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Research Article

On the Impact of Environmental Policies and Green Technology Diffusion on Climate Change Mitigation: Evidence from a Panel Quantile Approach

Çevre Politikaları ve Yeşil Teknoloji Yayılımının İklim Değişikliğinin Azaltılmasına Etkisi Üzerine: Panel Kantil Yaklaşımından Kanıtlar

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Abstract

This paper investigates the role of environmental policy stringency (EPSI) and its causal determinants in climate change mitigation across EU countries from 2000 to 2021. Using a panel quantile regression model, we analyze the effects of key variables such as CO_2 emissions, foreign direct investment, and economic expansion, green technology diffusion on climate change mitigation efforts. Our findings reveal significant heterogeneity in the impact of these factors across different quantiles, with EPSI showing a stronger positive influence on climate change mitigation at higher levels of mitigation outcomes. Economic growth, green technology diffusion, and foreign direct investment exhibit nonlinear effects, while CO_2 emissions play a more critical role in contexts with higher mitigation outcomes. The presence of long-term cointegration between climate change mitigation, EPSI, and these determinants, as well as Granger causality, underscores the need for integrated, adaptive policy strategies. Furthermore, the findings indicate a sustained relationship between climate change mitigation and EPSI, underscoring the importance for policymakers to scrutinize measures and strategies aimed at fostering the development of green technologies and energy sources to effectively address climate change.

Keywords: *Environmental Policy, Climate Change Mitigation, Green Technology, Green Economy, Panel Quantile Regression Model*

Öz

Bu çalışma, 2000-2021 yılları arasında AB ülkelerinde iklim değişikliğinin azaltılmasında çevre politikası katılığının rolünü ve nedensel belirleyicilerini araştırmaktadır. Çalışmada, panel kantil regresyon modeli kullanarak, karbon emisyonları, doğrudan yabancı yatırım ve ekonomik büyüme, yeşil teknoloji yayılımı gibi temel değişkenlerin iklim değişikliği azaltma çabaları üzerindeki etkilerini analiz edilmektedir. Çalışmanın bulguları tüm faktörlerin farklı kantiller üzerinde heterojen etkisini ortaya koymaktadır; çevre politikası katılık endeksinin daha yüksek kantil seviyelerinde iklim değişikliğinin azaltılması üzerinde daha güçlü bir pozitif etki göstermektedir. Ekonomik büyüme, yeşil teknoloji yayılımı ve doğrudan yabancı yatırım doğrusal olmayan etkiler sergilerken, karbon emisyonları daha yüksek azaltma sonuçlarına sahip kantillerde daha önemli bir rol oynamaktadır. İklim değişikliğinin azaltılması, çevre politikası sıkılık endeksinin ve bu belirleyiciler arasındaki uzun vadeli eşbütünleşmenin varlığı ve Granger nedenselliği, uyarlanabilir politika stratejilerine olan ihtiyacı vurgulamaktadır. Ayrıca bulgular, iklim değişikliğinin azaltılması ile çevre politikası katılık endeksi arasında sürdürülebilir bir ilişki olduğunu göstermekte ve politika yapıcıların iklim değişikliğiyle etkili bir mücadele için

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yeşil teknolojilerin ve enerji kaynaklarının geliştirilmesini teşvik etmeyi amaçlayan önlem ve stratejileri incelemesinin önemini vurgulamaktadır.

Anahtar Kelimeler: *Çevre Politikası, İklim Değişikliğinin Azaltılması, Yeşil Teknoloji, Yeşil Ekonomi, Panel Kantil Regresyon Modeli*

1. Introduction

Climate change and dependence on nonrenewable energy resources represent grave and widespread threats to the future of our planet, given their interrelated and adverse effects on the environment, ecosystems, human health, and socio-economic stability. The burning of nonrenewable energy sources releases large quantities of carbon emissions into the environment, contributing significantly to global warming and climate change, and setting off a chain of repercussionsIn recent years, the Intergovernmental Panel on Climate Change (IPCC) has indicated that the global average temperature has increased by about 1.5 degrees Celsius compared to pre-industrial levels. In response to this alarming trend, the European Union (EU) has emerged as a frontrunner in the global fight against climate change, implementing rigorous environmental policies aimed at promoting sustainability. A key aspect of this transition involves evaluating the strictness of these policies in the context of climate change mitigation, particularly in the pursuit of a green economy.

Over the past three decades, Beckerman (1992) has argued that resource constraints do not limit growth and that the economic influence of climate change is minimal compared to the significant welfare losses faced by populations lacking access to clean water and air. Thus, it asserts that current environmental challenges should take priority over future concerns, questioning the validity of the sustainable growth concept. On the other hand, Popp (2011) investigates the literature on environmental technology transfer, noting that technology diffusion is gradual and facilitated by early policy adoption in developed countries. The results highlight the roles of international trade and foreign investment in accessing clean technologies and mentions that some technologies may spread to developing nations even without specific policies.

Against a backdrop of escalating environmental challenges and growing recognition of the imperative for sustainable development, understanding the effectiveness of environmental policies becomes paramount. The aim of this study is to examine the potential role of the Environmental Policy Stringency Index (EPSI) on climate change mitigation technologies. While existing literature has extensively explored the influence of various economic, political, and environmental factors on climate change mitigation policies (Abid et al., 2023; Ferreira et al., 2020; Ganji et al., 2024), this study specifically focuses on the unique contribution of EPSI in shaping the effectiveness and implementation of these technologies.

Numerous theoretical and empirical investigations have been conducted to tackle environmental challenges, particularly those centered around climate change and natural resource depletion. The significance of adaptation and mitigation policies related to climate change is underscored by their potential to profoundly affect various dimensions of human well-being, including economic, environmental, technological, and socio-political realms. Scholars have extensively investigated the impacts of climate change on environmental policies, exploring causal factors in existing literature. More importantly, various studies (Albulescu et al., 2022; Garrett et al., 2020; Ladenburg et al., 2024; S. Li et al., 2023) point out the role of EPSI and climate change mitigation technologies on environmental sustainability and reducing CO_2 emissions.

