International Journal of Contemporary Economics and Administrative Sciences
ISSN: 1925 – 4423
Volume: XV, Issue: 2, Year: 2025, pp.757-781

Impact of Trade Openness, Green Energy, Economic Growth and Military Expenditures on Carbon Emissions in E-7 Countries: Panel Quantile Regression

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Received:03.05.2025, Accepted: 23.12.2025
10.5281/zenodo.18147030

Abstract

Increasing economic growth and environmental improvement are the ways to achieve sustainable development goals. In developing countries, increases in military expenditures, which are part of public expenditures, and the level of foreign trade may affect environmental quality. This study examines the impact of economic growth, trade openness, green energy and military expenditures on carbon emissions in E-7 countries for the period 1993-2023. The results confirm the existence of cross-sectional dependence, slope heterogeneity and cointegration relationship among the variables. Panel quantile regression results show that economic growth and trade openness increase carbon emissions and decrease environmental quality, while green energy and military expenditures reduce carbon emissions and increase environmental quality. The results are checked for robustness using FMOLS, DOLS, FE-OLS and Driscoll-Kraay estimators' long-term estimators and the results confirm the quantile regression results. These results provide important policy insights for E7 countries, which have significant potential in terms of the world economy. The study findings provide a broad perspective on environmental problems.

Key words: Trade Openness, Green Energy, Economic Growth, Military Expenditure, Carbon Emissions, Panel Quantile Regression

JEL Code: F18, F43, Q51, C33

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1. Introduction

Climate change, global warming, greenhouse gas emissions and similar issues remain topical and important on a global scale. The creation of a livable environment within the context of sustainable development is not a matter of national or international desire; rather, it is an obligation that must be fulfilled (Mihai et al., 2023; Türkeş, 2024). In this context, research planned at identifying the essence causes of environmental degeneration and at mobilizing policy makers to address these issues is crucial (Mao & Li, 2024).

One of the most important factors affecting economic welfare is the quest for economic growth. Economic growth is the main aim for countries and brings with it challenges related to environmental sustainability. Human beings are in steady pursuit of their essential needs, and the energy required to meet these needs is a crucial component of that pursuit. However, increase in carbon emissions has a negative impact on environmental quality. Using fossil fuels to make energy leads to more production, which causes damage to the environment because of CO2 emissions (Bayar & Dabakoglu, 2024). The first stage of economic growth is frequently related to carbon emissions, a consequence of heightened industrial activity and increased energy consumption. Many studies have shown that the energy used for industrialisation, which is often linked to economic growth, leads to higher CO2 emissions (Sarkodie et al., 2020). Similarly, it has shown that economic growth leads to higher energy consumption, which causes more damage to the environment. Another factor affecting economic growth and environmental quality is economic integration and globalisation. Environmental degradation has increased dramatically with the rise in carbon emissions caused by industrial expansion. (Cengiz et al., 2025).

Determining the effect of military expenditure on environmental quality is a critical issue that must be examined. The primary objective of national defence is to protect the sovereignty and benefits of the nation. It is crucial for armies to ensure regional and global stability. (Ramos & De Melo, 2005). Military expenditures are closely related to countries' threat perceptions. The enemy state's measures regarding arms build-up, the possibility of terrorist attacks and increasing global security concerns are driving an arms competition. Regions with less geopolitical tension are associated with relatively modest expenditures on defence. Military expenditure is a significant factor in protecting a nation's sovereignty. Yet it also plays a significant role in helping to boost demand, develop infrastructure, increase production, reduce unemployment and promote overall economic growth. Nevertheless, it has been proven that the increased use of fossil fuels in military spending and operations causes an increase in CO2 emissions and negatively impacts the environment. Amidst armed conflicts, the natural world suffers radical changes, affecting all life forms in its ecosystem. This violence against living and non-living components of nature is a consequence of armed conflicts. During periods of peacetime, the defence industry's expenditure and preparations for war contribute to increased CO2 emissions (Dudley et al., 2002).

Many studies have shown a link between military spending and carbon emissions, and a direct relationship between military spending and environmental degradation (Gökmenoğlu et al., 2020). The use of military equipment, together with the intensive consumption of fossil fuels, leads to the generation of significant amounts of waste material. These materials have the potential to contaminate water and soil with harmful substances (Jorgensen & Clark, 2009). Studies have shown that military expenditure causes atmospheric destruction by increasing toxic emissions and energy consumption (Zandi et al., 2019). Military forces that are prepared for emergency situations engage in a kind of activity. The operation of these activities has been demonstrated to result in adverse effects on the natural environment. As Bradford (2017) points out, the existence of capital-intensive armies has negative effects on the environment, which leads to increased carbon emissions. This view is also supported by Jorgensen & Clark (2009), who argue that military activities have a damaging effect on environmental sustainability. In addition, the environmental impact of military expenditure extends beyond the issue of emissions. For instance, Neimark emphasises the significant carbon footprint of the military during wartime and conflict (Neimark, 2023).

