DO ENVIRONMENTAL POLICY STRINGENCY AND INNOVATION REDUCE CARBON EMISSIONS: EMPIRICAL EVIDENCE FROM G-7 COUNTRIES[1]

Kafkas University
Economics and Administrative
Sciences Faculty
KAUJEASF
Vol. 14, Issue 28, 2023
ISSN: 1309 – 4289
E – ISSN: 2149-9136

Article Submission Date: 17.08.2023 *Accepted Date: 13.12.2023*

Cengizhan GÜLER
Research Assistant
Faculty of Economics,
Administrative and Social Sciences,
İstanbul, Türkiye,
ceguler@gelisim.edu.tr
ORCID ID: 0000-0002-9059-3676

Başak ÖZARSLAN DOĞAN
Assistant Professor
İstanbul Gelişim University
Faculty of Economics,
Administrative and Social Sciences,
İstanbul, Türkiye,
bozarslan@gelisim.edu.tr
ORCID ID: 0000-0002-5126-7077

ABSTRACT | Public policies have gained significant importance in technological innovations that have come to the fore in reducing the environmental impact of economic activities. Especially in developed countries, significant progress has been made in policies in this area. Reducing the negative externalities that cause environmental pollution in production and reducing their adverse effects on natural resources such as air and water is an indicator of how seriously these policies are taken. In this context, the study aims to empirically examine the effect of innovations and environmental policy strictness on the reduction of carbon emissions in G-7 countries for the period 1994-2019 using linear panel regression methods. After performing various specification and assumption tests, the Driscoll-Kraay random effects model was used to obtain coefficient estimates. In the study, the environmental policy stringency index was used to represent environmental policy strictness. The study findings indicate that an increase in environmental policy stringency reduces carbon emissions, while an increase in innovation increases carbon emissions.

Keywords: *Environmental policy strictness, innovation, carbon emissions, panel data econometrics*
JEL Codes: *Q5, C23, G18*

Scope: *Economics*
Type: *Research*

DOI: 10.36543/kauiibfd.2023.34

Cite this article: Güler, C. & Özarslan Doğan, B. (2023). Do environmental policy stringency and innovation reduce carbon emissions: empirical evidence from G-7 countries. *KAUJEASF, 14*(28), 847-870.

[1] It has been declared that the relevant study complies with ethical rules.

ÇEVRE POLİTİKASI KATILIĞI VE İNOVASYON KARBON EMİSYONLARINI AZALTIYOR MU: G-7 ÜLKELERİNDEN AMPİRİK KANITLAR

Kafkas Üniversitesi
İktisadi ve İdari Bilimler Fakültesi
KAÜİİBFD
Cilt, 14, Sayı 28, 2023
ISSN: 1309 – 4289
E – ISSN: 2149-9136

Makale Gönderim Tarihi: 17.08.2023 Yayına Kabul Tarihi: 13.12.2023

Cengizhan GÜLER
Araştırma Görevlisi
İstanbul Gelişim Üniversitesi
İktisadi, İdari ve Sosyal Bilimler Fakültesi,
İstanbul, Türkiye,
ceguler@gelisim.edu.tr
ORCID ID: 0000-0002-9059-3676

Başak ÖZARSLAN DOĞAN
Dr. Öğr.Üyesi
İstanbul Gelişim Üniversitesi
İktisadi, İdari ve Sosyal Bilimler Fakültesi
İstanbul, Türkiye,
bozarslan@gelisim.edu.tr
ORCID ID: 0000-0002-5126-7077

ÖZ | Ekonomik faaliyetlerin çevresel etkilerinin azaltılmasında ön plana çıkan teknolojik yeniliklerde kamu politikalarının rolü büyük önem kazanmıştır. Özellikle gelişmiş ülkelerde bu alandaki politikalarda önemli ilerlemeler kaydedilmiştir. Üretimde çevre kirliliğine neden olan olumsuz dışsallıkların azaltılması ve bunların hava, su gibi doğal kaynaklar üzerindeki olumsuz etkilerinin azaltılması bu politikaların ne kadar ciddiye alındığının da bir göstergesidir. Bu bağlamda çalışmanın amacı, doğrusal panel regresyon yöntemleri kullanarak 1994-2019 dönemi için G-7 ülkelerinde inovasyonların ve çevre politikası katılığının karbon emisyonlarının azaltılması üzerindeki etkisini ampirik olarak incelemektir. Çeşitli spesifikasyon ve varsayım testleri yapıldıktan sonra, katsayı tahminlerini elde etmek için Driscoll-Kraay tesadüfi etkiler modeli kullanılmıştır. Çalışmada çevre politikası katlığını temsil etmesi için çevre politikası katılık endeksi kullanılmıştır. Çalışma bulguları, çevre politikası katılığındaki bir artışın, karbon emisyonlarını azalttığını fakat inovasyon artışının ise karbon emisyonlarını arttırdığına yönelik kanıtlar içermektedir.

