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Testing the Mediating Role of Fiscal Policy in the Environmental Degradation in Portugal: Evidence from Multiple Structural Breaks Co-integration Test

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Abstract

Using Portugal, the present study explores the nexus between fiscal policies advancement and environmental emissions through the channel of carbon-income function framework. We used recent second-generational time series econometrics tests that comprise bounds testing in conjunction with multiple break structural break test of Maki co-integration and gradual shift causality test and wavelet coherence method for soundness of analysis. Furthermore, to circumvent omitted variable bias issues, energy consumption was disaggregated into non-renewable energy and renewable consumption, with GDP growth incorporated as additional variables. Empirical evidence for the Portuguese economy shows that economic growth, non-renewable energy intake, and fiscal policy all dampen the quality of the environment in Portugal. These findings have environmental implications for sustainability targets in Portugal which is currently on the trajectory for healthy and sustainable energy intake. Additionally, renewable energy consumption shows statistically significant strength to improve environmental quality as it reduces CO_2 emission, as reported by our study regression. On the direction of causality analysis, we observed that non-renewable energy and fiscal policy drive pollution emission one-way as reported by the gradual shift causality analysis. From a policy lens, there is need for more strides in action plans on fiscal policy development to achieve environmental sustainability in Portugal. Further insights are elucidated in the concluding remarks section.

Keywords Fiscal policy · GDP growth · Environmental sustainability · Energy consumption · pollution · Portugal

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Introduction

Climate change and its significant negative environmental impacts are undoubtedly one of the most serious issues confronting the modern world. Human action, particularly utilization of energy, has been identified as one of the primary contributors to climate change in recent decades (Adebayo, 2020). As a result of the global warming issue, there is increasing anxiety about insufficient energy sources on the one hand and a new model of a green economy on the other. The association between economic growth, utilization of energy, and CO_2 emissions has been the subject of intense discussion in recent years (Sarkodie et al., 2020; Shahbaz et al., 2016). Higher economic growth and energy use, for example, have resulted in higher CO_2 emissions and deterioration of the environment. Energy demand is heavily reliant—to a large degree—on the production and use of fossil fuels.

Significant project initiatives take up the lion's share of each nation's economic growth expenditures. Governments raise their expenditures on consumer products and provide new investment possibilities for investors in order to strengthen their nation's economy. Government uses contractionary (tight) and expansionary (loose) macroeconomic policies in accordance with its economic circumstances in order to improve societal welfare. States used expansionary monetary policy to boost their economies during tough periods like the 2008 global financial meltdown. Because it enhances the economy, fiscal policy has profound significance in the confluence of its macroeconomic policies (Akbar et al., 2021; Gerlagh et al., 2018).

According to earlier research (Abbass et al., 2022; Akbar et al., 2021; Ike et al., 2020; Eslami et al. 2021; Syed & Bouri, 2021; Wang et al. 2022; Katircioglu and Katircioglu, 2018a, b; Yuelan et al., 2019) an economy's fiscal spending is essential for reducing CO_2 emissions as an environmental pollutant. Nevertheless, research has shown that investing in public products instead of private ones can better conserve our environment. Nevertheless, in terms of other ecological degradation factors, fiscal regulations, such as business (Cole & Elliott, 2003), consumer response (Baiocchi et al., 2010), and economic growth (Grossman and Krueger, 1991), are confirmed to be more extreme in influencing environmental initiatives and keeping track of the increased contamination. This pertains to taxation and spending by the government for management, laws, safety subsidies, society, and other benefits for the private sector. Meanwhile, public funding on environmental pollution reduction is spent on human-centered activities rather than capital-intensive physical operations (Yilanci & Pata, 2022).

Ecological deterioration is a major issue because of advancements in technology and industrialization, which might negatively impact biodiversity and provide risks to human life (Katircioglu and Katircioglu, 2018a, b). Consequently, the planet will suffer extreme weather, calamitous events including sea level rise, glacier melt, and destruction of natural systems worldwide (Sun & Razzaq, 2022; Dabbous & Tarhini,2021; Ferreira et al. 2022;Yuelan et al., 2019). While this has been happening, governments of developed and advanced nations have raised their level of public expenditures, spending more on things like public health, education, igniting fossil fuels, and ecological defenses using modern technologies (Gerlagh et al., 2018; Katircioglu and Katircioglu, 2018a, b; Yilanci & Pata, 2022). On the flipside, emerging nations struggle to safeguard the ecosystem due to a lack of resources, weak financial laws, and the use of low-cost technologies in the burning and extraction of fossil fuels (Akbar et al., 2022; Ike et al., 2020).

Portugal recognizes that sustainable development is more than just a passing fad; it is a way of looking at the future. In the past 10 years, businesses and organizations have increasingly viewed investing in this strategic growth route as a moral commitment and a means of advancing their economies. Portugal has made incredible strides in this area, emerging as a global leader in the switch to renewable energy. Portugal is heavily dependent on foreign energy because of its lack of fossil fuel resources and the variety of industries it had established due to its late industrialization (GLOBAL AFFAIRS, 2023). The inability of hydroelectric power to satisfy demand led to an increase in the importation of coal, particularly hydrocarbons, making Portugal one of the European nations with the largest levels of energy reliance (approximately 80% in 2010). The Portuguese government has also shown a firm dedication to renewable energy sources by promoting the National Strategy for Green Hydrogen as crucial. This approach encourages the gradual integration of hydrogen into various economic sectors to facilitate the shift to a decarbonized economy. Additionally, this plan seeks to establish a green hydrogen export center for Europe, which is crucial for expanding the sector's globalization.