The selection of the E-7 countries as the sample group in this study was a carefully considered action. The E7 countries, with half of the world's population, have become the key players in the global market for goods and services due to their production factors and capacities. According to an analysis conducted by the accounting firm Price Waterhouse Coopers (PWC) in 2011, the E7 countries were expected to pass the G7 countries in terms of economic size by 2020. This prediction, which was expected to be realized in 2020, came to pass sooner, with the economies of the E7 countries surpassing those of the G7 countries. A further analysis by the same company predicts that by 2050, the E7 countries will have a GDP that is 25-75 per cent higher than that of the G7 countries (PWC, 2019). It is likely that these predictions regarding the economies of these country groups will become a reality sooner. In 2018, these countries accounted for 47% of the world's population, 26% of global GDP and over 40% of global energy consumption. It is estimated that the economies of the E7 countries will expand at an average annual rate of 3.5% between 2016 and 2050, whereas the rate for the developed G7 countries is expected to be 1.6% (Aydoğan & Vardar, 2020). Current projections imply that these developing countries will exceed the purchasing power of the G7 by the year 2050. It is evident from an analysis of economic data and projections that the E7 countries have significant economic influence on the global economy, both in the present and with respect to future projections.

According to the Global Carbon Project 2022, China alone accounts for 11.4% of global carbon production. According to data from the same study, all E7 countries are among the top twenty countries with the highest CO_2 emissions. It is anticipated that the utilisation of renewable resources in place of fossil fuels for the purpose of energy generation will result in a reduction in the volume of carbon emissions released into the environment. Global Carbon Project reports have shown that fossil fuels are the largest source of carbon emissions worldwide. This is because fossil fuels, when burned, release carbon dioxide (76% of the world's greenhouse gases), the most important greenhouse gas (International Energy Agency IEA, 2012). Consequently, the demand for renewable energy production and consumption is increasing on a daily basis worldwide. The present study analyses the effect of economic growth, trade openness, renewable energy, military spending and population on CO_2 emissions in the E7 countries. A review of the literature shows that the correlation between military expenditures and the environment has been analyzed for many different groups of countries (G7, Developed and Developing Countries, African Countries, Asian Countries, etc.). When considering the E7 countries in the studies on military expenditure and the environment, the countries in the E7 group have been examined separately. Some of these studies focus on Brazil (Bildirici, 2018), China (Wang et al., 2021), India (Wang et al., 2021), Indonesia (Uddin et al., 2024), Russia (Isiksal, 2021), and Turkey (Gökmenoğlu et al., 2020). This study seems to be the first to analyse the environmental impacts in E7 countries using the variables of economic growth, renewable energy, trade openness, and military expenditure. The first part of the study consists of an introduction and a literature review. The following section provides explanatory information about the variables and empirical findings, along with the data set.

2. Literature Review

The relationship between economic growth, trade openness, renewable energy and carbon emissions is an important topic that has been examined extensively in literature. In existing literature, many studies are often found that use different methodologies to examine the relationship between these two variables and address various countries and country groups. In the following subsections, the relationships between economic growth and CO_2, renewable energy and CO_2, and trade openness and CO_2, which are frequently used in literature, are summarized. The impact of military expenditure on CO_2 is discussed in detail.

Economic growth and carbon emissions

With climate change becoming a global problem, the environmental problem has become the center of discussions. The EKC hypothesis has been frequently tested in the literature on the environment and economy. The essence of this hypothesis is the relationship between GI and CO_2. In the presence of an inverted-U shaped relationship between the variables in question, it is decided that the EKC hypothesis is valid (Li et al., 2024; Aydin & Degirmenci, 2024). It has been observed that time series and panel data methodologies are frequently used. In these studies, CO_2 emissions are generally preferred as the variable representing the environment. It has been determined that GDP per capita is used as the economic growth variable (Özbek and Oğul, 2022; Ali et al., 2024; Güler et al., 2025).

A considerable amount of study has been investigated on the relationship between economic growth and carbon emissions (Saidi & Omri, 2020). Studies examining the relationship between these variables in country groups, within the context of the OECD (Sun et al., 2020; Ozcan et al., 2020), BRICS (Banday & Aneja, 2020), G7 (Destek et al., 2020), Developing Countries (Sikder et al., 2022), European Union Countries (Onofrei et al., 2022), African Countries (Namahoro et al., 2021), ASEAN Countries and similar country groups. Similar studies have also been conducted on E7 countries in the literature (Aydoğan and Vardar, 2020; Gövdeli, 2024). According to the existing literature, the relationship between economic growth and carbon emissions is mostly positive (Namahoro et al., 2021;

Onofrei et al., 2022). According to the findings of the studies, economic growth increases carbon emissions.

Renewable energy and carbon emissions

Many studies have been carried out on the correlation between renewable energy and carbon emissions. These studies employ a variety of methodologies and focus on different countries and country groups. Several studies on country groups have been conducted within the scope of a specific country group. The OECD (Perone, 2024), G7 (Xu et al., 2022), ASEAN (Pata et al., 2023), BRICS (Sadiq et al., 2024), Developing Countries (Akram et al., 2020), European Union Countries (Chang et al., 2022), African Countries (Ali et al., 2022), Asian Countries (Rahman & Alam, 2022), and similar country groups. Several studies have been conducted in E7 countries in academic literature. (Aydoğan & Vardar, 2020; Şimşek et al., 2025).