This study offers a fourfold contribution to the existing literature. First, it distinguishes itself by highlighting the critical importance of EPSI in promoting climate change mitigation, a factor that has frequently been neglected in previous studies. Second, the research broadens its focus by integrating a wide array of elements that affect environmental sustainability, including economic expansion, foreign direct investment (FDI), CO_2 emissions, and the dissemination of green technologies. This comprehensive approach enables a more nuanced understanding of how these various factors interact to influence climate policy outcomes. Thirdly, it utilizes the panel quantile regression model to capture the varying effects of these determinants across different levels of CO_2 emissions. The findings reveal a significant causal relationship between the implementation of EPSI and successful climate change mitigation, while CO_2 emissions exhibit a diminishing impact on mitigation efforts. Lastly, this study underscores the necessity of advancing a green economy, emphasizing the critical role of renewable energy adoption and the integration of innovative green technologies in ensuring long-term environmental sustainability. These insights highlight the importance of targeted policies and technological advancements in achieving meaningful progress in global climate efforts. This study continues by conducting a theoretical framework in Section 2, followed by the literature review in Section 3. Later, Section 4 shows the data and empirical findings. Finally, Section 5 provides a summary of the conclusions drawn from the study and discusses their implications for policy.

2. Theoretical Framework

Environmental policies and technology diffusion are potential drivers in addressing the global challenge of climate effects. The theoretical foundation of this study draws on several key concepts from environmental economics, innovation theory, and policy analysis, framing how stringent environmental regulations such as EPSI and the creation and diffusion of environmental friendly technologies contribute to climate change mitigation efforts.

Climate change has emerged as one of the most pressing global issues, necessitating effective mitigation strategies to reduce CO_2 emissions and limit global temperature rise. In this context, the role of environmental policies and green technology diffusion has become crucial for ensuring sustainable growth and promoting climate change mitigation. Theoretical and empirical research underscores the importance of EPSI in encouraging cleaner production and innovation in green technologies (Porter and Van Der Linde, 1995). The Porter Hypothesis suggests that well-designed environmental regulations not only promote environmental protection but also enhance economic performance by stimulating innovation in cleaner technologies.

Environmental policies, particularly stringent regulations, create incentives for firms and industries to adopt environmentally friendly technologies (Ambec et al., 2011). These policies also aim to mitigate the negative externalities associated with industrial growth by internalizing the cost of pollution. Additionally, environmental regulations play a key role in stimulating innovation by promoting the adoption and widespread use of clean technologies. These regulations encourage the development and integration of green energy systems, energy-efficient machinery, and other eco-friendly innovations that contribute significantly to reducing greenhouse gas emissions (Popp, 2002). By setting higher environmental standards, such policies not only push industries to improve their sustainability practices but also foster a competitive environment where technological advancements thrive. Moreover, the diffusion of these technologies across sectors and regions has the potential to create economic opportunities, generate green jobs, and increase the overall resilience of industries to environmental challenges.

Green Technology Diffusion: Green technology diffusion refers to the process by which innovations in clean technologies spread across markets, particularly from developed to developing economies. Theoretical models suggest that the diffusion of such technologies often follows an S-curve, starting slowly, accelerating during widespread adoption, and finally leveling off as the market becomes saturated. In this context, international trade, foreign direct investment (FDI), and knowledge spillovers are essential channels for the transfer of green technologies across borders, aligning with the Technology-Push and Demand-Pull Models.

Green technology diffusion, often referred to as the process of transferring environmentally sound technologies across borders, is pivotal for developing economies to achieve climate goals. In high-income countries, new technologies are first developed, and their diffusion into developing regions can contribute to global emissions reduction (Dechezleprêtre et al.,2011). The Clean Development Mechanism (CDM), established under the Kyoto Protocol, has facilitated this transfer by incentivizing the adoption of green technologies in developing countries, thereby promoting global climate change mitigation efforts (UNFCCC, 2014).

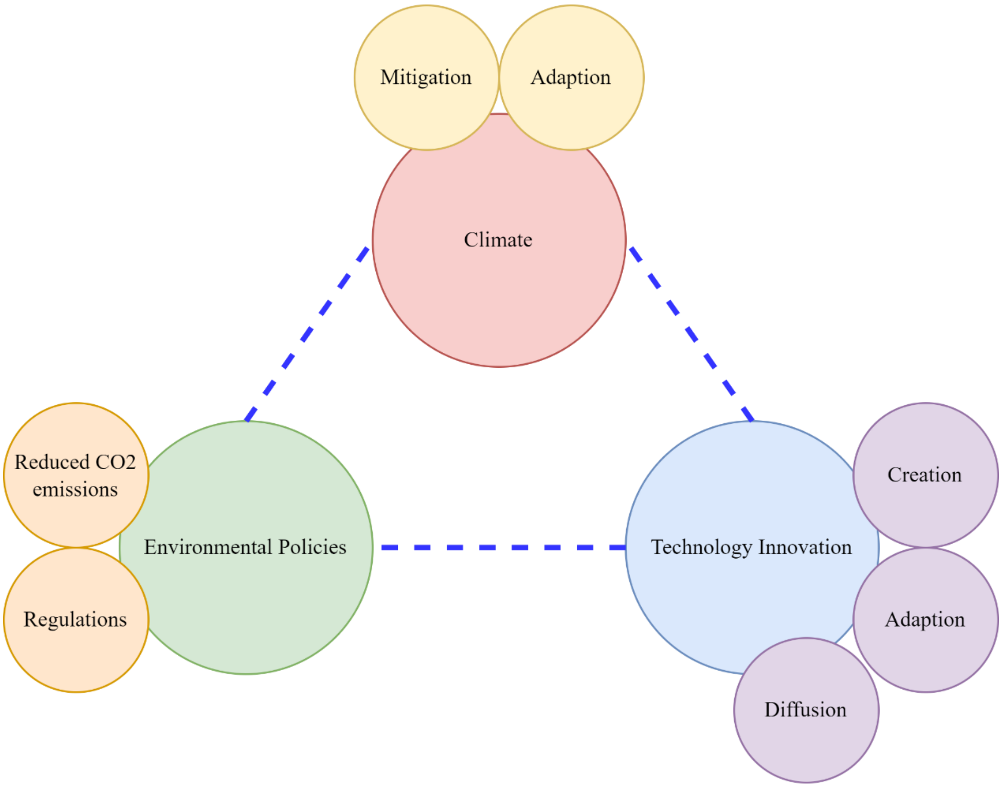
In terms of mechanisms, green technology diffusion can be fostered through international trade, foreign direct investments (FDI), and knowledge spillovers (Frankel et al., 1991). The deployment of these technologies is critical for achieving long-term sustainability goals and reducing the effects of climate change. Another study by Allan et al. (2013) indicate that the diffusion process, however, is gradual, and early adoption of stringent environmental policies in developed countries accelerates technology creation, making it easier for developing countries to transition to green practices.

