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The Role of Fiscal Policy in G20 Countries in the Context of the Environmental Kuznets Curve Hypothesis

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Abstract: Fiscal policy is an essential tool that policymakers use for guiding the economy. Thus, the effects of fiscal policy may affect many aspects of our lives, including the impact of carbon dioxide (CO_2) emissions. This article investigates the role of fiscal policy, in addition to gross domestic product (GDP), innovation, and financial development, in mitigating CO_2 emissions in the context of the Environmental Kuznets Curve theory in the Group of Twenty (G20) countries from 1995 to 2019. The study implied the autoregressive distributed lag of pooled mean group (ARDL-PMG) approach to analyze the suggested model. The results revealed the validity of the model for the G20 countries, as well as a long-run cointegration between the study variables. The results also showed that fiscal policy is associated positively with CO_2 emissions. Hence, we recommend reconsidering the applied financial policy, redirecting it to support clean energy projects, provide incentives for projects combating environmental degradation, and relying on environmentally friendly energy.

Keywords: fiscal policy; carbon dioxide; Environmental Kuznets Curve; G20; ARDL-PMG

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1. Introduction

Due to human activity and energy use, notably in the last century, the world has faced serious climatic concerns, particularly regarding carbon dioxide (CO_2) emissions [1]. Governments have been compelled to raise public awareness of the environmental problems brought on by the rapid exploitation of natural resources and the resulting rise in CO_2 emissions that have coincided with global economic growth and advancements in human well-being [2].

The mitigation of global warming and CO_2 emissions is a crucial goal of worldwide efforts to prevent the negative impacts of environmental change globally. Since 2011, many governments worldwide have developed plans for dealing with global warming and its environmental impact at the national level, addressing it, and mitigating its adverse effects under the UN Framework Convention on Climate Change [3]. However, because these plans were prepared at a local level, they were not unified and did not show coordination between countries, which may question their effectiveness in combating global warming and CO_2 emissions [4]. To enhance cooperation to combat global warming and CO_2 emissions, as well as raise awareness about the world's environmental risks, the Paris Agreement was signed on April 2016. All parties to the Paris Agreement committed to strengthening the global response to climate change by increasing the ability of all to adapt, build resilience, and reduce vulnerability [5].

Reducing CO_2 emissions is contingent on the willingness of the leading CO_2-producing countries to achieve global emissions reduction [6]. In general, the commitment of big polluters, especially the Group of Twenty (G20) countries, which are considered the most significantly responsible for global warming [7], and the effectiveness of energy use are crucial for the success of efforts to reduce global CO_2 emissions [8]. Figure 1 shows the leading CO_2-producing countries.

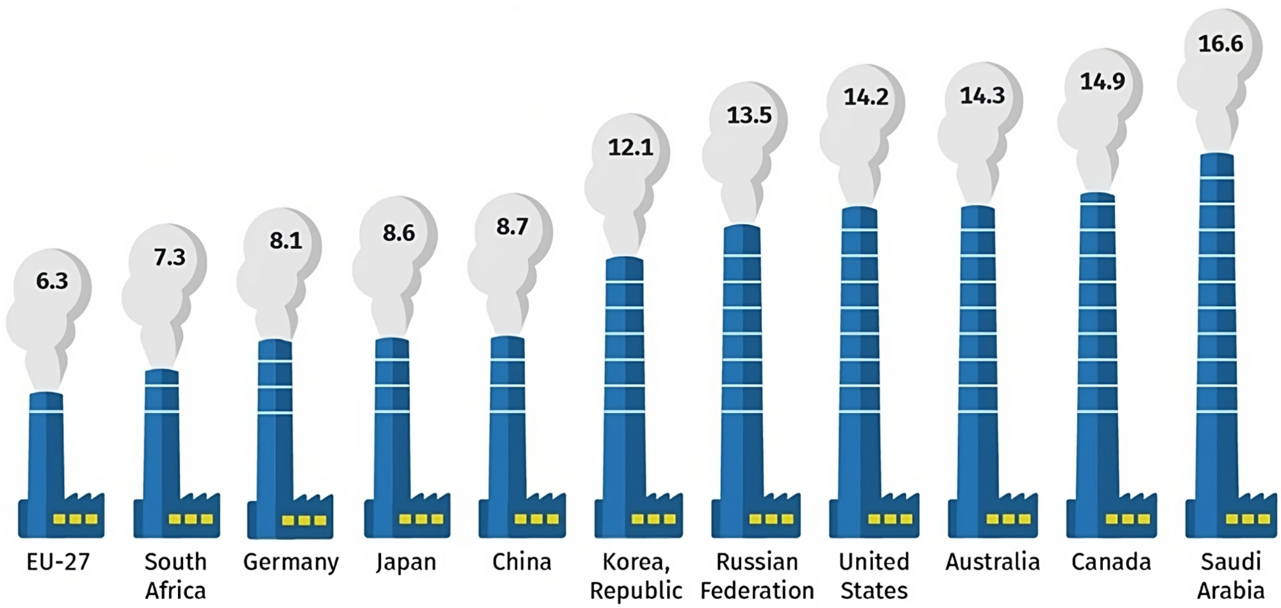

Figure 1. The main producers of CO_2 in metric tons. Source: [9].

