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Energy productivity, financial stability, and environmental degradation in an Eastern European country: Evidence from novel Fourier approaches

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ABSTRACT

The global transition to net zero is largely based on the existential threats of carbon emissions to humanity and global sustainability. Policymakers have committed to finding pathways that reduce the amount of carbon dioxide emitted. To get insights for policy making, this study aims at investigating the effect of financial stability and energy productivity on environmental degradation in Bulgaria using novel Fourier estimators. The outcomes of the study indicate (i) both energy productivity and financial stability have positive effects on environmental degradation; (ii) rising economic growth exerts a positive effect on CO_2 emissions. The outcomes offer weighty policy insights on energy productivity investments for the government of Bulgaria, particularly on smart energy technologies; energy productivity financing; smart manufacturing; efficient transportation, energy use behavioral change, and smart water infrastructure. Additionally, the government of Bulgaria could enact policies for financial stability improvements; and for controlling fossil fuel-facilitated economic growth. Finally, given that price stability policy focus failed during the 2008 global financial crisis, a major policy focus could be to improve on the new macroprudential policy framework for Bulgarian Central Bank towards delivering financial stability and environmental sustainability.

1. Introduction

Environmental degradation has, for several years, become one of the most heavily discussed issues in both academic and policy circles. Climate change and global warming have been recognized as the leading environmental issues of our times. Besides increasing extreme weather events, climate change alters precipitation patterns, intensifies storms, reverses ocean currents, and raises sea levels. These changes have been observed to exert disastrous effects on the functioning of ecosystems, wildlife, and human existence. However, to reduce carbon emissions, sustain economic development and assure global sustainability, it is imperative to understand the linkages between financial stability, energy productivity, and environmental degradation.

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Financial stability has been observed to play a huge role in mobilizing and utilizing savings for productive activities across the world. According to the World Bank, financial stability concerns the ability of the financial system to function in times of crisis. As investment activities are facilitated through lending, trade activities are facilitated, and firm-level risks are better managed. As Schumpeter recognized in the 19th century, Economic growth relies heavily on the financial sector. In recent years, this has drawn serious academic attention, especially since the discovery of endogenous growth theory and the expansion of empirical studies. after the seminal work of [1]. In spite of this, experts acknowledge that economic activity has irreparably damaged the environment [2]. Ensuring an efficient financial system is vital for improving environmental quality [3]. As a result of a financially efficient economy, corporations are now adopting eco-friendly and energy-efficient technologies that emit fewer carbon emissions [4–6].

One of the recent findings in scholarly activity for policy focus is the recognition of the role of energy productivity in carbon emissions [7]. This is mainly due to the understanding that economies can accurately determine energy use through energy productivity metrics at low cost. To several scholars, energy productivity can improve the quality of the environment by reducing the volume of energy required for production and similarly ensuring a reduction in energy expenditure [7,8]. Experts explain energy productivity to be a measure of economic benefits on a unit of energy consumption and is usually calculated by dividing gross domestic product (GDP) growth by the quality of energy utilized. Energy productivity is a tool for determining economic gains from consuming a unit of energy in economic production.

Bulgaria is best suited for investigating the effect of energy productivity and financial stability on environmental degradation across the European Union. In Bulgaria, well-capitalized banks dominate the financial sector and account for 83% of the financial sector's total capitalization. Commercial banks are mostly under foreign ownership, with domestic accounting for a share of only 22% of total assets. By joining the European Banking Union in July 2020, the European Central Bank (ECB) will henceforth supervise the five largest banks in Bulgaria directly. The banking system maintains strong liquidity buffers, with a coverage ratio above the required minimum of 100% since 2017, reaching almost 270% as of September 2020. In the energy sector, Bulgaria's annual energy balance is the total consumption of 32.34 billion kWh of electricity. The total production of all-electric energy is 42 bn kWh, indicating an average per capita of 4688 kWh. Coal was the largest energy consumed by a source at 27.88%, while total fossil fuels consumption stood at 68.08% in 2021. Bulgaria's nationally determined contribution (NDC) to CO_2 emissions reduction in the power sector by 40% between 1990 and 2025 means the economy uses fewer coal plants towards reducing pollution per capita (in international constant). Fig. 1 shows Bulgaria's electricity production.

