DETERMINANTS OF POLLUTION: COMPARATIVE ANALYSIS OF DEVELOPED AND DEVELOPING COUNTRIES IN THE EU

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ABSTRACT

DETERMINANTS OF POLLUTION: COMPARATIVE ANALYSIS OF DEVELOPED AND DEVELOPING COUNTRIES IN THE EU

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This master thesis examines the determinants of pollution, comparing and contrasting these determinants for developed and developing countries within the European Union (EU). In this study, we try to analyze the main determinants of pollution for developed and developing EU countries and the EU as a whole for the years between 2000 and 2019 in the context of the Environmental Kuznets Curve Theory. In order to do this, we employed the Panel Vectoral Autoregression model (PVAR model) which is the main econometric method for capturing common characteristics for countries that have different economic, political, and structural backgrounds. In our study, we found that use of environment related technologies, environmental tax, natural resource rent, consumption of renewable energy, urbanization level, and GDP per capita have a significant impact on our dependent variable carbon emissions per capita. The findings of this study contribute to a deeper understanding of pollution dynamics in the EU, and it also offers policymakers valuable insights for creating effective strategies to combat pollution in developed and developing countries in the EU.

Keywords: Pollution, Carbon Emissions, PVAR model, Developed/Developing Countries

ÖZ

KİRLİLİĞİN BELİRLEYİCİLERİ: AB'DEKİ GELİŞMİŞ VE GELİŞMEKTE OLAN ÜLKELERİN KARŞILAŞTIRMALI ANALİZİ

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Bu yüksek lisans tezi, Avrupa Birliği (AB) içinde gelişmiş ve gelişmekte olan ülkeler için kirliliğin belirleyicilerini karşılaştırarak inceler. Bu çalışmada, 2000 ve 2019 yılları arasında Çevresel Kuznet Eğrisi Teorisi bağlamında gelişmiş ve gelişmekte olan AB ülkeleri ve AB'nin geneli için kirliliğin ana belirleyicilerini analiz etmeye çalışıyoruz. Bunları yapmak için, farklı ekonomik, politik ve yapısal geçmişe sahip ülkeler için ortak özellikleri yakalamak amacıyla buna uygun ekonometrik yöntem olan Panel Vektörel Otoregresyon modelini (PVO modeli) kullandık. Çalışmamızda, çevre ile ilgili teknolojilerin kullanımı, çevresel vergi, doğal kaynak kirası, yenilenebilir enerji tüketimi, kentleşme düzeyi ve kişi başına düşen GSYİH'nin, bağımlı değişkenimiz olan kişi başına düşen karbon emisyonları üzerinde önemli bir etkisi olduğunu bulduk. Bu çalışmanın bulguları, AB'deki kirlilik dinamiklerine daha derin bir bakış açısı ortaya koymakta ve aynı zamanda politika yapıcılara AB'deki gelişmiş ve gelişmekte olan ülkelerde kirliliği azaltmak için etkili stratejiler oluşturma konusunda önemli öngörüler sunmaktadır.

Anahtar Kelimeler: Kirlilik, Karbon Emisyonu, PVO Modeli, Gelişmiş/Gelişmekte olan ülkeler

To My Beloved Mom Perlay and My Love Kübra

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LIST OF ABBREVIATIONS

EKC	: Environmental Kuznets Curve
EU	: European Union
GMM	: Generalized Method of Moments
MAIC	: Modified Akaike Information Criterion
MBIC	: Modified Bayesian Information Criterion
MLE	: Maximum Likelihood Estimation
MQIC	: Modified Hannan-Quinn Information Criterion
PVAR	: Panel Vectoral Autoregression

CHAPTER 1

INTRODUCTION

Our world faces a significant challenge to preserve the balance between economic development and environmental preservation. Climate change, driven primarily by carbon emissions, significantly threatens global well-being. In the ongoing research to ensure a balance between economic development and environmental sustainability, the challenge of addressing climate change is significant. Carbon emissions are critical factors to combat climate change for countries.

Within the European Union (EU) which is composed of both developed and developing member states, the relationship between carbon emissions, environmental policies, and broader economic and environmental factors creates complexities and obstacles to sustainable development. These complexities arise from the diverse characteristics of the EU Member States, each of them has unique economic structures and environmental challenges. To ensure harmony between economic development and environmental sustainability, environmental policies should be tailored to the specific circumstances of each country.

In the context of our study, we must consider the international agreements that have set an agenda for global climate action. The Kyoto Protocol and the Paris Climate Agreement are significant milestones in the ongoing struggle to combat climate change.

The Kyoto Protocol, established in 1997, is a turning point in international climate diplomacy. This agreement imposed legally binding greenhouse gas (GHG) emission reduction targets on developed countries, considering the historical responsibility of these countries as the primary contributors of GHG emissions. Even if the Kyoto Protocol's overall effectiveness has remained a subject of debate, it has accelerated international cooperation and paved the way for subsequent agreements. Its lessons in the areas of accountability and the distribution of responsibility provide valuable insights for continuing climate change discussions.

The Paris Climate Agreement, ratified in 2015, has been a significant shift in the approach to climate action. Unlike the Kyoto Protocol, it allowed each country to determine its emission reduction targets, revealing the growing recognition of different national circumstances. This flexibility, combined with a shared commitment to transparency, accountability, and increased dedication over time, uncovered the need for global climate policies that respect the different circumstances of all nations. The Paris Agreement symbolizes a shift from historical responsibility to common responsibility in the global fight against climate change.

By investigating the relationships between carbon emissions as a proxy for pollution and its determinants in the diverse landscape of the European Union, we try to contribute to the contemporary conversation about the effectiveness and implementation of international climate agreements, with a particular focus on the EU Member States. This study addresses the critical question of how different environmental and economic policies within the EU, adapted to individual country conditions, influence carbon emissions and environmental degradation.

Our findings offer essential insights for policymakers. In our study, we explore how environmental technologies, environmental taxes, utilization of natural resources, adoption of renewable energy, urbanization, and GDP per capita growth affect environmental degradation and emissions levels in the EU. These determinants create both positive and negative impacts on carbon emissions and pollution levels. Thus, it is of paramount importance for countries to carefully design and implement policies that ensure sustainable development while protecting the environment. Moreover, differences between developed and developing countries are also taken into consideration. This knowledge can inform policymakers regarding the design of effective environmental policies and strategies for sustainable development.

In the context of sustainable development, this research gives prominence to relationships between technological innovation, environmental taxation, use of natural resources, renewable energy, urbanization structure, GDP per capita, and environmental well-being. By comparing developed and developing countries within the EU, we aim to shed light on how countries with different economic and environmental backgrounds can achieve prosperity and economic development while safeguarding the environment. This specific approach is essential for addressing the diversity of challenges faced by developed and developing countries.

In this study, we investigate the determinants of pollution and carbon emissions per capita for the EU countries using the Panel Vector Autoregression (PVAR) econometric technique. Our objective is to analyze the main determinants of carbon emissions per capita as a proxy for pollution levels, demonstrating their significance in addressing the reduction of emissions. We analyze how these variables are also effective in reducing pollution levels within the context of the Environmental Kuznets Curve Theory (EKC). Additionally, we delve into the comparison of developed and developing countries in the EU regarding the reduction of carbon emissions per capita, recognizing the specific challenges faced by each group.

The application of the PVAR model, our chosen econometric method, is unconventional in the literature and thus contributes to methodological diversity in the field. Moreover, by providing tailored policy recommendations for both developed and developing countries in their struggle to combat environmental degradation while pursuing sustainable development, this study tries to contribute to the literature on different aspects of sustainability and the theory of EKC. Our study addresses various aspects of sustainability, enlightening the diversified paths toward a more environmentally harmonious world.

The following chapters of this thesis will examine the subject matter in a detailed way. In the theoretical background chapter, we elaborate on how the analysis will be explained in the context of EKC theory. Moreover, In the literature review chapter, we provide an extensive overview of different and contrasting arguments about our independent variables one by one. This approach will offer a comprehensive understanding of the relationship between each independent variable and our dependent variable, namely carbon emissions per capita (CPC). In the data and methodology chapter, we explain our country set, data, and variables in detail. We elaborate on our econometric methodology, which is the Panel Vector Autoregression, and its components in detail. In the empirical results chapter, we analyze the relationship between our independent variables and CPC, demonstrating the importance of these variables in explaining our dependent variable. Then, we examine the developed and developing countries in the EU separately, highlighting the similarities and differences between them and identifying the key independent variables that influence CPC. These insights are vital for creating tailored policies that address the unique challenges faced by each group of countries.

In the conclusion chapter, we synthesize our empirical findings with the literature review and our EKC theory, offering a comprehensive understanding of how independent variables impact our dependent variables. We provide policy recommendations to mitigate the negative consequences of carbon emissions and pollution, taking into account the specific needs of developed and developing countries. We also elaborate on the differences between developed and developing countries in the EU regarding their challenge with climate change and pollution mitigation.

In conclusion, given the diversity of Member States within the European Union, this study offers a global perspective on the challenges and opportunities associated with climate change and pollution mitigation. It acknowledges the necessity of country-specific approaches to address these issues effectively. Moreover, this study strives to advance our understanding of the relationship between carbon emissions, pollution, and the key independent variables within the European Union. It aims to provide insights for policymakers and contribute to the global conversation on sustainable development and climate change mitigation, within the specific context of the EU and EKC theory, encompassing both developed and developing Member States. This research represents a significant step toward finding a balanced and effective approach to environmental protection and economic development.

CHAPTER 2

THEORETICAL BACKGROUND

Our study is based on the EKC theory. In this chapter, we explain what the EKC theory is and how it is evolved. Then, we will answer why we construct our model as it is and how the variables are selected. According to Özcan and Öztürk (2019), there is a controversy regarding whether economic development contributes to the environment. Since the era of industrialization, scholars have endeavored to find the underlying reasons for environmental degradation and solutions for it. In that vein, EKC theory helps to explain the reasons for environmental degradation, and it also supports the creation of policies to diminish the negative consequences of environmental problems.