There is broad scientific consensus that human activities, economic activity, technological advancements, and the development of political and financial institutions are to be blamed for the exponential increase in CO_2 emissions around the world [10,11,12]. G20 countries represent the greatest economies worldwide and have a significant effect on the global greenhouse effect by being responsible for about 80% of the world's CO_2 emissions [7].

G20 is the largest economic grouping around the world, representing 85% of the global gross domestic product (GDP) and contributing to 75% of international trade. It is also the most prominent economic group that emits CO_2. Nevertheless, because of their extensive impact on the entire world through technology, business, industry, and development funding, G20 nations are well positioned to lead global efforts to mitigate and decrease the negative impact on the environment through implementing comprehensive fiscal and structural reforms while taking effective climate action [5].

This paper studies the relationship between CO_2 emissions and four main variables: GDP, innovation, financial development, and fiscal policy. This paper aims to (1) verify the validity of the Environmental Kuznets Curve hypothesis in the G20 countries during 1995–2019 (hence, the GDP square was introduced to infer the existence of the invited U-shape) and (2) investigate the impact of the fiscal policy on CO_2 emissions in the G20. Therefore, two models were used: fiscal policy was introduced in the second model. This study was motivated by the literature and previous studies' shortage regarding the impact of fiscal policy on CO_2 emissions, especially in the G20 countries. The importance of the study arises from shedding light on the validity of the Environmental Kuznets Curve hypothesis in the G20 countries and the investigation of the critical role that fiscal policy plays in influencing CO_2 emissions.

The study applied the Westerlund test [13] to examine the long-run relationship between the variables, using the panel autoregressive distributed lag (ARDL) with three estimators: pooled mean group (PMG), mean group (MG), and dynamic fixed effect estimator (DFE). The Hausman test [14] was applied to choose the appropriate estimator. The interest in the long-term relationship between study variables and CO_2 emissions arises from the fact that government strategies and policies to combat climate change cannot reduce CO_2 in short periods [15].

The rest of the paper is organized as follows. Section 2 exhibits the literature review and highlights related previous studies. Section 3 presents the data and methodology employed in the study. Section 4 discusses the result of the study. Finally, the conclusion is presented in Section 5.

2. Literature Review

The relationship between financial and economic variables and CO_2 emissions has attracted many scholars, organizations, and governments worldwide. Researchers sought to study the various effects of these variables to clarify the nature and direction of the relationship and try to provide solutions that may contribute to mitigating CO_2 emissions [16]. Next, we briefly explore the relationship between the study's variables and CO_2.

2.1. The Relationship between CO_2 and Economic Development

Hypothesis 1: *The relationship between economic development and carbon dioxide emissions takes an inverted U-shape.*

Environmental degradation and the high rate of CO_2 emissions are a matter of concern globally. Therefore, many countries try to develop policies to reduce the rate of CO_2 emissions [3]. The relationship between economic growth and CO_2 emissions is complicated. Many factors contribute to the high rate of CO_2, the most important of which is the high rate of production and consumption of individuals and factories, especially in developed countries. This leads to an increase in energy demand and hence is considered one of the main factors of pollution, in addition to the obsolescence of technology and the lack of development-friendly technology, especially in developing countries [17]. However, the most popular tool that justifies the relationship between economic growth and CO_2 emissions is the Environmental Kuznets Curve (EKC) hypothesis, which shows that this relationship takes the inverse U-shape [18]. Based on the EKC, in the early stages of economic growth, the consumption of energy and natural resources increases and thus leads to environmental degradation until this economic boom reaches its peak. At this point, the economy will be able to work more efficiently and make greater use of the available resources. From here begins the second stage, which is based on economic growth with less consumption of resources and, thus, a decrease in environmental degradation [19].

However, there is no consensus among experts regarding the precise axis of the relationship between economic development and CO_2 emissions. Even though the EKC hypothesis, which holds that the relationship between economic expansion and pollution follows the shape of an inverted U-shape, is widely accepted [20,21], Bae et al. [19] found a positive relationship between economic growth and CO_2. Others found a bidirectional relationship [16,22].

2.2. The Relationship between CO_2 and the Fiscal Policy

Hypothesis 2: *Fiscal policy helps reduce carbon dioxide emissions.*

Fiscal policy is considered to be one of the main components of the macroeconomy. It plays a significant role in all economic aspects since government spending and taxes are the primary tools of fiscal policy and therefore play a significant role in consumption and production. This applies to not only energy but also all economic activities, which makes the fiscal policy a key player in influencing CO_2 emissions and environmental degradation [23]. Governments can achieve economic expansion by controlling the tools of fiscal policy, especially spending, which can be directed to environmentally friendly economic activities and businesses [24–26]. The government might also control environmental degradation through taxes, and it might impose environmental taxes to increase the share of environmentally friendly products in the market [15,27]. To combat climate change, based on what was adopted in the Paris Agreement, there was an urgent need to take government policies that would reduce CO_2 emissions. One suggestion is to issue new tax policies towards economic activities to control environmental degradation and pollution. The new government policies are not limited to the imposition of environmental taxes but may also include tax exemptions for environmental products in a way that encourages institutions and individuals to rely on renewable energy [28,29]. Despite the few studies that dealt with the relationship between fiscal policy and CO_2 emissions, they all agreed that fiscal policy negatively affects CO_2 emissions, and therefore its tools, whether taxes or government spending, can be used to reduce environmental degradation and climate change [23,24,30–32].

