Environmental Science and Pollution Research (2023) 30:75183–75194
https://doi.org/10.1007/s11356-023-27733-4

RESEARCH ARTICLE

Effects of public expenditures on environmental pollution: evidence from G-7 countries

Ayfer Ozyilmaz[1] · Yuksel Bayraktar[2] · Mehmet Firat Olgun[3]

Received: 7 April 2022 / Accepted: 13 May 2023 / Published online: 22 May 2023

Abstract

In this study, the effect of public expenditures and, their sub-components on environmental pollution is discussed in G-7 countries. Two different periods were used in the study. These are the period 1997–2020 for general public expenditure, and the period 2008–2020 for public expenditure sub-components. For cointegration, Westerlund cointegration test was used, and according to the analysis result there is a cointegration relationship between general government expenditure and environmental pollution. Panel Fourier Toda-Yamamoto causality test was used to determine the causality relationship between public expenditures and environmental pollution and the result indicates that there is bidirectional causality between public expenditures and CO_2 on a panel basis. For models estimation, System the Generalized Method of Moments (GMM) method was used. The findings of the study indicate that general public expenditures decrease environmental pollution. Considering at the results of the sub-components of public expenditures, housing and community amenities, social protection, health expenditure, economic affairs, recreation, culture & religion expenditures have a negative effect on environmental pollution. Other control variables generally have a statistically significant effect on environmental pollution. Energy consumption and population density increase environmental pollution but environmental policy stringency index, renewable energy and GDP per capita reduce environmental pollution.

Keyword Government expenditures · COFOG · Fiscal policy · Environmental pollution · CO2

Introduction

In recent years, maintaining the balance between environmental quality and economic growth is one of the common goals of fiscal and monetary policies. Thus, ecological sustainability requires a common combination of monetary and fiscal policies. In this context, environmental quality is one of the main problems faced by the world in recent years (Ullah et al. 2021) In fact, the main purpose of fiscal policy instruments is to support the real economy rather than environmental quality (Yuelan et al. 2019). However, fiscal policy is an important public policy tool with its incentive mechanism for low carbon investment as well as influencing and managing the national economy (Kamal et al. 2021). Fiscal policies can be decisive in reducing the harmful impact on the environment with policies that will support the minimization of greenhouse gas emissions and R&D expenditures for renewable energy. Therefore, effective fiscal policies are of primary importance in minimizing pollution indicators (Ullah et al. 2021; Khan et al. 2021).

Fiscal policy plays an important role in reducing CO_2 emissions, which are the most dangerous environmental pollutants, especially arising from financial activities and rapid industrialization. Contrary to this fact, many researchers argue that the environment is a luxury good and that the focus should be on the environment only after other economic issues have been resolved (Abbass et al. 2021). Despite all this, environmental protection, climate change, and global warming have become issues of concern over the past few decades. Because CO_2 emissions and other greenhouse gases are the main cause of global warming that

Responsible Editor: Eyup Dogan

✉ Mehmet Firat Olgun
mfolgun@kastamonu.edu.tr

[1] Department of Foreign Trade, Kocaeli University, Kocaeli, Turkey

[2] Faculty of Political Sciences, Ankara University, Ankara, Turkey

[3] Technology Transfer Office, Kastamonu University, Kastamonu, Turkey

causes climate change. At this point, many researchers agree that CO2 emissions as an important source of global warming (Mallick and Tandi 2015).

The effect of public expenditures on environmental pollution occurs both directly and through transmission channels. The direct impact includes direct pollution by the consumption of energy-related products as well as other polluting products by the public, or direct public policies to improve the environment. When considered in the context of households, how the increased consumer incomes through public expenditures will affect the environment may differ depending on the local people (Adewuyi 2016).

Three mechanisms can be mentioned in the indirect effect of fiscal policy on the environment. These are the income effect, the composition effect, and the technical effect, respectively. According to the income effect, increased public expenditure increases income, which can increase the demand for a better environment. However, according to some studies, financial expenditures on education, health, research, and development sectors increase the current and future income of the consumer, which may deteriorate the environmental quality through the income channel. As a matter of fact, there is a large literature dealing with the relationship between growth and environmental pollution. According to the composition effect, increased fiscal spending encourages human capital-intensive activities that are less damaging to the environment than physical capital-intensive activities. As a result, human capital, and R&D investments, the development and widespread use of environmentally friendly production technologies cause pollution. According to the technical effect, increased labor productivity due to higher public spending in the health and education sectors leads to a reduction in environmental pollution (Kamal et al. 2021; Aysu et al. 2020; Yuelan et al. 2019; Olgun and Ozyilmaz 2020; Lopez et al. 2011; Lopez and Palacios 2010).