The present study further examines Portugal's ambitions for decarbonization by 2050 in light of the above emphasis regarding Portugal, particularly from the viewpoints of energy profile. As an objective, this paper is planned to evaluate the role of energy and fiscal policy in Portugal's pursuit of ecological quality. Thus, the primary questions of the paper are as follows: (i) Does Portugal's economic growth trajectory contribute to ecological degradation? (ii) What is the role of clean energy towards carbon neutrality target in Portugal? (iii) Can fiscal policy contribute to ecological sustainability in Portugal?

The study's contribution is as follows. Over the years, scant studies have been documented regarding the role of fiscal policy on the environment ((Akbar et al., 2022; Gerlagh et al., 2018; Halkos & Paizanos, 2016; Wang et al., 2021; Yilanci & Pata, 2022; Yuelan et al., 2019). However, no single study is dedicated for the case of Portugal (see Table 1 for summary of studies). Therefore, we fill this gap by evaluating the environment-fiscal policy nexus in Portugal and also taking into account the role of energy and economic growth. Unlike prior studies (Abbass et al., 2022; Akbar et al., 2022; Katircioglu and Katircioglu, 2018a, b; Yilanci & Pata, 2022) that utilized time domain approaches such as PVAR, FMOLS, MMQR, CCR, QR, OLS, and ARDL methods, the present study employed both time-domain and time-frequency approaches to capture the role of fiscal policy on ecological quality. The analysis employed the wavelet coherence (WTC) technique which catches the interrelationship between two times series at different frequencies and time-period. Also, we applied the Maki co-integration, to capture long-run equilibrium among the series by taking into consideration five breaks. Moreover, the study used the gradual shift causality technique to capture the causal effect of fiscal policy, energy use, and renewable energy on environmental degradation.

Table 1 Review of studies

Author(s)	Period	Country(s)	Techniques	Conclusion
(Kasman & Duman, 2015)	1992–2010	EU countries	PARDL	EKC is valid
(Le, 2022)	1970–2014	Vietnam	ARDL	$GDP \neq CO_2$
(Zhang et al., 2021)	1970–2019	Malaysia	ARDL	GDP ↑ CO_2
(Adedoyin et al., 2021)	1995–2015	Top ten earners	DOLS and FMOLS	GDP ↓ CO_2
(Su et al., 2023)	1980–2018	Iceland	Fourier Approach	GDP ↓ CO_2
(Adedoyin et al., 2020)	1990–2015	BRICS.	Panel ARDL	GDP ↑ CO_2
(Awosusi et al., 2022)	1960–2019	France	DOLS, CCR	GDP ↑ CO_2
(Olanrewaju et al., 2022)	1970–2017	Thailand.	CCR, FMOLS and ARDL	FF ↑ CO_2
(Siddique et al., 2020)	1983–2014	South-Asia	ARDL	FF ↑ CO_2
(He et al., 2021)	1990–2019	Mexico	DOLS, ARDL, FMOLS	FF ↑ CO_2
(Ben Cheikh et al., 2021)	1980–2015	12 MENA countries	PSTR	FF ↑ CO_2
(Abbass et al., 2022)	1965–2015	Pakistan	ARDL	FF ↑ CO_2
(Adebayo, 2020)	1970–2016	Mexico	ARDL, Wavelet Coherence	FF ↑ CO_2
(Kirikkaleli and Adebayo, 2020)	1990-2016	Global	FMOLS, DOLS, BC causality	REC ↓ CO_2
(Koengkan and Fuinhas, 2020)	1980–2014	Five South-American Nations	PVAR	REC ↓ CO_2
(Koengkan et al., 2020)	1990–2014	Latin American & Caribbean Nation	PARDL	REC ↓ CO_2
(Omri & Saidi, 2022)	1990–2014	E7 countries	FMOLS, VECM	REC ↓ CO_2
(Rahman & Vu, 2020)	1960–2015	Australia and Canada	ARDL, VECM Granger causality	Mixed findings
(Piłatowska et al., 2020)	1970–2018	Spain	TVAR	REC ↓ CO_2
(Yilanci & Pata, 2022)	1980–2000	G7 nations	Time domain causality	FP ↓ CO_2
(Ike et al., 2020)	2002–2014	Thailand	ARDL	FP ↓ CO_2
(Katircioglu and Katircioglu, 2018a, b)	1960–2013	Turkey	ARDL,	FP ↓ CO_2
(Halkos and Paizanos, 2013)	1980–2000	77 countries	FE-OLS	FP ↓ CO_2
(Yuelan et al., 2019)	1972–2014	China	ARDL	FP ↓ CO_2

GDP economic growth, *AGRIC* agriculture, CO_2 carbon emissions, *EC* energy consumption, *FP* fiscal policy. *REC* renewable energy consumption

Table 2 Description of variables

Variable	Description	Units	Sources
CO_2	Environmental degradation	Metric tons per capita	BP (2022)
GDP	Economic growth	GDP per capita constant $US, 2015	WDI (2022)
FP	Fiscal policy	General government final consumption expenditure at constant 2015 US$	WDI (2022)
REC	Renewable energy consumption	Twh	BP (2022)
FF	Fossil fuel energy consumption	Twh	BP (2022)

Table 3 Descriptive statistics

	$LnCO_2$	LnFF	LnGDP	LnFP	LnREC
Mean	1.3912	5.0928	9.5984	23.882	3.5355
Median	1.5419	5.2438	9.6824	24.054	3.4755
Maximum	1.8986	5.6089	9.9812	24.402	4.4331
Minimum	0.5622	4.0796	8.9436	22.618	2.6661
Std. dev.	0.3884	0.4335	0.3065	0.5254	0.5035
Skewness	−0.5122	−0.7291	−0.5194	−0.9301	0.2477
Kurtosis	1.9216	2.2360	1.8083	2.6772	2.0725
Observations	51	51	51	51	51

These sections will be followed by others: The research procedure and related data are shown in "Data, Model, and Methodology" section. The "Result and Discussions" and "Conclusion and Policy Directions" sections disclose the results and conclusion, respectively.