Anahtar Kelimeler: *Çevre politikası katılığı, inovasyon, karbon emisyonları, panel veri ekonometrisi*
JEL Kodları*: Q5, C23, G18*

Alan: *İktisat*
Türü: *Araştırma*

1. INTRODUCTION

Today, environmental deterioration because of population growth and, accordingly, in industrial production and the policies for solving of these deteriorations are among the issues that scientists frequently draw attention to. It is argued that one of the leading causes of environmental pollution is the increase in energy supply and demand, which economies use while performing their growth activities (Kırıkçı, 2022, p.192). The fact that many countries use fossil fuels more while producing gives rise to an increase in carbon emissions, constituting approximately 60% of the total greenhouse gas emissions (Lau, Choong, & Eng, 2014). The increase in carbon emissions, otherwise, causes changes in the structure of climates and, as a result, environmental problems related to global warming.

Various policies and practices have been developed in the international arena to draw attention to the effects of global warming in the world. The first is the Rio Summit the United Nations (UN) held in 1992. At the said summit, various measures were discussed to reduce the countries' greenhouse gas emissions, and the United Nations Framework Convention on Climate Change was signed at the end of the summit. Another attempt to draw attention to the effects of global warming is the Kyoto Protocol, which came into force in 2005. Today, the EU and 191 countries are parties to the Kyoto Protocol. Among the measures to be taken to reduce greenhouse gas emissions in the protocol are energy efficiency, development of sustainable agriculture, reduction of greenhouse gas emissions, recovery of methane emissions, protection of forest and vegetation, and use of renewable energy technologies. (Kılıç, Dönmez & Adalı, 2021, p. 44; Aydoğdu & Özşahin, 2023, p.135).

Another critical initiative against global warming is the Paris Agreement. The Climate Change Conference in Paris in 2015 was realized through negotiations within a complex geopolitical and international relations network. The Paris Climate Change Agreement, agreed upon due to negotiations, has become an international agreement with legal binding on climate change. The aim of the Paris Climate Agreement, which entered into force in 2016, is expressed as keeping global warming below 2 ºC, preferably below 1.5 ºC compared to the period before the Industrial Revolution. In realizing this target, it is aimed that countries reach a global peak in greenhouse gas emissions as soon as possible to become climate-neutral by 2050 (UN, The Paris Agreement, 2015; Ergün & Sezer, 2023, p. 151). Figure 1 shows global carbon emissions.

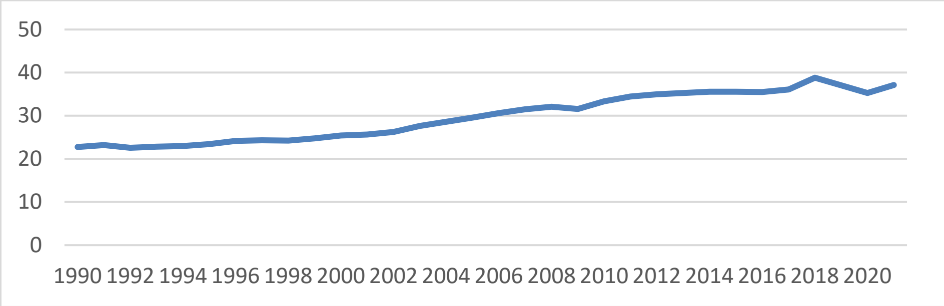

Figure 1: Global GHG Emissions (1990-2021)

Source: Climate Watch Data, 2023.

The amount of greenhouse gas emissions, about 22 Gt at the beginning of the 90s, increased gradually in the following years. There are two periods in which the amount of increase is relatively low. The first of these is the year 2008-2009. In these years, the worldwide decrease in production due to the global crisis's effect was effective. The second striking period is the 2019-2020 period. During this period, the effect of the contraction experienced worldwide with COVID-19 is seriously seen. However, with the disappearance of the effect of the pandemic, it is seen that carbon emissions have started to increase as of 2021.

In recent years, there has been significant interest in the role of public policy in promoting technological innovations that help decrease the effects of carbon emissions from economic activities. Particularly in developed countries, serious progress has been made in this regard. Considerable reductions in the damage of pollutants to air and water and improvements in waste management can be given as examples (Johnstone, Haščič, Poirier, Hemar, & Michel, 2012).

The importance of strict environmental regulations in reducing carbon emissions and environmental deformations is drawing more attention daily in the environment and economy literature. Policymakers are increasingly applying environmental regulations to lay the foundation for green growth, especially in terms of efficiency in energy use, and to prevent climate change and protect natural resources. In this context, laws encouraging the use and manufacturing of sustainable energy have become widespread in many countries, including the introduction of environmental taxes on fossil fuel-based fuels, for example, oil, coal, and natural gas (Li, Samour, Irfan, & Ali, 2023). In addition, the advantages of strict environmental restrictions are emphasized, especially in developed countries. For example, these countries are willing to implement strict environmental rules to decrease the cost of societal pollution and the price gap between clean and non-clean technologies (Demiral, Akça, & Tekin, 2021).