According to Özcan and Öztürk (2019), when we look at the origination of the EKC, it is affected by Kuznets' study where there is an inverse U-shaped relationship between income inequality and economic growth Kuznets (1955). Income inequality begins to diminish as the economic growth of countries continues. Leaning on the logic of the Kuznets Curve hypothesis of environmental Kuznets curve is developed. The hypothesis assumes that as the economies of the countries grow in the initial phase environmental deterioration increases. After surpassing a certain level, economic growth brings about a decrease in environmental deterioration. According to Özcan & Öztürk (2019), EKC also explains why countries differ from each other in terms of the environmental harm they create.

According to the EKC, economic growth is the solution for the environmental complications. As long as countries continue to grow, environmental problems initially increase then throughout time it tends to diminish. Özcan and Öztürk (2019) state that there are three phases of economic development, which are the preindustrial stage, the industrial stage, and the postindustrial stage. In the initial stage, environmental pollution increases since at that period agricultural activities take place, resource extraction is escalated and there are no or insufficient endowments to set aside for environmental preservation. Moreover, inadequate tax collection and regarding environmental problems as an admissible result of economic growth also exacerbate the environmental problems. According to Özcan and Öztürk (2019), in the preindustrial stage, there occurs a scale effect which indicates that expansion in the scale of the economy results in creation of increased pollution, emissions and wastage. After the initial period, there is industrial stage, in that period people tend to gain awareness about environmental problems and they begin to demand environmentally friendly goods and call for environmental regulations. According to Özcan and Öztürk (2019), in that phase environmental growth transmit its impact through composition effect. That effect implies structural transformation in which the weight of sectors in the economy changes through shift from industrial to the service sector. In the last phase, the postindustrial stage, economic growth results in a decrease in environmental pollution. Since, in that period, the effects of structural changes and the implications of the regulations are realized. According to Özcan and Öztürk (2019), in that period effect of economic growth is channelized through the technique effect. It implies that outdated technologies and production techniques are replaced by environmentally friendly technologies and brand-new techniques. Thus, it results in a decrease in the pollution and emissions level. Preindustrial, industrial, and postindustrial stages and how the explained effects take place on environmental degradation are revealed below in Figure 2.1 the Environmental Kuznets Curve

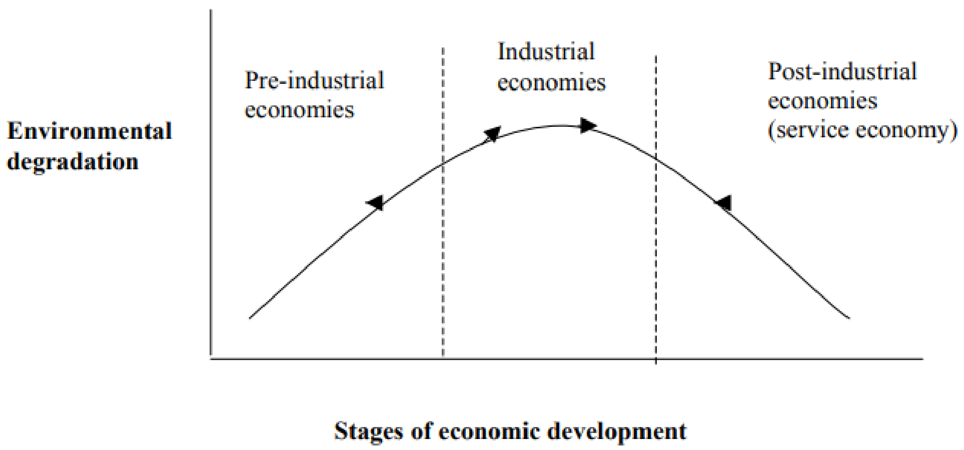

Figure 2. 1. The environmental kuznets curve.

According to Bhattacharya (2019), in the literature, the EKC hypothesis is one of the most tested phenomena. EKC hypothesis simply tries to answer the argument whether there is a relation between the determined indicator of environmental pollution and the income per capita. As evident from the Environmental Kuznets curve above, it examines the quadratic relationship between the dependent environmental pollution variable and its determinants. According to Bhattacharya (2019), even if there is immense amount of literature about the EKC theory, there is no reached consensus about the presence of EKC and shape of the curve. The shape of the EKC remains uncertain with different determinants of pollution and there is also no compromise on the per capita income level where the decreasing trend starts. Moreover, Bhattacharya (2019) states that in the initial studies of EKC, it is simply regression of independent variables of income levels in quadratic form on the dependent pollution variable as indicated below.

$$\ln(\text{carbon emissions per capita})_{it} = \alpha_i + \gamma_t + \beta_1 \ln(\text{GDP per capita})_{it} + \beta_2 \ln(\text{GDP per capita})_{it}^{2} + \beta_3 \ln(\text{GDP per capita})_{it}^{3} + \varepsilon_{it} \tag{2.1}$$

Here, ln is the representation of the natural logarithm. In addition, α_i is the intercept term and implies carbon emissions per capita which changes across the countries and the income levels of the countries. Moreover, i denotes the regions or the countries and t represents the time periods. In the stated model, γ_t is the time-specific intercept, and it incorporates omitted time-variant variables and common stochastic shocks for the countries and ε_{it} is the error term.

According to Bhattacharya (2019), in later studies, different additional variables such as infrastructure, investments, trade, etc. are added to the model in place of $_t$. Bhattacharya (2019) states that these earlier studies could not find a universal shape for the EKC, and diverse outcomes have occurred across and within the countries due to the different characteristics of the countries and different econometric methods. Moreover, studies showed that the paths of developed and developing countries are different from each other throughout their economic growth. Thus, according to Bhattacharya (2019), in order to ensure sustainable economic development countries should adopt effective environmental policies in the early stages of economic development before the turning point that the EKC reveals.

According to Inglesi-Lotz (2019), in recent studies, tourism development, financial development, urbanization, population, and energy consumption are added to the EKC hypothesis. According to Inglesi-Lotz (2019), in most of the studies with tourism development variables, it has a positive impact on pollution levels. Moreover, in most of the studies, financial development has a negative effect on pollutant variables, and urbanization has both positive and negative effects on pollution levels and carbon emissions. Energy consumption has also a mixed effect on the dependent variable. Different from early and recent studies, we also do a literature survey regarding our EKC model. The survey related to our model's theoretical background is revealed in Table 2.1 below.

Table 2. 1. Summary table of the theoretical background literature review.

Studies	**Country/Years**	**Variables**	**Model**	**Findings**	**EKC Hypothesis**
(Pata, 2018)	Turkey / 1974-2014	CO_2, Y, Y^2, URB, FD, REC, AEC, HEC	Autoregressive Distributed Lag (ARDL)	Y, URB, FD have an increasing effect on CO_2 and REC, AEC and HEC have no effect on CO_2	It is not rejected
(Tao et al., 2021)	Emerging Seven (E7) Countries / 1995-2018	CE, ECO, ERT, GDP, GDP^2	Cross-sectional ARDL (CS-ARDL)	ECO, ERT, and GDP^2 has a decreasing effect on CE; and GDP has an increasing effect on CE	It is not rejected
(Awan et al., 2022)	33 high income countries / 1996-2014	TCO_2, , GDP, GDP^2, GDP^3, INNOVATION, URBAN	Fully Modified Ordinary Least Squares (FMOLS) and Dynamic OLS (DOLS)	GDP, GDP^3 and URBAN has increasing effect on TCO_2 and GDP^2 and INNOVATION has a decreasing effect on TCO_2	It is not rejected
(Chen et al., 2022)	Newly Industrialized Countries (NICs) / 1990-2019	CO_2, NRR, GTI, GDP	Cross-sectional ARDL (CS-ARDL)	NRR and GDP have an increasing effect on CO_2 , and GTI has a decreasing effect on CO_2	It is not rejected
(X. Wang et al., 2022)	China / 1995-2017	CE, EF, EP, ER, TI	Vector Error Correction Model (VECM)	ER, EP has a decreasing effect, and EF, TI has an increasing effect on CE	It is not rejected

Table 2.1 (cont'd)

(Q. Wang et al., 2022)	134 countries in different income groups / 1994-2015	PGDP, UB, CO_2, EF, OPEN, AGP, RE, RENT	Panel Threshold Regression Model	UB, OPEN, and RENT has an increasing effect on CO_2 and EF; and AGP and RE has a decreasing effect on CO_2 and EF, PGDP has a non-linear effect on CO_2 and EF	It is not rejected for the lower middle-income group It is rejected for high-income group countries
(Jahanger, Yu, et al., 2022)	NAFTA countries / 1990 - 2018	CO_2, REC, Y, NRR, FDI	Method of Moments Quantile Regression (MMQL)	Y and NRR have an increasing impact on CO_2; REC and FDI has a decreasing impact on CO_2	It is not rejected
(Aydin et al., 2023)	European Union / 1990-2018	GDP, EF, REN, GP, RD	Second-Generation Panel Methods	REN, GP, and RD have mixed effects on EF for each country in the EU	It is rejected except for Finland
(Bozatli & Akca, 2023)	OECD countries / 1994-2018	EFP, TAX, GDP, REN, TECH	Cross-sectional ARDL (CS-ARDL)	TAX and REN have a decreasing effect on EFP and TECH has no effect on EFP and GDP has an increasing effect on EFP	It is rejected for the short-run
(Alola et al., 2023)	France, Germany, Italy, Spain / 1995-2020	CE, Y, PD, RE, AG, ET, CP	Method of Moments Quantile Regression (MMQR)	Y, PD, CP has increasing effect on CE and AG, RE, ET, DE, RE decreasing effect on CE	It is not rejected
(Sultana et al., 2023)	Next 11 Countries / 1990-2019	CO_2, GDP, GDP^2, POP, REC, GLOB	Method of Moments Quantile Regression (MMQR)	GDP and GLOB has increasing effect on CO_2 GDP^2, POP and REC decreasing effect on CO_2	It is not rejected
(Dam & Sarkodie, 2023)	Turkey / 1965-2018	ILCF, GDP, REC, TO	Autoregressive Distributed Lag (ARDL)	GDP and REC have increasing effects and TO has a decreasing effect on ILCF in the long run. In the short run GDP and TO have an increasing effects but REC has decreasing effect on ILCF	It is not rejected