Data, Model, and Methodology

Data

This examination utilized a yearly time series data for Portugal starting from 1970 to 2020 which was sourced from the WDI database and the British Petroleum (BP) database. The data for this analysis include CO_2 pollutions, economic growth, clean energy, and energy intake. As used by Katircioglu and Katircioglu (2018a, b) and Ike et al. (2020) fiscal policy (overall government final intake spending at constant 2015 USD). Following the analysis of Abbasi et al. (2022) as well as Adebayo (2020), we disintegrate energy into fossil fuel and renewable energy. The selection of the timeframe for the analysis was limited to the accessibility of data on the nation as we provide a summary of the description of the variables in Table 2.

Table 3 displays the descriptive statistics analysis for the study. LnFP (23.882) has the highest mean which ranges from 22.618 to 24.402 which is accompanied by LnGDP (9.5984), which ranges between 8.9436 and 9.9812, LnFF (5.0928) which ranges from 4.0796 to 5.0928, LnREC (3.5355) which ranges between 2.6661 and 4.4331, and $LnCO_2$ (1.3912) which ranges from 0.5622 to 1.8986. Moreover, LnFP and $LnCO_2$ are the most volatile and least volatile. Moreover, all the series are platykurtic while the skewness values show that all the variables are negatively skewed with the exemption of LnREC. Furthermore, Figs. 1 and 2 present the brief information on the variables used.