In this study, the effect of public expenditures on the environment in the G-7 countries is discussed. This study is expected to contribute to the literature in several ways. The first of these is to analyze the impact of public expenditure sub-components on environmental pollution as well as general public expenditures. The public expenditures variable is generally used in the studies. As far as we know, there are no studies investigating the environmental impact of all sub-components (According to the COFOG classification). Second, in addition to the coefficient estimation, the relationship between the variables was examined from different aspects, with both cointegration and current causality analyzes.

The remainder of the paper is organized as follows. In section 2 following the introduction, the literature review was examined, in section 3, the methods and data were presented, and in section 4, the analysis findings were discussed.

Literature

Studies investigating the relationship between public spending and environmental pollution have directly examined the impact of public spending or a few sub-components on the environment. In these studies, there is no consensus on how public expenditures will affect environmental pollution. While some studies focus on the direct relationship of public expenditures on pollution (He et al. 2017; Bernauer and Koubi 2006; Lopez and Palacios 2010), some studies focus on both direct and indirect effect channels (Zhang et al. 2017; Adewuyi 2016; Halkos and Paizanos 2013).

The main argument in studies suggesting that public expenditures increase environmental pollution is the scale effect. Accordingly, public expenditures increase economic activity, which leads to more pressure on the environment, thus, environmental pollution is increase even more. In this framework, Le and Ozturk (2020) analyzed the effects of globalization, financial development, public expenditures, and institutional quality on CO_2 emissions in 47 Emerging Market and Developing Economies (EMDEs) within the framework of the EKC hypothesis. According to the study, public expenditures increase CO_2 emissions. According to the study, increased public expenditures can positively affect economic activities, and increased trade and investments through this channel can increase CO2 emissions with a scale effect. Kamal et al. (2021) discussed the fiscal policy and the impact of some variables on environmental pollution in 105 countries. They found that public expenditures significantly increase environmental pollution. On the other hand, public expenditures on education, health, research, and development sectors can increase environmental degradation by increasing income. However, public expenditures on public transport and environmental regulations within the scope of green energy can positively affect environmental quality.

Mohammed Saud et al. (2019) investigated the effect of public spending on environmental degradation in the context of the environmental Kuznets curve (EKC) hypothesis in Venezuela. According to the study, public expenditures increase carbon emissions in the atmosphere not only in the long run but also in the short run. The study findings support scale effects, which suggest that government spending will increase economic activity and this will increase environmental pollution. So, the scale effect is stronger in Venezuela. Yuelan et al. (2019) analyzed the impact of fiscal policy on the environment in China. The findings reveal that public expenditures increase environmental degradation in China. Morshed et al. (2018) discussed the relationship between public spending and environmental quality in

Bangladesh. In the study, it has been revealed that public expenditures deteriorate air quality and consume resources in the long run. The fact that public expenditures in Bangladesh support urbanization, which causes deforestation in the long run, is one of the reasons that public expenditures increase environmental pollution. Bernauer & Koubi (2006), discussed the relationship between public spending and SO2 concentrations in 42 countries. According to the study, public expenditure increases SO2. The study also found unidirectional causality from CO2 emissions to public expenditures in the long run.

On the other hand, according to the view that public expenditures reduce environmental pollution, public expenditures increase income, and increased income strengthens environmental awareness and, increases the demand for a better environment. For example, Ullah et al. (2021) analyzed the effects of monetary and fiscal policy instruments on environmental pollution in Pakistan. According to the study, positive and negative shocks in monetary policy instruments increase environmental pollution in the short run, but positive and negative shocks in fiscal policy instruments reduce environmental pollution in the long run. Therefore, the fiscal policy helps to improve environmental quality by reducing carbon pollution in Pakistan. According to the study, it can be determinative that public expenditures on education and health have a positive effect on environmental quality through the income channel and this effect is stronger than physical capital. Mughal et al. (2021) discussed the effects of monetary and fiscal policies on environmental quality in ASEAN countries. According to the study, expansionary fiscal policy reduces CO_2 emissions. Because ASEAN economies allocate a significant share to public expenditures to improve environmental quality such as health, education, green transportation, environmental protection and green infrastructure. Bulus and Koc (2021) found that public spending reduces CO_2 emissions in Korea. In these results, Korea's role in green growth could be decisive These findings show that public spending in Korea is beneficial to the environment. Zeraibi et al. (2021) discussed the relationship between public spending and environmental degradation in 31 Chinese provinces. Accordingly, government expenditures have a direct impact on improving environmental quality in provinces with increasing economic growth in China. Huang (2018) analyzed the impact of government spending on environmental protection in China. According to the study, government spending on environmental protection reduces SO2 emissions. Katırcıoğlu and Katırcıoğlu (2018) investigated the effect of expansionary fiscal policy on CO_2 emissions in Turkey. According to the study, fiscal policies reduce pollution levels. On the other hand, the findings confirm the validity of the fiscal policy-based EKC hypothesis and suggest that there is a long-term equilibrium relationship between fiscal development and carbon emissions in Turkey through energy consumption and real income growth. Halkos and Paizanos (2016) discussed the effect of expansionary fiscal policy on CO_2 in the USA. According to the study, public expenditures have a negative impact on CO_2 emissions from both production and consumption generated CO2 emissions. According to the study, the fact that the income effect, which suggests that public expenditures will reduce environmental pollution in developed countries such as the USA, is stronger than the scale effect, which has the opposite effect, may be decisive. Lopez and Palacios (2010) analyzed the role of public expenditures and energy taxes on environmental quality in 21 European countries, and it was concluded that there is a negative relationship between public expenditures and air pollution. In many European countries, priority policies for the provision of public goods have resulted in a positive impact of public expenditure on the environment.