Stricter environmental policies ensure green growth through eco-efficiency and recycling, prevent the spread of negative externalities, and ensure more efficient use of resources. In this way, stricter environmental policies are supported in measuring the effectiveness of industrial environmental standards. Table 1 shows the positive results of the strict policies to reduce environmental pollution and the positive externalities that will occur economically. According to Table 1, it is understood that policy measures to be taken regarding transportation, energy, agriculture, and urban life will bring advantages in terms of environmental and economic aspects.

Table 1: Examples of the Environmental and Economic Benefits of Strict Environmental Policies

Industries	**Environmental Benefits**	**Economic Benefits**
Transportation: Setting strict standards to reduction sulfur in fuels	Reduce in acid rain events, thus less forest and crop damage and less acidification of soils	Eliminating lead from gasoline globally would provide economic benefits of around 4% of global GDP.
Agriculture: Integrated landscape management	Protection of biodiversity and critical ecosystem services, hydropower production, develop the water quality and quantity	Reduction in healthcare costs from water-related diseases. Lower water and sanitation costs due to improved watershed management.
Cities: Increasing vegetation and green spaces	Develop air quality, reduce heat island effects, reduce floods, block pollutants	Increased property value, air conditioning costs reduction.
Energy: Supplying clean energy and increasing energy efficiency	Improved air quality	Doubling the share of renewable energy by 2030 will generate 1.1% global GDP growth and 24 million jobs.

Source: (Adapted from UNEP, 2016, p. 8 & Polat and Ergun, 2023, p.116.)

This study aims to empirically examine the impact of strict environmental policies and technological innovation on carbon emissions. In this context, the Environmental Policy Stringency Index (EPS) calculated by the OECD was used to represent strict environmental policies in the study. In the following sections of the study, firstly, international studies in this field are included. Then, the model and data set that reviewed the effects of strict environmental policies and technological innovation on carbon emissions were introduced. Finally, the findings obtained as a result of the study are given.

2. THEORETICAL BACKGROUND

An essential part of the relationship between the environment and economics can be evaluated in the context of externalities. In this context, the scientific pursuit of internalizing the negative externality emitted by environmental pollution, a kind of market failure, is one of the leading research subjects of environmental economics. The relationship of negative externality between individuals and firms within the scope of economic theory can be examined in a particular theoretical framework with the help of an analytical model. This review reveals the importance of the role of the government and provides a theoretical insight into the environmental policy stringency and innovations examined in the study.

While creating environmental policy or internalizing negative externality, many uncertainty and complexity problems exist, as in all economic relations. For this reason, reaching the outputs of the analytical model requires making some assumptions. Drawing the boundaries in analytical models essentially contributes to realizing analytical progress. In this context, in addition to the assumptions of complete information and perfect competition, parallel to the neo-classical economic theory, assumptions of no pre-existing pollution, current pollution, and fixed pollution technologies are made. Within the scope of these assumptions, efficient allocation occurs on the axis of two conditions between firms and individuals.

$$-C'_j(e_j) = D'_i(E) \quad \textbf{(1)}$$

$$-C'_j(e_j) = -C'_k(e_k) = \dots = -C'_n(e_n) \quad \textbf{(2)}$$

In Equation 1, $C_j(e_j)$ is the function for the cost of reducing environmental pollution created for firm j, and $D_i(E)$ is the damage function for individual i, which shows the welfare loss caused by environmental pollution up to E. The point where the first-order derivatives are equated to each other in the equation is considered the first condition of efficient allocation, which is the output of the social objective function aimed at reducing emissions. e_j the cost function shows the emissions produced by the firms. If the actual value is higher than the intended value ($e_j < \hat{e}_j$), the cost increases. Another condition is that the marginal reduction costs of the firms in the market are equal. The first derivative of the cost function in equations 1 and 2 is called the marginal abatement cost (Phaneuf & Requate, 2017).

In the axis of this relationship, while individuals try to compensate for their welfare losses, firms that pollute the environment face the cost of reducing pollution while internalizing negative externalities. The party's agreement on the axis of property rights, such as the related efficient allocation Coase theorem, can solve it. Apart from this, the government can also solve this efficient allocation problem with market-based economic policy tools and/or command and control-style regulatory practices. However, knowing the marginal cost functions of all firms in command and control style applications brings practical difficulties. In addition, discriminatory regulatory practices required by the heterogeneous structure of firms create problems in legal applicability. On the other hand, emission taxes, auctioned pollution permits, tradable pollution permits, and incentives, which can be considered applications in the market dynamics axis, can be used. The ability of firms to determine the marginal abatement costs in the market and the ability of the market actors to buy and sell emissions in the market without increasing the intended total emissions in the axis of a specific environmental pollution standard or to transfer income to the people suffering from welfare loss through taxation of the created pollution are some of the market-based practices. These market-based applications aim at a maximization-minimization process through the competitive structure of the market, based on the equilibrium price level (Wiesmeth, 2012).