Table 2.1 (cont'd)

(Long et al., 2023)	China / 2000-2020	CO_2, NTR, HMD, GDP	Bootstrapped ARDL (BARDL)	HMD has a decreasing effect on CO_2 and NTR and GDP have an increasing effects on CO_2	It is not rejected
(Naimoglu & Akal, 2023)	Turkey / 1990-2019	CO2, TNREC, EEC, REC, GDP, GDP2	Fully Modified Ordinary Least Squares (FMOLS)	EEC, REC and GDP^2 has decreasing effect on CO_2 and GDP has increasing effect on CO_2	It is not rejected
(Hasan et al., 2023)	BRICS countries / 1990-2020	CO_2, I, I^2, REC, FFC, FD, TO	Fully Modified Ordinary Least Squares (FMOLS) and Dynamic OLS (DOLS)	I and FFC have increasing effects on CO_2 , and I^2, REC, FD, TO has decreasing effect on CO_2	It is not rejected

(Variables in the Study of **(Pata, 2018) :** CO_2: per capita CO_2 emissions, Y: per capita GDP, Y^2: per capita GDP^2, URB: urbanization, FD: financial development, REC: per capita renewable energy consumption, AEC: alternative energy consumption, HEC: hydropower consumption; Variables in the Study of **(Tao et al., 2021):** CE: carbon emissions, ECO: eco-innovation, ERT: environmental taxes, GDP: economic growth, GDP^2: EKC hypothesis effect; Variables in the Study of **(Chen et al., 2022):** CO_2: CO_2 emissions, NRR: natural resources rent, GTI: green technology innovation, GDP: economic growth; Variables in the Study of **(Awan et al., 2022):** TCO_2: transport sector based CO_2 emissions, GDP: GDP per capita, INNOVATION: patents, URBAN: percentage of urban population ;Variables in the Study of **(X. Wang et al., 2022):** CE: CO_2 emissions, EF: energy efficiency, EP: economic performance, ER: environmental regulation, TI: technological innovation; Variables in the Study of **(Q. Wang et al., 2022):** PGDP: GDP per capita, UB: urbanization, CO_2: per capita CO_2 emissions, EF: ecological footprint, OPEN: trade openness, AGP: population aging, RE: renewable energy, RENT: natural resources rent; Variables in the Study of **(Jahanger, Yu, et al., 2022):** CO_2: CO_2 emissions per capita, REC: renewable energy consumption, Y: economic growth, NRR: natural resources rent, FDI: foreign direct investments ; Variables in the Study of **(Aydin et al., 2023):** GDP: GDP per capita, EF: ecological footprint, REN: renewable energy consumption, GP: green patent, RD: energy R&D investments; Variables in the Study of **(Bozatli & Akca, 2023):** EFP: ecological footprint, TAX: environmental taxes, GDP: economic growth, REN: renewable energy consumption, TECH: environmental technological development; Variables in the Study of **(Alola et al., 2023):** CE: carbon emissions, Y: GDP, PD: population density, AG: agricultural value added to GDP, ET: environmental related tax, CP: crop production index ; Variables in the Study of **(Sultana et al., 2023):** $CO_{2,:}$ Carbon emissions GDP: per capita GDP, POP: population, REC: renewable energy consumption, GLOB:globalization **;**Variables in the Study of **(Dam & Sarkodie, 2023):** ILCF: inverted load capacity factor, GDP: real income, REC: renewable energy consumption, TO: trade openness; Variables in the Study of **(Long et al., 2023):** GDP: economic growth, NTR: natural resources, HMD: human development; Variables in the Study of **(Naimoglu & Akal, 2023):** TNREC: advancements in fossil fuel technology, EEC: efficient energy utilization, REC: renewable energy usage, GDP: per capita economic growth ; Variables in the Study of **(Hasan et al., 2023):** CO_2: CO_2 emissions, I: industrial growth, REC: renewable energy consumption, FFC: fossil fuel consumption, FD: financial development, TO: trade openness)

As we see from the literature review above, most of the studies have modified the original EKC regression by adding different independent variables through changing γ_t term in the original model. Thus, in our study we have also added independent variables to the original model in order to catch omitted time-variant variables and common stochastic shocks for countries in the EU. Moreover, since we also inspired from the article “The Role of Green Finance and Energy Innovation in Neutralizing Environmental Pollution: Empirical Evidence from the MINT Economies” by Li (2022), our thoretical model which we will analyze and modify further through our econometric techniques in our empirical findings chapter becomes as follows:

$$\ln(cpc_{it}) = \alpha_i + \gamma t + \beta_1 ln(patents_{it}) + \beta_2 ln(envtax\_pct_{it}) + \beta_3 ln(nrr_{it}) + \beta_4 ln(rec_{it}) + \beta_5 ln(urb_{it}) + \beta_6 \ln(GDP\ per\ capi_{it}) + \varepsilon_{it} \tag{2.2}$$

In our model cpc refers to carbon emissions per capita, patents refers to patents related with environmental technologies, envtax is environmental tax, nrr denotes natural resources rent, rec is renewable energy consumption, urb is urbanizaiton and GDP per cap is the GDP per capita. Moreover, ε_{it} α_{i0} and γt terms are already explained above in the original model.

CHAPTER 3

LITERATURE REVIEW

In this part, the relationship between our dependent variable and the independent variables is investigated in the literature. Different and contrasting arguments in the literature are revealed here in order to grasp a better understanding regarding different and composite mechanisms in the relationship of our variables.

3.1. Literature Review about Patents Related with Environmental Technologies

The Analysis made by Mensah et al. (2019)examines the relationship between economic growth, urbanization, climate change-related patents, and trademarks over carbon emissions for OECD countries in Asia, Europe, America, and Oceania between the years 1990 and 2015. Mensah et al. (2019) say that an increase in climate-related patents as a proxy for patents related to environmental technologies decreases CO2 emissions in the OECD block which contains Europe, America, and Oceania regions in the long run. However, in the short run, an increase in the patents related to environmental technologies exacerbates the emission levels in the OECD America region.

The study made by Ahmad et al. (2020) examines the effect of natural resources, technological innovation, and economic growth on the ecological footprint which includes carbon footprint, in 22 emerging market economies in the time frame between the years of 1984 and 2016. The study made by Ahmad et al. (2020) reveals that there is a negative relationship between technological innovations and ecological footprint.

Moreover, the study of Jahanger et al. (2022) explains the impacts of technological innovation, natural resources, human capital development, globalization, economic growth, and financial development on the ecological footprint figures of 73 developing countries between the years 1990-2016. According to A. Jahanger et al. (2022) state that technological innovation has a contractionary effect on adverse environmental effects related to natural resource consumption.

The study by Bigerna et al. (2023) mainly examines how environmental patents, taxes, and trade globalization affect environmental efficiency in 29 OECD countries between 2005 and 2020. Bigerna et al. (2023) find that environmental innovations have a decreasing effect on carbon emissions and polluting emissions. Moreover, environmental technologies are a significant tool to ensure sustainable economic growth. It ensures sustainability by using fewer natural resources to produce per economic good. Thus, in that way, the negative environmental impacts of economic activities could be lessened. Environmental technologies as a nexus to patents related to environmental technologies are important tools to combat carbon emissions. The patents are also significant for the sustainable development of developing countries by inhibiting environmental degradation. Moreover, due to differences among countries, collective and collaborative efforts among countries are significant in order to improve environmental technologies' strategies to combat environmental degradation.

Contrary to those views some studies find that environmental patents have a positive impact on carbon emissions. The Study by Raiser et al. (2017) examines different literature regarding the relationship between patents as a nexus to intellectual property rights and climate change mitigation. According to Raiser et al. (2017), patents serve as a mechanism designed to facilitate the innovation and the adoption of technologies and their commercialization. Moreover, they are considered crucial for addressing the mitigation of carbon emissions. Patents give its owner to hold the profits from commercialization. Thus, any access to benefit from mitigation technologies relies on the capitalization desire of its owner. Therefore, such a situation creates obstruction of transfer of carbon mitigation technologies internationally and discourages technological developments including mitigation technologies. Privatization of environmental technologies increases the price of knowledge and by doing so it limits access to innovations, especially for developing countries. It inhibits technology transfer to poor developing countries. In short, high prices and monopoly rights of the patents inhibit further advancements in environmental technologies and their transfer to areas that need mitigation technologies. Consequently, this situation creates more dependence on old technologies and utilization of non-renewable energy resources which in turn creates more CO_2 emissions which is contributing to environmental degradation. Thus, according to Raiser et al. (2017), we could infer that these patents related to environmental technologies have a decreasing and positive role in developed countries while they do not have the same effect in developing countries.

According to the study by Cheng et al. (2019), which is conducted over BRIICS countries for the years 2000-2013. It investigates the impacts of renewable energy, environmental patents, economic growth, exports, and foreign direct investments over CO_2 emissions. The reason for the positive impact of patents on carbon emissions per capita is mainly the absence of environmental regulation. It is seen as the connection between the reduction in carbon emissions per capita and technological innovations. Since, specifically, regulations are delivering environmental-related patents to the market. Environmental regulations also enable patents related to environmental technologies to operate smoothly. Moreover, according to Cheng et al. (2019), restrictions regarding the dissipation of environmental technologies and high utilization fees of patents and intellectual property rights are among the obstacles that inhibit the application of carbon reduction innovations all over the world.

The study by Usman and Hammar (2020), scrutinizes the impact of technological innovation, financial development, economic growth, renewable energy consumption, and population on the ecological footprint of Asian Pacific Economic Cooperation Countries between the years 1990 and 2017. According to their analysis, an increase in technological innovations leads to degradation in environmental quality. It implies that technological innovations as a proxy for patents related with environmental technologies increase pollution levels. In the study by Usman and Hammar (2020), it is debated that technological advancements in some of the developed economies do not mitigate the pollution level. In fact, industrialization and the accumulation of human capital that generates technological improvement contribute to a rise in the production level. Thus, technological advancement amplifies environmental degradation. Moreover, according to Usman and Hammar (2020), many inventors and vendors are highly protective of their innovative ideas and are cautious about sharing them with other investors. As a result, technological developments have largely depended on established conventional technologies, fostering the continued use of traditional energy sources that contribute significantly to environmental pollution.