In addition to green technology diffusion, the concept of "Environmental Kuznets Curve" (EKC) has been discussed in relation to environmental policy and economic development. The EKC hypothesis posits that as economies grow, environmental degradation increases up to a certain point, after which cleaner technologies and policies lead to an overall reduction in environmental impacts (Dinda, 2013). Thus, the interaction between economic growth, environmental policy stringency, and technology diffusion is integral to understanding how nations can achieve climate change mitigation.

On the other hand, empirical studies support the EKC hypothesis in relation to CO_2 emissions and climate change efforts. For instance, (Stern, 2008) found evidence of an EKC pattern in carbon dioxide emissions, showing that emissions rise with economic growth in early stages but eventually fall as economies mature and adopt stricter environmental standards. Similarly, Islam et al., (1999) emphasize the importance of economic and institutional indicators in shaping the EKC, arguing that well-designed environmental policies and investments in green technologies expedite the downward trend of emissions in higher-income countries.

Overall, the EKC provides a theoretical framework for comprehending the intricate linkage between economic expansion, environmental policy, and the diffusion of green technologies in the context of climate change mitigation. This model suggests that as economies grow, they initially experience environmental degradation, but after reaching a certain level of income, the trend reverses, leading to improved environmental quality. The effects of EPSI in shaping the EKC highlights the importance of stringent regulatory frameworks in promoting sustainable growth. Meanwhile, green technology diffusion allows developing nations to transition towards low-carbon economies without enduring the severe environmental degradation historically experienced by early industrializers.

Figure 1: The interconnectedness of climate change, environmental policies, and innovation



Source: Author's own elaboration

Figure 1 illustrates the complex relationship between climate change, environmental policies, and technology innovation. It highlights how environmental policies play an important role in driving technological innovation, particularly in green technologies, which are essential for mitigating the climate change effects. Climate is integrated with adaptation and mitigation, which serves as the primary motivation for enacting robust environmental policies, which in turn encourage research and development (R&D) into new technologies, such as renewable sources and environment-efficient systems. These innovations reduce CO_2 emissions and foster more sustainable development pathways. The continuous feedback loop between these indicators emphasizes the importance of policy coherence and international collaboration for achieving long-term climate goals.

The diagram illustrates the interconnected relationship between climate change, environmental policies, and technology innovation. Climate change, addressed through mitigation (reducing emissions) and adaptation (adjusting to impacts), is at the center of this interaction. Environmental policies are essential in reducing CO_2 emissions and setting regulations that guide industries and governments toward sustainable practices. These policies foster technology innovation, which involves the creation, adoption, and diffusion of new technologies that mitigate to climate change. The dashed blue lines in the diagram represent the cyclical nature of these relationships that environmental policies drive technological advancements, which in turn enable more effective mitigation and adaptation measures. The process is dynamic, as stronger policies and innovations continuously reinforce one another, creating a sustainable pathway to address climate change.

Considering this theoretical framework showcases the role of policy stringency in accelerating technological advancements and underlines the significance of adopting an integrated approach to address climate challenges.

3. Literature Review

This study investigates the effect of EPSI, CO_2 emissions, GDP per capita, FDI, and green technology diffusion on climate change mitigation technologies. The first strand covers previous studies on the connection between climate change mitigation and macroeconomic factors. For instance, Bosetti et al. (2009) analyze the economic re-percussions of climate change, noting that while initial effects may appear positive, they ultimately transition to negative impacts over the long term. A pioneering study by Millner and Dietz (2015) explores how developing countries can effectively respond to climate change, focusing on the investment balance between traditional productive capital and adaptive capital. When applying their model to sub-Saharan Africa, they find that focusing on the growth of the adaptive sector is typically advantageous in the coming decades.

Later, Tol, (2018) underscores the alignment between poverty reduction efforts and the reduction of CO_2 emissions, presenting a strategy to mitigate climate change impacts. Similarly, Khan, (2020) conduct a comprehensive analysis focusing on the estimation of long term economic costs and benefits associated with climate change mitigation. Their study highlights the significance of technological advancements, particularly in research and development investments and energy efficiency technologies. Another study by Li and Shao (2023) explores the macroeconomic effects of climate change mitiga-tion strategies in Zimbabwe and Venezuela. Their findings conclude that simultaneous implementation of mitigation strategies has the potential to enhance economic welfare and facilitate successful implementation.

The second strand focuses on the dynamic effects of climate change mitigation on both sustainable development and economic growth through empirical investigations. In preliminary inquiries, Li et al. (2022) delve into the correlation between climate change mitigation and various factors, including energy efficiency, cleaner technology, and financial development, and economic expansion. Their findings suggest that renewable energy and financial development possess the capacity to decrease CO_2 emissions and mitigate climate change effects. Similarly, Magazzino et al. (2023) scrutinize the interplay between economic development and environmental quality within the framework of climate change mitigation and the Kuznets curve. They present evidence supporting the presence of an inverted U-shaped interaction between GDP growth and CO_2 emissions.

Later, Jafri and Liu, (2023) examines factors driving green energy consumption in China, finding that environmental taxes, strict policies, technology innovations, and education all significantly boost energy consumption in the long term. It recommends that policymakers promote research and eco-innovation while enforcing strict environmental laws to encourage clean energy investments. Moreover, Song et al. (2021) examines the development of climate change was driven by a focus on green inventions, increased research intensity, and economic growth, while the decline from 2011 to 2015 was due to reduced attention on green innovation.

Over time, Wang et al., (2023) explore how rising oil prices influence the development of climate change mitigation technology (CCMT) across 30 economies from 1990 to 2019. The findings show that higher oil prices boost CCMT by reducing energy intensity, increasing renewable energy use, and driving R&D in energy technologies. The impact is powerful for technologies related to energy generation, efficiency, CO_2 emissions, and transportation. Tiwari et al., (2023) study the influence of the circular economy on the growth of CO_2 emissions taking into account factors like energy transition, and climate policy stringency. The results indicate that a robust circular economy, along with stringent climate policies, significantly lowers carbon emissions.