In the efficient allocation problem, while the Coase theorem effectively solves more local problems, the government is needed because it contains complexity in environmental problems, and the market cannot fully internalize the problem. In this context, environmental policy stringency, one of the subjects researched in the study, focuses on both market and non-market-based applications. The effect of this relationship on carbon emissions, a common negative externality, allows theoretical implications for the efficient allocation problem.

The impact of innovations on carbon emissions can be evaluated by extending the damage-abatement cost approach. Equation 3 can be obtained by adding the investment factor to the firm's cost function.

$$-C_K^j\left(e_j, K_j\right) < 0, -C_{eK}\left(e_j, K_j\right) < 0 \text{ for } e_j < \hat{e}_j) \quad \textbf{(3)}$$

Equation 3 suggests that investments reduce both the total and marginal abatement costs. In addition, the structure of firms' cost functions maintains its convexity. The necessary conditions obtained according to the social objective function aimed at minimizing emissions are given in equations 4 and 5.

$$-C_K^{j\prime}(e_j K_j) = D_i'(E) \quad \textbf{(4)}$$

$$-C_K^{j\prime}(e_j K_j) = 1 \quad \textbf{(5)}$$

The first condition in Equation 4 parallels the condition in Equation 1. In addition, equation 5 suggests that the last investment in reduction costs for cost reduction should be equal to its unit value (Phaneuf & Requate, 2017).

As seen in the basic analytical model, environmental stringency policies and innovations are closely related to the welfare of households and the cost structures of firms. The environmental policy, created with regulations and economic policy tools, can solve the efficient allocation problem in society on the axis of the firms' costs and the households' welfare. On the other hand, the abatement costs caused by the fact that the emissions caused by the firms are more than the aimed emissions encourage the emergence of innovative applications that produce fewer emissions.

3. LITERATURE REVIEW

In recent years, public policies have been important in technological innovations that have come to the fore in reducing the environmental impact of economic activities. Significant progress has been made in policies in this area, especially in developed countries. Reducing negative externalities in production that cause environmental pollution and reducing their negative impact on natural resources such as air and water indicates how seriously these policies are taken. Undoubtedly, some changes and transformations occurred in economic activities in implementing this policy, such as reducing fossil fuel power plants and promoting renewable energy sources or preferring coal with lower sulfur content (Johnstone et al., 2012).

This study aims to empirically examine the effect of innovations and environmental policy strictness on reducing carbon emissions in G-7 countries. In this context, This study aims to empirically examine the impact of innovation and environmental policy stringency on reducing carbon emissions in G-7 countries. In this context, selected literature in this field is summarized in the table below.

Table 2: Summary of Selected Literature on the Relationship Between Environmental Policy Stringency, Innovation and Carbon Emissions

Author(s)	Methodology	Term	Country	Results
Liu et a. (2023)	NARDL	1991-2021	Asia Pacific Region	According to the analysis results, a positive shock in EPS has a significant negative impact on CO2, while a negative shock in EPS has a significant positive impact on CO2 in both the short and long term.
Assamoi and Wang (2023)	NARDL	China from 1995Q1 to 2020Q4 United States from 1985Q1 to 2020Q4	China and United States	The empirical findings of the study examining the impact of EPU and EPS on environmental quality show that, improvement in EPU deteriorates environmental quality in both countries. However, a negative change in EPU reduces emissions in China and increases them in the United States. In addition A positive change in EPS will lead to fewer emissions, while a negative change will worsen environmental damage.
Li et al.	Panel	1990-2019	BRICS	The study contains

(2023)	asymmetric ARDL		Countries	substantial evidence that environmental policy stringency has a negative effect on carbon emissions.
Albulescu et al. (2022)	Quantile fixed-effect panel data approach	1990-2015	32 Countries	The study findings show that increasing policy stringency has a negative impact on emissions, with environmental stringency having a stronger impact in countries with lower levels of carbon emissions.
Yirong (2022)	Non-linear panel ARDL model	1990-2019	USA, China, Russia, India, and Japan	According to the study, increasing environmental policy strictness to develop environmental quality by reducing CO2 emissions in the long run. So, according to the study, an adverse change in environmental policy strictness also reduces CO2 emissions in the long run.
Hassan and Rousseliere (2021)	SYS GMM, Driscoll–Kraay	1990-2015	27 OECD countries	The study results Show that increasing environmental policy stringency leads to accelerated environmental innovation

Wang et al. (2020)	SYS-GMM	1990-2015	23 OECD countries	Study results showed that environmental policy stringency (EPS) has a negative impact on CO2 emissions.
Ouyang et al. (2019)	Panel Threshold	1998-2015	OECD countries	In the study examining the impact of environmental policy stringency on air quality, they found different effects on PM2.5 at high, medium and low levels.