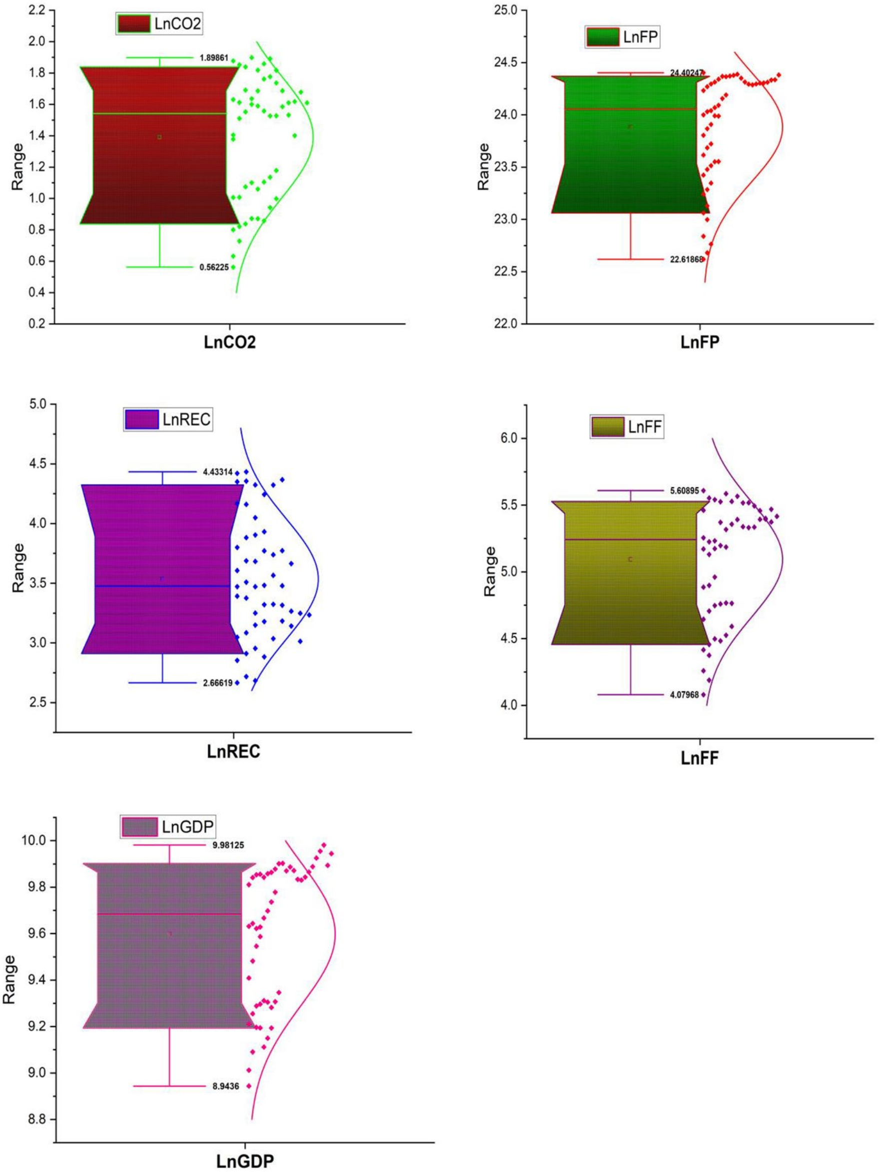


Fig. 1 Box lot of series

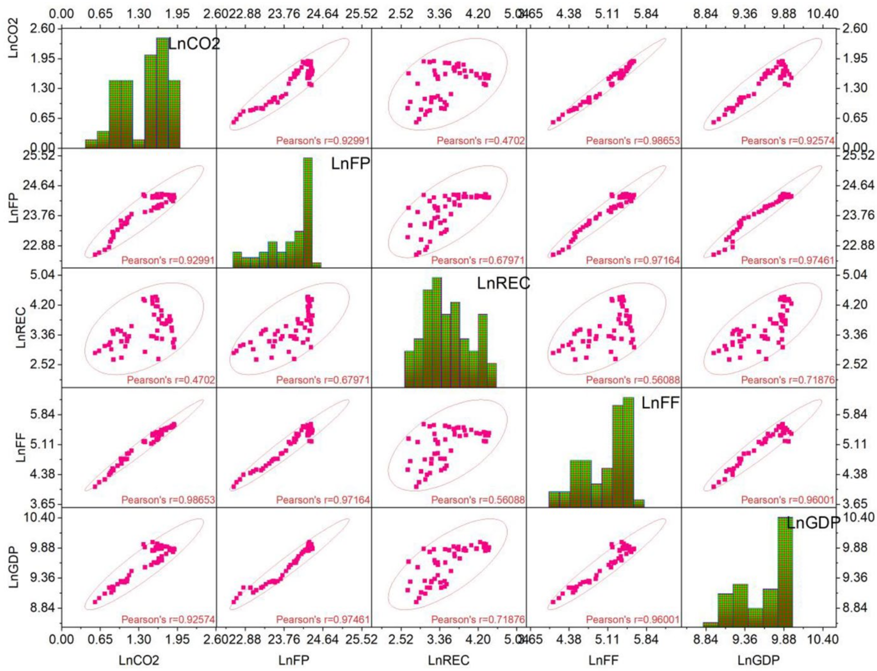


Fig. 2 Scatter plot

Model

The current study improves on the Katircioglu and Katircioglu (2018a, b) and Ike et al. (2020) studies by incorporating the role of disintegrated energy into the model. The economic function of the study is highlighted in Equation 1 as follows:

$$CO_{2\mathrm{t}} = f\left(GDP_{\mathrm{t}}, REC_{\mathrm{t}}, FF_{\mathrm{t}}, FP_{\mathrm{t}}\right) \tag{1}$$

Next, to assure homoscedasticity of the variables indicating the elasticities of the connections for consideration, Equation 1 is transformed into its natural logarithm form as shown in Equation 2:

$$LnCO_{2\mathrm{t}} = \beta_0 + \beta_1 LnGDP_{\mathrm{t}} + \beta_2 LnREC_{\mathrm{t}} + \beta_3 LnFF_{\mathrm{t}} + \beta_4 LnFP_{\mathrm{t}} + \varepsilon_{\mathrm{t}} \tag{2}$$

Given that $\beta_{1,\,2,\,3,\,4\ \mathrm{and}\ 5}$ depicts the coefficients of the regressors. FF, REC, GDP, FP, and CO_2 denote fossil fuel, renewable energy, economic growth, fiscal policy, and CO_2 emissions while ε_t denotes the error term.

Methodology

To accomplish the stated goal, this investigation employed the ARDL model proposed by Pesaran et al. (2001). In comparison to the Johansen-Juselius co-integration and the Engle-Granger co-integration techniques, the ARDL produces a better and more robust outcome. The ARDL method has several advantages over other co-integration techniques. To begin with, unlike other co-integration techniques, the ARDL approach is flexible when dealing with data from a relatively small sample. Second, the ARDL technique can regress a series integrated at level [I (0)], order one [I (1)], or both. Third, simultaneous estimation of short- and long-run co-integration does not compromise long-run co-integration outcomes. The ARDL co-integration Equation is illustrated as follows:

$$\begin{aligned}\Delta LnCO_{2t} = {} & \omega_1 + \beta 1\mathrm{LnCO}_{2t-1} + \beta 2\mathrm{LnGDP}_{t-1} + \beta 3\mathrm{LnFP}_{t-1} + \beta 4\mathrm{LnREC}_{t-1} \\ & + \beta 5\mathrm{LnFF}_{t-1} + \sum_{j=1}^{q} \varphi_{1j}\Delta LnCO_{2t-j} + \sum_{j=1}^{q} \varphi_{2j} LnGDP_{t-j} \\ & + \sum_{j=1}^{q} \varphi_{3j}\Delta LnFP_{t-j} + \sum_{j=1}^{q} \varphi_{4j}\Delta Ln\mathrm{REC}_{t-j} \\ & + \sum_{j=1}^{q} \varphi_{5j}\Delta LnFF_{t-j} + \varnothing_1 ECT_{t-1} + \mu_t\end{aligned} \tag{3}$$

where ω_1 denotes constant, $\varphi 1 - \varphi 5$ are the outcomes from the short run variables and β_1–β_5 are also the outcomes from the long-run variables, p indicates the optimal lags of the dependent variable, q denotes the independent variables' optimal lag, Δstands for the order one of the short-run variables, and μ_t is the error term for the analysis. However, the ECT represents the error correction term for the estimation. Moreover, if the ECT coefficient, denoted by $\varnothing_1$, is to be statistically significant, it must also have a negative sign.