The extant literature demonstrates that the impact of renewable energy on carbon emissions is predominantly negative. However, the findings are not entirely conclusive, as some studies report a neutral effect (Pata et al., 2023).

Trade openness and carbon emissions

The relationship between trade openness and CO_2 represents an significant field of discussion that includes global sustainability and climate change. It is seen that the studies conducted in this context have revealed various findings. Haseeb et al. (2023) conducted a study on BRICS countries. Driscoll-Kraay standard error analysis was used as the empirical method. The results show that increasing trade openness increases CO_2 emissions. Shahbaz et al. (2013), who investigated the relationship between trade openness and CO_2 with data from South Africa for the period 1965-2008, used the ECM model. The findings showed that trade openness reduces CO_2. A similar research question was answered by Koç and Buluş (2020) for South Korea during the period 1971-2017. The results again showed that trade openness reduced CO_2 emissions in the relevant period in South Korea. Sun et al. (2020) investigated the period 1990-2014 in Sub-Saharan African countries. FMOLS and DOLS are used as empirical methods. The results show that trade openness reduces environmental degradation.

Similarly, the relationship between trade openness and CO_2 is an issue with many aspects, which have been extensively studied in the literature. Within the broader context of research on country groups, numerous studies have been examined on the OECD (Gözgör, 2017), G7 (Li & Haneklaus, 2022), developing countries (Ertugrul et al., 2016), European Union countries (Ho & Iyke, 2019), Asian countries (Hultberg, 2018), and African countries (Sun et al., 2020) and similar country groups. A review of the extant literature shows that the effect of trade openness on CO_2 emissions is positive (Li & Haneklaus, 2022), while some studies find it to be negative. Ursavaş (2025) investigated the relationship between CO_2 and trade openness using data from MIST countries for the period 1970-2021. In the study using panel data techniques, it was concluded that trade openness increased CO_2 emissions. Barkat et al. (2025) revealed the existence of direct and indirect effects of trade openness on CO_2in OECD countries. Rahman (2013), Kander and Lindmark (2005), on the other hand, differed from other studies and stated that there was no statistically significant relationship between the relevant variables.

Military expenditures and carbon emissions

There are limited studies in the literature on how military spending affects CO_2 emissions. However, there is increasing interest in this topic. A comprehensive review of the existing literature reveals a variety of studies that use a variety of methodologies to analyze the relationship between the two variables. These studies focus on different countries and groups of countries. A significant number of the studies have proved that military expenditures increase carbon emissions (Jorgensen & Clark, 2009; Zandi et al., 2019; Gökmenoğlu et al, 2020; Isiksal, 2021; Eregha et al, 2022; Uddin et al, 2024; Chang et al, 2023; Efayena & Olele, 2024). On the other hand, some studies have shown that military expenditures reduce carbon emissions (Ullah et al., 2020; Konuk et al., 2023; Cutcu et al., 2024).

Jorgensen and Clark (2009) examined the structural determinants of the ecological footprint on per person. The data set for the study comprised 5-year periods between 1975 and 2000 (1975, 1980, 1985, 1990, 1995, 2000). A sample of 53 developed and less developed countries was analyzed using panel data analysis, which revealed that military expenditures are associated with an increased ecological footprint. Bildirici (2017) analyzed the relationship between energy consumption, economic growth, militarization, and CO_2 in the US. Using data for the period 1960-2013, the study includes the results obtained from the ARDL bounds test as well as the FMOLS, DOLS, and CCR estimators. The results of the study show a positive correlation between military expenditure and CO2 emissions. Bildirici (2018) employed an annual dataset covering the period 1985–2015 in their study on G7 countries. The study examined the cointegration relationship by employing Pedroni (1995) and panel Johansen tests. The findings, which have been obtained from the utilisation of FMOLS and DOLS estimators, demonstrate a positive correlation between economic growth and militarisation on the one hand, and an increase in CO2 emissions on the other. Moreover, this increase has been found to be statistically significant.

Zandi et al. (2019) examined the determinants of environmental degradation in six ASEAN countries. In this context, the study used military expenditure, corruption, and democracy variables and used a sample period from 1995 to 2017. The FMOLS estimator and DOLS estimation method were used in the study. Empirical findings show that military expenditure increases CO2 emissions. Ahmed et al. carried out a study in 2020 on the Pakistani economy during the period 1971-2016. The study used the ecological footprint variable as an environmental variable and revealed the increasing impact of military spending on CO2 emissions. Işıksal (2021), who studied the economies of the 10 countries with the highest military expenditure, analysed the 1993-2017 period. The study used the new generation cointegration estimators. It concluded that military expenditure increases CO2 emissions and reduces renewable energy consumption. In the study, Gökmenoğlu et al. (2020) investigated the relationship between CO2 emissions and military expenditure in Turkey, using data from the 1960-2014 study period. The findings of the study, employing the FMOLS and Toda-Yamamoto methods, concluded that military expenditures were associated with an increase in environmental degradation. Conversely, it was determined that energy consumption and economic growth led to an increase in environmental degradation, while financial development resulted in a decrease. In the study carried out on Ghana with data from 1971-2018, Kwakwa (2022) focused on the factors influencing CO2 emissions. In the study, ARDL bounds test was employed, utilising a combination of industrialisation and public expenditure variables, in addition to military expenditures. Empirical evidence has shown that military expenditures have a negative effect on CO2 emissions. The study established a negative correlation between public expenditure and CO2 emissions. It was concluded that population and industrialization increased CO_2 emissions.