Trade has been cited to reduce carbon emissions from an economy over the years. The study calculated Bulgaria's consumption-to-production carbon emission ratios. An economy is considered a net importer by consuming more energy than it produces. An economy that produces more energy than it consumes is also known as a net emissions exporter. To calculate the ratio, consumption-based carbon emissions (CCE) were divided by production-based carbon emissions (PCE). It is said to be a net importer of carbon emissions, the ratio should be higher than one. The economy is considered a net exporter of carbon emissions if the calculated ratio is less than one. Bulgaria's case is calculated as:

$$\text{Average ratio} = \frac{CCE}{PCE} \;\; ; \quad \text{Average ratio} = \frac{32,34BN}{42.00BN} \; ; \; \text{Average ration} = 0.77$$

The results indicate Bulgaria has a production-based energy consumption economy and a net exporter of electricity in the region.

Notwithstanding, foremost among several challenges facing Bulgaria is the energy sector, accounting for an estimated $7 billion Recovery and Resilience Plan from the EU Recovery and Resilience Facility to develop a low carbon economy towards ensuring 40% reduction of electricity sector emissions by 2025 and improve on energy productivity. Energy production remains the largest source of sulfur dioxide emissions and one of the largest contributors to nitrogen oxide emissions. Bulgaria has recently witnessed increasing fossil-fuel consumption and rising air emissions. Among the pollutants, PM10 is the most serious offender responsible for deteriorating

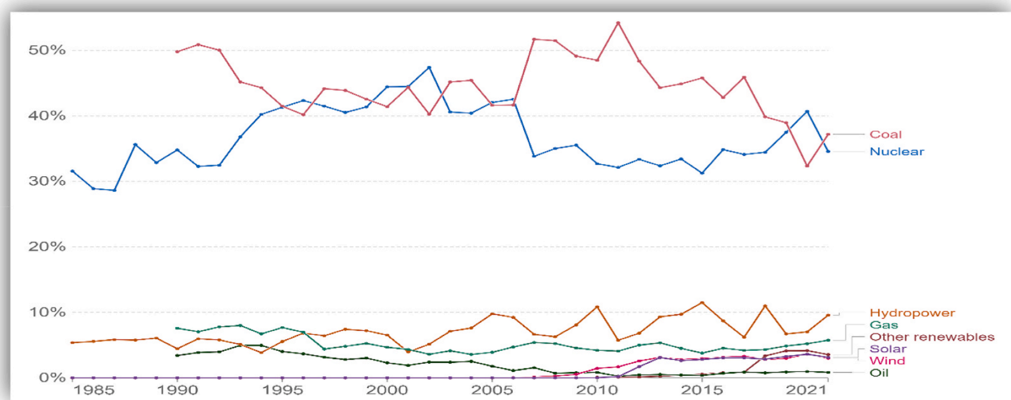

Fig. 1. Bulgaria's electricity production by source.
Source: Statistica (see, https://www.statista.com/statistics/1234904/bulgaria-distribution-of-electricity-production-by-source/).

ecosystems. From 1990 to 2012, PM10 emissions were reduced by 66%, from 885 kt to 303 kt. Under the UNFCCC and the Kyoto Protocol, Bulgaria has committed to reducing GHG emissions by 8% from 1988 to 2012.

The research aims to assess financial stability and energy productivity effects on Bulgaria's environmental degradation. No study has investigated determinants of carbon emissions for Bulgaria through the lens of economic growth, financial stability, and energy productivity. Findings will provide new policy insights; while adding to the existing literature on environmental degradation. Further, outcomes will indicate both energy productivity and CO_2 emissions are endogenously determined or are context specific. The Fourier ARDL approach used is very novel in long-run cointegration analysis. The paper is further arranged: the next section is the existing literature review; section three is methodology; Section four is empirical outcomes and discussions; and the last section concludes the study.

2. Literature review

Due to their role in the devastating effects of climate change, carbon dioxide emissions have recently taken center stage in academic and global policy debates. Globally existing biophysical resources are at danger due to climate change. According to Atasoy [9], carbon dioxide is a major factor in the ozone layer's depletion, which causes climate change and contributes to global warming. A recent environmental study by Kirikkaleli and Sowah [10] indicated that global temperatures have risen by approximately 1.4 °F during the 1800s, while nearly 75% of the world's plant and animal species have vanished. Besides endangering human health, climate change is also responsible for extreme weather events, a decline in agricultural output, growing inequality, air pollution, food shortages, and, most lately, wildfires. Leaders of the world's largest climate activists emphasized the necessity of collectively controlling global warming and combating climate change during the most recent COP-26 session in Glasgow. According to International Panel on Climate Change Report, the energy sector fundamentals continue to serve as the principal source of carbon dioxide emissions, suggesting that economies must implement climate mitigating policies (to stop the current extreme trajectory of the globally rising average temperature down to the acceptable 1.5° Celsius relative to pre-industrial levels). To support policy initiatives, scholars are further investigating determining factors that help reduce carbon emissions. This literature review focuses on the vital roles of financial stability, energy productivity and economic growth on carbon emissions.