The current studies on environmental policies in the literature have largely centered on identifying the determinants that affect the efficacy of environmental taxes and the enforcement of stringent environmental regulations. Previously, Johnstone et al. (2010) analyze the influence of environmental policies on innovation in green energy from 1978 to 2003. The findings indicate that public policy significantly influences patent applications for renewable technologies. Wolde-Rufael and Weldemeskel (2020) examine the influence of Environmental policies in reducing CO_2 emissions in 20 European countries from 1995 to 2012. This study shows a significant negative interactions between CO_2 emissions and both environmental taxes (including total, energy, and transport taxes) and policy stringency. Higher environmental taxes and stricter policies lead to greater reductions in emissions.

In the same vein, Martínez-Zarzoso et al. (2019) analyze the weak and strong versions of the Porter hypothesis and employs the EPS index and panel-quantile regression model. The findings reveal that stricter environmental policies boost patent applications in higher quantiles and total factor productivity (TFP) across all quantiles. Sadik-Zada and Ferrari (2020) investigate the pollution haven conjecture, EPSI, and refined carbon emissions data for 26 OECD countries from 1995 to 2011. The empirical findings challenge the optimistic view that long-term economic growth reduces atmospheric pollution. Later, Ahmed (2020) finds that stringent environmental regulations promote environmental innovation and sustainable development in 20 OECD countries. Exports reduce carbon emissions short-term, while imports increase them. This study concludes revisiting trade-related environmental policies to meet Paris Agreement goals. On the other hand, Chen and Tanchangya (2022) examine how environmental innovations and EPSI affect economic development in China using the ARDL model. The results indicate that environmental friendly technologies significantly promotes economic development. However, environmental policy negatively impacts growth in the short run and shows no significant effect in the long run.

Furthermore, Niu et al. (2022) examine factors driving renewable energy transition in 21 OECD countries using renewable energy R&D. They find that while GDP hinders the transition, policy stringency, environmental taxes, and technology development promote it. Later, Fatima et al. (2023) examine the connections between financial globalization, the stringency of environmental policies, financial development, and innovation in relation to CO_2 emissions across 36 OECD countries. Their findings indicate that financial globalization has a negative impact on CO_2 emissions, whereas financial development, EPSI, and innovation are positively associated with environmental degradation.

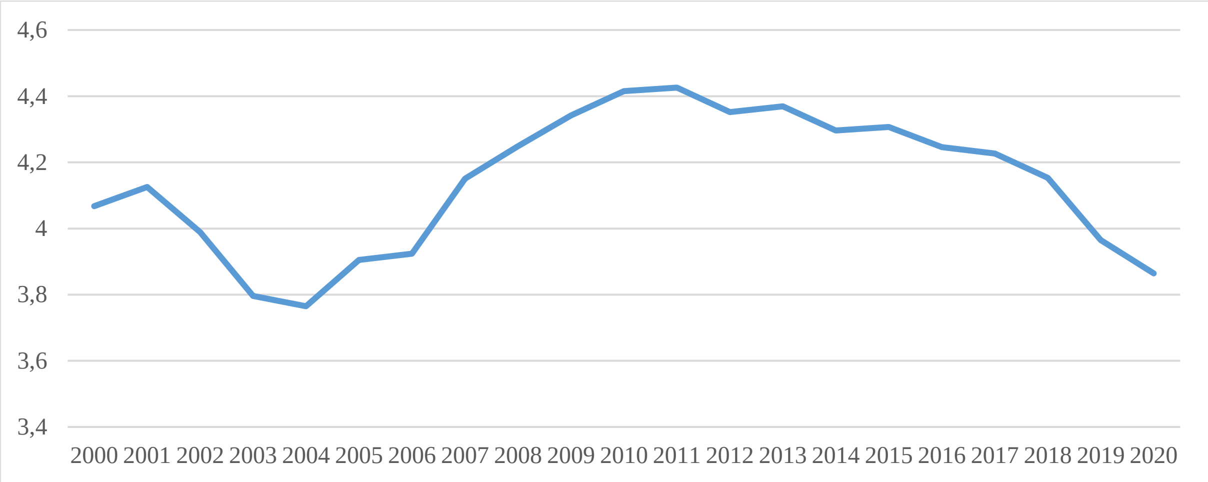
Recently, Liu et al., (2023) examines the link among EPSI and CO_2 emissions in the most polluted Asia Pacific countries from 1991 to 2021 using nonlinear panel ARDL methods. The empirical findings conclude that positive EPSI shocks decrease CO_2 emissions, while negative EPSI shocks increase them, both in the short and long term. Later, Dmytrenko et al. (2024) explore the influence of EPSI and taxes on CO_2 emissions in eight European countries. The results indicate that stringent policies are effective only in Western Europe, while R&D spending is the key factor in both regions. Regional and economic differences are important in assessing policy effectiveness. Balsalobre-Lorente et al., (2024) investigate how economic complexity, geopolitical risk, and uncertainty affect environmental pollution in G-20 countries. These results show that economic policy uncertainty worsens environmental pollution.

Therefore, this study fills the gap in the literature by contributing to the existing literature in several ways. First, it emphasizes the pivotal role of the Environmental Policy Stringency Index (EPSI) in driving climate change mitigation, addressing a gap often overlooked in prior research. Second, it adopts a holistic perspective by incorporating a diverse range of factors influencing environmental sustainability, including economic growth, foreign direct investment (FDI), CO2 emissions, and the diffusion of green technologies. Third, the study employs the panel quantile regression model, enabling an analysis of how these determinants vary across different levels of CO2 emissions.

4. Data and Empirical Findings

This study employs annual data spanning from 2000 to 2020, covering a total of 30 European Union countries. The selection of these countries and periods is determined by the availability and accessibility of relevant data. Data on climate change mitigation is based on the patent application, and efforts encompass six distinct sub-categories, including energy generation, transmission and distribution, water treatment and waste management, information and communication technologies (ICT), transportation, and building production or goods processing. Figure 2 presents a time-series depiction of the overall levels of climate change mitigation across EU countries from 2000 to 2020.