3.2. Literature Review about Environmental Tax

In the study conducted by Fredriksson (2001) for the firms in the USA how they react to changes in environmental tax. Fredriksson (2001) claims that pollution tax as a nexus for environmental tax has a positive impact on pollution. Due to the presence of pollution abatement subsidies, taxes on pollution have unintended repercussions on the revenues and public welfare. Since in general taxes are set by the central government and subsidies are imposed by local governments, decisions made regarding subsidies are open to be influenced by local industrialists and environmental interest groups. To illustrate, if the lobbying efforts of industrialists become stronger than the environmentalists, it could be more appealing to policymakers to act in favor of the industry lobbies by granting more subsidies to them rather than increasing taxes.

Fredriksson (2001) also states that pollution abatement subsidy reduces the additional cost incurred upon polluting companies for the pollution of goods produced, which in turn encourages more production. Consequently, pollution levels may rise with an increase in the pollution abatement subsidy rate. This is realized when the positive impact of the subsidy on production outweighs the cost incurred by the reduction in pollution. In other words, pollution might increase even though the subsidy itself aims to reduce pollution. It is possible that a considerable amount of subsidy increases might also lead to a fall in net tax revenues. Moreover, revenues of pollution tax could be used in a rent-seeking manner so, this situation could lessen the efficiency of the tax. Thus, the effects of a pollution tax could be antagonistic to the intended policy results.

Similar to previous studies, Sinclair (2009) develops an argumentative approach to the effectiveness of green taxes in Britain. Sinclair (2009) argues that green taxes have an inclination to hinder the escalation of carbon emissions. However, the estimation of the correct social cost of carbon emissions and setting the environmental tax in accordance with that is vital for the effectiveness of the environmental tax. According to the author, setting it too high creates inefficiency and distortions in the market whereas setting it too low creates a risk for greater global warming. Moreover, since governments are unable to become politically objective in setting environmental taxes in different sectors, it creates inefficiencies and distortions in the market and contributes positively to existing emission levels.

Different from the studies cited above, Pretis (2022) investigates the commencement of carbon taxation in British Columbia and Canada from 1990 to 2016 and finds that carbon tax as a proxy for environmental tax has a diminishing impact on carbon emissions. Taxes on the transportation sector lead to the reduction of emissions effectively. Moreover, carbon taxes also result in the closure of emission-intense industries and a shift from fossil fuel-driven electricity production to hydropower or other environmentally friendly resources-driven electricity generation. According to Pretis (2022), even if there is not a vividly detectable statistically significant effect of tax on curbing emissions in the short time frame, it is very promising for future reductions in the emissions level. Furthermore, policy mixes are also stated as effective tools to combat emissions.

In line with the study of Pretis (2022) the study made on the 287 cities of China between 2010 and 2019 by Xu et al. (2023) shows that carbon taxes have positive effects on reducing pollution. The study by Xu et al. (2023) investigates how environmental taxes affect pollution composed of industrial wastewater, solid waste, and exhaust emission discharges. Firstly, they cause firms to internalize the negative externalities caused by economic growth and guide them towards environmental preservation. Secondly, the revenue generated from environmental taxes can be channeled into research and development studies for green energy technologies, fostering eco-friendly industrial development, cleaner manufacturing, and diminishing adverse impacts on ecosystems and the environment. Thirdly, environmental taxation plays a pivotal role in curbing emissions of pollutants into the air, water, and soil. Areas with higher tax rates tend to have stricter regulations on pollutant emissions, which help prevention of pollution spillover. Moreover, environmental taxes could be used for the construction of environmental protection infrastructures. Levying the taxes on particular sectors leads to the channelization of investments towards the production of environmental protection products like sewage treatment facilities, recycling services, energy-saving equipment… etc. In short, environmental taxes could enable the internalization of environmental externalities, contribute to green innovation activities, and help to construction of environmental protection facilities.

Analysis by Rakpho et al. (2023) examines the effects of environmental taxes, fossil fuel consumption, renewable energy consumption, GDP per capita, labor force, and gross capital on CO_2 emissions for G7 countries from 1994 to 2020. According to Rakpho et al. (2023), if the environmental tax rate is less than the optimal level, it decreases the per capita carbon emissions more, compared to the tax rate which is above the optimal level. Thus, the effect of environmental tax on the emissions per capita diminishes when the tax is above the optimal level. If the tax rate is above the optimum level, carbon emissions will tend to increase. Rakpho et al. (2023) argues that imposing high taxes on carbon-emitting activities could inflict high costs on businesses. Then, businesses decide not to mitigate their carbon emissions to lower their costs and increase their profits as a result this situation creates more carbon emissions. Due to high environmental tax, they lack incentive to invest in emission-reducing investments and they simply pay taxes and go on with their polluting activities without doing anything. In short, determining an optimal rate is essential for reducing CO2 emissions per capita in general.

3.3. Literature Review about Natural Resources Rent

The study by Balsalobre-Lorente et al. (2018)scrutinizes the impacts of economic growth, trade openness, renewable electricity consumption, energy innovation, and natural resource abundance, on CO_2 emissions in EU-5 countries for 1985-2016. According to Balsalobre-Lorente et al. (2018), natural resource rent has a decreasing effect on pollution with environmental consciousness and regulations.

Another analysis by Danish et al. (2019) conducted for 5 BRICS countries between 1990 and 2015 investigates the effect of natural resources and renewable energy on environmental pollution. Danish et al. imply that developing countries that have different structural backgrounds have different outcomes for environmental pollution. Natural resources rent a has positive effect on carbon emissions for South Africa, but it has a negative effect on the emissions for Russia. Since Russia has rich natural resources, there is no need for fossil energy imports. By utilizing its own vast energy resources, fewer carbon emissions occur compared to countries where high utilization of fossil fuels is present. On the contrary, South Africa as a developing country, for accelerated industrialization and economic development, natural resource extraction, and unsustainable use of fossil fuels increases. Consequently, carbon emissions rise.

The study by Zafar et al. (2019) explores the effects of natural resources, human capital, and foreign direct investment on ecological footprint utilizing U.S. data from 1970 to 2015. The results of the study by Zafar et al. (2019) also support the previous views, an increase in natural resources rent decreases ecological footprint as a proxy for carbon emissions decreases. Thus, environmental quality could be ensured with regenerative forces of natural resources, implying that alleviating the countries' dependence on fossil fuel imports, for reduction of carbon emissions. Moreover, the study also concludes that controlling the excessive use of natural resources by educating people to alter their patterns of consumption, such as; mitigation of deforestation and fishing, cautionary use of water and energy resources, increasing the widespread utilization of energy-efficient products, and preventing excessive use of natural resources contribute to minimization of carbon emissions.

Kongbuamai et al. (2020) analyze ASEAN countries, for the 1995- 2016 period, and look at how economic growth, energy consumption, tourism, and natural resources affects the ecological footprint. According to Kongbuamai et al. (2020), natural resources rent plays a significant role in enhancing environmental conditions by reducing carbon emissions. This can be attributed to the fact that abundant natural resources can contribute to the balance of the ecosystem. Additionally, the proximity of local communities to these resources enables them to actively protect them, since they know the local conditions and management challenges. Additionally, natural resources rents provide aid to recycle the emissions and wastes from human activities. The reduce-reuse-recycle approach helps to loosen the pressure on natural resources.

The study by Tufail et al. (2021) inspected seven developed nations from the period 1990 and 2018 and look at the relation between carbon emissions with the independent variables of GDP, institutional quality, total natural resources rent, and fiscal decentralization. According to Tufail et al. (2021), expeditious development of the economy inclines countries to the industrialization phase which further accelerates the extraction of natural resources and as a result contributes to carbon emissions. However, in developed countries with high fiscal decentralization, natural resources rent contribute to the environmental quality by diminishing its undesirable consequences. Fiscal decentralization establishes an environment for accountability at the local government level. Thus, it decreases the carbon dioxide leakage to the environment.

The study of 26 OECD countries from 1980 to 2016 by Ulucak et al. (2020) examines the carbon emissions, ecological footprint, and carbon footprint as dependent variables and per capita GDP, renewable energy consumption, non-renewable energy consumption, and natural resources rent as independent variables which are same for the three mentioned dependent variables. According to Ulucak et al. (2020), The social and economic structures of the countries have a determining role for the effect of natural resources rent on emissions.

According to Ulucak et al. (2020), over-exploitation of natural resources led countries to depend on imports of non-renewable energy sources which creates further degradation of the emissions. Moreover, poor resource management and flawed ownership structure with rent-seeking behavior of policymakers and corruption also contribute to unsustainable natural resource use which further increases the emissions.

The study by Ahmad et al. (2020) examines the link between ecological footprint, economic growth, natural resources, and technological innovation in the time frame from 1984 to 2016 for 22 emerging economies. According to M. Ahmad et al (2020), natural resources rent has a positive impact on carbon emissions as a proxy for carbon emissions per capita. Emerging market economies put a huge burden on natural resources, putting upward pressure on emissions.

The study by Ullah et al. (2021) for the top 15 renewable energy consumption countries and the years between 1996 and 2018 examines the relationship between the dependent variable the ecological footprint and independent variables renewable energy consumption, natural resources rent, industrial value added, and urbanization. According to Ullah et al. (2021), environmental degradation increases with the rise of natural resources rent.

The study conducted by Huang et al. (2023) on the USA between the years of 1995-2015, investigating the impact of natural resource rent, financial development, and urbanization on carbon emissions, implies that natural resources rent is positively related to carbon emissions in the long run.

3.4. Literature Review about Renewable Energy Consumption

According to a study by Cheng et al. (2019) whose analysis information is mentioned before, if the related technology and equipment are at low levels, the effect of renewable energy supply with extra investment is high on reduction of the carbon emissions compared to countries whose technology and equipment level is at high levels. Therefore, according to Cheng et al. (2019), renewable energy has a diminishing marginal effect on carbon emissions per capita. When the equipment and technology increase above a certain level, the mitigation effect of renewable energy on carbon emissions begins to decrease as a result of diminishing marginal effect.