The ARDL co-integration procedure begins with a bound technique, which is then regressed using the ordinary least squares (OLS) technique. The null hypothesis (H_0) of $\beta 0 = \beta 1 = \beta 2 = \beta 3 = \beta 4$ is checked against the alternate assumption (H_1) of $\beta 0 \neq \beta 1 \neq \beta 2 \neq \beta 3 \neq \beta 4$ represent the variables are connected in the long run. Testing the null hypothesis was done with the use of Wald-F statistics and crucial values. If the Wald-F statistics exceed the upper bound threshold level, then the null assumption is rejected, suggesting that the variables are connected over the long run. Lastly, it is equivocal with respect to the null assumption, provided it lies between the upper and lower CV.

Next, we employ the wavelet coherence which identifies the co-movement as well as causality between the study variables. Additionally, the gradual shift causality test initiated by Nazlioglu et al. (2016) to identify causality between series.

Figure 3 shows the flow of the study and techniques employed.

Result and Discussions

Preliminary Tests Results

The ADF and the PP were utilized to assess if the coefficients were stationary. Based on the examination of Table 4, it is seen that, at level, none of the factors was stationary with the exemption of REC. However, at first difference of both techniques, all the series were stationary at a 1% significance level. Conventional ADF and PP unit root technique are unable to detect structural break; thus, bias results will energy using such techniques. Therefore, to circumvent the wrong integration properties in

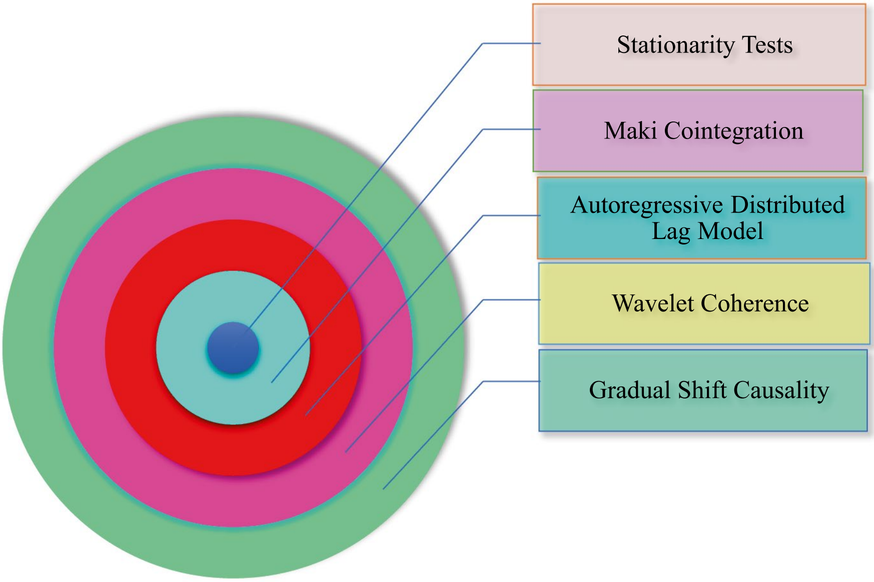


Fig. 3 Flow of the study

Table 4 ADF and PP unit root outcomes

	ADF unit root technique		PP unit root technique	
	I(0)	I(1)	I(0)	I(1)
CO_2	−0.9156	−6.7674*	−1.0643	−6.8065*
GDP	−2.0119	−4.5167*	−1.8354	−4.2435*
FF	−0.9478	−6.6453*	−0.9478	−6.6564*
FP	−0.2933	−6.8088*	−0.2719	−7.1818*
REC	−5.1639*	-	−5.2390*	-

* stands for 1% significance level

Source: Author's compilation

Table 5 Zivot-Andrew unit root results

	CO_2 Level	GDP	FF	FP	REC
T-statistic	−3.816	−3.059	−4.165	−2.782	−6.818*
Break date	1989	1999	1998	1991	2010
	First difference				
T-statistic	−5.083**	−5.001**	−6.708*	−5.126**	-
Break date	2006	1985	1990	1989	-

* and **stand for 1% and 5%

Source: Authors' compilation

Table 6 Maki co-integration test

	Model	T-statistics	CV 5%	Break years
Model 0	CO_2=f(GDP, FF, FP, REC)	−34.370*	−6.306	1976, 1973, 1982, 1988, 2016
Model 1	CO_2=f(GDP, FF, FP, REC)	−5.2012	−6.494	1977, 1981, 2015, 2013, 2010
Model 2	CO_2=f(GDP, FF, FP, REC)	−31.081*	−8.869	1976, 1982, 2013, 2007, 2015
Model 3	CO_2=f(GDP, FF, FP, REC)	−18.435*	−9.482	1973, 1977, 1987, 1999, 2009

* stand for 5% significance level

Source: Authors' compilation

Table 7 Bound test

F-statistics		8.11*			
10%		5%		1%	
LB	UB	LB	UB	LB	UB
2.72	3.77	3.23	4.35	4.29	5.61

NB: * denote a 1% level of significance, and LB and UB denote lower and upper bounds critical values, respectively

Source: Authors' compilation

the variables, the Zivot and Andrews (ZA) unit is used to capture a single structural break in this study, as reported in Table 5. The findings show that all the series with the exception of REC are stationary at first difference with their accompanied single break.