Figure 2: Climate Change Mitigation, 2000-2020



Source: Author's own elaboration

Climate change mitigation technologies (CMM) are based on patent applications from OECD statistics. EPSI is also taken from OECD statistics based on environmental and climate change mitigation policies with 13 policy instruments CO2 emissions are taken from the World Development Indicator (WDI). Economic growth is measured in GDP per capita (constant 2015 US$), and foreign direct investments (FDI) are measured net (BoP, current US$). Green Technology Diffusion (GTD) is based on patent applications from OECD statistics. Table 1 presents the indicator, informations, and sources of the variables considered.

Table 1: Data information

Indicator	***Information***	***Source***
CMM	Climate change mitigation technologies	OECD.STAT
EPSI	Environmental policy stringency index	OECD.STAT
GTD	Green technology diffusion	OECD.STAT
CO_2	metric tons per capita	WDI
FDI	BoP, current US$	WDI
GDP	per capita (current US$)	WDI

Within the framework of Sustainable Development Goals (SDGs), these studies explore multiple dimensions, including the effects of climate change, shifting precipitation patterns, and extreme weather events on ecosystems, biodiversity, and natural resources. In addition, they examine the far-reaching results of climate change on human health, livelihoods, and socio-economic systems, aiming to identify effective mitigation and adaptation strategies to promote long-term environmental sustainability.

In this context, we introduce an empirical model designed to investigate the mediating role of the EPSI index alongside key causal factors in addressing climate change. The model integrates several explanatory variables such as economic growth, CO_2 emissions, Foreign Direct Investment (FDI), and the dissemination of green technologies within EU nations. It aims to capture the dynamics between stringent environmental regulations and their effects on reducing emissions and fostering sustainable development. By accounting for both direct and indirect influences on environmental outcomes, this model provides a comprehensive approach to understanding how economic activities, policy interventions, and technological advancements interact to combat climate change. The articulated model is as follows:

$$LCCM_{it} = \beta_{it} + \alpha_{2i}EPSI_{it} + \alpha_{3i}LCO2_{it} + \alpha_{4i}LFDI_{it} + \alpha_{5i}LGDP_{it} + \alpha_{6i}LGTD_{it} + \varepsilon_{it} \quad (1)$$

where LCCM represents climate change mitigation Technologies, EPSI denotes environmental policy stringency index, LCO shows CO2 emissions, LGDP denotes GDP per capita, and also LFDI represents foreign direct investment. Lastly, LGTD denotes green technology diffusion. All variables are taken at their natural logarithm level, except for EPSI which is the index value. In this study, the logarithmic transformation of the EPSI values is not applied, as the index is already normalized and exhibits a linear relationship with the dependent variables, consistent with previous studies (Botta and Koźluk, 2014; Udeagha and Muchapondwa, 2023). This study develops an empirical model by integrating the quantile approach in the following manner:

$$Q_\tau(LCCM_{it}) = \beta_\tau + \alpha_{2\tau}EPSI_{it} + \alpha_{3\tau}LCO2_{it} + \alpha_{4\tau}LFDI_{it} + \alpha_{5\tau}LGDP_{it} + \alpha_{6\tau}LGTD_{it} + \varepsilon_{it} \quad (2)$$

where the panel quantile regression is represented as Q, with the specific quantile point denoted by τ.

Table 2 provides a summary of descriptive statistics for all indicators. The results indicate that GDP per capita exhibit the highest mean value.

Table 2: Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
LCCM	630	4.139	2.134	0.010	8.933
EPSI	630	2.509	0.989	0.166	4.888
LGDP	630	10.30	0.672	8.698	11.62
LCO	630	0.899	0.351	0.466	4.418
LGTD	630	4.416	0.550	2.973	5.946
LFDI	630	2.291	0.079	1.840	2.473

Table 3 shows the correlation estimates for all indicators. Most variables exhibit a positive correlation coefficient; however, the variable LFDI demonstrates negative correlation.

Table 3: Correlation Matrix

Variable	LCCM	EPSI	LGDP	LGTD	LFDI	LCO
LCCM	1.0000					
EPSI	0.1954*	1.0000				
LGDP	0.1426*	0.2283	1.0000			
LGTD	0.6931*	-0.0205	0.0565*	1.0000		
LFDI	-0.1212*	0.1612*	0.2882	0.2359*	1.0000	
LCO	0.0507	-0.1046	0.0512*	0.0259	0.0896	1.0000

Note: *denote significance levels at 5%.

Before proceeding with model estimation, we conduct cross-sectional dependency tests, as illustrated in Table 4. These tests include Pesaran's (2021) test, Friedman's test, and Frees' test. The statistical results for each variable indicate the presence of cross-sectional dependency. Following this evaluation, we advance to second-generation unit root tests to assess the stationarity of the data.

Table 4: Cross-sectional dependence test

CD Tests			
Model*	Pesaran CD Test	Friedman CD Test	Frees CD Test
Test stat.	15.103***	98.283***	5.932***

Note: * denotes the model.

Acknowledging the presence of cross-sectional dependency, the outcomes of the second-generation unit root tests are presented in Table 5. To evaluate the stationarity of the variables, several panel unit root tests are applied, such as Pesaran’s (2007) cross-sectionally augmented Im-Pesaran-Shin (CIPS) test and the Augmented Dickey-Fuller (CADF) test. The tests consistently confirm the presence of a unit root under both constant and trend conditions, with the exception of EPSI, GTD, LFDI, and LGTD, which show stationarity at both levels. The results indicate that all series achieve stationarity after first differencing. Thus, it is concluded that the variables in this study exhibit mixed-order integration.