The analysis of 28 OECD countries between the years of 2004-2015 by Soukiazis et al. (2019) looks at how the human development index, total energy consumption, renewable energy, and human capital affect CO_2 emissions. In line with the previous studies, Soukiazis et al. (2019) show that renewable energy has a negative effect on carbon emissions per capita and a positive contributing effect on environmental sustainability. That decreasing effect occurs mainly through the development of human capital since escalated skills of human capital play a pivotal role in the advancement of renewable energy technologies. As a result, renewable energy makes a significant contribution to both sustainable development and the economic conditions of a country.

According to a study by Ulucak et al. (2020) whose details are explained before, renewable energy consumption has a negative but statistically insignificant effect on carbon emissions. That situation is explained by less renewable energy utilization in the production process in the service and industrial sectors. Even though renewable energy consumption is significant in curtailing the undesirable environmental effects that stem from the activities of human beings, and it is an effective way to attain economic, environmental, and social sustainability; its role in the production activities in the economy is not sufficient yet. As a result, even if it has a decreasing effect on emissions, its impact on the bigger picture remains insufficiently limited.

The study by Doğan et al. (2020) investigates the effects of economic complexity index, renewable energy consumption, total population, and GDP on CO_2 emissions for 28 OECD counties between the years of 1990-2014. The study by Doğan et al. (2020) also says that an increase in renewable energy consumption decreases carbon emissions. Furthermore, the merger of technologies such as artificial intelligence, high-tech internet, etc. with industrial processes affects the energy structure to have control over the level of carbon emissions.

According to a study by Ullah et al. (2021) which its information is elaborated before, if countries switch their energy policy from non-renewable energy consumption to renewable energy consumption, the switch has a positive impact on environmental quality by helping to decrease environmental degradation

The study by Kaygusuz (2009), elaborates on how renewable energy development affects the environment in an argumentative manner. Different from the previous studies, according to Kaygusuz (2009), the issue of the life cycle should be considered even if it is a minor situation compared to total carbon emissions and the pollution level. The manufacturing, transportation, and decommissioning of renewable energy equipment can produce emissions, depending on the energy sources and processes involved. Kaygusuz (2009) states that renewable energy production from solar panels needs the generation of the panels, land, construction of buildings, transmission lines, roads, etc. As a result, it affects the environment. In fact, toxic materials and fluids used in the production of panels to produce renewable energy, have also serious repercussions on the natural habitat and the emissions.

Likewise, a study by Owusu and Asumadu-Sarkodie (2016) is also argumentative and elaborates on renewable energy according to its sources and their use. According to Owusu & Asumadu-Sarkodie (2016), despite many advantages of renewable energy consumption in combatting carbon emissions per capita and environmental degradation, it has some shortcomings. For example, since renewable energy production is dependent on climatic conditions, due to seasonal volatilities there could be some discontinuity in the production of energy, thus it affects renewable energy consumption. However, with the advancement of technology applicable to renewable energy production, these problems can be overcome through time. In addition, for example, hydropower generation and bioenergy as some forms of renewable energy could have some adverse impacts on the environment. The former could put a burden on environmental integrity due to the transportation of water with pipelines through mountains and the extraction of water from lakes and rivers. Moreover, the latter could harm the environment through overexploitation of forests, and land, and overuse of water. In short, renewable energy consumption, life cycle emissions, land use, energy transmission and ecosystem impacts should also be considered in combating carbon emissions and pollution in general.

3.5. Literature Review about Urbanization

The study by Wu et al. (2016) investigates how population, energy consumption, and urbanization structure affect carbon emissions for 288 cities in China between 2002 and 2011. According to Wu et al. (2016), the geographical scattering of population and economic activities across the cities are the main constituents of carbon emissions. Negligence of spatial distribution of economic activities and population in urban policies are one of the key determinants of the higher carbon per capita emissions in China. Moreover, considering how economic activities are spread within and between cities, greater population density contributes to the ecological sustainability of the urban areas. Cities having higher population density with warmer winters and cooler summers have less production of carbon emissions per capita. The study shows that colder winters result in higher carbon emissions per capita because of higher home heating. Moreover, heavy industries and chemical firms that use outdated technology in that northern region of China also contribute the carbon per capita emissions. Moreover, the high productivity of the vast cities is accomplished through higher amounts of carbon emissions per capita compared to small cities. However, according to Wu et al. (2016), we also should consider the efficiency of emissions, which is more relevant for developing countries that are trying to restore harmony between their economic and environmental goals. Additionally, the relocation of economic activities and population from cities with higher carbon emissions efficiency to cities with lower carbon emissions efficiency are deteriorating the carbon emissions in China. The study elaborates that urban development policies have a significant impact on carbon emissions per capita. In short, population density, geographic and climatic characteristics of the cities, and carbon emission efficiency are the key factors for struggling carbon emissions per capita in developing countries according to the study. Large cities have lower carbon emissions per capita and higher efficiency of carbon emissions in China, and it is a key model in urbanization policy for combating carbon emissions.

According to an analysis by Mensah et al. (2019) whose information is mentioned before, in the long run, an increase in the rate of urbanization raises carbon emission by %12 in OECD countries. Mensah et al. (2019) say that migration from rural areas to urban areas leads to economic growth, which accelerates the increase of carbon emissions. Additionally, the expansion of facilities and infrastructure, and the increase of production in industries to meet the demand for goods and services are also contributing to carbon emissions positively.

Additionally, the study by Anwar et al. (2020)) on Far East Asian countries between the years 1980 to 2017 scrutinizes the effects of urbanization, GDP, and trade openness on CO_2. Anwar A. states that urbanization increases carbon emissions and escalated urbanization is responsible for approximately 70 percent of the consumption of energy and the same percentage of total carbon emissions. Moreover, according to the study by Anwar et al. (2020), because of the current pace of urbanization and the demand for more energy consumption, energy consumption in those Far East Asian countries will double in the near future thereby resulting in much more carbon emissions.

The study by Musah et al. (2021) on West Africa for the period 1990-2018 examines how urbanization, renewable energy consumption, and GDP affect carbon emissions. The study by Musah et al. (2021) implies that a significant proportion of the population in West Africa moves to urban areas to look for employment opportunities and improved living standards. Escalation in urbanization rate drives the construction of more infrastructure, such as roads, bridges, waste management facilities, hospitals, schools, community centers, and markets. These construction activities heavily rely on fossil fuels such as natural gas, and coal, cause more carbon dioxide emissions.

Furthermore, the growth of industries and businesses, fueled by the rapid urbanization, necessitates the use of environmentally harmful energy sources. In addition, the emissions from vehicles are a primary contributor to environmental pollution in West Africa. In urbanized areas, personal transportation is preferred to public transportation, exacerbating emissions rates in these regions. Furthermore, urbanization encourages the widespread use of high-energy-consuming household appliances such as air-conditioners, refrigerators, heaters, and others, leading to an increase in carbon dioxide emissions. Moreover, the increase in the population of urban areas leads to higher consumption of nonrenewable energy sources, thereby increasing emissions more. Therefore, in developing countries, urbanization is a crucial factor in influencing emissions. Moreover, according to a study by Ullah et al. (2021) which is mentioned before, the escalation of urbanization leads to more consumption of energy resources which results in more environmental degradation both in developed and developing countries. The study conducted by Huang et al. (2023) whose details are explained before implies that the expansion of urban areas causes more carbon emissions.

Different from previous studies cited above, the analysis by Fan et al. (2023) investigates how smart city construction influences green total factor productivity for 233 cities in China from 2004 to 2019. The study by Fan et al. (2023) reveals that the construction of smart cities as a type of urbanization has a positive effect on both carbon emissions and pollution levels. Integration of high technology with urbanization forms the concept of smart cities. Smart cities by ensuring sustainable transportation through monitoring real-time emissions generated by vehicles and construction of smart transportation systems could be able to curb carbon emissions. Moreover, by promoting the advancement of industrial transformation which saves energy and reduces emissions of industrial sulfur oxide, wastewater, and industrial smoke, the construction of smart cities could attain contraction in pollution and carbon emissions. Likewise, the study by Su et al. (2023) examines the effects of smart city development on the environment in China between the years 2008 and 2015. The study by Y. Su et al. (2023) confirms the same results as the study by Fan et al. (2023). However, this study simply adds the concept of greening to the construction of smart cities. It is argued that green infrastructure such as trees, gardens, green roofs, and roadside vegetation is a significant tool for mitigating the adverse effects of pollution and carbon emissions.

3.6. Literature Review about GDP Per Capita

According to a study by Cheng et al. (2019) in which the details of the study explained, GDP per capita has a positive effect on carbon emissions per capita. In other words, a rise in GDP per capita leads to more carbon emissions per capita, and the idea is also supported by the EKC hypothesis. In fact, during the era of the industrialization process of the economy, economic development escalates carbon emissions. Since industrialization needs extensive natural resources, the depletion of natural resources superfluously causes significant environmental problems. The process from developing countries to developed ones, economic expansion increases carbon emissions. As the economy keeps expanding, countries enter a phase of post-industrial development. During this post-industrial era, there could be a heightened focus on environmental preservation, the implementation of new laws and regulations, and a shift in the economic structure towards the service sector. Thus, these changes lead to a decrease in carbon emissions per capita.

According to the analysis by Doğan et al. (2020), GDP per capita has a positive and significant effect on carbon emissions. In the study, it is stated that since the developing countries in OECD increasingly rely on energy resources for escalation of their industrialization and economic growth, as a result it leads to an increase in carbon emissions.

According to Ulucak et al. (2020) whose study is elaborated before, an increase in GDP per capita has a positive impact on economic activities like agriculture, industrialization, and the extraction of natural resources. Therefore, it contributes to carbon dioxide emissions positively. However, as national income rises, there could be changes in lifestyles, production, and consumption patterns. People tend to be more aware of the environment they live in and begin to demand environmentally friendly products that promote sustainable material usage and improve environmental quality. Additionally, increasing income can enhance a country's capacity to recycle waste generated by human activities and invest in clean technology. Throughout that journey of development, information, and communication technologies play a crucial role in raising awareness and disseminating global concerns which contribute to reducing environmental degradation. These arguments are also aligned with the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between GDP per capita and environmental degradation.