On the other hand, renewable energy use and economic growth variables were added to the empirical model. The study investigated the period 1990-2018. The present study uses panel cointegration and cross-sectional autoregressive distributed lag models to explore the relationship between militarization and environmental sustainability. The findings reveal a positive correlation between an increase in militarization and an increase in the ecological footprint of nations. Moreover, an increase in military capital intensity seems to worsen environmental damage. Cutcu et al. (2024) investigated the long-term relationship between foreign trade and military expenditures of the US economy. To this end, annual data from 1970 to 2018 were examined. Maki (2012) cointegration test, a novel method that identifies five structural breaks, was employed to analyze the cointegration relationship. The FMOLS, DOLS, and CCR methods were utilized to examine the impact of independent variables on dependent variables. The study's findings indicate that military expenditures, exports, and agricultural areas have a negative effect on ecological footprints, while imports have a positive effect.

Literature gap

In the literature research, it was seen that CO_2 emissions, which are among the most important representatives of environmental degradation, are frequently used. In empirical literature, the relationships between economic growth, renewable energy, trade openness and military expenditure on CO2 emissions were examined. It was determined that there are many studies in literature on the relationships of relevant variables on CO_2 emissions. However, it has been determined that most of these studies are single-country studies and focus on the bilateral relations of CO_2 and many variables. In the literature, no study has been found on the E7 countries that addresses the combined effects of economic growth, renewable energy, trade openness, military expenditures and population. On the other hand, the fact that the current period data set of 1993-2023, when the E7 countries experienced significant structural transformations, was used in this study is another contribution of the study to literature. Finally, the study was designed by combining current methods and robustness tests, which distinguishes it from other studies. Thus, it is considered that it will contribute to literature.

3. Model, Data and Methodology

Model construction

The paper investigates the effect of economic growth (GDP), trade openness (TO), green energy (REN), military expenditures (MEX) and population (POP) on carbon emissions (CO2). In the literature, when calculating the impact of different variables on environmental quality, CO_2 emissions are often preferred. Countries generally supply their energy needs from fossil fuels. This can deepen environmental degradation. However, the use of clean energy instead of fossil fuels will contribute both to the achievement of the economic growth target and to the formation of a clean environment in the context of sustainable development. The reason for the inclusion of trade openness in the model is that an increase in trade openness enables imported technologies, including environmental technologies. This will pave the way for the international movement of technologies to reduce environmental degradation. Thus, environmental degradation can be reduced. In the perspective of these factors, the following model has been developed.

$$\mathrm{CO2}_{it} = \mathrm{f}(\mathrm{GDP}_{it}, \mathrm{GE}_{it}, \mathrm{TO}_{it}, \mathrm{MEXP}_{it}, \mathrm{POP}_{it}) \quad (1)$$

$$\mathrm{CO2}_{it} = \beta_0 + \beta_1 \mathrm{GDP}_{it} + \beta_2 \mathrm{GE}_{it} + \beta_3 \mathrm{TO}_{it} + \beta_4 \mathrm{MEXP}_{it} + \beta_5 \mathrm{POP}_{it} + \varepsilon_{it} \quad (2)$$

where i is the cross section of E-7 countries, t is the time series and ε is the error term. CO_2 refers to carbon emissions; GDP indicates economic growth; GE, green energy; TO, trade openness; MEXP, military expenditures, POP, population. In the econometric model, the natural logarithm of each variable has been taken to reduce variability and to smooth the data.

Data sources

In the current research, E-7 countries (Brazil, China, India, Indonesia, Mexico, Mexico, Russia and Turkey) are included as a panel group and annual data for the period 1990-2020 are considered. The nexus between economic growth, green energy, trade openness, military expenditures, population and carbon emissions is analysed. The dependent variable, carbon emission, is taken as metric tonnes per capita. Per capita reel GDP is included in the model as economic growth variable. Green energy is expressed as renewable energy consumption (% of total final energy consumption); trade openness as trade (% of GDP); and military expenditure as military expenditure (US$ per capita). Table 1 lists the variables of the model and the source of these variables.