2.1. Financial stability and carbon emissions

In recent academic research on rising energy use and carbon emissions, financial stability has come under increased intellectual investigation for its moderating effect on CO_2 emissions. Financial stability is a broad concept employed to explain different spheres on aspects of finance & the entire financial system. It involves the financial infrastructure, institutions, and markets. The financial system entails both the monetary system and activities in the financial institutions. Financial stability is defined as the ability to ensure the efficient allocation of financial resources to promote economic activity in the economy. Theoretically, the financial sector facilitates economic growth and helps to ensure economic stability [11]. However, the financial sector relies heavily on fossil energy which leads to environmental degradation [12,13]. Additionally, financial stability enhances investments through financial services access and allocates funds to production sectors [14]. Moreover, the financial sector helps corporations to adopt efficient and eco-friendly technologies for the reduction of carbon emissions. Finally, in financially stable economies, tax benefits are provided to firms engaged in green practices [4]. But critics claim it is rather financial instability that drastically slows down economic activities and improves environmental quality [15,16]. Additionally, they contend that although the developed financial sector generates economic growth, it also causes more pollution and irreversible environmental damage through corporate resource exploitation [17].

Empirically, Yuxiang and Chen [18] assessed the linkages between financial stability and industrial pollution using provincial economic data from China; and discovered environmental improvements in the selected provinces as a result of financial sector development. The study additionally maintained that improving income and corporate capital, investing in green technologies, and setting up environmental rules are all methods by which financial stability improves the condition of the environment. Jalil and Feridun [19] investigated the impact of energy consumption, economic growth, and financial development on CO_2 emissions in China from 1953 to 2006. The findings indicated that the coefficients of financial ability on carbon emissions were negative, indicating that China's financial success had not cost environmental degradation. But contrary to these findings, Zhang [20] assessed the relationship between financial stability and carbon emissions in China between 1980 and 2009 and found that China's financial sector was a significant driver of rising carbon emissions. The relationship between financial sector development, trade, economic growth, energy use, and carbon emissions was explored by Ozturk and Acaravci [21] in Turkey from 1960 to 2007. Findings indicated that financial stability was negatively related to carbon emissions. Talukdar and Meisner [22] used data from 44 emerging economies collected over nine years to assess the effect of the private sector on environmental degradation between 1987 and 1995. They determined that financial stability and foreign direct investments have beneficial effects on the environment. Using panel data ranging from 1992 to 2004. A study was done by Tamazian et al. [17] on the linkage between financial stability, economic output, and environmental quality for the case of BRIC countries. Per their findings, environmental degradation is reduced as economic and financial activity increases. Tamazian and Rao [23] used a sample of 24 transition economies for the years 1993–2004 to investigate the effect of economic, financial, and institutional development on environmental pollution. Their findings demonstrated that if financial liberalization is carried out within a solid institutional framework, it improves on environmental quality. According to Dasgupta et al. [3], financially efficient market economies have cleaner environments than economies with less developed financial markets. Several studies claim, a healthy and effective financial sector attracts foreign direct investment and promotes economic progress in a nation. Foreign businesses utilize greener practices and are more energy-efficient than domestic businesses. Modern energy technologies push companies to embrace advanced finance structures, which leads to fewer emissions of energy pollutants. Based on this review, the study hypothesizes that financial stability results in reduced carbon dioxide emissions in Bulgaria, i.e., $\vartheta_1 = \frac{\vartheta LCO_2}{\vartheta LFSit} < 0$. where ϑ_1 refers to the parameter of interest; LCO_2 represents the log of carbon dioxide emissions; and LFS_{it} represents the log of financial stability of Bulgaria.

Another variable attracting academic focus and policy interest in global carbon emissions discourse is energy productivity [7,24,25]. Energy productivity has been seen in using smart energy technologies, energy productivity funding; smart industrial development; mobility and critical smart water systems. Global clean energy markets are transforming while governments, corporations, and citizens look for methods to achieve a prosperous economic future and environmental protection. Leaders from the public and private sectors must rethink energy production and use it to achieve the expected reductions in CO_2 emissions set in the Paris agreement. Any approach to reducing emissions must include energy productivity as a crucial complement to the utilization of clean energy sources. In this study, energy productivity is assumed to cause an increase in carbon emissions in Bulgaria.