Co-integration Outcomes

The study proceeds by exploring the co-integration between the indicators using the Maki (2012) co-integration technique. The findings of the co-integration presented in Table 6 indicate that there are four models from the estimation where CO_2 emission was used as the dependent element. The models affirm co-integration at 5% significance level. Therefore, CO_2 and the regressors have an association in the long run.

The bounds test is also used in the current investigation as a robustness check for the Maki co-integration. The result from the ARDL bounds test, as indicated in Table 7, uncovers evidence of co-integration in the long term. This result validates the long-run association among the series, which proves co-integration among the elements.

Autoregressive Distributed Lag (ARLD) Estimation Outcomes

The identification of co-integration interrelationships among this study's variables implies the presence of a long-run connection. Table 8 shows the long-run result

Table 8 ARDL long-run and short-run outcomes

Long-run outcomes			
Regressors	Coefficient	T-statistic	Prob.
GDP	0.6572**	2.1229	0.042
FP	0.0474***	1.7538	0.090
FF	0.8840*	5.4766	0.000
REC	−0.1939**	−8.5310	0.000
Short-run outcomes			
GDP	0.8599*	3.4465	0.001
FF	0.0324	1.4545	0.156
REC	−0.1939*	−10.422	0.000
ECT(-1)	−0.4364	−7.4577	0.000
R^2	0.99		
Adj R^2	0.99		
Post-estimation tests			
$\chi 2$ ARCH	1.07 (0.42)		
$\chi 2$ RESET	0.23 (0.81)		
$\chi 2$ Normality	0.23 (0.88)		
$\chi 2$ LM	0.11 (0.84)		

NB: *, **, and *** stand for 1%, 5%, and 10% significance levels

Source: Author's compilation

of this analysis. From Table 8, it can be seen that economic advancement was positively significant, with emissions at a 5% level. This shows that a percentage rise in economic growth will boost carbon emissions by 0.657%, and it confirms the outcomes of Gyamfi et al. (2022), Ağa et al. (2023), and Kirikkaleli and Adebayo (2020). This result lends credence to our claim that the policymakers in Portugal are primarily concerned with attaining their economic objectives while placing a weak focus on the environment. Aiming to increase and achieve their economic objectives at the cost of their environmental stewardship is the ambition of numerous economies including the Portuguese economy.

Moreover, the result indicates a positive connection between fiscal policy and ecological degradation. This means that fiscal policy is an obstacle toward ecological sustainability in Portugal. The study findings affirm the finding of Yuelan et al. (2019) for the Chinese economy and Akbar et al. (2022) who reported positive CO_2 emissions-fiscal policy nexus. From a policy perspective, fiscal policy policies should be transformed into the progressive taxation or promotion of renewable energy usage opportunities by tax waivers and specific federal grants. In particular, in the fiscal restructuring, national authorities can devote more budgets for ecological programs to shift toward healthier and more sustainable societies with low-carbon operations

Also, the results obtained for renewable energy consumption are negative and statistically significant. This shows that a rise in the REC decreases the ecological degradation in the Portuguese economy. This outcome accords with the studies of Danish and Ulucak (2020) and Kartal et al. (2023) who reported the environmental benefit of renewable energy. Lastly, fossil fuel energy impact CO_2 emissions positively, thereby decreasing ecological quality in Portugal. This shows that fossil fuel consumption raises environmental dilapidation in the Portuguese economy, thus affirming the findings of Alola et al. (2019), Adedoyin et al. (2020, (2021), and Caglar et al. (2022).

Moreover, from the short-run analysis, the ECT (0.4364) is significant and negative, demonstrating the long-run connection between the factors. Furthermore, economic progress has a positive influence on CO_2, while clean energy impacts CO_2 negatively.

Diagnostic estimations establish that the model lacks of heteroscedasticity as well as serial correlation. This is from the fact that all the post-estimation techniques are statistically insignificant. To confirm the stability of the ARDL technique, this study employed the CUSUM (see Fig. 4a) and CUSUMSQ (Fig. 4b) tests, and the results show that the model is stable at 5%.

Wavelet Coherence Results

Moreover, the wavelet coherence (WTC) is employed to identify the coherence/causality regarding CO_2 and the regressors (GDP, FF, REC, and FP). This approach is based on physics and is used to collect previously unobserved facts. In Fig. 5a–d, the short, medium, and long terms depict 0–4, 4–8, and 8–16, correspondingly. In addition, the time and frequency are illustrated by horizontal and vertical axes. Figure 5a shows the WTC regarding CO_2 and FP between 1970 and 2021. In the medium and long terms, most arrows are rightward, demonstrating an in-phase relationship (positive correlation). This indicates that a rise in fiscal policy is attended by enhance in CO_2 pollutions. Figure 5b portrays the WTC among CO_2 and FF from the period 1970 and 2021. At high and medium frequencies between 1970 and 1985, the majority of the arrows are rightward, which depicts a positive coherence between FF and CO_2. Furthermore, in the long term between 1970 and 2019, the majority of the arrows are rightward, showing that an FF increase increases CO_2. Furthermore, high and low dependence is illustrated by yellow and blue color. Moreover, left and right arrows illustrate negative and positive coherence. Figure 5c shows the WTC between CO_2 and REC from the period 1970 and 2021. At high frequency, between 1990 and 2012, the majority of the arrows are leftward, which depicts negative correlation between REC and CO_2, which shows that increase in REN is accompanied by a decrease in CO_2. Figure 5d portrays the WTC between CO_2 and GDP from the period 1970 and 2019. In the medium and long terms, the majority of the arrows are rightward which illustrates a positive correlation among economic growth and CO_2, which implies that a rise in GDP drives CO_2 emissions in Portugal.