Table 1: List of the variables

Variable	Symbol	Explanation	Source
Carbon Emission	LCO_2	Metric tons per capita	Our World in Data
Economic Growth	LGDP	Gross Domestic Product per capita current 2015 US$	WDI
Green Energy	LGE	Renewable energy consumption (% of total final energy consumption)	Our World in Data
Trade Openness	LTO	Trade (% of GDP)	WDI
Military Expenditure	LMEXP	Per capita current US$	SIPRI
Population	LPOP	Population, total	WDI

Source: Authors' calculations

Econometric methodology

International Journal of Contemporary Economics and Administrative Sciences
ISSN: 1925 – 4423
Volume: XV, Issue: 2, Year: 2025, pp.757-781

There are two points of separation in the panel data methodology. In this context, cross-section dependency (CSD) and homogeneity tests are applied first. As a result of these tests, appropriate panel unit root test, panel cointegration test and panel cointegration estimators are used. Chudik and Pesaran (2013) have drawn attention to the fact that cross-sectional dependence may occur in countries forming panel data sets along with the globalization process. It is argued that a shock/structural change occurring in any of the cross-sectional units in the panel data set will also affect the shock/structural change in other countries in the panel. In this context, tests that take cross-sectional dependence into account are considered important to avoid biased and inconsistent parameter estimates (Kızılkaya et al., 2024). The CSD test suggested by Pesaran (2015) is applied in the study. Afterwards, the homogeneity test is performed. After two separation points, the CIPS unit root test, which considers heterogeneity and CSD, is applied. After understanding that all series are I(1), the panel LM cointegration test is applied. As a result of this test suggested by Westerlund and Edgerton (2007), the existence of a long-term relationship is revealed. In long-term estimates, the panel quantile regression method was first used. It is possible to examine the relationships in more detail with the panle quantile method. This method differs from the classical panel regression method and can reveal how the policy effects of the variables in the model differ at low and high values. This method, which is extremely useful in this respect, is not limited to the average effect. More clearly, empirical analyses are carried out by separating the effects of the variables in the lower and upper segments of the conditional distribution (Guris & Sak, 2019). Thus, more effective and purposeful policies can be implemented. Finally, panel FMOLS, DOLS, FE-OLS and Driscoll-Kraay methods are used as a robustness test.

CSD test

In the present study, some pre-analyses are required before proceeding to the estimation of the model. The first of these is to test the CSD of the series. Increasing political, cultural and economic globalisation, increasing economic integration and decreasing foreign trade barriers have increased the degree to which countries affect each other. In other words, a shock occurring in one country has the potential to affect other countries as well (Tufail et al. 2022). The type of unit root test and cointegration test to be used is also determined by the findings from CSD tests. In this study, weakly exogenous CSD developed by Pesaran (2015) was used to detect CSD.

$$\text{CSD} = \sqrt{\frac{2T}{N(N-1)N}\left(\sum_{I=1}^{N-1}\sum_{K=I+1}^{N}\widehat{Corr}_{I,t}\right)} \quad (3)$$

Slope homojenity test

The problem of slope heterogeneity gains importance in econometric studies conducted with panel data. The homogeneity or heterogeneity of the model also determines the cointegration test to be used as well as the long-run coefficient estimation to be used. For this reason, Delta tests by Pesaran and Yamagata (2008) are used. The equations for small samples and large samples give test results.

$$\tilde{\Delta}= \sqrt{N}\left(\frac{N^{-1}\hat{S}- k}{\sqrt{2k}}\right) \quad (4)$$

$$\hat{\Delta}_{Adj}= \sqrt{N}\left(\frac{N^{-1}\hat{S} -E(\tilde{z}_{iT})}{\sqrt{Var(\tilde{z}_{iT})}}\right) \quad (5)$$

Unit root test

There are various tests developed to test the stationarity of variables (Maddala & Wu, 1999; Breitung, 2001; Choi, 2001; Im et al, 2003). In the empirical literature, there are studies in which the null hypothesis indicates the presence of a unit root or, alternatively, stationarity (Koçak & Özbek, 2020). However, these tests ignore the testing of problems such as CSD and slope homogeneity (SH). One of the second-generation tests to test the stationarity of variables in the presence of CSD and SH is the "Cross-Sectionally Augmented ADF" test proposed by Pesaran (2007). In this test, lagged cross-sectional averages of the ADF regression are considered. After the CADF test statistic values are calculated, CIPS statistic values are calculated as follows:

$$\mathrm{CIPS}\ (\mathrm{N,T}) = \frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{N}} \mathrm{t_i(N,T)} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{N}} \mathrm{CADF_i}}{\mathrm{N}} \quad (6)$$

Panel cointegration test

After assessing the stationarity of the variables, the cointegration relationship between the variables is estimated with the LM bootstrap panel cointegration test introduced by Westerlund and Edgerton (2007). The main advantages of this approach are that it takes CSD and SH into account and gives consistent results even in small samples. The null hypothesis H_0 indicates that there is a cointegration relationship between the variables. The form of this cointegration test is as follows:

$$\mathrm{LM}_{\mathrm{N}}^{+} = \frac{1}{\mathrm{NT}^2}\sum_{\mathrm{i=1}}^{\mathrm{N}}\sum_{\mathrm{t=1}}^{\mathrm{T}} \hat{\omega}_{\mathrm{i}}^{-2}\, \mathrm{s}_{\mathrm{it}}^{2} \quad (7)$$

In this equation, T indicates time; N donates to sample dimension; $\mathrm{s}_{\mathrm{it}}^{2}$ represents the sum of the error terms; $\hat{\omega}_{\mathrm{i}}^{-2}$ points to the variance of the error terms in the long term.