2.3. The Relationship between CO_2 and Technology

Hypothesis 3: *Technology combats carbon dioxide emissions.*

Technological innovation can be evident in the development of new technologies. It usually takes one of two forms: the development of new technology or the creative application of existing technology. It is regarded as a vital solution to environmental difficulties and long-term growth, particularly if oriented to address environmental degradation concerns. According to the endogenous theory of economic growth, advancement in technical innovation may improve economic production and resource use efficiency, reducing waste resources and CO_2 emissions [2]. However, some researchers still question the feasibility of innovation and technological progress in improving the quality of the environment. They believe that technology has a negative impact on the environment, claiming that technology can increase the effectiveness of resource usage, but their marginal impact is waning, and a fast expanding economic scale may nevertheless necessitate increased investment in natural resources rather than technology [33].

The debate about the effects of technology encourages scholars worldwide to examine the role of technological progress in reducing CO_2 emissions. The majority of scholars found a negative relationship, where technology mitigates CO_2 emissions and contributes significantly to environmental sustainability and combating climate change [34,35]. Furthermore, they found that a higher level of technology in high-income countries can reduce CO_2 in local and neighboring countries [2] and offset the positive impact of economic growth regarding CO_2 that arises from the large energy consumption and resources in the economic expansion [1]. However, some still argue that the impact of technological progress and innovation on environmental quality, particularly, CO_2 emissions, is still not clear and needs further investigation [36].

2.4. The Relationship between Financial Development and CO_2

Hypothesis 4: *Financial development is inversely proportional to carbon dioxide emissions.*

The role of financial development in combating CO_2 emissions is not always clear, and the results of the studies can differ according to whether it is a developing or developed country, especially since no specific variable has been agreed upon that represents financial development. Yet, the majority of the previous studies showed that financial development reduces CO_2 emissions, as the relationship is negative in the long run; the higher level of financial development is considered the engine that leads to a decrease in CO_2 emissions [6,15,37] through the adoption of environmentally friendly financial technology. Additionally, the developed financial system contributes to attracting foreign direct investment and thus the development of the economic system, which contributes to improving the quality of the environment [38]. In addition, the development of the financial system may increase the ability of the banking system to support environmental projects locally through environmental activities adopted by the government or private institutions to support and protect the environment [39]. Other studies found no significant effect of financial development on CO_2 [16,40].

Generally, scholars have paid close attention to the impact of financial development on CO_2 emissions, as well as their mutually inextricable relationship, considering the importance of financial development in sustainability and energy efficiency. The majority sees financial development as a driving force behind the advancement of energy-efficient or environmentally friendly technology. As a result, pollutants in the environment, such as CO_2, will be reduced [37]. The empirical literature is summarized in Table 1.

Table 1. Summary of the previous studies.

Authors	Region	Period	Method	Type of Relationship
Economic growth				
[22]	Indonesia	1975–2011	VECM	Bidirectional causality
[20]	Sub-Saharan countries	1971–2009	ARDL	Inverted U-shape
[16]	13 European and 12 East Asia and Oceania countries	1989–2011	PVAR	Bidirectional causality
[19]	15 post-Soviet Union	2000–2011	GMM	Positive relationship
[21]	Pakistan, India, and Bangladesh	1996–2016	ARDL	Inverted U-shape
Fiscal policy				
[24]	USA	1973–2013	VECM	The negative effect of government spending
[23]	Turkey	1960–2013	ARDL	Negative relationship
[41]	China	1980–2016	VECM	Negative relationship
[31]	Thailand	1972–2014	Causality test	Negative relationship
[32]	G7	1875–2016	Frequency domain causality test	Negative relationship
Technology				
[35]	Malaysia	1971–2013	VECM	Negative relationship
[36]	OECD countries	1996–2015	PQR	No significant effect
[34]	OECD countries	1999–2014	Static panel model and GMM	Negative relationship
[2]	96 countries	1996–2008	Spatial dynamic panel model	Negative relationship
[1]	OECD countries	1996–2015	PQR	Negative relationship
Financial development				
[6]	BRIC countries	1992–2004	Random-effect	Negative relationship
[22]	Indonesia	1975–2011	ARDL, VECM causality	Negative relationship
[16]	13 European and 12 East Asia	1989–2011	ARDL	No significant effect
[40]	Kuwait	1980–2013	ARDL, VECM causality	No significant effect
[37]	China	2001–2015	Static panel model	Negative relationship

Note: ARDL stands for an autoregressive distributed lag, VECM refers to Vector Error Correction Model, QRPD refers to quantile regression panel data, GMM is the generalized method of moments, and finally PVAR represents panel vector autoregressive model.

3. Data and Methodology

3.1. The Data

This study employs annual data for the period from 1995 to 2019 for G20 countries which include Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, the Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, and the United States. Descriptions of the variables and their sources are listed in Table 2.

Table 2. Descriptions and source of the variables.