2.2. Energy productivity and carbon dioxide emissions

Enhancing energy productivity not only helps control carbon emissions but it could also help meet the requirements of sustainable economic progress and prosperity. It is now discovered that energy productivity is a major driver of carbon emissions in an economy. It is commonly acknowledged in the literature that is using energy, particularly fossil fuels, promotes economic growth and generates CO_2 emissions [26]. Enhancing energy productivity levels under demand-side pathways by effectively reducing fuel use without affecting total energy needs [27]. Energy productivity improvements may reduce the trade-off between economic growth and carbon dioxide emissions. Improvement in energy productivity is found in the literature to be beneficial in reducing carbon dioxide emissions. But critics argue that very little is known at the macro-economic level to support the rebound effect of energy productivity. Critics contend that the little will stimulating realized from aby energy productivity measures increased consumption and further energy demand, usually termed as indirect energy intensity of consumption with income gains [28,29]. Further, the critics argue that income effects from energy productivity policies are not comparable with technological gains. The theoretical debates on energy productivity measures have been inconclusive when analyzed from the neoclassical growth theoretical perspectives following the Solow–Swan model for economic growth and energy consumption requirements, as applied by Saunders [30]. Using a Cobb–Douglas and a nested CES function to model output and energy consumption under certain energy productivity measures, Saunders indicated this does realize any significant energy savings and claims a backfire effect. This finding received support from Wei [31], although the theoretical assumptions of this neoclassical growth framework have since been questioned by Howarth [32]. Moreover, there are general equilibrium theoretical frames used as supplemental to explaining growth and pollution linkages in the context of energy productivity gains. According to Dimitropoulos and Sorrell [33], although these studies provide some insights, they have varied specifications, parameterization and simulation procedures for reliable policy action. Given that very little effect has been felt by the arguments of the critics, the study hypothesizes that energy productivity leads to reduced carbon dioxide emissions in Bulgaria, i.e., $\vartheta_2 = \frac{\vartheta LCO_2}{\vartheta LEPRit} < 0$. where ϑ_2 refers to the parameter of interest; LCO_2 represents the log of carbon dioxide emissions; and $LEPR_{it}$ represents the log of energy productivity of Bulgaria.

2.3. Economic growth and carbon emissions

Historically, one of the earliest theories to explain the linkages between environmental degradation and economic growth was the EKC [34]. The theory explains how rising income influences technology, the composition of GDP and environmental policy; and how variations in these factors impact on environmental pollution over time until a turning point. Since then, several empirical studies on the linkages between environmental degradation and economic growth have been done to check the validity or otherwise of the theory. A number of these empirical studies include Copeland and Taylor [35], ; Dasputa et al. [36]; Dinda [37]; Apergis and Payne [38] and Al-Mulali et al. [39] find evidence of an inverted U-shape. Nonetheless, this paper assumes that an increase in economic growth has a positive impact on CO_2 emissions in Bulgaria; hence the study formulates this hypothesis (3) as:

Bulgaria's average GDP between 1980 and 2018 was US$ 29.28bn. However, average primary energy consumption increased from 45 to 52% between 2000 and 2016, while the share of renewable energy in Bulgaria reached 6.5% in 2015, but critics claim this is below the 2020 target. The study hypothesizes that economic growth leads to increased carbon emissions in Bulgaria, i.e., $\vartheta_3 = \frac{\vartheta LCO_2}{\vartheta \mathrm{LGDPit}} > 0$.

Given this review, the effect of financial stability and energy productivity on the quality of the environment has seen very limited study. This study closes the gap in the literature on Bulgaria. To realize the objective of this paper, Fourier ARDL and FMOLS estimators are employed. Particularly significant is the use of Fourier ARDL in such investigations as the approach can apply irrespective of integration order.

3. Methodology

The study investigates the financial stability and energy productivity effects of environmental degradation in Bulgaria. The study controlled economic growth. All data were sourced for this study based on their contributions to the literature on environmental degradation. All variables were kept in their log forms for the empirical analysis to avoid scaling. (i) In lieu of economic growth, data was sourced on GDP per capita (in constant 2015 USD) from the validated World Bank dataset; (ii) Data on CO_2 emissions were sourced from UNFCC; (iii) Data on energy productivity was sourced from European Union database; and (iv) Data on Financial stability was sourced from the World Bank. Fig. 2 shows the analysis flowchart of the study.

To realize the objectives of this paper, the empirical work is modeled as

$$CO_2 = EPR, FS, \text{GDP} \tag{1}$$

The study next specifies the model by taking natural logarithms of all variables for the empirical work to avoid exponential trend as shown below

$$LCO_{2t} = \beta_1 LEPR_t + \beta_2 LFS_t + \beta_3 LGDP_t + \varepsilon_t \tag{2}$$

where LCO_2, LEPR, LFS and LGDP stand for production-based CO_2 emissions, energy productivity, financial sector, and economic growth, respectively.