*EPS: Environmental policy stringency, EPU: Economic policy uncertainty

One of the other important studies conducted in this field is Zarzoso et al. (2019)'s study. Zarzoso et al. (2019) examined the impact of environmental policy constraints on innovation and productivity in their study with data from 1990-2011 for 14 OECD member countries. The study findings show that a stricter environmental policy, both in the long and short term, is associated with increased patent applications and total factor productivity (TFP). The study claims that stricter environmental regulations encourage cleaner production processes that can help increase energy efficiency. Another critical study in this field is the studies of Carrion Flores and Innes (2010). The authors examined the relationship between emissions, technological innovation, and environmental policy strictness from 127 manufacturing industries for the period 1989 to 2004. According to the findings, innovation, which is affected by environmental policies, reduces emissions. One of the studies measuring environmental policy strictness and climate change due to carbon emissions is Angelis et al. (2019) work. The study found evidence that the environmental policy rigidity index, used to explain environmental regulation, exhibits negative and enormously significant coefficients. Furthermore, that policy strictness effectively reduces environmental damage associated with economic growth.

Another critical study in this field is the study of Ahmed (2020). In the study, the role of strict environmental regulations on eco- friendly technological improvement, carbon emissions, GDP, exports, and imports from about 20 OECD countries has been empirically investigated. The study's empirical findings show a long-term equilibrium correlation between the variables and that the current environmental regulations stimulate green(clean) innovation in the sample countries. In addition, according to the study, strict environmental policies combined with eco- friendly innovations are also a driving force for sustainable development. On the other hand, (Lanjouw & Mody, 1996; Jaffe & Palmer, 1997; Brunnermeier & Cohen, 2003; Johnstone, Haščič & Popp, 2010; Fischer & Newell, 2008) are some of the studies that take environmental policy stringency and technological innovation into account. When the studies on environmental policy strictness are evaluated, it has been observed that it significantly affects carbon emissions and related areas in most of the studies. However, the sample group, the method used, and the time interval have changed.

4. DATA SET, METHOLOGY AND EMPIRICAL RESULTS

4.1. Data Set

In the study, the impacts of environmental policy stringency and innovations on reducing carbon emissions are investigated within the scope of the G-7 countries, covering the period of 1994-2019. Empirically, coefficient estimates were obtained using linear panel data econometrics methods. Compared to time series models, panel data models increase the number of samples by combining many unit sizes and time dimensions. Explanations of abbreviations of the variables used in the study are given in Table 3.

Table 3: Abbreviations of Variables

Abbreviations	Explanations	Source
CO_2	Carbon Emissions Metrics Ton Per Capita (Annual)	World Bank
GDP	Gross Domestic Product Per Capita (Annual)	World Bank
EnUse	Energy Consumption Per Capita (Annual)	Our World in Data
EnIno	Patent Applications Environmentally Related Technologies (Annual)	OECD
EnStr	Environmental Policy Stringency Index (Annual – Takes value between 0-6)	OECD
Renew	Renewable Energy Consumption (Annual % of Total Final Energy Consumption)	World Bank
HumCap	Human Capital Index (Annual-Takes value between 1-4)	Penn World Table

All the variables used in the study were analyzed by taking their natural logarithms. The data on the descriptive statistics created on the axis of the logarithmic values of the variables are given in Table 4.

Table 4: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
LCo_2	182	2.262458	.4177849	1.495033	3.018951
LGDP	182	10.48045	.2762936	9.869808	11.08399
LEnUse	182	10.9083	.4104178	10.28243	11.68824
LEnIno	182	7.328153	1.170823	5.157617	9.264424
LEnStr	182	.8144953	.4788887	-.6931472	1.552279
LRenew	182	1.989519	.8153971	-.1625189	3.121924
LHumCap	182	1.219174	.0949621	.9708053	1.328028

$$LCo2_{i,t} = B_0 + B_1 LGDP_{i,t} + B_2 LEnUse_{i,t} + B_3 LEnIno_{i,t} + B_4 LEnStr_{i,t} + B_5 LRenew_{i,t} + B_6 LHumCap_{i,t} + u_{i,t} \quad \textbf{(6)}$$

The equation created to test the relevant theoretical structure is included in equal 6. The equation follows the specification Mahmood et al. established (2022). In addition to the study above, energy consumption and per capita gross domestic product variables were added to the model as control variables in this study. As another difference, the EnStr variable used includes both market-based and regulation-based environmental policy following the relevant theoretical structure. In this sense, while environmental regulations are measured only by taxation in the specification created by the authors, a more holistic environmental policy variable is used in this study.