In some studies, the relationship between public expenditures and environmental pollution is analyzed both directly and through transmission channels. For example, Zhang et al. (2017) found that both direct and indirect effects (via GDP) of public expenditures in China were determined by different pollution indicators (SO2, soot, and COD) have been dealt with. According to the study, the estimated total impact of public spending is negative for SO2 and SOD, but positive for SOOT after per capita GDP reaches $7500. The indirect impact of public expenditures depends on the impact of per capita GDP on environmental quality. As GDP per capita increases, SO2 and SOOT emissions show a downward trend; COD continues to increase. Adewuyi (2016) discussed the impact of household, firm, and public expenditures on total and sectoral carbon emissions in world economies. According to the study, public expenditures affect total carbon emissions negatively. On the hand, the negative direct effect of government expenditures weakens the positive indirect effects and increases the total carbon emissions in the long run. Halkos and Paizanos (2013) investigated the impact of public spending on the environment in 77 countries. According to the study, public expenditures have both direct and indirect effects on pollution. The indirect effect occurs when public expenditures affect income and income affects pollution. In direct effects, public expenditures reduce SO2 but are statistically insignificant for CO_2. In indirect effects, as the income level increases, public expenditures increase SO2 emissions and decrease CO_2 emissions. In this context, in countries with higher income levels, reducing government expenditures leads to improvements in both income and environmental quality.

In some studies, the relationship between public expenditures and pollution has been categorized and discussed. One of the focal points of the study is to investigate the impact of its sub-components on the environment as well as public expenditures. When the existing literature on this subject is examined, it is seen that the sub-components used are limited and the effect of all public expenditure components has not been investigated. For example, Abbass et al. (2021) estimated the impact of total expenditures, education expenditures, and health expenditures on CO_2 emissions in Pakistan. According to the study, public expenditures in the public sectors (education and health) reduce CO_2 emissions. Public services lead to lower CO2 emissions when compared to the real sector, and therefore, it is an expected result that increased public service expenditures will reduce pollution. In addition, spending on the education sector can reduce pollution by increasing the workforce focused on clean production technology in R&D. Aysu et al. (2020) discussed the impact of public spending on CO_2 in 30 countries. According to the study, public expenditures reduce CO_2 emissions. Because the environment is a luxury good, the growth of the public sector primarily contributes to the provision of basic public services and then to improving environmental quality. And public expenditures were also classified and it was revealed that the findings differ. In this context, the increase in expenditures on economic services, education, and social protection services positively affect environmental quality however, general public services, health, and environmental protection services do not have a statistically significant effect on carbon dioxide emissions. It is an expected result that education expenditures will have a positive impact on the environment by contributing to the accumulation of human capital. In addition, social transfers aimed at improving income distribution increase the demand for environmental quality and thus positively affect environmental quality. On the other hand, the reason why general public services are statistically insignificant can be the diversity of expenditure types included in this service group. And the low share of environmental protection services in total expenditures may be determinative in the fact that environmental protection expenditures are not statistically significant. Hua et al. (2018) examined the impact of public expenditures on the environment in China through direct and indirect channels. In the study, both general public expenditures and some of their sub-components were used. According to the study, education and R&D expenditures reduce environmental pollution in some regions and pollution indicators, but this effect is slight, and in others, it is statistically insignificant. The impact of education expenditures is stronger than R&D expenditures. This weak effect of R&D expenditures may be due to the fact that companies do not care enough about pro-environmental technologies. On the other hand, general public expenditures increase environmental pollution.