Applying the classical estimation approaches such as ordinary least squares (OLS), to unit-rooted variables yields spurious estimates because of structural changes [40]. As a solution to this estimation weakness, the Fourier ADF and ADF Unit Root tests were carried out to verify the integration properties of variables in this study [41–43].

Benerjee et al. [44] used the Fourier ADL cointegration test originally to detect cointegration in time series variables. "The existence of cointegration was estimated using the Fourier ADL cointegration approach, which factors unknown structural breaks, time, and structure. The results offered by this method are more effective than those offered by VECM analysis. In the long-run, before detecting concealed cointegration, cumulative positive and negative shocks must be established in the variables. In addition, Fourier functions can identify structural changes, although, for the Fourier-based ARDL method, no additional structural changes test is needed" [42] who argued that Traditional ARDL methods are not as robust as Fourier-based ARDL methods. Using the Fourier function, we can detect structural changes in the model, as shown in equation (3) [42].

$$d(t) = \sum_{k=1}^{n} a\text{ksin}\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} b\text{kcos}\left(\frac{2\pi kt}{T}\right) \tag{3}$$

"where 'n' indicates the number of frequencies, $\pi = 3.14$, 'k' is the number of special frequencies selected, 't' is the trend, and 'T' is the sample size" [42].

$$d(t) = \gamma_{1\ sin}\left(\frac{2\pi kt}{T}\right)_{+\gamma 2\ cos}\left(\frac{2\pi kt}{T}\right) \tag{4}$$

The FARDL model for this paper is stated in equation (5).

$$\begin{aligned}\Delta LCO2\text{t} = {} & \beta 0 + \gamma 1\ sin\left(\frac{2\pi kt}{T}\right) + \gamma 2\ cos\left(\frac{2\pi kt}{T}\right) + \beta 1 LCO2\text{t} - 1 + \beta 2 LEPR\text{t} - 1 + \beta 3 LFS\text{t} - 1 + \beta 4 LGDP\text{t} - 1 \\ & + \sum_{i-1}^{\rho-1} \varphi\text{i}' \Delta LCO2\text{t} - \text{i} + \sum_{i-1}^{\rho-1} \delta\text{i}' \Delta LEPR\text{t} - \text{i} + \sum_{i-1}^{\rho-1} \varnothing\text{i}' \Delta LFS\text{t} - \text{i} + \sum_{i-1}^{\rho-1} \vartheta\text{i}' \Delta LGDP\text{t} - \text{i} + e\text{t}\end{aligned} \tag{5}$$

This study also uses an FMOLS estimator to support the outcomes of the Fourier ARDL test.

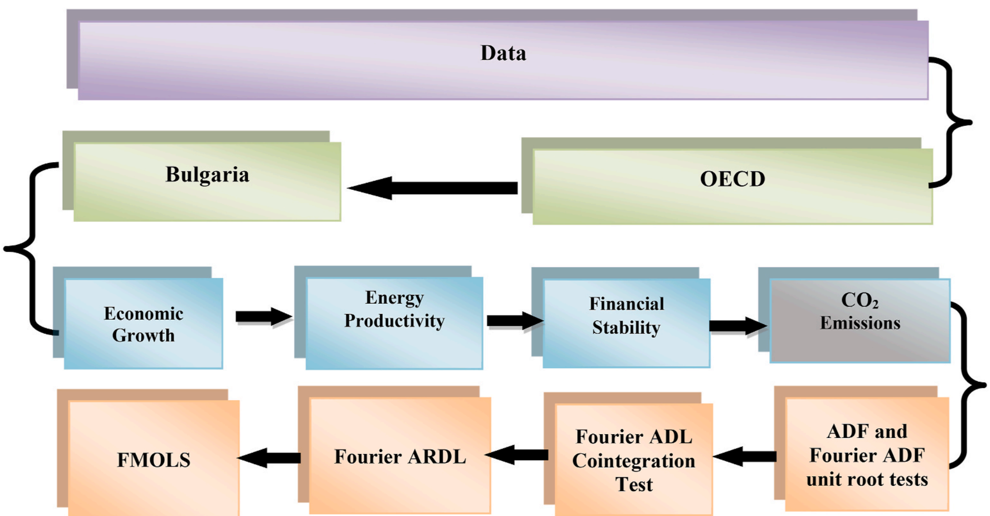

Fig. 2. Author's analysis flowchart.

4. Empirical outcomes and discussions

The research aims to assess financial stability and energy productivity effects on Bulgaria's environmental degradation in 1990Q1-2019Q4, using Fourier ARDL estimators. Table 1 is the summary and description of variables used forth the study.