4.2. Methodology and Specification Tests

Panel regression models include the Ordinary Least Squares (OLS) assumptions. In addition, it is crucial to examine the cross-sectional dependency since a panel is formed within the framework of different units. On the other hand, the model has another difference: the units and/or a specific time have a unique effect. If only unit or time effects are found in the model, one-way models should be used, and if both effects are found in the model, two-way models should be used. If neither effect is present in the model, then Pooled OLS (POLS) models are used. In this context, POLS can be characterized as a panel regression method in which units are added to the OLS estimator.

The type of unit and/or time effects directly affect the estimation methods. The mentioned effects are divided into fixed and random in this context. These effects are associated with error components. The error component equation created for panel data models can be shown as equation 7.

$$u_{it} = \mu_i + \nu_{it} \quad \textbf{(7)}$$

u_{it} generates error components in a panel regression model for unit i and time t. μ_i represents the unobservable unit effects for the unit i, and v_it represents the error term. In fixed effects models, μ_i unobservable unit effects have fixed and predictable parameters. Also, the error term ν_{it} has a stochastic structure and is identically distributed $\nu_{it} \sim \text{IDD}(0, \sigma_\nu^2)$.

Random effects model, on the other hand, μ_i is considered to have a random structure. Also, μ_i is independent of the error term ν_{it}. Since unobservable unit effects are assumed to have a random effect, unit effects are identically distributed $\mu_i \sim \text{IDD}(0, \sigma_\mu^2)$ (Baltagi, 2005).

Various tests can determine the existence and nature of these effects. In this context, the study used F and Likelihood Ratio (LR) tests for model specification. The relevant test results are shown in Table 5.

Table 5: Specification Tests for Unobservable Effects

F Test		
Type of Effect	**Test Statistics**	**Probability**
Unit Effect	375.05	0.0000
Time Effect	0.24	0.9999
Likelihood Ratio (LR) Test		
Type of Effect	**Test Statistics**	**Probability**
Unit Effect	433.61	0.0000
Time Effect	0.00	1.0000

Related tests test the H_0 hypothesis, which states that the unit and time effects are not present in the model. When the data obtained from both tests are examined, it is seen that this hypothesis is rejected for unit effects rather than for time effects. In this context, there are unit effects in the model. Since there are only unit effects in the model, one-way panel data models should be used in the later stages of the study.

After determining that the unit effects are in the model, it should be determined whether the structure of this effect is a predictable fixed parameter or has a random structure. The test developed by Hausman (1978) examines the difference between random effects and fixed effects models and offers the opportunity to choose between the two models. The hypothesis tested in the test is shown in Equation 8.

$$H_0: E(X_{it} | \nu_{it}) = 0 \quad \textbf{(8)}$$

The H_0 hypothesis established that the explanatory variables do not correlate the error term and the unit effect. Rejecting the hypothesis is considered a better estimator choice of the fixed effects model. It is shown in table 6.

Table 6: Hausman Specification Test

Test	Test Statistics	Probability
Hausman	162.78	0.0000
Robust Hausman	4.15	0.6563

Looking at the results obtained in Table 6, it is seen that two different inferences can be made. It is seen that the fixed effects model is suitable according to the classical Hausman test, and the random effects model is suitable according to the robust Hausman test. The Robust Hausman test provides a robust choice in the presence of violations from the assumptions in the model. For this reason, it will be decided which estimator to use as a result of testing the violations from the assumptions regarding the one-way panel regression model.

Various assumptions must be tested to obtain an unbiased and efficient coefficient estimate in panel regression models. These are the absence of autocorrelation, heterogeneity, and cross-sectional dependency. In addition, multicollinearity in the random effects model also leads to biased estimation results. In case of violation of assumptions, robust estimators can be used, which correct the standard errors and provide an unbiased and efficient coefficient estimation. In this context, the tests performed to determine the assumptions in question are shown in Table 7.

Table 7: Tests of Assumptions

Test	Test Statistics	Probability
Levene, Brown & Forsythe (W0)	8.8257498	0.00000002
Levene, Brown & Forsythe (W50)	5.2738454	0.00005081
Levene, Brown & Forsythe (W10)	7.7632223	0.00000021
Breush Pagan LM	179.91	0.0000
Breush Pagan ALM	4.36	0.0367
Pesaran's Cross-Sectional Dependence Test	2.818	0.0048

Levene, Brown and Forsythe developed tests to determine the heteroskedasticity problem. Levene (1960) proposed a robust heterogeneity test despite violating the normal distribution. This robust test, shown as the Levene test statistic, is shown as W0. In addition, Brown & Forsythe (1974) created W50 and W10 test statistics by improving this test, such as changing the median and trimming the 10% segment. All three test statistics are based on the H_0 hypothesis that the model has no heterogeneity problem. Considering the relevant test results, it is seen that there is a heterogeneity problem in the model, which is also valid in all test statistics.