Table 5: Panel unit root tests

Series	Model	CIPS[a]	CIPS[b]	CADF [a]	CADF [b]
LCCM	Constant	-1.343	-3.048***	-1.394	-3.698**
	Constant&Trend	-2.173	-5.143***	-1.982	-3.991**
EPSI	Constant	-2.153**	-4.032***	-3.521**	-4.146***
	Constant&Trend	-3.193***	-5.993***	-3.984*	-4.442***
LGDP	Constant	-1.104	-4.329***	-1.832	-3.983**
	Constant&Trend	-2.393	-4.931***	-2.038	-4.783**
LGTD	Constant	-2.932**	-4.239***	-3.732**	-4.412***
	Constant&Trend	-3.837***	-5.255***	-3.834*	-4.983***
LFDI	Constant	-2.938***	-2.873***	-2.560	-3.770**
	Constant&Trend	-3.027***	-3.437***	-3.992*	-4.576**
LCO	Constant	-1.483	-4.675***	-1.632	-4.446***
	Constant&Trend	-1.929	-4.940***	-2.034	-5.140***

Note: *, ** and *** indicate significance at 10%, 5% and 1% level, respectively. a denotes the unit root test model at the level, whereas b denotes the unit root test model at the first difference. CADF critical values at 10%, 5% and 1% level (constant:-3.01, -3.43, -4.35 and constant&trend: -4.97, -4.01, -3.56) and CIPS values at 10%, 5% and 1% level (constant: -2.32, -2.15, -2.07 and constant&trend: -2.83, -2.67, -2.58)

Following the stationarity tests, Table 6 displays the outcomes of the bootstrapped Westerlund co-integration test across all panels, employing two different sets of statistics. The null hypothesis, which posits that there is no co-integration, is rejected at the 5% significance level. This rejection indicates a significant long-term relationship between LCCM and the various indicators examined in this study.

Table 6: Panel cointegration tests

Statistic		Value	*p*-value	Robust *p*-value
Gt		7.6629	0.0000**	0.0000***
Ga		-6.4643	0.0001***	0.0000***
Pt		-6.0439	0.0000***	0.0000***
Pa		-2.0113	0.0002***	0.0000***

Note: ** and *** indicate significance at 5% and 1% level, respectively.

Figure 3 indicates the results from the panel quantile regression models across several quantiles, specifically the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th percentiles. By utilizing nine quantiles, the study explores the varying effects of EPSI, economic growth, green technology diffusion, foreign direct investment, and CO_2 emissions on climate change mitigation. The coefficients of the independent variables show that the impact of each independent variable on climate change mitigation (LCCM) changes at different points in the distribution, highlighting how their influence varies depending on the specific quantile being analyzed

The panel quantile regression highlights distinct variations in coefficients across different quantiles. Specifically, the results show that the influence of EPSI on climate change mitigation (LCCM) is heterogeneous and significantly positive between the 20th and 80th quantiles. LGDP has a positive and significant impact on LCCM at all quantiles. Similarly, the effect of LGTD is also positive and significant on LCCM at all quantiles. Furthermore, the impact of LFDI on LCCM is heterogeneous at all quantiles. LCO has positive and significant impacts on LCCM.

The results from the panel quantile regression model indicate that the influence of EPSI on climate change mitigation strengthens as we move across higher quantiles. This concludes that in countries or contexts with more substantial climate mitigation outcomes, stringent environmental policies are increasingly effective in reducing emissions. Similarly, the relationship between GDP and climate change mitigation is not linear; instead, it fluctuates across the quantiles. Higher impacts are seen at both the lower and higher ends, indicating that economic output plays a crucial role in shaping mitigation efforts, particularly in both less and more economically developed regions. The U-shaped pattern of GDP's impact—with negative effects in the middle quantiles and positive ones at the extremes—highlights the complex and context-specific nature of the interaction between economic development and mitigation.

Green technology diffusion also shows a mixed impact depending on the level of climate mitigation achieved, with the diffusion of green technology being most effective in countries at the extreme ends of mitigation outcomes. At lower levels of mitigation, the adoption of green technology may be slow or ineffective, while at higher levels, the existing infrastructure and policies may facilitate more impactful technological changes. The role of FDI also becomes more pronounced at higher quantiles. While FDI has little to no effect in contexts with lower climate mitigation, it plays a more significant role in economies with higher mitigation outcomes, suggesting that investment in greener technologies or industries becomes more impactful as countries progress in their mitigation efforts.

Additionally, CO_2 emissions show a progressively increasing positive effect on climate change mitigation as we move toward higher quantiles. This implies that in regions where mitigation outcomes are more advanced, measures to control and reduce CO_2 emissions are more effective, likely due to more stringent environmental policies and the presence of better infrastructure for enforcing emission reductions. At the same time, the panel quantile regression results highlight the diminishing effects of high CO_2 emissions on mitigation efforts across different quantiles. This indicates that the impact of emissions on mitigation efforts varies significantly depending on the level of mitigation already achieved in the country or region.

As a result, each variable's influence on climate change mitigation varies across different levels of mitigation. EPSI and FDI have a progressively stronger positive effect as mitigation outcomes increase, while GDP and green technology diffusion show nonlinear impacts. CO_2 emissions control becomes more significant in higher mitigation scenarios, indicating that in countries or regions with stronger mitigation outcomes, emissions decreasing plays a crucial role in the effectiveness of policies.

Moreover, we have pointed that there is a cointegration between climate change mitigation, EPS, and the causal determinants analyzed in this study. The Dumitrescu & Hurlin (2012) test reveals a causal relationship between EPS, CO_2 emissions, and climate change mitigation across all levels of significance.

In line with this, the Dumitrescu & Hurlin (2012) Granger non-causality test is applied to investigate the causal relationships, with the findings summarized in Table 7. The findings represent a bidirectional causality between LCCM and LEPSI and LCO across all significance levels. Similarly, a bidirectional relationship is observed between LCCM and LGDP. Additionally, bidirectional causality is found between LCCM and LGTD, as well as between LCCM and LFDI.

Figure 3: Change in panel quantile regressions coefficients of Climate Change Mitigation

Source: Author's own elaboration

Table 7: Panel causality test results

Null Hypothesis	W-Stat	Zbar-Stat	Probability
LCCM → LEPSI	1.9985	4.3525	0.0000
LEPSI → LCCM	4.9611	7.8400	0.0000
LCCM → LGDP	1.8574	3.7374	0.0002
LGDP → LCCM	2.6848	7.3437	0.0000
LCCM → LGTD	5.8766	9.8556	0.0000
LGTD → LCCM	3.1637	3.8829	0.0001
LCCM → LFDI	3.5123	4.6503	0.0000
LFDI → LCCM	3.1142	3.4037	0.0005
LCCM → LCO	2.5124	6.5925	0.0014
LCO → LCCM	2.1526	5.0241	0.0000

5. Conclusion and Policy Recommendations

This study provides an in-depth analysis of the factors influencing climate change mitigation (LCCM) across different quantiles, focusing on the role of Environmental Policy Stringency (EPSI), economic growth (GDP), green technology diffusion (GTD), Foreign Direct Investment (FDI), and carbon emissions between 2000 and 2021. Through the use of panel quantile regression models, we uncover the heterogeneous impacts of these factors across varying levels of climate change mitigation efforts.