Fourier analysis is used both in Fourier ADF unit root tests and ADF unit root with breakpoint tests with to check for series unit roots. To do that, the statistical significance of the Fourier function must first be determined. It is easy to conduct the Fourier ADF unit root test using the stationarity of F-STAT before checking the variables' integration order. As an alternative, the standard ADF unit root with a breakpoint is employed. The results can be seen in Table 2.

The results clearly indicate that the time series variables were not stationary at level, except for LGDP and LFS, while LCO_2 and LEPR variables were integrated at the order I(1) with several breakpoints in 1991Q2, 1993Q1, 1993Q2, 1997Q4, and 2001Q1, respectively (Table 2). At a 5% significance level, LEPR & LGDP appears stationary based on Fourier ADF unit root estimates, indicating variable integration at I (0). The results show a mixed integration order, making it likely to perform Fourier ARDL-based test in this research. The paper checks the cointegration relationship between the selected variables to capture the effect of energy productivity on environmental pollution in Bulgaria.

The outcomes of diagnostic results for the ARDL model are demonstrated at Table 5 and Table 6; and at Figs. 3 and 4. After verifying that the model is stable without serial autocorrelation or heteroscedasticity, the Fourier-based ARDL bounds test is used to check for cointegration properties. This test applies despite the integration order. According to Yilanci et al. [45], the Fourier ARDL estimator is an improvement of the traditional Bootstrap ARDL model because it can detect hidden aspects of breakpoints.

As could be seen in Table 4, first, the outcomes of Fourier ARDL test show that (i) the coefficients of energy prductivity and financial stability are negative, implying that an increase in both energy prductivity and financial stability has negative effects on CO_2 emissions by −0.5576% and −0.0381% respectively. However, LGDP increases CO_2 emissions. In support of Raihan and Tuspekova [46], the outcome indicates that LGDP leads to rising LCO_2. Additionally, reducing LCO_2 through a unit investment in LEPR and LFS supports recent findings by Hossain et al. [47] as well as Emenekwe et al. [48]. Finally, the outcomes support hypothesis (H_1) & (H_2) established for the study.

Notwithstanding these outcomes, this study suggests: (i) First, Coal was the largest energy consumed by the source at 27.88%; while total fossil fuels consumption stood at 68.08% in 2021. But coal consumption presents a health threat and is environmentally destructive (as coal burning produces carbon monoxide polluting the air; and can lead to long-term respiratory problems, such as asthma attacks and chest pains). Bulgaria should take ambitious steps to phase out coal dependency by hugely increasing its current investments in renewable technologies validated as less environmentally harmful; (ii) Second, Bulgaria has presented its economy as a champion of globalization. However, since major energy investments occur in carbon-polluting sectors, the government must assess and rethink their environmental impacts before permitting is given.

Second, the Fourier ARDL Long Run estimates suggest LGDP and LFS exert long-run positive effects on CO_2 emissions. These findings support several empirical outcomes. For example, the findings that in Bulgaria, LGDP has positive effects on LCO_2 (carbon emissions) support several empirical findings in the literature (i.e., Addai et al. [49]). From the perspective of the EKC hypothesis, economic growth creates opportunities for further and sustained economic progress and industrial activities, which normally requires more energy demand and creates another cycle of carbon emissions with destructive consequences. However, recent scientists claim economic growth has positive social and monetary benefits, making it possible to maintain environmental sustainability and economic growth balance despite the conventional macroeconomic theory of a trade-off between the two [50]. This result indicates that Bulgaria should expedite its program of phase-out of nuclear and coal and enhance expenditures in ongoing renewable technologies.

Although these results align with the literature, they portray a worrying trend that slaps the global energy transition journey, especially when such results are found in a European economy like Bulgaria, an economy committed to both the EU and Paris Agreement on climate change. Bulgaria wants an adequate compensation mechanism from the EU before implementing policies to reduce CO_2 emissions by 55% by the end of 2030. To ensure a balance between the individual member states in the delivery of the annual emissions targets, Bulgaria needs adequate investments from the European Union towards developing a phase-out coal plan to meet the EU's emission reduction targets.

Implications of these outcomes are far-fetched. First, Bulgarian leadership could invest hugely in both LFS and LENPR as they

Table 1
Descriptive statistics.

Description/Variables	LCO_2	LGDP	LEPR	LFS
	Production-based co2 emissions	GDP (constant 2015 US$)	Energy Productivity	Financial Risk Index
Mean	4.682361	10.60546	3.727061	3.468876
Median	4.674979	10.59548	3.711179	3.560087
Maximum	4.918956	10.76693	3.926005	3.721669
Minimum	4.587960	10.46006	3.569700	2.708050
Std. Dev.	0.059626	0.091608	0.115626	0.223410
Skewness	1.002860	0.059407	0.160118	−1.292776
Kurtosis	4.794679	1.519319	1.465351	3.930538
Jarque-Bera	36.21893	11.03267	12.28850	37.75489
Probability	0.000000*	0.004021*	0.002146*	0.000000*

Note: the star * denotes 1% level of statistical significance.