In line with the previous analysis, a study by Rakpho et al. (2023) which is also explained before, reveals that if GDP is below a certain level, an increase in GDP per capita results in an increase in carbon emissions but if GDP exceeds that certain level increase in GDP per capita results in decrease in carbon emissions. Moreover, according to the study, provided that real GDP per capita reaches approximately 299.000 USD, carbon emissions will decline.

Similar to the analysis elaborated by Rakpho et al. (2023), the study by Soukiazis et al. (2019) which is mentioned before, argues that in line with the EKC hypothesis, the governments realize that at some point they should seek alternative policies for mitigating environmental pollution They also recognize that reduction of pollution level depends on the development level. In fact, Escalation in economic development increases capital stock and quality of human capital which have a decreasing impact on carbon emissions and in general environmental pollution.

CHAPTER 4

DATA AND METHODOLOGY

4.1. Data

In this study, we examine the determinants of pollution for developed and developing countries in the EU between the years 2000 and 2019. In our analysis, initially we examine the EU and then we examine the developed and developing countries in the EU. Our independent variables are patents on environment-related technologies, environmental taxes as a percentage of total tax revenues, total natural resources rent as a percentage of GDP, renewable energy consumption as a percentage of total final energy consumption, the urban population as a percentage of total population and GDP per capita (2015 USD) with the dependent variable of carbon emissions per capita. The data covers 25 EU countries Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden over the period 2000-2019 due to data availability. Then, we examine the developed and developing countries separately. Our dependent and independent variables are the same throughout the analysis. Moreover, our data covers 25 EU countries. 12 EU countries Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxemburg, Netherlands, Spain, and Sweden are grouped as developed countries. Other 13 EU countries Bulgaria, Croatia, Czechia, Estonia, Greece, Hungary, Latvia, Lithuania, Poland, Portugal, Romania, Slovak Republic, and Slovenia are grouped as developing countries in the EU.

When categorizing the EU countries into developed and developing groups, we use the EU Cohesion Policy as the reference criterion. Cohesion Policy funds are directed towards less developed European countries and regions to reduce economic, social, and territorial disparities within the EU, helping them to catch up with more prosperous counterparts. The 13 EU countries mentioned above are the countries which take the majority of the cohesion fund, so we take them as developing countries in the EU and the other 12 countries are taken as developed countries. Since our data is composed of 500 observations in the first part, 240 observations for the developed countries, and 260 observations for the developing countries in the second part, the sample size is sufficient to conduct PVAR (Panel Vectoral Autoregression) analysis. Moreover, throughout the analysis, we take the natural logarithm of the variables to ensure more stable estimation results. Our dependent and independent variables, their description, and the information regarding their data are revealed below in Table 4.1.

Table 4. 1. Description of variables.

Variable	Symbol	Description	Source
Carbon emissions per capita	CPC	CO2 emissions (metric tons per capita)	WDI
Patents related with environmental technologies	patent	Patents on environment related technologies	OECD
Environmental Tax	envtax_pct	Percentage of environmental taxes in total tax revenues data	Eurostat
Natural Resources Rent	nrr	Total natural resource rent as a percentage of GDP	WDI
Renewable energy consumption	rec	Renewable energy consumption as percentage of total final energy consumption	WDI
Urbanization	urb	Urban population as percentage of total population	WDI
GDP per Capita	gdp_per_cap	GDP per capita (2015 USD)	WDI

Our dependent variable carbon emissions per capita include carbon dioxide emissions produced during the consumption of solid, liquid, and gas fuels and gas flaring. Patents related with environmental technologies composed of all of the climate change mitigation technologies related to energy generation, wastewater treatment, disposal of greenhouse gases, transportation, production of goods, information and communication technologies, etc. Environmental taxes variable measures the share of environmental taxes in total revenues from taxes and social contributions. It is composed of energy, transport, pollution, and resource taxes. Total natural resources rents are composed of oil rents, natural gas rents, coal rents, mineral rents, and forest rents. It is calculated as the difference between the price of a commodity and the average extraction or harvesting costs. It is mainly the contribution of natural resources in the form of economic rents. Countries use such rents to support current consumption or invest in new capital to replace used natural resources. Another independent variable of renewable energy consumption is the share of renewable energy in total energy consumption. Our urbanization variable is the Urban population as a percentage of the total population. In our variable, urban population refers to people living in urban areas. GDP per capita is the gross domestic product per capita which is constant at 2015 prices in USD terms.

4.2. Methodology

In the construction of our model and the selection of our variables, we are inspired by the article "The Role of Green Finance and Energy Innovation in Neutralizing Environmental Pollution: Empirical Evidence from the MINT Economies" by (Li et al., 2022) and the EKC theory. We conduct our analysis on all the EU countries and also examine the developed and developing countries in the Union separately to grasp a broader understanding of the differences and similarities between the developing and developed countries regarding the determinants of pollution in the EU. Moreover, instead of a green finance variable, we use environmental taxes.

In our study, the econometric technique of PVAR analysis has been utilized[1]. The PVAR approach is an adapted version of the traditional VAR method for panel data sets. The PVAR model, initially studied by Holtz-Eakin et al. (1988), extends the traditional VAR model structure of (Sims, 1980) to panel data by incorporating the cross-sectional dimension. It has been observed that including the cross-sectional dimension in models provides stronger results. In the VAR model, which assumes all variables in the system to be both endogenous and independent, each variable is composed of its own lagged values as well as the lagged values of other variables.

[1] In our study, Stata 18 statistics program has been utilized and for the panel VAR model predictions we use codes which are elaborated in Abrigo and Love (2016)

Moreover, PVAR models enable us to analyze common features of variables for countries which have different structural backgrounds.

Under the assumption that all variables are endogenous, the maximum p-lagged PVAR model constructed with panel data is expressed as follows:

$$y_{it} = a_{1i0} + \sum_{j=1}^{p} a_{11j}\, y_{it-j} + \sum_{j=1}^{p} a_{12j}\, x_{it-j} + f_{1i0} + n_{10t} + \varepsilon_{yit} \quad (4.1)$$

$$x_{it} = a_{2i0} + \sum_{j=1}^{p} a_{21j}\, y_{it-j} + \sum_{j=1}^{p} a_{22j}\, x_{it-j} + f_{2i0} + n_{20t} + \varepsilon_{xit} \quad (4.2)$$

When we interpret it in closed form:

$$z_{it} = \Gamma_0 + \Gamma_1 z_{it-1} + f_i + \lambda_t + e_t \quad (4.3)$$

$$z_{it} = \begin{bmatrix} y_{it} \\ x_{it} \end{bmatrix}, \Gamma_0 = \begin{bmatrix} a_{1i0} \\ a_{2i0} \end{bmatrix}, \Gamma_1 = \begin{bmatrix} a_{11j} & a_{12j} \\ a_{21j} & a_{22j} \end{bmatrix}, z_{it-1} = \begin{bmatrix} y_{it-j} \\ x_{it-j} \end{bmatrix}, f_i = \begin{bmatrix} f_{1i0} \\ f_{2i0} \end{bmatrix}, \quad (4.4)$$
$$n_t = \begin{bmatrix} n_{10t} \\ n_{20t} \end{bmatrix}, e_t = \begin{bmatrix} \varepsilon_{yit} \\ \varepsilon_{xit} \end{bmatrix}$$

In the first equation y_{it} represents the dependent variable and a_{1i0} is the intercept term. In the equations "i" represents countries and "t" symbolizes time. Moreover, y_{it-j} as a lagged version of the dependent variable together with x_{it-j} symbolizes our lagged independent variables. In addition, a_{1nj} is the coefficients, a_{1i0} symbolizes fixed effects, n_{10t} reveals unobservable random time effects and ε_{yit} is the error term. Likewise, in the second equation, x_{it} represents our dependent variable which was previously the independent variable in the first equation. In addition, y_{it-j} and x_{it-j} are independent variables. Moreover, a_{2i0} is the intercept term, a_{2nj} are coefficients, f_{2i0} is fixed effects, n_{20t} is unobservable random time effects and ε_{xit} is the error term. The third equation represents them as a linear regression and the fourth equation is the matrix form of first and second equations. According to Türküz (2016), to overcome the challenges encountered with the addition of cross-sectional dimensions, the Panel VAR method necessitates the constraint that each cross-sectional dimension shares the same underlying structure. As a result, it is assumed that the parameter vector is the same for all units.

However, the inclusion of past lags of variables as additional features in the model, when fixed effects are present, could lead to correlations between the fixed effects and the lagged variables of the dependent variable. To remove fixed effects from the model, differencing methods based on group means can result in biased parameter estimates. Thus, to overcome that biasedness problem, Arrellano and Bover (1995) suggest using the "Helmert Method" by taking forward differences to attain the necessary orthogonality assumptions and the unbiasedness of the estimators. In that vein, we use forward orthogonal deviations in our analysis to remove panel-specific fixed effects and to ensure unbiasedness in our estimation (Türküz, 2016).

The process of forecasting a Panel VAR model involves stages such as model selection, construction, causality relationship, stability analysis, variance decomposition, and impact-response analysis.

Firstly, the Panel VAR analysis is based on selecting the appropriate lag length, which determines the specification of the Panel VAR model and its moment conditions. In fact, our Generalized Method of Moments (GMM) estimation process depends on our lag selection. Therefore, we determine the lag length according to Modified Bayesian Information Criterion (MBIC), Modified Akaike Information Criterion (MAIC), and Modified Hannan-Quinn Information Criterion (MQIC) values. These model selection criteria are developed by Andrews and Lu (2001) to be used in the GMM estimation process which is based on Hansen and J statistics. MBIC, MAIC and MQIC model selection criteria which are developed by Andrews and Lu (2001) parallel respectively with the model selection criteria of Bayesian Information Criterion (BIC) (Schwarz, 1978; Rissanen, 1978; Akaike, 1977), Akaike Information Criterion (AIC) (Akaike, 1969) and Hannan-Quinn Information Criterion (HQIC) (Hannan and Quinn, 1979) (Türküz, 2016).