Another assumption, the absence of autocorrelation, was tested with the Breush-Pagan LM and ALM tests. The difference between the ALM test from the LM test is that the ALM test creates an adjusted version of the LM test for the presence of random unit effects. In this context, the ALM test tests the H0 hypothesis that the random unit effect and the LM test have an autocorrelation coefficient equal to zero. The ALM test results are more reliable in the presence of random unit effects. H_0 hypothesis, which shows that the variance of the unit effect and autocorrelation is equal to zero according to the results obtained in Table 6, was rejected for the ALM and LM tests, and it was concluded that there was an autocorrelation problem in the model.

Another assumption unique to panel data econometrics, the lack of cross-sectional dependence, is one of the necessary conditions to obtain an unbiased and efficient estimation result. In this context, Pesaran's test was used to test the cross-sectional dependence in the model. According to the test based on the H_0 hypothesis that there is no cross-sectional dependence, the hypothesis in question is rejected in the model, and it is concluded that there is cross-sectional dependence.

When the test results obtained are evaluated, it is seen that there is heterogeneity, autocorrelation, and cross-sectional dependence in the model. When the Hausman test is re-evaluated on the axis of violations from these assumptions, the robust Hausman test's results should be considered. This is because the robust Hausman test can give robust results despite deviations from the assumptions. In this context, it can be interpreted that the unit effects in the model have a random structure and one-way random effects models should be used to select the estimator (Tatoğlu, 2021).

4.3. Driscoll-Kraay Random Effects Estimation Results

After the specification tests, it was determined that the suitable estimator for the model was the random effects model. However, it was concluded that the assumptions regarding the lack of autocorrelation, heterogeneity, and cross-sectional dependence required for the random effects estimator to give an efficient and unbiased coefficient estimation were violated. In this context, the results obtained from the classical random effects model will be biased and ineffective.

The method proposed by Driscoll-Kraay (1998) provides an efficient and unbiased estimation opportunity by correcting the standard errors in the random effects model in violation of the assumptions above. Table 8 shows the coefficient estimates obtained from the classical and the Driscoll-Kraay random effects models.

Table 8: Driscoll-Kraay Estimation Results

Random Effects Estimation				Driscoll-Kraay Random Effects Estimation			
Variable	**Coefficient**	**Standard Errors**	**Probability**	**Variable**	**Coefficient**	**Driscoll-Kraay Std. Errors**	**Probability**
LGDP	.0968652	.0903148	0.283	**LGDP**	.0968652	.0481446	0.055*
LEnUse	.6981932	.0579091	0.000***	**LEnUse**	.6981932	.0419439	0.000***
LEnIno	.0585244	.0144782	0.000***	**LEnIno**	.0585244	.0079982	0.000***
LEnStr	-.2311085	.0582998	0.000***	**LEnStr**	-.2311085	.0453332	0.000***
LRenew	-.0557971	.0227027	0.014**	**LRenew**	-.0557971	.0208243	0.013**
LHumCap	.7645807	.1960042	0.000***	**LHumCap**	.7645807	.1418759	0.000***
Constant	-7.43062	.7369121	0.000***	**Constant**	-7.43062	.2964597	0.000***
Probability: 0.0000				**R^2:** 0.8503			
Normality on Error Term: 0.7751				**Normality on Unit Effect Error Term:** 0.0518			
Variance Inflation Factor				3.29			

Note: ***, **, * represents %99, %95, %90 confidence intervals, respectively.

According to the results obtained from both estimators in Table 8, the increase in income positively affects carbon emissions. Still, while the coefficient is statistically insignificant in the classical random effects estimator, it is statistically significant in the 10% confidence interval according to the Driscoll-Kraay estimator. Today, the energy required for economic growth in most developed and developing countries is provided by traditional sources such as oil, coal, and natural gas. Growth based on fossil resources is the leading cause of CO2 emissions. In many studies, high pollution is associated with economic growth in large economies. Study findings are consistent with Arı and Zeren (2011); Lane (2011).

In the results of both estimators in the study, energy use affects carbon emissions positively, and the coefficient is significant in both estimators. The positive correlation between energy consumption and carbon emissions found in the study indicates the intense use of traditional fuels in energy in G-7 countries. In this context, encouraging the increase in the use of alternative energy sources gains importance at this point. In addition, the study findings are compatible with Atgür (2021); Çetin and Yüksel (2018).

Another variable whose impact on carbon emissions is examined within the scope of the study is technological innovation. In the study, the effect of innovation on carbon emissions was positive, and the coefficient was significant in both estimator results. Innovation is expected to reduce CO2 emissions without compromising economic development. Still, although innovation contributes to reducing carbon emissions, it may not always have a reduction impact on energy consumption. Otherwise, the impact of technological innovations in all sectors of the economy is not at the same level (Erdoğan, Yıldırım, Yıldırım, & Gedikli, 2019). The result obtained from the study shows that technological innovation in G-7 countries is insufficient to provide high-quality output and minimize environmental deformation. To put it more clearly, the technological innovations made in these countries are not sufficiently environmentally friendly, or the environmental factor cannot be sufficiently included in the innovation activities. Kırıkkaleli, Adebayo and Kondoz (2022); Khan and Ozturk (2021) are also compatible with study findings.