Panel Quantile Regression and Robustness Tests

The ordinary least squares (OLS) method is one of the basic techniques commonly used in econometric analyses. However, the fact that economic variables have extreme values and deviate from the normal distribution may make it difficult for this method to produce reliable results. Especially in the presence of non-normal distribution of error terms and long-tailed distributions, the OLS method may be inadequate. As an alternative to such situations, the quantile regression method was developed by Koenker & Bassett Jr. (1978) (Waldmann, 2018; Chen et al., 2019;

Opoku & Aluko, 2021). The quantile regression method was adapted to the panel data structure by Koenker (2004) and in this context, a fixed effect panel quantile regression model was developed. Panel data and quantile regression models, which have become popular in applied empirical studies recently, have begun to become widespread. Quantile regression models allow the researcher to account for unobserved heterogeneity and heterogeneous covariate effects, while the availability of panel data allows the researcher to include fixed effects to control for some unobserved covariates (Tekin and Bastak, 2022). Recently, some researchers have associated these two methodologies and named it Panel Quantile Regression (Güloğlu, et al. 2016). Quantile regression model,

$$Y_t = X_t'\beta + u_t \quad (8)$$

When defined as;

$$min_{\beta\epsilon\mathbb{R}}\left[\sum_{t\epsilon\{t:Y_t\geq X_t'\beta\}}\theta|Y_t - X_t'\beta| + \sum_{t\epsilon\{t:Y_t<X_t'\beta\}}(1-\theta)|Y_t - X_t'\beta|\right] \quad (9)$$

It is estimated by minimization calculated as. θ in the equation indicates different quantile levels between 0 and 1. The non-additive fixed effect panel quantile estimation method used in the study was developed by Powell (2016). The method includes non-additive fixed effects, unlike the additive fixed effects model, which includes additive fixed effects separated by error terms. It provides information about the distribution of the dependent variable $\frac{Y_{it}}{X_{it}}$ which includes cross-sectional units and time dimension. The panel quantile approach developed by Powell (2016) produces consistent and asymptotically normal estimates even at small T. It is stated that the method gives good results even when instrumental variables and additive fixed effect panel quantile estimators perform poorly (Powell, 2016). On the other hand, panel FMOLS, DOLS and FE-OLS methods, which are frequently used in literature, were also used as robustness tests in this study. Long-term coefficient estimators in panel data analysis are DOLS and FMOLS methods developed by Pedroni (2000, 2001). In the FMOLS method, deviations originating from problems such as heteroscedasticity and autocorrelation in standard fixed effect estimators are corrected. In addition, the DOLS method has the feature of including dynamic elements in the model and eliminating deviations originating from endogeneity problems in static regression (Oğul, 2022). In addition, the Fixed Effect Least Squares (FE-OLS) method, strengthened with Driscoll and Kraay standard errors used in the study, is a reliable estimator under the presence of autocorrelation and CSD.

4. EMPIRICAL RESULTS

This section presents empirical results. First, Table 2 presents descriptive statistics.

According to the results in Table 2, the highest standard deviation is observed in the military expenditure (LMEXP) variable. The mean value of LMEXP is approximately 4.031, the minimum value is 1.440 and the maximum value is 6.619. The standard deviation is 1.143. When the skewness and kurtosis coefficients were analysed, it was seen that the values of many variables were outside the limits of ± 1.5.

Table 2. Descriptive statistics

	LCO_2	LGDP	LGE	LTO	LMEXP	LPOP
Mean	1.177188	8.472762	2.223581	3.770540	4.099028	19.37464
Median	1.170656	8.800977	1.957773	3.845607	4.031683	19.06447
Maximum	2.533816	9.596525	3.918629	4.566286	6.619591	21.08657
Minimum	-0.308560	6.333942	0.907161	2.749550	1.440666	17.89303
Std. Dev.	0.733103	0.823605	0.744880	0.354370	1.143994	1.063121
Skewness	0.171211	-0.896642	1.020379	-0.678281	-0.027608	0.574170
Kurtosis	2.227603	2.632253	3.115445	3.171549	2.322247	1.831063
Jarque-Bera	6.454387	30.29959	37.77624	24.28190	4.180842	24.28190
Probability	0.039669	0.000000	0.000000	0.000213	0.123635	0.000005
Observations	217	217	217	217	217	217

Source: Authors' calculations

According to the results in Table 2, the highest standard deviation is observed in the military expenditure (LMEXP) variable. The mean value of LMEXP is approximately 4.031, the minimum value is 1.440 and the maximum value is 6.619. The standard deviation is 1.143. When the skewness and kurtosis coefficients were analysed, it was seen that the values of many variables were outside the limits of ± 1.5.

This finding indicates that the data do not conform to normal distribution. The results of the Jarque-Bera normality test also support this finding and the null hypothesis of normal distribution is rejected for all variables except military expenditures. In empirical analyses, it is of great importance to determine the distributional characteristics of variables, since non-normally distributed series require the selection of appropriate estimation methods.

Table 3 shows the results regarding cross-sectional dependence.

Table 3: Outcomes of cross-sectional dependency

Variables	Test statistic	Probability
LCO_2	13.31*	0.000
LGDP	22.91*	0.000
LGE	12.13*	0.000
LTO	1.96* *	0.050
LMEXP	19.38*	0.000
LPOP	13.34*	0.000

Note: *,** respectively symbol indicate that the level of significance 1% and 5%.