Table 2
Fourier ADF & ADF tests.

Variable	F-STAT	FADF	ADF with Break Point
LCO_2	2.858572	−2.218946	−2.838 (1993Q2)
LGDP	6.035581**	−4.854286**	
LEPR	1.275745	−3.115451	−2.100 (2001Q1)
LFS	2.510837	−2.734195	−5.766*** (1997Q4)
DLCO2			5.919*** (1991Q2)
DLGDP			
DLEPR			−7.060*** (1993Q1)
DLFS			

Note: denote 10%, 5%, & 1% significance levels (see Table 3). There are three significance levels −10%, 5%, and 1% -.marked by the following symbols: *, **, & ***.

Table 3
Fourier ADL cointegration.

Model	t-Statistic	Freq.	Min AIC
LCO_2 = f(LGDP, LEPR, LFS)	−7.651	2	−4.589

The results indicate variables are integrated, which enables proceeding with Fourier ARDL-based long run estimation toward capturing the effect of energy productivity and financial stability on carbon emissions in Bulgaria.

Table 4
Fourier ARDL.

Variable	Coef.	Std. Error	t-Statistic	Prob.
LGDP	0.945135	0.117072	8.073089	0.0000
LEPR	−0.557606	0.118553	−4.703435	0.0000
LFS	−0.038195	0.013107	−2.914161	0.0044
C	−0.516471	0.165055	−3.129081	0.0023
CointEq(-1)	−0.170091	0.036900	−4.609531	0.0000

Table 5
Breusch-Pagan-Godfrey heteroskedasticity assessment.

F-statistic	0.435014	Prob. F(13,103)	0.9533

Table 6
Breusch-Godfrey serial correlation LM test.

F-statistic	0.643214	Prob. F (2,84)	0.5282

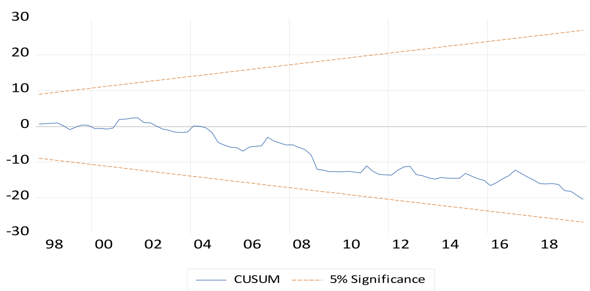

Fig. 3. Cusum.

contribute immensely in reducing carbon emissions in the country. The government could by this prioritize the Energy Efficiency and Renewable Sources Fund (EERSF). The Sustainable Energy Development Agency (SEDA) which is responsible for energy efficiency monitoring and evaluation at national and sectoral levels, should be empowered to work effectively. Given that the Bulgarian Energy Efficiency target is delivered through the Integrated Energy and Climate Plan of 2021–2030, effective monitoring is the surest way of ensuring a reduction of primary energy use by 27.89% (of 17,466 ktoe); and 31.67 (10,318 ktoe % fall) in total energy consumption compared to the reference scenario of PRIMES 2007.

Second, the outcomes have indicated that upwards changes in LFS help to reduce LCO_2 in Bulgaria. This finding suggests the

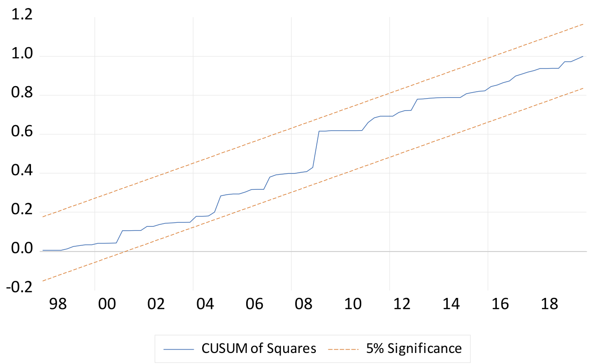

Fig. 4. Cusum sq.

government of Bulgaria could ensure policies that ensure financial stability are implemented with the aim of eventual improvements in the environmental quality of the economy. This outcome equally validates the theoretical claims by Soukhakian [11] on the relationship between financial development and green growth. This financial sector development has implications for corporate adaptation of efficient and eco-friendly technologies which help reduce carbon emissions. Corporate managers could request incentives and tax breaks which could facilitate further delivery of environmentally friendly outcomes.