In addition, there are studies in the literature suggesting that the relationship between public expenditures and pollution differs according to region/country or different parameters. For example, He et al. (2017) analyzed the impact of local government investments on CO_2 emissions in China. According to the study, local government investments reduce carbon emissions, but this effect differs according to region. This effect is significant in the western and central regions of China but statistically insignificant in Eastern and Northeastern regions. The impact of public investments on CO_2 is stronger, especially in regions where investments in energy-saving technologies are increasing. Galinato and Islam (2017) discussed how public expenditures affect consumption-based pollution in 33 countries. According to the study, government spending mitigating market failure affects consumption pollution through two balancing mechanisms. These are the income channel of consumers, which can increase consumption pollution, and the regulatory tax channel on firms, which can reduce consumption pollution. When the second effect dominates the first, consumption pollution decreases as spending on public goods increases. The overall effect of spending on public goods reduces pollution from consumption in democratic countries because the effect through regulation outweighs the effect through income. When the government is autocratic, the results are the opposite.

Discussing the relationship between public expenditures and environmental pollution in the context of causality, Akbar et al. (2021) analyzed the relationship between fiscal policy instruments (government expenditures and tax revenues) and CO_2 emissions in the transport, industry, electricity, and heat sectors for BRI. The findings suggest that there is a strong correlation between fiscal policy instruments and CO_2 emissions in the industry, electricity, and transport sectors. The study also highlighted that public expenditures are stronger policies to reduce CO2 emissions in the transport and industrial sectors. Özcan and Karter (2020) discussed public expenditures and the impact of terrorism on the environment in countries where terrorism is intense. Empirical findings are generally indicate that public expenditures are the cause of environmental degradation. On the country level, the existence of a causal relationship between the variables was determined.

In some studies, it is claimed that public expenditures are not effective on pollution. For example, Ozmen et al. (2022) investigated the impact of fiscal policies on the environment in some selected developed countries. According to the study findings, the impact of public expenditures are not effective environment pollution. Othman et al. (2020) analyzed the impact of public spending on CO_2 emissions in Malaysia. According to study, public expenditures do not directly contribute to the reduction in CO_2 emissions.

Data and methods

In this study, the effect of public expenditures on the environment pollution is discussed the period of 1997–2020 in G7 countries. Cointegration test, causality test and System GMM were used in the study. For causality and cointegration, panel Fourier-Toda Yamamoto causality test and Westerlund (2008) cointegration test was used respectively, and for model estimation System GMM methods were used. In addition to public expenditures, sub-components of public expenditures were also used and the United Nations' COFOG (Classification of Government Functions) was taken as a basis in the classification of public expenditure. For public expenditures sub-components the period of 2008–2020 was used. The reason why the sub-components of public expenditures are used for different periods is the accessibility of the data. The variables used in the analysis and their sources are given in Table 1.

Ten models were used in the study. In Model 1, general public expenditures are used as well as control variables. Model 2—Model 10 include public expenditure sub-components according to the COFOG classification. Environmental protection expenditure data in the USA are included in the housing and community amenities expenditure (Halkos and Paizanos 2016), therefore, environmental protection expenditures of other countries are combined with the housing and community amenities expenditure. The econometrics models are defined as follow:

Model 1

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LGOV_{it} + \beta_4 LEPSI_{it} + \beta_5 LPOPDENS_{it} + \beta_6 LRENW_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

Model 2

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LEPSI_{it} + \beta_4 LPOPDENS_{it} + \beta_5 RENW_{it} + \beta_6 LGPS_{it} + \mu_i + \varepsilon_{it} \quad (2)$$

Model 3

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LEPSI_{it} + \beta_4 LPOPDENS_{it} + \beta_5 RENW_{it} + \beta_6 LDEF_{it} + \mu_i + \varepsilon_{it} \quad (3)$$

Model 4

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LEPSI_{it} + \beta_4 LPOPDENS_{it} + \beta_5 RENW_{it} + \beta_6 LPOS_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

Model 5

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LEPSI_{it} + \beta_4 LPOPDENS_{it} + \beta_5 RENW_{it} + \beta_6 LEA_{it} + \mu_i + \varepsilon_{it} \quad (5)$$

Model 6

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LEPSI_{it} + \beta_4 LPOPDENS_{it} + \beta_5 RENW_{it} + \beta_6 LHCA_{it} + \mu_i + \varepsilon_{it} \quad (6)$$

Model 7

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LEPSI_{it} + \beta_4 LPOPDENS_{it} + \beta_5 RENW_{it} + \beta_6 LHE_{it} + \mu_i + \varepsilon_{it} \quad (7)$$

Model 8

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LEPSI_{it} + \beta_4 LPOPDENS_{it} + \beta_5 RENW_{it} + \beta_6 LEE_{it} + \mu_i + \varepsilon_{it} \quad (8)$$