Source: Authors' calculations

Table 3 reports the results of the CSD analysis. According to the results of the test statistics, the null hypothesis H_0 'weak CSD is rejected. Accordingly, H_1 'strong CSD' is verified. In this case, second generation unit root tests should be used to determine the stationarity of the variables. Table 4 shows the homogeneity results.

Table 4: Outcomes of slope heterogeneity test

Slope homogeneity tests	Test Value	P-value
$\tilde{\Delta}$	15.455*	0.000
$\hat{\Delta}_{Adj}$	17.210*	0.000

Note: *, symbol indicate that the level of significance 1%.

Source: Authors' calculations

Table 4 presents the results of the slope homogeneity test proposed by Pesaran and Yamagata (2008). The findings demonstrate that the slope coefficients of the model are not homogeneous and that the slope varies across countries. It is reported that the null hypothesis H_0, which claims that the slope coefficients are homogeneous, is rejected at 1% significance level. Table 5 shows the panel unit root results.

Table 5: Outcomes of panel unit root analysis

	CIPS			
Variable	At level	%1 Cricitical Value	At 1st difference	%1 Cricitical Value
LCO_2	-1.978	-3.06	-4.978*	-3.1
LGDP	-2.244	-3.06	-4.074*	-3.1
LGE	-3.552*	-3.06	-6.086*	-3.1
LTO	-3.228*	-3.06	-4.707*	-3.1
LMEXP	-2.679	-3.06	-5.616*	-3.1
LPOP	-1.980	-3.06	-3.381*	-3.1

Note: *, symbol indicate that the level of significance 1%.

Source: Authors' calculations

As shown in Table 5, the variables are not stationary at level value. First differences of the series were taken. Thus, the series became stationary in their first differences at 1% significance level. Table 6 presents the panel cointegration test findings.

Table 5: Outcomes of panel cointegration analysis

Constant		Constant & trend	
LM-statistic	Bootstrap p-value	LM-statistic	Bootstrap p-value
6.605	0.563	12.410	0.292

Source: Authors' calculations

Westerlund and Edgerton (2007) panel cointegration analysis results are tabulated in Table 6. The result indicates that the null hypothesis H_0, which states that there is a cointegration relationship between the variables, is approved. Table 7 shows the panel quantile test findings.

Table 6: Outcomes of panel quantile regression analysis

	10th	20th	30th	40th	50th	60th	70th	80th	90th
LGDP	0.710*	0.709*	0.709*	0.708*	0.707*	0.707*	0.706*	0.706*	0.705*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
LGE	-0.139**	-0.131*	-0.121*	-0.116*	-0.103*	-0.095*	-0.090**	-0.081***	-0.068
	(0.012)	(0.005)	(0.001)	(0.001)	(0.001)	(0.004)	(0.011)	(0.062)	(0.234)
LTO	-0.123**	-0.119**	-0.113*	-0.109*	-0.102*	-0.096*	-0.094**	-0.088**	0.079
	(0.031)	(0.014)	(0.004)	(0.002)	(0.001)	(0.004)	(0.011)	(0.050)	(0.176)
LMEXP	-0.068***	-0.073**	-0.080*	-0.084*	-0.092*	-0.098*	-0.101*	-0.107*	-0.116*
	(0.090)	(0.030)	(0.004)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.005)
LPOP	0.471*	0.506*	0.547*	0.575*	0.625*	0.662*	0.682*	0.722*	0.778*
	(0.006)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: * significant at 1%; ** significant at 5%;*** significant at 10%. The values in parentheses indicate the probability value.

Source: Authors' calculations

After identifying the long-run relationship between the variables, the study continues with panel quantile regression. With panel quantile regression, the coefficients of the factors affecting environmental degradation in E-7 countries in percentages (between 10th and 90th) were evaluated. Panel quantile regression results are reported in Table 7.

The elasticity coefficient of the LGDP coefficient is positive and statistically significant. The positive effects of economic growth on environmental degradation are valid for E-7 countries. The elasticity coefficient of green energy (LGE) is negative and statistically significant. The findings indicate that green energy used as an input in E-7 countries will reduce environmental degradation. The elasticity parameter of the LTO variable used as an expression of trade openness is negative and statistically significant. Increasing foreign trade improves environmental quality by allowing the import of environmentally friendly technologies. In addition, the elasticity parameter of military expenditures is negative and statistically significant. The evolution of military forces consisting of human resources to technologically intensive military equipment is seen to reduce environmental degradation. More precisely, providing more funds for research and development efforts in the military concept and incentives for the use of environmentally friendly military equipment have a positive impact on environmental quality. Population variable increases carbon emission. The findings confirm that this is the case for the E-7 countries. Fig. 1 visualises the elasticity coefficients obtained.