The Variables	Symbols	Definitions	Sources
Dependent variable			
CO_2	CO_2	CO_2 emissions per capita	World Development Indicators
Independent variables			
GDP	GDP	The output of a country in a year	World Development Indicators
Technology	TEC	Total patent applications	World Development Indicators
Financial development	FDV	The degree of development of financial institutions and markets; this indicator considers the development of both the financial institution and financial market	IMF
Government spending		Government expenditure in a given year as a percentage of GDP	World Development Indicators
Tax revenue		Compulsory transfers to the central government for public purposes as a percentage of GDP	World Development Indicators

The natural logarithm was taken for the variables of the study, specifically CO_2, GDP, technology, and financial development. Fiscal policy (FSP) was constructed from government spending and tax burden by using principal component analysis. The main function of the model can be written as follows:

$$CO_2 = f(GDP, TEC, FDV, FSP)$$

The main function of the model can be generalized to a simple panel model as follows:

$$CO_{2_{it}} = a_0 + \beta_1 GDP_{it} + \beta_2 TEC_{it} + \beta_3 FDV_{it} + \varepsilon_{it} \quad (1)$$

$$CO_{2_{it}} = a_0 + \beta_1 GDP_{it} + \beta_2 TEC_{it} + \beta_3 FDV_{it} + \beta_4 FSP_{it} + \varepsilon_{it} \quad (2)$$

CO_2 refers to the dependent variable, CO_2 emissions, i stands for the cross-sectional unit, t refers to the time, a_0 is a constant, β_1, $\beta_2, and\ \beta_3$ represent the linear parameter of GDP, TEC stands for technology, FDV is financial development, FSP_{it} is a vector representing the fiscal policy, containing the government expenditure and tax burden, and ε represents the error term.

3.2. The Methodology

3.2.1. Principle Component Analysis (PCA)

PCA is a common dimensionality reduction technique that enables us to reduce variance in a set of variables into a fewer number of factors. The objective of PCA identifies components $Y = [Y_1, Y_2, \dots, Y_p]$; that is, a linear combination $e = [e_1, e_2, \dots, e_p]'$ of the main series $x = [x_1, x_2, \dots, x_p]$. The purpose of this technique is to re-orient the information from a large set of variables to a few number of factors or components that catch the majority of information in the original set [42]. In addition to reducing a large set of data to a small number of factors, PCA has another advantage. It can be used in the case of existing collinearity between the predictor variables that it will account for. It takes the important information from these correlated variables and combines it into a few number of variables [43].

3.2.2. Unit Root Test

To test the stationary variables, the study used the Maddala and Wu test [44], known as the MW test, and the Pesaran test [45], known as the CIPS test. Wu [44] discussed the different panel unit root tests, such as LL and IPS tests. They argued that these tests are not efficient and lack power. They suggested a new unit root test based on the principle of Fisher. The suggested test permits the heterogeneity in the panels and can be written as follows:

$$P_{MW} = -2\sum_{i=1}^{N} log\ \pi_i \quad (3)$$

Pesaran [45] introduced a new panel data unit root test. It can be seen as a modified version of the IPS test. The suggested test is based on Dickey–Fuller regression and permits heterogeneity and allows the existence of an unobserved common factor while considering the serial correlation. It is possible to calculate it as follows:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} t_i(N,T) \quad (4)$$

3.2.3. ARDL Model

Since we are not interested in testing the EKC hypothesis that has been previously tested and proven [20,21], we follow the literature by adopting a linear model for the relationship between economic development and CO_2 [19].

Selecting a specific model to analyze the data, whether a dynamic or static model, is usually based on the unit root test result. In case the variables are mixed or integrated, we cannot use the static panel model because it will generate spurious regression; instead, the dynamic model will be favorable [43]. It is common in economics and finance that most observations are not integrated at I (0), so in case the study variables are mixed or integrated, the panel ARDL is appropriate to analyze the model. The ARDL model was introduced by Pesaran and Smith [46] and Pesaran et al. [47]. Although the ARDL approach's restriction is on only a one level-relationship among the variables under examination and does not allow for more long-term relationships, the ARDL method can be used to test the cointegration in a one equation model at different spans, long run and short run, by utilizing three estimators to analyze the data: PMG, MG, and DFE.

The PMG estimator permits heterogeneous dynamic panels, and the DFE estimator might be utilized when the variables of each country are pooled and only the intercepts are permitted to vary between groups, while the MG estimator allows for slope and disturbance terms to differ across countries [48]. The model of panel ARDL (p, q, q, …, q) based on Pesaran et al. [47] can be written as follows:

$$\Delta CO_{2_{it}} = \alpha_i + \sum_{j=1}^{m-1} \beta_{ij}\Delta CO_{2_{i,t-j}} + \sum_{l=0}^{n-1} \varphi_{il}\Delta GDP_{i,t-1} + \sum_{r=0}^{n-1} \varphi_{il}\Delta GDPS_{i,t-1} + \sum_{v=0}^{p-1} \gamma_{ir}\Delta TEC_{i,t-r} + \sum_{w=0}^{s-1} \theta_{iu}\Delta FDV_{i,t-u} + \sigma_1 CO_{2_{i,t-1}} + \sigma_2 GDP_{i,t-1} + \sigma_2 GDPS_{i,t-1} + \sigma_3 TEC_{i,t-1} + \sigma_4 FDV_{i,t-1} + \varepsilon_{i,t} \quad (5)$$

$$\Delta CO_{2_{it}} = \alpha_i + \sum_{j=1}^{m-1} \beta_{ij}\Delta CO_{2_{i,t-j}} + \sum_{l=0}^{n-1} \varphi_{il}\Delta GDP_{i,t-1} + \sum_{r=0}^{n-1} \varphi_{il}\Delta GDP_{i,t-1} + \sum_{v=0}^{p-1} \gamma_{ir}\Delta TEC_{i,t-r} + \sum_{u=0}^{s-1} \theta_{iu}\Delta FDV_{i,t-u} + \sum_{w=0}^{v-1} \delta_{iw}\Delta FSP_{i,t-w} + \sigma_1 CO_{2_{i,t-1}} + \sigma_2 GDP_{i,t-1} + \sigma_3 TEC_{i,t-1} + \sigma_4 FDV_{i,t-1} + \sigma_5 FSP_{i,t-1} + \varepsilon_{i,t} \quad (6)$$