Table 1 Description of variables

Variables	Descriptions	Sources of data
LCO2	CO2 emissions (metric tons per capita)	OECD
LGDP	GDP per capita (constant 2015 US$)	World Bank Open Data
LENERGY	Energy consumption per capita (kWh)	Our World in Data
LGOV	General government total expenditure (% of GDP)	OECD, World Bank TCdata360
LEPSI	Environmental Policy Stringency Index	OECD
LRENW	Renewable Energy (% of Primary Energy Supply)	OECD
LPOPDENS	Population Density (people per sq. km of land area)	World Bank Open Data
LGPS	General public services expenditure (% of GDP)	OECD
LDEF	Defence expenditure (% of GDP)	OECD
LPOS	Public order and safety expenditure (% of GDP)	OECD
LEA	Economic affairs expenditure (% of GDP)	OECD
LHCA	Housing and community amenities expenditure (% of GDP)	OECD
LHE	Health expenditure (% of GDP)	OECD
LEE	Education expenditure (% of GDP)	OECD
LRCR	Recreation, culture&religion expenditure (% of GDP)	OECD
LSP	Social protection expenditure (% of GDP)	OECD

L indicates that the natural logarithm of the variable is taken

Model 9

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LEPSI_{it} + \beta_4 LPOPDENS_{it} + \beta_5 RENW_{it} + \beta_6 LRCR_{it} + \mu_i + \varepsilon_{it} \quad (9)$$

Model 10

$$LCO_{2,it} = aLCO_{2,it-1} + \beta_1 LGDP_{it} + \beta_2 LENERGY_{it} + \beta_3 LEPSI_{it} + \beta_4 LPOPDENS_{it} + \beta_5 RENW_{it} + \beta_6 LSP_{it} + \mu_i + \varepsilon_{it} \quad (10)$$

In this study, the causality relationship between public expenditures and CO2 emissions was examined using the panel causality test with a Fourier Function developed by Yilanci and Gorus (2020). This test also called the panel Fourier Toda-Yamamoto approach (Yilanci and Gorus 2020). Fourier Function was added to the causality test developed by Emirmahmutoglu and Kose (2011) in the Fourier Toda-Yamamoto panel causality approach. Emirmahmutoglu and Kose (2011) developed the panel causality test in which the causality relationship can be examined regardless of the level of stationarity and cointegration relationship of the series based on the Toda and Yamamoto (1995) causality test. The model for this test can be represented as follows:

$$y_{it} = \mu_i + \sum_{j=1}^{k_i+dmax_i} A_{11} y_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{12} x_{i,t-j} + u_{i,t} \quad (11)$$

$$x_{it} = \mu_i + \sum_{j=1}^{k_i+dmax_i} A_{21} y_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{22} x_{i,t-j} + u_{i,t} \quad (12)$$

Yilanci and Gorus (2020), on the other hand, added the Fourier function to the test developed by Emirmahmutoglu and Kose (2011) and developed a panel causality test in which structural changes can be monitored. The model for the panel Fourier Toda-Yamamoto panel causality test is as follows:

$$y_{it} = \mu_i + \sum_{j=1}^{k_i+dmax_i} A_{11} y_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{12} x_{i,t-j} + A_{13} \sin\left(\frac{2\pi t f_i}{T}\right) + A_{14} \cos\left(\frac{2\pi t f_i}{T}\right) + u_{i,t} \quad (13)$$

$$x_{it} = \mu_i + \sum_{j=1}^{k_i+dmax_i} A_{21} y_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{22} x_{i,t-j} + A_{23} \sin\left(\frac{2\pi t f_i}{T}\right) + A_{24} \cos\left(\frac{2\pi t f_i}{T}\right) + u_{i,t} \quad (14)$$

Here t; trend, T; the number of observations, and f indicates the optimal frequency value, the value of which can be determined by the information criteria. In this test, causality results are given for each unit and panel. The basic hypothesis states that there is no causality. Critical values and p values are calculated with the bootstrap method (Yilanci and Gorus 2020).

The System GMM method was used in the estimation of the models. This method was developed by Arellano and Bover (1995), Blundell and Bond (1998). The System GMM method gives efficient estimation results against the endogeneity problem, sample bias and omitted invariant variables. (Caporale et al. 2015; Heo et al. 2021). The system GMM equation is as follows.

$$y_{it} = ay_{i,t-1} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (15)$$

here y_{it} is dependent variable, $y_{i,t-1}$ is lag of dependent variable, X_{it} is the independent variable vector, β' is the estimated coefficient vector, μ_i is the unobserved random variables, ε_{it} is the random error term.