Table 8 summarises the results of robustness estimates. The evidence is like the results of the panel quantile regression. Figure 1 Graphical reresentation of the effect of variables on environmental degradation

International Journal of Contemporary Economics and Administrative Sciences
ISSN: 1925 – 4423
Volume: XV, Issue: 2, Year: 2025, pp.757-781

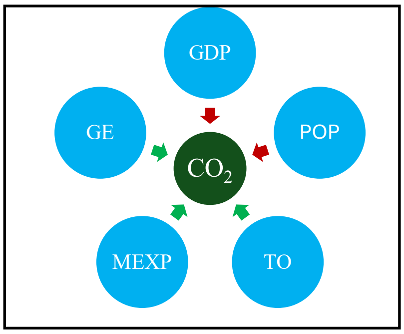
Table 8: Outcomes of robustness estimates

	FMOLS	Prob.	DOLS	Prob.	FE-OLS	Prob.	Driscoll-Kraay FE	Prob.
LGDP	0.736*	0.0000	0.708*	0.0000	0.707*	0.0000	0.708*	0.000
LGE	-0.101***	0.0575	-0.105**	0.0062	-0.105*	0.0001	-0.105**	0.041
LTO	-0.113**	0.0485	-0.103***	0.0482	-0.103*	0.0002	-0.102***	0.075
LMEXP	-0.107*	0.0017	-0.091*	0.0713	-0.091*	0.0000	-0.091**	0.018
LPOP	0.609*	0.0004	0.617*	0.0002	0.617*	0.0000	0.618*	0.003

Note: * significant at 1%; ** significant at 5%;*** significant at 10%.

Source: Authors' calculations

Figure 1. Summary of empirical estimates



Source: Authors' calculations

5. CONCLUSION AND POLICY IMPLICATIONS

The E7 nations represent half of the global population. They account for more than 40% of the world's energy consumption. This group is among the top twenty countries with the highest CO_2 emissions. China, which accounts for about 12% of carbon production, is also in this group. Each of these members is a sign that the E7 Group is facing unprecedented environmental challenges. From this perspective, it is important to identify the macroeconomic factors that are causing environmental degradation to worsen in this group of countries. One of those factors is military expenditure. In this context, the present study examines the degree of impact of economic growth, green energy, trade openness, military spending and population on carbon emissions using annual data for the period 1990-2020. This study employs second-generation econometric methods. The CD test of Pesaran (2015) for CSD, and the delta tests developed by Pesaran and Yamagata (2008) to test for slope homogeneity/heterogeneity in the data are included. Pesaran (2007) CIPS unit root test is used to test the stationarity of the variables used in the analysis. On the other hand, the LM bootstrap panel cointegration test developed by Westerlund and Edgerton (2007) is used to analyze cointegration properties. The long-run coefficients are determined by panel quantile regression technique, and the FMOLS, DOLS, FE-OLS and Driscoll-Kraay estimators are considered to verify the robustness of the long-run estimates.

The initial finding of the study indicates that economic growth has a significant positive correlation with CO_2 emissions across all quantiles and other estimators. The primary factors contributing to the observed increase in growth rates within the E-7 countries, particularly in China and India, are industrialization and the development of foreign trade. This has led to an increase in fossil fuel consumption, which has in turn led to increased carbon emissions because of greater economic activity. Economic growth is a fundamental element for the development and prosperity of societies. Energy consumption has been identified as a primary driver of economic growth. In the process of sustainable development, it is considered desirable to establish economic growth as a fundamental goal, while utilising energy sources that contribute to enhancing environmental quality. In this context, one of the main findings of the study is that green energy consumption has a significant impact on reducing CO2 emissions across all quantiles and other estimators.

Many studies have shown that military operations are linked to a rise in fossil fuel consumption, which in turn leads to an increase in environmental degradation. The findings from the panel quantile regression technique employed in this study demonstrate that an increase in military expenditures leads to a decrease in carbon emissions across all quantiles and estimators utilised for the robustness assessment. In addition to the increase in technological innovation, the production of military equipment and weapons with high technology based on R&D appears to be a significant factor in reducing the carbon emissions associated with military expenditures. Moreover, the utilisation of renewable energy sources in the production of military technologies contributes to a reduction in carbon emissions. Consequently, the use of environmentally friendly military equipment has a beneficial effect on environmental quality.

On a global scale, there is an increasing trend of steps towards the use of alternative and clean energy sources in the military industry. As reported by the International Renewable Energy Agency (IRENA), China has the highest global production of renewable energy, with a total of 1,453,701 MW. China's projection of building its military development by increasing its investments in the field of alternative energy is noteworthy. According to the IRENA, Brazil has been ranked third in terms of total renewable energy installed capacity. India has been ranked fourth, Turkey eleventh, and Russia twelfth in this regard (IRENA, 2024). This is a significant development in the context of renewable energy production within the E-7 group.

The necessity of security and defense, as well as the responsibility of a state organism to undertake them, are advocated by all economic systems. Within the framework of this understanding, military activities, being environment-oriented and supportive of environmental quality, will contribute to security, which is a fundamental need, and the establishment of a livable ecosystem. In this context, public authority should support and encourage institutions and companies operating in the military industry, in both the public and private sectors, to carry out their production activities with a production structure that prioritizes green energy.

Public authority also should develop rules and regulations for industries that increase environmental damage in a way that respects the ecological balance. Specifically, it should establish legal frameworks and economic incentives to enhance the incorporation of green energy in production and consumption patterns.

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