$CO_{2_{\mathrm{it}}}$ is the dependent variable at time t for i unit, α is a constant to the units, GDP, INV, FDV, and FSP are the dependent variables, $\beta_{\mathrm{ij}}, \phi_{\mathrm{il}}, \gamma_{\mathrm{ir}}, \theta_{\mathrm{iu}}, \delta_{\mathrm{iw}}$, and ρ_{iz} stand for the short-run parameters, $\varepsilon_{\mathrm{I,t}}$ is the identical disturbance term for the model, and β

stands for the error correction model; it has to be significantly negative and less than one to infer the existing long-run relationship and conclude that the variables are cointegrated. The first equation does not contain the financial policy variable, as it was included in the second equation to show the difference in the results of the two models before and after the introduction of the fiscal policy.

3.2.4. Cointegration Test

Based on the suggested methodology by Menegaki [49], estimating the panel ARDL model usually needs a robustness test after estimating the panel ARDL. The study uses the error-correction-based cointegration tests for panel data suggested by Westerlund [13]; this cointegration test presents coherent results even in case of presence heterogeneity and cross-sectional dependence. The error-correction model can be written as follows:

$$\Delta y_{it} = \delta_i' d_t + \alpha_i\left(y_{i,t-1} - \beta_i' x_{i,t-1}\right) + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{ij} \Delta x_{i,t-j} + e_{it} \quad (7)$$

where it stands for cross-sectional countries and time series, respectively, y refers to the dependent variable, x is the independent variable, j, p are the lagged period, α_i denotes the speed of adjustment, d_t is the deterministic component, and e_{it} is the error term.

4. Empirical Result

4.1. PCA

The best variable that can express the fiscal policy is government spending and taxes, and to obtain all the vital information embedded in the fiscal policy tools, we used PCA, which enables us to collect the critical information from the fiscal policy tools in one variable instead of two.

As it is clear in Table 3, the new factor has a variance of 1.60 and can explain about 80% of the total variance. From the same table, in the second column, we can reduce the two variables into one factor since the eigenvalue of the first component is greater than 1; the criterion to select the number of the reduced factors is whether located above the threshold of one or not. The Supplementary Materials provides evidence that the number of selected factors in our case is one factor.

Table 3. Principal component analysis.

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	1.60148	1.20297	0.8007	0.8007
Comp2	0.398516		0.1993	1

4.2. Unit Root Test

Table 4 presents the result of the unit root test based on the Pesaran and Maddala and Wu tests [44,45], MW and CIPS, respectively; the null hypothesis for MW and CIPS tests is that the series are integrated at first order I (1).

Table 4. The result of the unit root test.

Variables/Tests	CIPS		MW	
	Constant	**Constant with Trend**	**Constant**	**Constant with Trend**
CO_2	0.348	0.714	10.436	47.559
	(0.636)	(0.763)	(1.000)	(0.138)
GDP	−3.255	−1.786	23.176	15.186
	(0.001)	(0.037)	(0.972)	(0.999)
TEC	−0.870	−1.406	101.592	86.344
	(0.192)	(0.080)	(0.000)	(0.000)
FDV	−4.194	−3.660	189.988	104.424

	(0.000)	(0.000)	(0.000)	(0.000)
FSP	−2.927 (0.003)	−2.487 (0.006)	80.241 (0.000)	62.437 (0.007)

The *p* value is in parentheses. The source: authors' calculations.

Table 4 shows that we cannot reject the null hypothesis for CO_2 based on CIPS and MW tests, meaning that we accept that CO_2 is integrated in the first order for both tests. At the same time, for GDP, the conflict between the results of the CIPS and MW tests is apparent.

Based on the CIPS test, we reject the null hypothesis in both cases of the constant and the constant with the trend for TEC. In contrast, the null hypothesis is accepted based on the MW test.

Regarding FDV and FSP, the null hypothesis is accepted by the CIPS and MW tests at the significance level of 5%. Since the variables are mixed stationary and integrated at level I (0) and first order I (1), the most appropriate method to test the models is the ARDL approach.

4.3. Cointegration Test

The study adopts the Westerlund test [13] to examine the long-run relationship between explained and explanatory variables. The Westerlund test [13] can produce credible results even in cross-sectional dependency and heterogeneity cases. Based on the results of Westerlund [13] in Table 5, the null hypothesis stated that no cointegration is rejected for all variables at a significance level of less than 1%, which provides evidence that the variables cointegrate in the long run.

Table 5. Westerlund cointegration results.

Cointegration	Gt	Ga	Pt	Pa
GDP	−4.408 (0.000)	−20.843 (0.000)	−11.153 (0.000)	−13.353 (0.000)
TEC	−3.868 (0.000)	−20.749 (0.000)	−10.753 (0.000)	−13.560 (0.001)
FDV	−3.768 (0.000)	−20.049 (0.000)	−9.435 (0.396)	−13.455 (0.001)
FSP	−4.010 (0.000)	−22.09 (0.000)	−10.16 (0.000)	−16.782 (0.000)

The *p* value is in parentheses. The source: authors' calculations.