Third, outcomes declare that LGDP has long-run positive effect of LCO_2. This implies that in Bulgaria, the rising economic growth has a detrimental impact on environmental quality in the long term. Theoretically, this result does not validate the EKC in the literature review, although the established hypothesis (see hypothesis 3) is upheld. For policy response, the Bulgarian government could ensure fossil fuel-facilitated long-run economic growth is controlled but replaced with huge investments in renewable energy sources as an alternative.

Given these estimation outcomes, the paper next checks for serial correlation and heteroskedasticity in the Fourier ARDL Long Run Form (model) using Breusch-Pagan-Godfrey Heteroskedasticity and LM estimators**.** Tables 5 and 6 illustrate the outcomes of the tests respectively.

Following that, a robust least square approach grounded on FMOLS is used to validate the outcome of the model (see Table 7). The outcomes serve as supplementary means of detecting symmetric long-run relationships; indicating that eventually, while both energy productivity and financial stability collectively help reduce carbon dioxide emissions in Bulgaria, economic growth rather increases CO_2 emissions in the country. Particularly significant is how the FMOLS outcomes confirm the Fourier ARDL estimates. Second, the FMOLS estimates on model robustness indicate, that the independent variables (i.e., LEPR, LFS, and LGDP) jointly explicate 86.8% of CO_2 emissions (i.e., the dependent variable) in Bulgaria. The estimates validly support recent research outcomes by Pata et al. (2020) on the effects of LGDP, LEPR and LFS on LCO_2 emissions. The summary of the outcomes of the present study is reported in Fig. 5.

5. Conclusion and policy insights

This research sought to investigate the effect of financial stability and energy productivity on environmental degradation in Bulgaria while controlling economic growth for the period between 1990Q1 and 2019Q4, using a novel Fourier ARDL estimator. The newly innovative Fourier ARDL estimator is found to provide reliable outcomes in long-run cointegration statistical analysis than the traditional ARDL methods. Second, by using this approach, several concealed structural breaks could be spotted., which hitherto could not be done. The outcomes of the study indicated: first, investments in both energy productivity and financial stability have negative effects on CO_2 emissions in Bulgaria; (ii) second, a rise in economic growth exerts a positive effect on CO_2 emissions in Bulgaria for the period. These findings offer significant policy insights for energy productivity investments for the government of Bulgaria, particularly on smart energy technologies; energy productivity financing; smart manufacturing; efficient transportation, energy use behavioral change, and smart water infrastructure. Additionally, the government of Bulgaria could enact policies for financial stability improvements; and for controlling fossil fuel-facilitated economic growth. The limitation of this article relates to the sole concentration of Bulgaria's economy which offers no room for comparative assessments. Future research could deliberate on the selection of economies and regions to enable energy productivity actions policies compared. This generates outcomes for robust policy suggestions based on contextual and country-specific factors.

Author contribution statement

Dervis Kirikkaleli: conceived and designed the experiments; contributed reagents, materials, analysis tools or data.
Kwaku Addai: performed the experiments; analyzed and interpreted the data.
Rui Alexandre Castanho and Kwaku Addai: wrote the paper.

Table 7
Robust test.

FMOLS				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LEPR	−1.041773	0.112067	−9.295970	0.0000
LFRI	−0.129067	0.019029	−6.782710	0.0000
LGDP	1.119123	0.136080	8.223998	0.0000
C	−2.856541	1.059605	−2.695855	0.0081

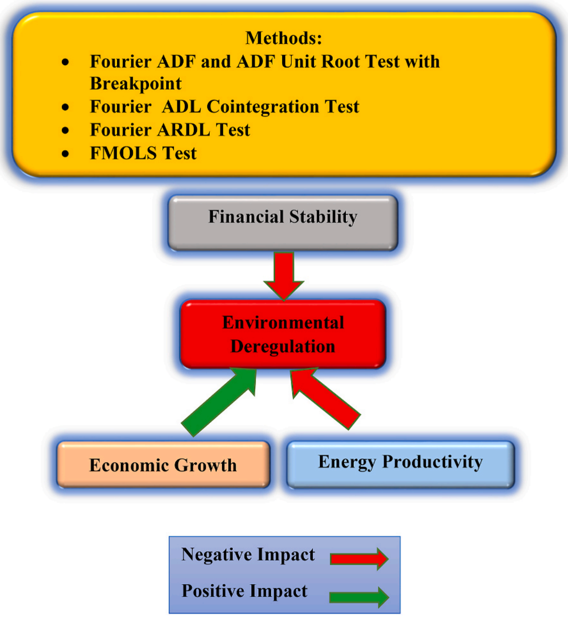

Fig. 5. Summary of Empirical Findings with Methods
Source: author.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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