The empirical results suggest that the influence of EPSI, economic conditions, and technological progress on climate change mitigation varies depending on different quantiles. More stringent environmental policies and greater FDI play progressively stronger roles in enhancing mitigation outcomes as the levels of climate change mitigation increase. GDP and green technology diffusion exhibit nonlinear effects, emphasizing the need for context-specific policy interventions. Controlling CO_2 emissions remains a critical factor in higher quantiles, where mitigation strategies are more effective.

Overall, our findings emphasize the complex, nonlinear relationships between economic and environmental factors and climate change mitigation. The study underscores the importance of adopting differentiated strategies based on a country's level of climate mitigation progress. While stringent environmental policies and foreign investments are crucial for promoting climate action, economic growth and green technology diffusion require nuanced approaches to maximize their effectiveness.

In conclusion, the long-term cointegration between climate change mitigation, EPSI, and other factors, supported by Granger causality results, underscores the importance of integrated policy measures. This study offers valuable insights for policymakers striving to harmonize economic growth with environmental sustainability, emphasizing the necessity of adaptive and flexible strategies. Building on prior research, our findings encompass an extended timeframe and multiple European economies, providing comprehensive and robust evidence in support of the green economy. To effectively tackle climate change mitigation, EU countries must prioritize the alignment and coherence of their policies, ensuring that they foster collaboration across various sectors. Furthermore, increased investment in renewable energy and energy efficiency initiatives should be at the forefront of these efforts. Achieving long-term sustainability goals requires not only strengthening coordination between government bodies and industries but also fostering innovation and enhancing the enforcement of environmental regulations. This holistic approach is instrumental in reducing reliance on fossil fuels, advancing clean energy technologies, and positioning the EU as a leader in the global transition to a low-carbon economy.

Based on the empirical findings of this study, there are several policy recommendations aimed at assisting decision makers in advancing green sustainability within countries and aligning with the environmental objectives of sustainable environmental. First, there's a pressing need to bolster the stringency of environmental policies across EU nations to effectively combat climate change, including setting ambitious emissions reduction targets and implementing stricter pollution regulations. Second, increasing investment in research, development, and deployment of green technologies is essential to accelerate the transition towards a sustainable economy, particularly in areas such as green energy and energy efficiency. Third, fostering international cooperation and knowledge sharing can enhance collective efforts in climate change mitigation, while promoting sustainable consumption and production patterns is vital to reduce environmental impact. Fourth, strengthening monitoring and evaluation mechanisms is crucial for tracking progress and ensuring accountability, while integrating climate action into economic policies can align environmental sustainability objectives with broader economic goals. By implementing these recommendations, EU countries can fortify their environmental policy framework and advance towards a more sustainable and resilient green economy.

Policymakers should prioritize enhancing the stringency of environmental regulations, especially in high emission countries, where such measures can lead to significant emission reductions. Additionally, governments need to increase support for research and development in green technologies, particularly in high-emission countries, where technology diffusion can drive long-term emission reductions. Tailored policy interventions are also essential, addressing the specific needs of countries at various emission levels. High-emission countries, in particular, may require more comprehensive strategies, such as financial incentives for clean energy adoption and infrastructure improvements, to achieve meaningful progress.

Future studies should consider expanding the range of variables to include social, political, and technological factors, as well as exploring different geographical regions, particularly emerging and developing economies, to understand how climate policies vary globally. Long-term temporal analysis using scenario projections could provide insights into the future role of environmental policies and economic shifts. Sector-specific studies, especially in industries like agriculture and transportation, would help to capture the varying impacts of environmental policy stringency. Additionally, employing advanced econometric methods, such as machine learning, and encouraging interdisciplinary research between economics, policy, and technology, could further enrich the understanding of climate change mitigation strategies.

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Araştırma Makalesi

On the Impact of Environmental Policies and Green Technology Diffusion on Climate Change Mitigation: Evidence from a Panel Quantile Approach

Çevre Politikaları ve Yeşil Teknoloji Yayılımının İklim Değişikliğinin Azaltılmasına Etkisi Üzerine: Panel Kantil Yaklaşımından Kanıtlar

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Genişletilmiş Özet

Bu çalışma, Avrupa Birliği ülkelerinde 2000-2021 yılları arasında uygulanan çevre politikalarının katılığı ve bu politikaların iklim değişikliğini azaltma mücadelesindeki nedensel belirleyicilerini kapsamlı bir şekilde incelemektedir. İklim değişikliği, son yıllarda küresel ölçekte öncelikli sorunlardan biri haline gelmiştir ve ülkelerin bu konuda aldıkları önlemler, küresel ısınmanın etkilerini azaltmada kritik bir öneme sahiptir. Bu çalışmada, iklim değişikliğiyle mücadelede çevre politikalarının etkinliğini analiz etmek amacıyla, panel kantil regresyon modeli kullanılmıştır. Modelde karbon emisyonları, doğrudan yabancı yatırım, ekonomik büyüme ve yeşil teknoloji yayılımı gibi temel değişkenlerin iklim değişikliği üzerindeki etkileri değerlendirilmiştir.

İlk olarak, çalışmada kullanılan veriler ve metodoloji hakkında detaylı bilgi verilmiştir. 2000-2021 yılları arasındaki döneme ait veri seti, Avrupa Birliği üye ülkelerinin çevre politikaları ve bu politikaların sonuçlarını içermektedir. Çalışmada, ülkelerin ekonomik büyüme hızları, karbon emisyon seviyeleri, doğrudan yabancı yatırımları ve yeşil teknoloji yatırımları gibi çeşitli faktörler de dikkate alınarak, çevre politikalarının katılığı ile bu faktörler arasındaki ilişkiler analiz edilmiştir. Çalışma, panel kantil regresyon modeli kullanarak, bu ilişkilerin farklı kantillerde nasıl değiştiğini incelemektedir. Bu regresyon modeli, özellikle farklı seviyelerdeki değişkenler arasındaki ilişkilere dair daha detaylı bilgi sunmakta ve politikaların etkisinin ülkelerin farklı ekonomik ve çevresel koşullarına göre nasıl farklılık gösterdiğini ortaya koymaktadır.