4.4. The ARDL Model

The study employs three estimators to address the relationship between CO_2 and GDP: Technology, financial development, and fiscal policy. Table 6 shows the estimation of Equation (5) in the first model and Equation (2) in the second model using MG, MPG, and DFE. The study utilizes Hausman [14] to determine the appropriate estimator of panel ARDL.

Table 6. Panel ARDL results.

Variable	First Model			Second Model		
	MG	PMG	DFE	MG	PMG	DFE
Long run						
GDP	2.871 (0.339)	1.275 (0.13)	2.004 (0.142)	9.356 (0.245)	1.212 (0.021)	2.028 (0.126)
GDPS	−0.504 (0.328)	−0.024 (0.111)	−0.040 (0.103)	−2.866 (0.243)	−0.0241 (0.016)	−0.040 (0.091)
TEC	−0.340	−0.024	−0.023	0.545	−0.016	−0.019

	(0.147)	(0.019)	(0.341)	(0.232)	(0.000)	(0.436)
FDV	−0.675 (0.211)	−0.606 (0.000)	−0.306 (0.278)	−2.264 (0.159)	−0.276 (0.000)	−0.279 (0.312)
FSP				0.821 (0.365)	0.095 (0.000)	−0.024 (0.678)
Short run						
GDP	−1.284 (0.765)	10.069 (0.120)	−1.090 (0.001)	−3.332 (0.573)	11.989 (0.122)	−1.083 (0.001)
GDPS	0.027 (0.709)	−0.174 (0.102)	0.0196 (0.001)	0.055 (0.757)	−0.206 (0.120)	0.0195 (0.001)
TEC	−0.271 (0.428)	0.027 (0.098)	0.004 (0.896)	0.016 (0.787)	0.032 (0.086)	0.001 (0.91)
FDV	0.377 (0.339)	0.1130 (0.207)	−0.029 (0.311)	−0.137 (0.460)	0.115 (0.124)	−0.034 (0.248)
FSP				0.014 (0.405)	0.005 (0.574)	0.009 (0.156)
ECT	−0.801 (0.002)	−0.126 (0.000)	−0.073 (0.000)	−0.463 (0.000)	−0.208 (0.005)	−0.076 (0.000)
Constant	−57.306 (0.486)	−2.161 (0.000)	−1.859 (0.209)	−15.485 (0.841)	−3.306 (0.005)	−1.968 (0.192)
Hausman		0.242	0.148		0.369	0.022
Turning point					8.086	

The *p* value is in parentheses. The source: authors' calculations.

4.4.1. First Model Result

The first model contains four explanatory variables, GDP, GDP square, Technology, and financial development. We can notice in Table 6 that ECT, which stands for the error correction model, is significant, less than one, and negative, which means that the variables in the model are cointegrated in the long run. Hausman's test [14] in the first model failed to reject the null hypotheses that PMG is a more efficient estimation than MG, and PMG is a more efficient estimation than DFE. It is clear that the GDP sign is positive and the sign of GDP square is negative, which is consistent with the EKC hypothesis which states that economic expansion is accompanied by the production of large quantities of CO_2 because many economic and production activities are based on energy, and therefore the relationship between economic growth and CO_2 production takes the inverted U-shape [19].

However, the EKC hypothesis, which demonstrates this inverted U-shape relationship, is the most widely used body of material to support the link between economic growth and CO_2 emissions [18]. Based on the EKC, in the early stages of economic growth, consumption of energy and natural resources increases and thus leads to environmental degradation until this economic boom reaches its peak. At this point, the economy will be able to work more efficiently and make greater use of the available resources. From here begins the second stage, which is based on economic growth with less consumption of resources and, thus, a decrease in environmental degradation [19].

The first model's findings are consistent with the EKC hypothesis, which postulates that the relationship between economic growth and CO_2 in the early stages of economic expansion takes the form of an inverted U-shape. However, it should be observed that for the three estimators in the first model, all model parameters are unimportant, which may be due to the absence of a leading variable. As a result, in the second model, we included the fiscal policy to see if the model's parameters would become important and, if so, to gather information concerning the impact of the fiscal policy on CO_2.

4.4.2. Second Model Result

The second model contains an additional variable, fiscal policy, to determine whether it affects CO_2 under the EKC hypothesis. Hausman [14] failed to reject the null hypotheses that there is long-run homogeneity restriction is tested against the alternative hypothesis, supporting that PMG is a more efficient estimation than MG, and PMG is a more efficient estimation than DFE. Hence, the appropriate estimator would be the PMG estimator.

The error correction model for the three estimators of the second model is negative, less than one, and statically significant. Hence, there is a long run cointegration between the explanatory and explained variables. Regarding the PMG estimator in the second model, we notice that the ECT value is about −20.8%, which means that the error in the short run is corrected by 20.8% in the long run.

Comparing the results of the first and second models, as shown in Table 6, we can note that the variables became statistically significant after introducing the fiscal policy variable into the model. Concerning the impact of GDP and GDP square on CO_2 emissions, we notice that the sign of GDP is positive, and GDP square is negative, and both are statically significant in the long run, which means that the model is consistent with the EKC hypothesis.