Gradual Shift Test

The gradual shift causality results are reported in Table 9. The time series causality technique is necessary to evaluate the predictability strength among the variables in terms of causality direction. The study uncovers a one-way causal direction among

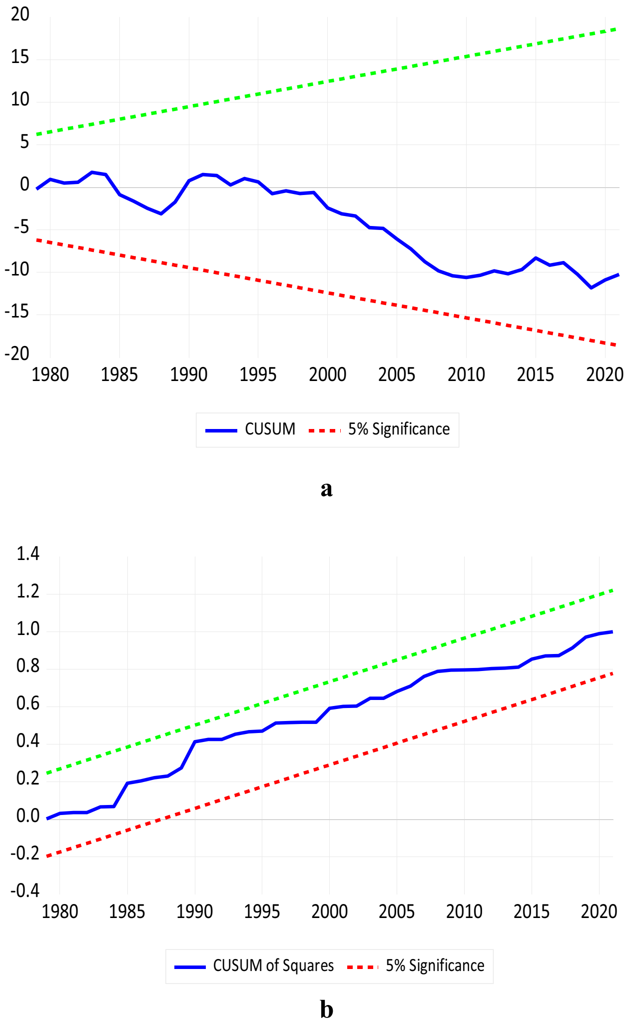


Fig. 4 **a** CUSUM, **b** CUSUM of square

these variables; i.e., economic growth, fiscal policy, renewable energy, and fossil fuel Granger cause CO_2 emissions, suggesting that all the regressors can predict CO_2 emissions (Fig. 6).

Conclusion and Policy Directions

The foremost objective of this analysis is to assess the examine the possible economic connections between (expansionary and contractual) fiscal policies and CO_2 emissions and the partnership of several factors of influence for the Portuguese