Ampirik sonuçlar, çevre politikalarının, ekonomik koşulların ve teknolojik ilerlemenin iklim değişikliğinin azaltılması üzerindeki etkisinin farklı kantillere bağlı olarak değiştiğini göstermektedir. Daha sıkı çevre politikaları ve daha fazla doğrudan yabancı yatırım, iklim değişikliğinin azaltılması seviyeleri arttıkça azaltma sonuçlarını iyileştirmede giderek daha güçlü roller oynamaktadır. Ekonomik büyüme ve yeşil teknoloji yayılımı doğrusal olmayan etkiler sergileyerek bağlama özgü politika müdahalelerine olan ihtiyacı vurgulamaktadır. Karbon emisyonlarının kontrolü, azaltma stratejilerinin daha etkili olduğu daha yüksek kantillerde kritik bir faktör olmaya devam etmektedir.

Genel olarak bulgularımız, ekonomik ve çevresel faktörler ile iklim değişikliğinin azaltılması arasındaki karmaşık, doğrusal olmayan ilişkileri vurgulamaktadır. Çalışma, bir ülkenin iklim değişikliğini azaltma teknolojilerine dayalı farklılaştırılmış stratejiler benimsemenin önemini vurgulamaktadır. Sıkı çevre politikaları ve yabancı yatırımlar iklim etkisini azaltmaya teşvik etmek için çok önemli olsa da ekonomik büyüme ve yeşil teknoloji yayılımı gibi faktörlerde iklim değişikliği etkisini azaltmakta anlamlı etkiler ortaya koymaktadır.

İkinci olarak, çalışmada karbon emisyonlarının rolüne vurgu yapılmıştır. Karbon emisyonları, iklim değişikliğinin en önemli nedenlerinden biri olarak kabul edilmekte olup, bu çalışmada özellikle yüksek

iklim değişikliği hafifletme sonuçlarına sahip ülkelerde daha kritik bir rol oynamaktadır. Ayrıca bu çalışma, ekonomik büyümenin iklim değişikliği üzerindeki etkisinin doğrusal olmayan bir yapıya sahip olduğunu ve yeşil teknoloji yayılımının bu etkiyi hafifletebileceğini göstermektedir. Benzer şekilde, doğrudan yabancı yatırımların da iklim değişikliğiyle mücadelede önemli bir rol oynadığı ortaya koyulmuştur. Doğrudan yabancı yatırımlar, özellikle yeşil teknoloji ve yenilenebilir enerji sektörlerine yapıldığında, ülkelerin çevre politikalarının etkinliğini artırabilir ve iklim değişikliğiyle mücadelede olumlu katkılar sağlamaktadır.

Çalışmanın önemli katkılarından biri de çevre politikalarının katılığı ile iklim değişikliği arasındaki uzun vadeli ilişkiyi analiz etmesidir. Pedroni, Westerlund ve Kao tarafından geliştirilen eşbütünleşme testleri kullanılarak yapılan analizler, iklim değişikliğiyle mücadele, çevre politikalarının katılığı ve bu çalışmada analiz edilen diğer belirleyiciler arasında uzun vadeli bir ilişki olduğunu göstermektedir. Bu sonuçlar, iklim değişikliğiyle mücadelede politika yapıcıların, çevre politikalarının uzun vadeli etkilerini dikkate almaları gerektiğini vurgulamaktadır. Ayrıca, Granger nedensellik testleri, çevre politikalarının katılığı ile iklim değişikliği arasındaki çift yönlü nedenselliği ortaya koymaktadır.

Bu çalışma, ekonomik büyümeyi çevresel sürdürülebilirlikle uyumlu hale getirmeye çalışan politika yapıcılar için değerli çıkarımlar sunarak, uyarlanabilir ve esnek stratejilerin gerekliliğini vurgulamaktadır. Önceki araştırmalara dayanarak, bulgularımız geniş bir zaman dilimini ve birden fazla Avrupa ekonomisini kapsamakta olup, yeşil ekonomiyi destekleyen kapsamlı kanıtlar sunmaktadır. İklim değişikliği azaltımıyla etkili bir şekilde mücadele etmek için, AB ülkeleri politikalarının uyumunu ve tutarlılığını önceliklendirmeli ve çeşitli sektörlerde iş birliğini teşvik etmelerini sağlamalıdır. Dahası, yenilenebilir enerji ve enerji verimliliği girişimlerine yapılan yatırımın artırılması bu çabaların ön saflarında yer almalıdır. Uzun vadeli sürdürülebilirlik hedeflerine ulaşmak, yalnızca hükümet organları ve endüstriler arasındaki koordinasyonu güçlendirmeyi değil, aynı zamanda inovasyonu teşvik etmeyi ve çevre düzenlemelerinin uygulanmasını geliştirmeyi de gerektirir. Bu bütünsel yaklaşım, fosil yakıtlara olan bağımlılığı azaltmada, temiz enerji teknolojilerini ilerletmede ve AB'yi düşük karbonlu bir ekonomiye küresel geçişte lider olarak konumlandırmada etkilidir.

Sonuç olarak, bu çalışma, Avrupa Birliği ülkelerinde çevre politikalarının katılığı ve bu politikaların iklim değişikliği üzerindeki etkilerini kapsamlı bir şekilde incelemektedir. Çalışmanın bulguları, çevre politikalarının katılığının, özellikle yüksek iklim değişikliği hafifletme sonuçlarına sahip ülkelerde, olumlu bir etki yarattığını göstermektedir. Ekonomik büyüme, doğrudan yabancı yatırım ve yeşil teknoloji yayılımı gibi faktörlerin de iklim değişikliğiyle mücadelede önemli bir rol oynadığı, ancak bu etkilerin doğrusal olmayan bir yapıya sahip olduğu ortaya konmuştur. Ayrıca, çalışma, çevre politikaları ile iklim değişikliği arasındaki uzun vadeli ilişkiye dikkat çekmekte ve politika yapıcıların entegre, sürdürülebilir ve uyarlanabilir stratejiler geliştirmeleri gerektiğini vurgulamaktadır. Bu bağlamda, yeşil teknolojilerin geliştirilmesi ve yenilenebilir enerji kaynaklarının teşvik edilmesi, iklim değişikliğiyle etkili bir şekilde mücadele etmek için kritik öneme sahiptir.