4.4.3. Hypothesis Results

Hypothesis 1: *The relationship between economic development and carbon dioxide emissions takes an inverted U-shape.*

The relationship between economic development and CO_2 takes an inverted U-shape. This result is consistent with the results of Kivyiro and Arminen [20,21] who found an inverted U-shape relationship between economic development and CO_2. The quantities of carbon released increase due to the need for energy to meet economic growth; hence, the effect of GDP on CO_2 is positive during economic expansions, where large quantities of energy are consumed during the extraction and transformation of raw materials and industrial production. After economic growth reaches maturity, the negative impact of economic growth begins on CO_2 emissions, as the country has been able to possess and develop environmentally friendly technologies, including renewable energy; thus, the effect of GDP square on CO_2 is negative [19].

Figure 2 shows the turning point of the environmental Kuznets curve for the study sample. Based on Halkos [50,51], accepting the Environmental Kuznets Curve (EKC) hypothesis means that a country may experience an initial increase in environmental damage during its earlier stages of economic growth, followed by significant improvement in the later stages. The EKC phenomenon is a result of structural changes that occur with economic growth but may not be desirable if critical environmental thresholds are surpassed irreversibly. The early stages of the EKC curve where worse environmental outcomes accompany growth may take a long time to overcome, which implies that the high rates of environmental damage in the present may offset the benefits of higher future growth and a cleaner environment. However, taking measures to reduce environmental damage now may be less costly than waiting until later.

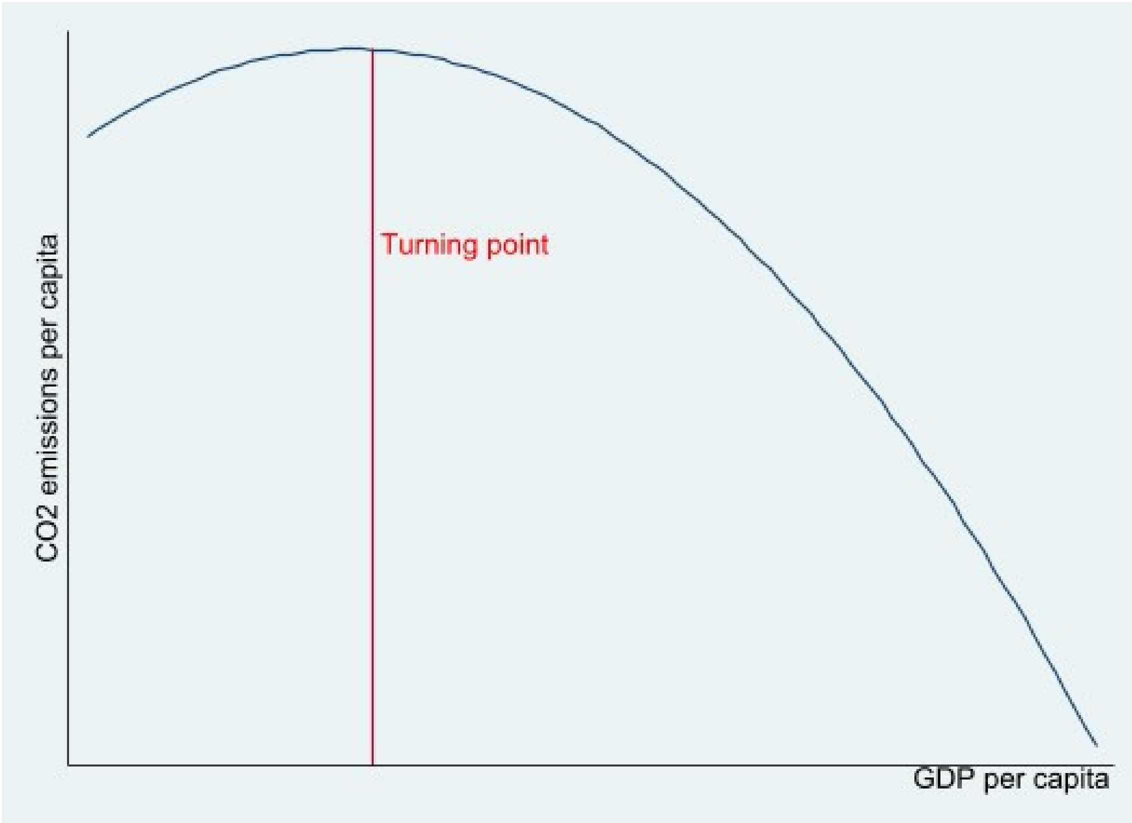

Figure 2. The Environmental Kuznets Curve turning point.

Hypothesis 2: *Fiscal policy helps reduce carbon dioxide emissions.*

According to the finding regarding the fiscal policy's impact on CO_2 emissions, which is both statistically significant and positive, the implemented fiscal policy in the study sample is a factor in the rise in CO_2. Analyzing the relationship between fiscal policy and CO_2 in the literature reveals that fiscal policy aids in the reduction of CO_2 emissions. For instance, many studies [23,31,32,41] discovered a negative correlation between the fiscal policy and carbon emissions.