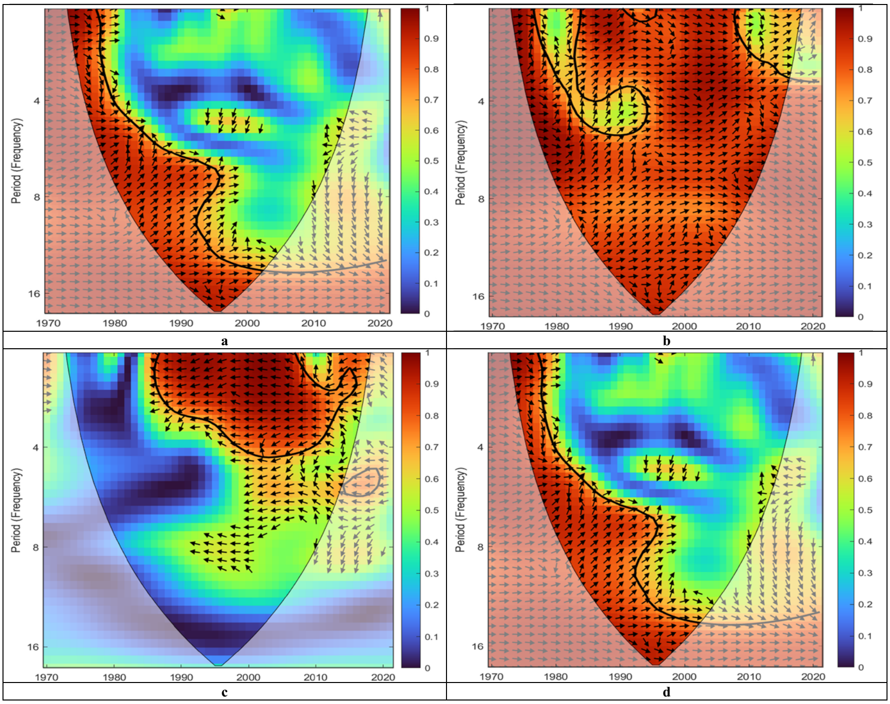


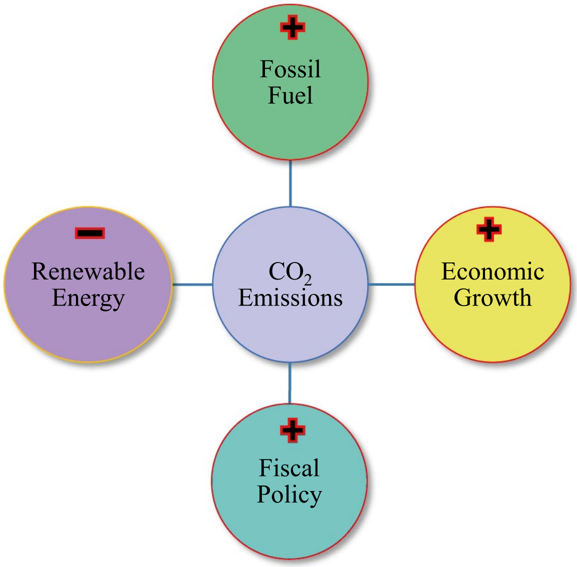
Fig. 5 **a** WTC between CO_2 and FP, **b** WTC between CO_2 and FF, **c** WTC between CO_2 and REC, **d** WTC between CO_2 and GDP

Table 9 Causality result

Causality path	Wald-stat	*F*	*P* value
CO_2 ➔ GDP	16.668	3	0.0196**
GDP ➔ CO_2	8.7896	3	0.2681
CO_2 ➔ FP	11.704	1	0.1107
FP➔ CO_2	18.843	1	0.0086*
CO_2 ➔ FF	10.311	2	0.1716
FF ➔ CO_2	14.360	2	0.0451**
REC ➔ CO_2	4.7442	2	0.6911
CO_2 ➔REC	22.549	2	0.0020*

* and ** stand for 1% and 5% significance levels. *F* denotes the Fourier number

Fig. 6 Summary of findings



economy between 1970 and 2019, including energy consumption from fossil fuel and clean energy consumption. The ADF, PP, and Zivot-Andrews (2002) all confirmed in harmony that there is stationarity at first difference [I(1)]. However, both the ARDL bounds and Maki co-integration techniques confirm the presence of a long-run connection regarding the factors of investigation.

From the ARDL technique, it was shown that economic growth was positively significant with emissions at a 5% significance level. This shows that a percentage rise in economic growth will increase carbon pollution by 0.657%. However, the outcome showed a positive relationship between fiscal policy and ecological deterioration. Moreover, the outcomes of the research for clean energy intake are adverse and significant to the environment. This implies that the sustainable energy use would minimize the greenhouse damage to the Portuguese economy. Nevertheless, energy consumption was reported to have a positive and significant impact on CO_2 pollutions. Notwithstanding, economic growth had a positive short-run significant connection with emissions while renewable energy had a negative short-run relationship with emissions. Furthermore, the findings of the novel wavelet coherence technique show a positive coherence regarding CO_2 pollutions as well as economic growth, energy consumption, and fiscal policy. As expected, there is an evidence of negative coherence regarding CO_2 pollutions and clean energy. The outcome of the wavelet coherence test confirmed the ARDL outcomes. The gradual shift causality technique which was proposed by Nazlioglu et al. (2016) was employed to access the causal direction for this study. From the analysis, a one-way causal direction among these variables was confirmed from carbon pollution as well as economic growth, fiscal policy, and CO_2 pollutions, energy consumption, and CO_2 emission as well as CO_2 emission and renewable energy consumption.

Focused on these results concerning public expenditure, Portugal's economy should allocate its resources to environmentally sustainable, green government services. Knowledge of private spending should lead Portugal's economy to encourage households as well as industries to use these environmentally friendly approaches or techniques for personal utilization and technologies of development including transportation. Portugal's economy should reduce carbon pollution by means of both fiscal and monetary tools, since government spending is not a particular remedy. The analytical study also confirms the energy-driven growth theory for the Portuguese economy—that sustainable and reliable energy resources (i.e., fossil fuel switches) should be promoted instead of saving energy. Authorities and various policymakers should promote funding for sustainable energy technology in a manner that does not inhibit energy production and usage in the nation, regardless of the enforcement of unreasonable carbon taxes on traditional energy sources. However, it is necessary to supplement the lower CO_2 pollutions from cleaner and sustainable energy resources before infrastructure is built up in the sustainable energy field

From a policy perspective, fiscal policy policies should be transformed into the progressive taxation or promotion of renewable energy usage opportunities by tax waivers and specific federal grants. In particular, in the fiscal restructuring, national authorities can devote more budgets for ecological programs in order to shift toward healthier and more sustainable societies with low-carbon operations. Due to the broad infrastructural requirements of the green energy field, a long-term infrastructural strategic project must be created, financed by carbon tax proceeds derived through the usage of carbon fuels. Furthermore, although there is a growing need to reduce fossil energy consumption in the wake of the growing quest for a sustainable environment, care must be taken when drawing up energy conservation strategies in the case of the Portuguese economy because fossil energy consumption causes expansion. Also, the Granger causality of carbon emissions and economic growth in Portugal suggest that steps should be taken to encourage a slow shift toward cleaner energy use while the country continues to grow economically and become more connected to the rest of the world.

Although the present study explored the nexus between the mediating role of fiscal policy in the environmental degradation in Portugal within the framework of multiple structural breaks co-integration test, thus, the study inferences are limited to Portugal or by extension to Southern European economies. The present study is also limited by data for other fiscal instruments. Future study can explore the mediating role of more fiscal instruments and demographic indicators like population, urbanization on environmental degradation on other Southern European economies or blocs for more informed policy formulation.

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Declarations

Ethical Approval The authors mentioned in the manuscript have agreed for authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.

Consent to Participate Note applicable

Consent to Publish Applicable

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