Secondly, once the appropriate lag length is determined, the Panel VAR model is constructed by incorporating the lagged values of each dependent variable along with the lagged values of other dependent variables and any external variables, if present. The estimation of the model is carried out using the GMM approach, as outlined by Holtz-Eakin et al. (1988). In fact, in our analysis, we use the system GMM which gives more robust estimates and reduces the prediction error.

Thirdly, in order to gain insights into the existence and direction of relationships among the variables included in the PVAR model, Granger causality tests are conducted for each equation present in the estimated PVAR model. The significance of this test implies the presence of Granger causal relationships among the tested variables (Türküz, 2016). After the test results, we could make inferences about traits of causality whether it is unilateral or bilateral Granger causality.

Fourthly, to test the stability of the Panel VAR model, eigenvalues are computed for each element in the estimated model. According to Lütkepohl (2005) and Hamilton (1994), all matrix elements having magnitudes less than one indicate the stability of the model. Additionally, the roots of the companion matrix being within the unit circle constitute the second criterion for stability analysis. Meeting the conditions of stability means that the roots of the Panel VAR model can be inverted, indicating that they represent infinite-order moving averages. Passing the stability test is important for the impulse-response analysis and the interpretation of the estimated error variance, as it allows for the prediction and interpretation of the estimated error variance (Türküz, 2016).

Fifthly, in the PVAR model, the analysis of dynamic relationships is mainly done with impulse-response analysis. The shocks are conveyed through the error terms of the variables. Impulse response graphs mainly reveal the impact of one standard error deviation on the current and future values of other endogenous variables. The impulse-response analysis assesses the effects of a random shock in one variable on other variables in the system, serving an important role in guiding economic policies. Impulse response analysis in which the short-term effects are analyzed, is conducted through the analysis of response variables' coefficients induced by the impulse of other variables on them. The impulse-response analysis is expressed in terms of two distinct magnitudes: an impulse in the direction of the variable giving the shock and a response in the direction of the variable receiving the shock (Türküz, 2016).

Lastly, the relationships among variables present in VAR and Panel VAR models can be interpreted through Granger Causality and Impulse-Response analysis, as well as through the Variance Decomposition method. Variance Decomposition aims to reveal the mutual relationships among variables by showing what percentage of a shock in one variable originates from itself and what percentage comes from other variables. When looking at the findings obtained from Variance Decomposition, if the entire forecast error variance of a variable is explained by itself, it indicates that the variable is exogenous. On the other hand, if the forecast error variance of a variable is explained by shocks from other variables, this suggests that the variable is endogenous. It can be claimed that while Variance Decomposition determines which variable has the most influence on macroeconomic indicators, whether this influential variable can be used as a policy tool is determined by impulse response functions (Türküz, 2016).

CHAPTER 5

EMPIRICAL RESULTS

After explaining our data variables and methodology, our models' representation is revealed below:

$$cpc_{it} = a_{i0} + \sum_{j=1}^{p}(\beta_{1j}\ cpc_{it-j} + \beta_{2j}patents_{it-j} + \beta_{3j}envtax\_pct_{it-j} + \beta_{4j}nrr_{it-j} + \beta_{5j}rec_{it-j} + \beta_{6j}urb_{it-j} + \beta_{7j}gdp\_per\_cap_{it-j}) + f_{1i0} + n_{10t} + \varepsilon_{yit} \tag{5.1}$$

Throughout our PVAR analysis of EU and developed and developing countries in EU, we use the mentioned model above, i represents our cross-section units and t represents our time period.

5.1. Analysis of the EU Countries between 2000 and 2019

Before starting the analysis we estimate the summary statistics for EU countries data which is elaborated below Table 5.1.

Table 5. 1. Summary statistics for the EU countries.

Variable	Observa-tions	Mean	Standard Deviation	Min	Max
CPC	500	7.727668	3.635178	2.926895	25.61044
patent	500	728.652	1828.228	1	10653
envtax_pct	500	7.37512	1.635873	4.32	11.75
nrr	500	0.5957807	0.7119454	0.0088736	5.695609
rec	500	17.69906	11.53647	1.28	52.88
urb	500	71.18891	12.25428	50.754	98.041
lgdp_per_cap	500	29425.82	21462.18	3721.051	112417.9

Initially, we utilize Peseran and Yamagata's test which investigates the heterogeneity of panel data. Since we reject the null hypothesis which is elaborated in the appendix part, we conclude that our data set is heterogeneous. Moreover, Panel VAR analysis which we conduct is suitable for elaborating this heterogeneous and dynamic relationship within this cross-sectional data.

Peseran's (2004) cross-section dependency test is a prerequisite for the determination of the type of panel unit root tests. Since, after conducting Peserans' (2004) cross-section dependency test we find that there is cross-section dependency, we have to use the 2nd generation panel unit root test for our variables in the model. However, if there were no cross-section dependencies, we would be using the 1st generation panel unit root test. Peserans' (2007) panel unit root test is utilized, and the stationarity of our variables is elaborated below in Table 5.2 We make the variables stationary by taking the differences of nonstationary variables and it is illustrated in Table 5.2 below.

Table 5. 2. Unit root test results for the EU countries.

Unit root tests at level	H0: (homogeneous non-stationary)				
N,T = (25, 20)	CIPS Value	Stationarity at % 1 level	Critical values at %10	Critical values at %5	Critical values at %1
d_ln_carbon_per_cap	-4.373	Stationary	-2.14	-2.26	-2.47
ln_patent	-3.831	Stationary	-2.14	-2.26	-2.47
d_ln_envtax_pct	-4.210	Stationary	-2.14	-2.26	-2.47
d_ln_nrr	-3.841	Stationary	-2.14	-2.26	-2.47
ln_rec	-2.517	Stationary	-2.14	-2.26	-2.47
d2_ln_urb	-3.958	Stationary	-2.14	-2.26	-2.47
d_ln_gdp_per_cap	-2.936	Stationary	-2.14	-2.26	-2.47

Our dependent variable carbon per capita (ln_carbon_per_cap) and our independent variables patents related with environmental technologies, environmental tax (ln_envtax_pct), natural resource rent (ln_nrr), and GDP per capita (ln_gdp_percap) are stationary at their first differences I (1). However, the urbanization (ln_urb) variable becomes stationary at its second difference I (2). Our independent variable renewable energy consumption (ln_rec) are stationary at its level I (0). After ensuring the stationarity of the variables, the correlation matrix indicates no serial correlation between our variables.

To determine whether our model is the random effect or fixed effect model, we utilize the Hausman test and fail to reject the null hypothesis and conclude that we have random effects. Thus, we can carry out our estimations with Panel VAR analysis. Although contemporary literature utilizes the estimation based on fixed effects, the Panel VAR model with random effects is also theoretically possible (Sigmund, 2017). Thus, we can carry out our estimations on our model which has random effects.

We conducted Maximum likelihood estimation (MLE) random effects with a multiplicative heteroscedasticity test and could not reject the null hypothesis. Thus, we also have a heteroscedasticity problem in our model. The heteroscedasticity test result is provided in the appendix. However, even if we have heteroscedasticity and cross-section dependence problems, it will not cause inconsistency when we study with big samples as in our analysis. In the presence of those problems, utilizing appropriate methods like GMM with forward orthogonal deviation is suggested (Yerdelen Tatoğlu, 2013).

5.1.1. Estimation Results of PVAR Model for the EU Countries

Initially, we determine the appropriate lag length for the estimation of the Panel VAR model. Therefore, the suitable lag length is determined by MBIC, MAIC, and MQIC criteria. Using the GMM and the model selection criteria, we determine the appropriate lag lengths. The results are provided in Table 5.3 below.

Table 5. 3. Suitable lag length results for the EU countries.

lag	CD	J	J p-value	MBIC	MAIC	MQIC
1	0.9927438	152.0818	0.3700169	-698.1406	-141.9182	-363.9074
2	0.9814862	105.3222	0.2884634	-461.4927	-90.67783	-238.6706
3	0.9743636	30.65475	0.9814044	-252.7527	-67.34525	-141.3416

When we look at the MBIC MAIC and MQIC criteria, they have their smallest values at the lag length one, so our Panel VAR model is estimated through system GMM with one lag length and results are elaborated in Table 5.4 below.

As we see from Table 5.4, environmental tax, and GDP per capita have positive coefficients implying that they have positive effects on the carbon emissions per capita. Moreover, patents related with environmental technologies, natural resources rent, renewable energy consumption and urbanization have negative coefficients which implies they have a negative impact on the CPC.

Table 5. 4. PVAR model estimation results for the EU countries.

	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
d_ln_cpc						
d_ln_cpc						
L1.	-.198147	.0433411	-4.57	0.000	-.283094	-.1131999
d_ln_gdp_pc						
L1.	.7118224	.0774073	9.20	0.000	.5601069	.8635378
d_ln_envtax						
L1.	.1481562	.03819	3.88	0.000	.0733052	.2230072
d_ln_nrr						
L1.	-.0189272	.004937	-3.83	0.000	-.0286036	-.0092509
d2_ln_urb						
L1.	-8.288319	2.055778	-4.03	0.000	-12.31757	-4.259068
d_ln_patent						
L1.	-.0250604	.0040947	-6.12	0.000	-.0330859	-.017035
ln_rec						
L1.	-.0354078	.0079958	-4.43	0.000	-.0510794	-.0197362

The estimated Panel VAR model must go through a stability analysis[2]. This is achieved by ensuring that the results of the stability analysis are met. According to Abrigo and Love (2016) "… Lutkepohl (2005) and Hamilton (1994) both show that a VAR model is stable if all moduli of the companion matrix are strictly less than one. Stability implies that the panel VAR is invertible and has an infinite-order vector moving average representation, providing known interpretation to estimated impulse-response functions and forecast-error variance decompositions…" (Abrigo and Love, 2016: p.788). Inspection of table results, and unit circle reveals that our model is stable and stationary, and it is also appropriate for Panel VAR analysis.