The role of fiscal policy in economic growth can justify the positive relationship between fiscal policy and CO_2 emissions. On the one hand, many scholars contend that fiscal policy significantly boosts economic growth by providing public financing for infrastructure and productive activity [52]. Considering different energy sources are required for these economic activities [17], which came based on an expansionary fiscal policy, CO_2 increases due to excessive energy use to boost economic growth. On the other hand, reducing taxes may drive up CO_2 emissions associated with consumption [24].

Hypothesis 3: *Technology combats carbon dioxide emissions.*

Regarding technology, the result indicates that technology negatively affects CO_2; hence, technological progress leads to decreased CO_2 emissions in the long run. Technology can improve the effectiveness of the raw materials used in production during economic growth [33]. This result is consistent with the literature, especially Cheng et al. [36] in Malaysia and Cheng et al. [1] and Hashmi and Alam [34] in OCED countries. Technology can reduce the positive impact of economic growth on CO_2 emissions derived from large energy consumption and resources [1].

Hypothesis 4: *Financial development is inversely proportional to carbon dioxide emissions.*

Finally, the findings of financial development reveal that it has a negative and statistically significant impact on carbon emissions in the long run, which suggests that it helps reduce CO_2. This result is consistent with Tamazian et al. [6], Shahnazi and Shabani [15], and Zhao and Yang [37] who consider that financial development is the engine for reducing CO_2 emissions as it contributes to the adoption and financing of environmentally friendly projects. Summary of hypothesis results presented in Table 7.

Table 7. Summary of hypothesis results.

Hypothesis	Result
The relationship between Economic development and carbon dioxide emissions takes an inverted U-shape.	✓
Fiscal policy helps reduce carbon dioxide emissions.	X
Technology combats carbon dioxide emissions	✓
Financial development is inversely proportional to carbon dioxide emissions.	✓

5. Conclusions

This paper investigated the impact of fiscal policy economic growth, technology, and financial development on CO_2 emissions in the context of the EKC hypothesis. The study sample consisted of the G20 countries covering the period 1995–2019.

This paper used two models to investigate the effect of the explanatory variables on the explained one. Fiscal policy was introduced in the second model to examine whether it is consistent with the EKC theory and whether it significantly affects CO_2. The two models were analyzed using the ARDL approach using three estimators, MG, MPG, and DEF. The Hausman test [14] was applied to choose the appropriate estimator.

The empirical result indicated the existence of cointegration between the variables in the long run after introducing the fiscal policy, and the explanatory variables were statically significant in the second model. The highly significant error correction term in the second model confirms the existence of a stable long-run relationship. The finding revealed that the relationship between economic growth and CO_2 emissions is the inverted U-shape. This result is consistent with the results of Kivyiro and Arminen [20] Mehmood et al. [21]. During economic expansions, there is a need for energy to meet economic growth; hence the relationship will be positive, while after economic growth reaches maturity, the negative impact of economic growth begins on CO_2 emissions, as the country has been able to develop and regulate environmentally friendly economic activities.

Regarding fiscal policy, it positively affected CO_2. This result is not consistent with the results of Katircioglu and Katircioglu [23], Ike et al. [31], Yilanci and Pata [32], and Yuelan et al. [41]. The positive relationship may be justified in the context of its role in economic development. As sound fiscal policy boosts economic activity during a recession, more energy sources are required to sustain this expansion, which could eventually increase carbon dioxide emissions. Fiscal policy was shown to be crucial in promoting economic expansion during times of economic prosperity, increasing reliance on the supply of resources, particularly energy sources and raw materials that produce a lot of CO_2.

Results also demonstrated that both technology and financial development were negatively associated with CO_2 emissions in the long run, as the increases in technology and financial development lead to a decrease in CO_2 emissions. The outcome of the technology is consistent with the literature [1,34], where the efficiency of raw materials utilized in production during economic expansion can be improved through technology.

The financial development variable for the study's variables was in line with the findings of Tamazian et al. [6], Shahnazi and Shabani [15], and Zhao and Yang [37]. This suggests that financial development promotes the adoption and financing of environmentally friendly projects, and financial development serves as the catalyst for lowering CO_2 emissions.

5.1. Policy Implications

- Policymakers should have a clear understanding of the type of relationship between economic development and CO_2 that take an inverted U-shape, which should be included in policy agendas.
- The fiscal policies of the G20 countries should be reviewed and redirected in order to reduce carbon dioxide emissions.
- Technology and financial development play a significant role in the G20 countries' efforts to cut carbon dioxide emissions, and governments should promote policies that support environmentally friendly technological innovations.

5.2. Policy Recommendation

The study findings lead to the following recommendations: (1) Closer attention should be paid to technology, especially those that support and adopt eco-friendly sectors that rely on environmentally friendly energy and promote technology that improve resource efficiency. (2) Financial growth should be encouraged so that it can offer the required assistance and funding for environmentally friendly initiatives and technology that reduces the carbon dioxide. (3) The applicable fiscal policy should be reexamined and redirected to assist clean energy projects, and incentives should be offered for initiatives that fight environmental deterioration.

Finally, this study emphasizes the significance of fiscal policy in the G20 countries in the context of the Environmental Kuznets Curve hypothesis. This sets the stage for future research to examine taxes and government spending independently from one another to better understand how each tool's impact may vary. Furthermore, it paves the way to investigate how different sources of carbon dioxide emissions, including gas and electricity consumption, are affected by fiscal policy so that the effects of financial policies on these sources of carbon dioxide emissions can be understood and clarified.

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