The validity of autocorrelation and instrument variables should be tested to determine whether the results from the System GMM estimation are valid. Arellano and Bond (1991) test is used to test the autocorrelation in the system GMM method. The null hypothesis shows that there is no autocorrelation. First-order autocorrelation is not a problem. However, there must be no second autocorrelation for the estimates to be effective. Hansen (1982) test tests the validity of instrument variables. The basic hypothesis shows that the instrumental variables are valid. If the basic hypothesis is rejected, it is decided that the instrumental variables are endogenous, if the basic hypothesis cannot be rejected, the instrumental variables are valid. If the probe value is greater than 0.01, 0.05, 0.1, it is decided that the basic hypothesis cannot be rejected at the 1%, 5%, and 10% significance level.

Results and discussion

In this study, cross-section dependency was tested to determine which unit root test to use. CIPS and MADF unit root tests, which are among the second generation unit root tests, were used because there is a cross-section dependency in the series. According to the unit root test results, the series are stationary in different level and therefore, the long-term relationship between the series was examined using the Westerlund cointegration test, which takes into account heterogeneity. The results of the basic tests are given in Appendix Table 4.

According to Westerlund's (2008) cointegration test results, there is a cointegration relationship between the series. The existence of a cointegration relationship indicates that there is a long-term relationship between general public expenditures and environmental pollution. In addition to the cointegration relationship, the causality relationship between public expenditures and environmental pollution was also investigated. Since the data on public expenditures sub-components are limited (covering the short term), these tests were not included.

The analysis findings obtained by using panel Fourier Toda-Yamamoto causality test results are given in in Table 2.

Looking at the panel Fourier Toda Yamamoto results, it is seen that there is bidirectional causality between public expenditures and CO_2 on a panel basis.

There is an endogeneity problem between public expenditures and environmental pollution (Halkos and Paizanos 2013; Liu et al. 2018). In the case of endogeneity, the estimates are biased due to unobservable heterogeneity. In this case, Instrumental Variables (IV) method or Generalized Method of Moments (GMM) methods are used to obtain consistent estimation results (Das Panchanan 2019). Due to the endogeneity problem, there are many studies investigating the relationship between public expenditures and environmental pollution using GMM or Two-Stage Least Squares methods (see Halkos and Paizanos 2013; Zhang et al. 2017; Prasetyani et al. 2021; Khan et al. 2020; Zeraibi et al. 2021; Song et al. 2020). In this study, for the main model and sub-components models estimated using System GMM method. All model findings are presented in Table 3.

Considering to System GMM estimation results in Table 3, energy consumption (per capita) and population density (people per sq. km of land area) increase carbon emissions per capita, while general government total expenditure (% of GDP), environmental policy stringency index and income per capita reduces carbon emissions in Model 1. It is seen that the most effective variable on carbon emissions is energy consumption per capita, as expected. A 1% increase in energy consumption per capita increases carbon emissions per capita by 0.097%. After energy consumption, the variable that affects carbon emissions is public expenditures. If public expenditures increase by 1%, carbon emissions decrease by 0.091% (ceteris paribus). That is, the public expenditure elasticity of carbon emissions is 0.09.

When the results of the effect of public expenditures sub-components on carbon emissions are examined in models 2–10, all main variables have a statistically significant effect on carbon emissions in the models. Energy consumption (per capita) and population density (people per sq. km of land area) increase carbon emissions per capita, while renewable energy (% of primary energy supply), environmental policy stringency index and income per capita reduces carbon emissions.

It is seen that the variables of economic affairs have a statistically significant and negative effect on carbon emissions. If economic affairs increase %1 carbon emissions increase %0.06 units (ceteris paribus). Housing and community amenities variable has the strongest effect on carbon emissions. Environmental protection expenditures are also included in this variable. It is seen that the variable has a negative effect on carbon emissions. This result is in line with expectations. A %1 increase in housing and community amenities reduces carbon emissions by %0.084 units. On the other hand, social protection, health expenditure and housing and community amenities also show a more significant effect on carbon emissions compared to other sub-indicators. The variable that has the least effect on carbon emissions is recreation, culture&religion expenditure. A 1% increase in recreation, culture religion expenditure reduces carbon emissions by %0.017.

