/greeneconomy (accessed on 28/03/2024).

[22] J. Hickel, G. Kallis, Is green growth possible? New polit. econ. 25 (4) (2020) 469–486.

[23] B.P. Badjeena, E. Ali, K.O. Wonyra, K. Tamou, Green entrepreneurship: opportunities and challenges for the transition to a circular economy in Togo, West Africa, World Dev. Sustain. (2024) 100181.

[24] J. Boyd, The nonmarket benefits of nature: what should be counted in green GDP? Ecol. Econ. 61 (4) (2006) 716–723.

[25] J.E. Hecht, National Environmental accounting: Bridging the Gap Between Ecology and Economy, Routledge, Melbourne, 2012.

[26] W.X. Wang, E.J. He, X.L. Zheng, Construction of green GDP accounting system, Adv. Mat. Res. 971 (2014) 2301–2304.

[27] S. Arogundade, A.S. Hassan, The path to green economy: do environmental taxes and renewable energy transition matter in OECD countries? World Dev. Sustain. 5 (2024) 100189.

[28] K. Kunanuntakij, V. Varabuntoonvit, N. Vorayos, C. Panjapornpon, T. Mungcharoen, Thailand green GDP assessment based on environmentally extended input-output model, J. Clean. Prod. 167 (2017) 970–977.

[29] D. Chakraborty, K. Mukhopadhyay, Estimates of green GDP, Glob. Issues Water (Basel) Policy 10 (2014) 165–187.

[30] L.Y. Guo, M. Lei, X.Q. Liu, Green GDP accounting research based on emergy analysis method: a case study of Shangluo city in Shaanxi Province, J. Nat. Resour. 30 (9) (2015) 1523–1533.

[31] X.Y. Shen, G.H. Wang, X.J. Huang, Green GDP accounting and spatio-temporal pattern in China from 1997 to 2013, J. Nat. Resour. 32 (10) (2017) 1639–1650.

[32] H. Zhang, M.S. Huang, X. Hu, Green GDP calculation of Fujian province based on energy analysis, Acta Geogr. Sin. 65 (11) (2010) 1421–1428.

[33] P.M. Robinson, Efficient tests of nonstationary hypotheses, J. Am. Stat. Assoc. 89 (428) (1994) 1420–1437.

[34] S. Erdogan, U.K. Pata, S.A. Solarin, I. Okumus, On the persistence of shocks to global CO2 emissions: a historical data perspective (0 to 2014), Environ. Sci. Pollut. Res. 29 (51) (2022) 77311–77320.

[35] M. Caporin, R. Gupta, Time-varying persistence in US inflation, Empir. Econ. 53 (2017) 423–439.

[36] D.N. Gujarati, C.D. Porter, Essentials of Econometrics, 4th Edition, Sage Publications, McGraw-Hill/Irwin: New York, 2010.

[37] R Smyth, Are fluctuations in energy variables permanent or transitory? A survey of the literature on the integration properties of energy consumption and production, Appl. Energy 104 (2013) 371–378.