In the study, when the energy policy strictness coefficient is examined, the effect of the coefficient on carbon emissions was found to be negative and statistically significant in both estimators. Strict environmental policies ensure green growth through eco-efficiency and recycling, prevent the spread of negative externalities, and ensure more efficient use of resources. The findings reported by Yirong (2022); Wang, Yan, Wang and Chang (2020) are also compatible.

Another variable whose effect on carbon emissions is examined is renewable energy. According to the results from both estimators, the effect of renewable energy use on carbon emissions is negative. In addition, it is seen that the variable coefficient is statistically significant. Renewable energy sources have become an excellent alternative to fossil-based energy sources in recent years. In this context, the widespread use of renewable energy sources, also called clean energy sources, helps to reduce carbon emissions by reducing environmental deformations. The results are also compatible with Adams and Acheampong (2019); Shepherd (2015).

The last variable discussed in the study is the human capital variable. The increase in human capital positively affects carbon emissions in classical random effects and the Driscoll-Kraay estimator. In addition, the coefficient was statistically significant in both estimators. The effect of human capital on carbon emissions has often been addressed through the income effect in the literature. Accordingly, the income effect mediates the relationship between human capital of economic growth and CO_2 emissions. It contributes to economic growth by causing higher physical capital investments with higher labor productivity (Yao, Ivanovski, Inekwe, & Smyth, 2020, p. 3). Economic growth causes more production and energy consumption. Although alternative sources are used, especially in developed countries such as the G-7, the dependence on fossil fuels in production also increases carbon emissions.

On the other hand, Normality tests and R^2 values are the same in both models. The differences between the two estimators consist of the probability values that change due to the standard errors being made resistant to the violation of assumptions and the differentiation of test statistics.

The classical random effects model and the Driscoll-Kraay random effects model are linear estimators. For this reason, the assumption of normality should also be tested to avoid an asymptotic violation. However, as can be seen in equation 7 in random effects models, the error component consists of the error term and the random unit effect. For this reason, it is necessary to perform a normality test for both components. As can be observed in Table 8, it is concluded that the model is normally distributed in the 99% confidence interval for the error term and the 95% confidence interval for the unit effect error term.

5. CONCLUSION

In recent years, due to population growth, rapid urbanization, and industrialization activities, environmental deformations have come to the fore in all developed and developing countries, and environmental pollution problems in air, water, and soil have emerged. At this point, many countries apply tax sanctions to reduce carbon emissions and/or technology standards within the scope of clean trade to solve these problems. At the point reached today, it is being discussed at the national and international levels whether these practices can meet the expectations to reduce environmental pollution and carbon emissions.

In this context, this study aims to empirically analyze whether environmental policy strictness and technological innovation reduce carbon emissions with the help of linear panel data econometric methods with the 1994-2019 period data for the G-7 countries. In the study, environmental policy strictness was associated with the Environmental Policy Stringency index calculated by the OECD and technological innovation was associated with Patent Applications of Environmentally Related Technologies. In addition, the effects of GDP, energy use, human capital, and renewable energy consumption on carbon emissions were also examined in the study.

The results of the study show that environmental policy strictness has a negative effect on carbon emissions, while technological innovation has a positive effect. In addition, it was found in the study that GDP, energy use, and human capital increase carbon emissions, but renewable energy consumption reduces carbon emissions. Suppose the effects of environmental policy strictness are complemented by the effects of renewable energy, which is a good alternative to fossil fuels. In that case, environmental deformation can be minimized, and carbon emissions reductions can contribute. Except for innovations, the results obtained in this context agree with the interested theory. However, the potential of environmental-based technological innovations to turn into a negative effect in the future with the spillover effect of technologies can be expected theoretically. Practically, it can be commented that already innovative technologies increase carbon emissions because they are produced with established resources. Studies that can be done with micro data on an industrial basis have the potential to analyze the source of this effect more effectively. In light of these outputs, policymakers in the countries examined can contribute to reducing carbon emissions through economic policy tools that consider market dynamics and command and control practices. In the future, new studies with different theoretical backgrounds, countries, and methods may enrich the empirical literature and contribute to reducing carbon emissions globally.

6. CONFLICT OF INTEREST DECLARATION

There is no conflict of interest between the authors.

7. FINANCIAL SUPPORT

This study did not benefit from any funding or support

8. CONTRIBUTIONS OF AUTHORS

The authors contributed equally to the study.

9. ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethics committee principles were followed in the study. There has been no situation requiring permission within the framework of intellectual property and copyrights.

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