Table 2 Panel Fourier Toda Yamamoto test results

	$H_0: Gov \nrightarrow CO2$		$H_0: CO2 \nrightarrow Gov$	
Test	Test statistics	*p* value	Test statistics	*p* value
Panel fisher	28.045	0.014	22.047	0.077
Bootstrap cv (%10)	21.577		21.134	
Bootstrap cv (%5)	24.609		23.933	
Bootstrap cv (%1)	31.045		29.521	

Critical values were obtained with 10.000 bootstrap.$\nrightarrow$ shows that there is no causality

Conclusions

In the world, increasing population and consumption mostly deepens environmental problems. Despite the increase in efforts to reduce pollution, which has become one of the important topics of discussion in recent years, it is impossible to talk about the existence of a strong policy in the world. Although raising awareness of individuals is an important step, public support is important at this point. Focusing on environmental problems as much as income, may enable stronger policies to be developed in the solution of the problem. Although the importance of public policies in minimizing environmental problems is mentioned, it is impossible to talk clearly about the direction of this effect. Because public expenditures have both direct and indirect effects on the environment. In particular, providing support for environmentally friendly investments can cause public policies to reduce environmental pollution.

Table 3 Estimation results

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
L.LCO2	0.945*** (0.013)	0.956*** (0.013)	0.955*** (0.012)	0.953*** (0.014)	0.931*** (0.010)	0.866*** (0.025)	0.969*** (0.013)	0.939*** (0.021)	0.927*** (0.015)	0.845*** (0.024)
LGOV	−0.091*** (0.032)	–	–	–	–	–	–	–	–	–
LENERGY	0.097*** (0.018)	0.129*** (0.018)	0.120*** (0.027)	0.100*** (0.025)	0.130*** (0.026)	0.220*** (0.037)	0.075** (0.030)	0.097*** (0.033)	0.150*** (0.021)	0.231*** (0.036)
LEPSI	−0.018* (0.010)	−0.063* (0.038)	−0.066* (0.0400)	−0.082* (0.050)	−0.059* (0.035)	−0.058* (0.035)	−0.050 (0.037)	−0.092* (0.052)	−0.083** (0.042)	−0.106** (0.040)
LGDP	−0.061*** (0.020)	−0.126*** (0.017)	−0.114*** (0.027)	−0.101*** (0.021)	−0.137*** (0.024)	−0.230*** (0.041)	−0.095*** (0.025)	−0.092*** (0.032)	−0.146*** (0.022)	−0.244*** (0.037)
LRENW	0.001 (0.005)	−0.009 (0.008)	−0.014*** (0.005)	−0.013** (0.005)	−0.019*** (0.006)	−0.039*** (0.013)	−0.028*** (0.009)	−0.024** (0.010)	−0.006 (0.008)	0.008 (0.010)
LPOPDENS	0.012*** (0.004)	0.017*** (0.004)	0.015** (0.006)	0.010* (0.005)	0.014** (0.005)	0.023*** (0.008)	−0.0007 (0.008)	0.004 (0.01)	0.017** (0.007)	0.050*** (0.010)
LGPS		−0.006 (0.011)								
LDEF			−0.005 (0.007)							
LPOS				−0.035 (0.029)						
LEA					−0.064*** (0.013)					
LHCA						−0.084*** (0.016)				
LHE							−0.139*** (0.047)			
LEE								−0.055 (0.039)		
LRCR									−0.017** (0.007)	
LSP										−0.145*** (0.028)
AR (1) (Prob)	−2.21 (0.027)	−1.80 (0.072)	−1.79 (0.074)	−1.77 (0.077)	−1.90 (0.058)	−1.71 (0.088)	−1.86 (0.063)	−1.79 (0.074)	−1.76 (0.079)	−1.85 (0.064)
AR (2) (Prob)	0.39 (0.696)	−0.09 (0.930)	−0.10 (0.920)	−0.11 (0.913)	0.08 (0.939)	−0.14 (0.887)	−0.04 (0.966)	−0.06 (0.949)	−0.07 (0.943)	0.04 (0.966)
Hansen Test (Prob)	0.08 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	1.72 (1.000)
Diff-Hansen Test (Prob)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	1.72 (0.887)
Period	1997–2020	2008–2020								

***,** and * indicates that the series is statistically significant at the 1%, 5% and 10% significance level. Values in parentheses indicate the std. error

In this context, the effect of public expenditures and subcomponents on environmental pollution is analyzed in the G7 countries. For general government expenditure and for subcomponents of general public expenditure 1997–2020 and 2008–2020 periods are used respectively. The cointegration relationship and causality relationship between general government expenditure and environmental pollution were investigated using Westerlund cointegration and Fourier Toda-Yamamoto causality tests. According to the Westerlund Cointegration test, there is a cointegration relationship between the public expenditures to environmental pollution. Fourier Toda-Yamamoto causality tests result indicates that there is bidirectional causality between public expenditures and CO2 on a panel basis. System GMM method was used for coefficient estimation for all models. According to model findings, general public expenditures decrease environmental pollution for G-7 countries. In obtaining these findings, developed countries' policies towards environmentally friendly technologies can be decisive.

Findings for public expenditures sub-components generally support each other in the models. In this context, housing and community amenities, social protection, economic affairs, recreation, culture&religion expenditures and health expenditure have a negative effect on environmental pollution. On the other hand, according to the findings of other control variables in the study energy consumption and population density increase environmental pollution but environmental policy stringency index, renewable energy and GDP per capita reduce environmental pollution.

The findings are mostly in line with expectations. For example, general public services consist of R&D general public services, Executive and legislative organs, public debt transactions, financial affairs, foreign aid, and general service etc. These expenditures are mostly not directly effective on environmental pollution. Therefore, it is an expected finding that this expenditure is statistically insignificant on environmental pollution. Similarly, public order and safety expenditures are also statistically insignificant. These expenditure components consist of Fire-protection services, police services, R&D public order and safety, prisons, etc. Since these expenditures consist of expenditures that do not directly cause pollution, it is an expected result to be statistically insignificant. With spending on housing and community amenities, the public sector can reduce environmental pollution by replacing the private sector, which puts more pressure on the environment. On the other hand, this expenditure component also includes public expenditures for environmental protection, so it is expected result that this variable will reduce environmental pollution. Recreation, culture, and religion expenditures, which include entertainment, broadcasting, sports, religion, and social services, do not consist of expenditures that are directly related to the environment. On the contrary, it supports the sectors that do not affect the environmental pollution, not the sectors that cause environmental pollution. For this reason, it is possible that these expenditures reduce environmental pollution.

Our findings are in line with many studies Ullah et al. (2021), Mughal et al. (2021), Zeraibi et al. (2021), Huang (2018), Katırcıoğlu and Katırcıoğlu (2018), (2016). Halkos and Paizanos (2016) suggesting that general public expenditures increase environmental pollution. Our findings are also supported by the following studies for the sub-components of public expenditures. Abbass et al. (2021), who emphasized the reducing effect of health expenditures on environmental pollution, reached similar findings. In addition, our results are in line with the study of Aysu et al. (2020), who found that general public service expenditures were statistically insignificant on environmental pollution.

The effect of public expenditures on environmental pollution reveals that these expenditures are a policy tool that can be used to reduce environmental problems. At this point, it is important to support environmentally friendly investments in order for public expenditures to reduce environmental pollution. The public sector can play an active role in the environment, sometimes by subsidizing environmentally friendly investments, and sometimes by making these projects mandatory for businesses.

Appendix

Table 4

Table 4 Cross-sectional dependency, unit root and cointegration test results

Cross-sectional dependency (for variables)					
Variables	CD_{BP}(T > N)		Pesaran (2004) CD (N > T)	Pesaran, Ullah and Yamagata (2008) LM_{adj}	
LCO2	330.6204***		17.615***	47.623***	
LGDP	320.909***		14.404***	46.124***	
LENERGY	432.049***		20.762***	63.274***	
LGOV	212.573***		12.644***	29.408***	
LESPI	404.829***		20.079***	59.074***	
LRENW	40.200***		2.417***	43.799***	
LPOPDENS	222.910***		9.022***	31.003***	
	Pesaran (2007) CIPS unit root test			Sarno (1998) MADF unit root test	
	Constant	Constant + Trend	First difference	Constant	First difference
LCO_2	−2.363**	−2.643	−4.738***	12.213	59.523***
LGDP	−1.702	−2.613	−3.066***	15.337	76.343***
LGOV	−2.285*	−1.860	−4.555***	27.506	61.603***
LENERGY	−3.195***	−3.682***	−5.398***	7.864	61.181***
LESPI	−3.004***	−2.335	−5.466***	53.856***	67.558***
LRENW	−1.354	−2.073	−4.575***	28.860	46.328***
LPOPDENS	−1.777	−1.605	−1.358	56.916***	29.838*
Bruesch Pagan (1980) cross-sectional dependency test results (for residuals)					
LM		134.928*** (0.000)			
Swamy(1970)-Pesaran and Yamagata (2008) Homogeneity test results					
Swamy(1970) S Test		99.248*** (0.000)			
$\widetilde{\Delta}$		908.36*** (0.000)			
$\widetilde{\Delta}_{adj}$		1135.45*** (0.0000)			
$\widehat{\Delta}$		6.246*** (0.0000)			
$\widehat{\Delta}_{adj}$		0.3009 (0.3817)			
Westerlund (2008) Cointegration test					
DH_g		4.843*** (0.000)			
DH_p		0.666 (0.253)			

*** indicate that the series are statistically significant at the 1% significance level

Author contributions Conceptualization, AO and YB; methodology and formal analysis, MFO.; writing—original draft preparation, writing—review and editing, visualization, and supervision were carried out by AO, YB and MFO.

Data availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflicts of interest The authors declare no conflict of interest.

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