When we conduct the Granger causality test, we find bilateral causality between carbon per capita and patents related with environmental technologies, natural resource rent renewable energy consumption, and urbanization. Moreover, there is

[2] Unit circle and the eigen values of the model are shown at the appendix part.

unilateral Granger causality from environmental tax and GDP per capita towards CPC. Thus, there are unilateral causal relationship between these two independent and the dependent variables. The hypothesis and p values of the analysis are shown in the appendix part.

In our analysis for the EU countries, the effect of one percent standard deviation shock of our independent variables on our dependent variable is revealed in Figure 5.1 below. IRF confidence intervals are estimated via 200 Monte Carlo Simulations based on our estimated model

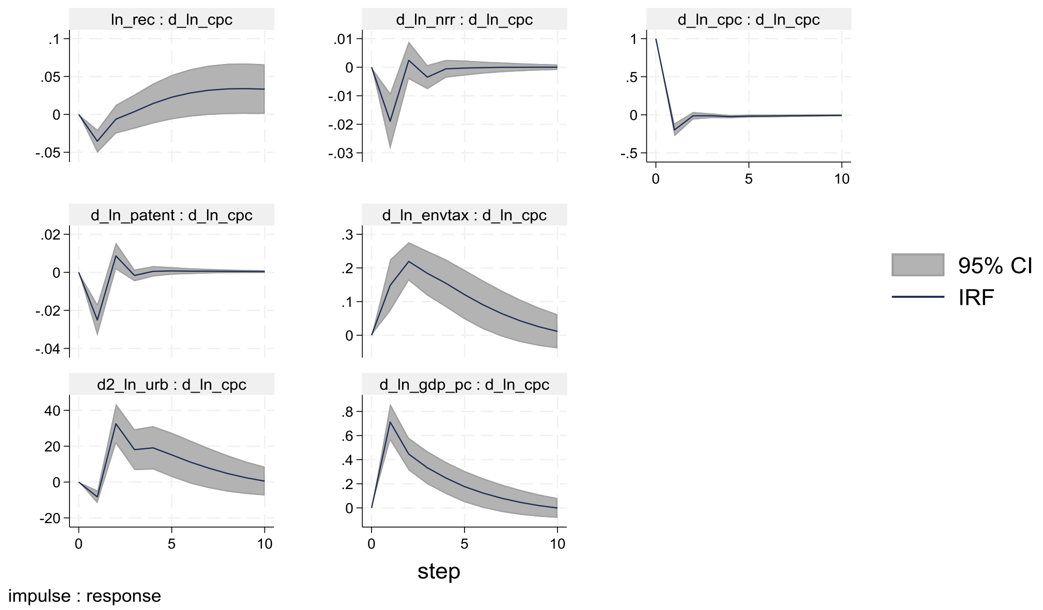

Figure 5. 1. Impulse- Response analysis graphs for the eu countries[3].

Based on Figure 5.1, we can argue that one standard deviation shock of CPC over itself creates a decreasing effect. After the second period that effect reverses from negative to positive but loses its strength. Following that period its effect diminishes and reaches equilibrium. When we gaze upon the shock from patents related with environment technologies on the CPC, we see a V-shaped effect which decreases in the first two periods and increases between the third and fourth periods while sustaining its negativity. From that period onwards, we can say that it nearly reaches

[3] In figure 5.1, "ln" stands for the natural logarithm and "d" stands for the first difference, likewise "d2" is the second difference. carbon_pc: Carbon emissions per capita, patent: Patents related with environmental technologies, envtax: Environmental Tax, nrr: Natural resources rent, rec: Renewable energy consumption, urb: Urbanization, gdp_percap: GDP per capita

equilibrium. The effect of environmental tax over CPC is positive and increasing in the first three periods, then after it, the effect commences to decrease and it reaches its equilibrium at the end of the tenth period. Furthermore, the shock of natural resources rent over CPC is negative and increases in the first two periods and then begins to decrease following the third to fourth periods. After the fifth period, the effect of the shock begins to diminish and reaches its equilibrium onwards. Moreover, the shock in renewable energy consumption over CPC has a negative and decreasing effect in the initial period. Following the second period, it begins to increase and from the third period to the end of the tenth period, the effect of the shock remains positive. The shock sustains its positive impact on CPC, but its effect remains weak. Moreover, one standard deviation impulse of urbanization has a decreasing and negative effect on the CPC in the first period. From the second period, it begins to increase till the third period and then, the positive effect begins to diminish. Following the consecutive periods, it starts to decrease and reaches equilibrium toward the tenth period. Lastly, we see an inverse V-shaped effect if we evaluate the shock of GDP per capita over CPC. In the first two periods, it has an increasing and positive effect. From the beginning of the third period, it begins to decrease, and the shock gradually diminishes and reaches its equilibrium remaining with no effect on CPC.

Table 5. 5. Variance decomposition results for EU countries.

Response variable and Forecast horizon				Impulse variable			
	d_ln_cpc	d_ln_gdp_pc	d_ln_envtax	d_ln_nrr	d2_ln_urb	d_ln_patent	ln_rec
d_ln_cpc							
0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0
2	.7389008	.0981639	.0797523	.0377745	.0014798	.0426371	.0012916
3	.6468037	.1073213	.1038819	.0328988	.067137	.0407968	.0011605
4	.6017463	.1127012	.1300249	.0327156	.0836915	.0380306	.00109
5	.572354	.1137255	.1434284	.0316344	.1014233	.0362335	.001201
6	.5562119	.1136842	.1503273	.030951	.1119199	.035341	.0015646
7	.5479014	.1134752	.1536139	.0305513	.1173605	.0349478	.0021499
8	.543956	.1132378	.154869	.0303256	.1198647	.0348481	.0028988
9	.5422878	.1130266	.1551353	.0302104	.1207159	.0348867	.0037373
10	.5416263	.1128413	.1549958	.0301575	.1208057	.0349771	.0045964

Following the findings obtained from the impulse-response analysis, an analysis for variance decomposition is conducted for each variable individually to examine how much of the forecast error variance "p" periods ahead originates from itself and how much from other variables in the system. The results are presented in Table 5.5 After examining the responses to unexpected shocks, the extent to which these responses stem from patents related with environmental technologies, environmental tax, natural resource rent, renewable energy consumption, urbanization, and GDP per capita is being researched. As we observe from Table 5.5, forecast error variance in CPC explained by itself decreases from 73.9% to 54.2%. When we consider the table as a whole, it is clear that other independent variables' explanatory power on the forecast error variance of CPC increases over consecutive periods. To illustrate, environmental tax is increased from 7.9% to 15.5%, renewable energy is increased from 0.13% to 0.46%, urbanization is increased from 0.15% to 12%, and GDP per capita is increased from 9.8% to 11.3% in their explanatory capacities over the forecast error variance of CPC. Meanwhile, the capacity for patents related with environmental technologies decreases from 4.3% to 3.5% natural resources rent decreases from 3.7% to 3.0%. In short, except for patents related with environmental technologies and natural resources rent, the explanatory power of all of the independent variables over the variance of dependent variable CPC increases in the long run.

5.1.2. Conclusion

As we see from our empirical results, our data is heterogeneous and there are cross-section dependency, heteroscedasticity and random effects issues for our model. As we mentioned before estimation with the appropriate tool such as system GMM with forward orthogonal deviations solves these issues.

Random effects represent entity-specific, unobservable characteristics that are unique to each entity in a panel dataset. Unlike fixed effects, these characteristics are assumed to follow a specific statistical distribution. They can influence the dependent variable but they are considered random and uncorrelated with the independent variables. Random effects help to control for unobserved heterogeneity among countries which reduces omitted variable bias and it also allows us to estimate the impact of time-varying independent variables while accounting for unobserved fixed characteristics.

We could infer from our analysis that even if the same policy set seems to be effective in combatting carbon emissions and pollution in general, there is a need for different approaches and policy tools to tackle the issues of carbon emissions per capita more effectively for developed and developing countries in the EU.

5.2. Analysis of Developed Countries in the EU

Before starting the analysis we estimate the summary statistics for developed countries in the EU which is elaborated below in Table 5.6

Table 5. 6. Summary statistics for the developed countries in EU.

Variable	Observations	Mean	Standard Deviation	Min	Max
CPC	240	9.023136	4.070437	3.401594	25.61044
patent	240	1335.612	2490.684	1	10653
envtax_pct	240	6.670333	1.607042	4.32	11.01
nrr	240	.305424	.4136034	.0088241	2.046105
rec	240	16.74079	13.66606	1.28	52.88
urb	240	79.07065	11.1694	57.115	98.041
lgdp_per_cap	240	46552.25	19222.12	23937.97	112417.9

Initially, we utilize Peseran and Yamagata's test which investigates the heterogeneity of panel data. Since we reject the null hypothesis, we conclude that our data set is heterogeneous. Moreover, Panel VAR analysis which we conduct is suitable for elaborating this heterogeneous and dynamic relationship within this cross-sectional data.

Before starting the analysis with panel unit root tests, we conducted the Peseran (2004) cross-section dependency test. That step is a prerequisite for the determination of 1st generation and 2nd generation panel unit root tests which are later used to ensure the stationarity of our variables. After conducting Peseran's (2004) cross section dependency test we find that there is cross section dependency. Thus, we decide to use 2nd Generation panel unit root test for our variables in the model

To attain the stationary of the nonstationary variables we take differences of them. The results indicate that our dependent variable carbon per capita (ln_carbon_per_cap) is stationary at level I(0) and the urbanization (ln_urb) variable becomes stationary at its second difference I(2). Other remaining independent variables are stationary at their first difference I(1). Unit root test results elaborated Table 5.7 below.

Table 5. 7. Unit root test results for developed countries.

Unit root tests at level	H0: (homogeneous non-stationary): bi = 0 for all i				
N,T = (12, 20)	CIPS Value	Stationarity at % 1 level	Critical values at %10	Critical values at %5	Critical values at %1
ln_carbon_per_cap	-2,711	Stationary	-2,14	-2,26	-2,47
d_ln_patent	-3,807	Stationary	-2,14	-2,26	-2,47
d_ln_envtax_pct	4,340	Stationary	-2,14	-2,26	-2,47
d_ln_nrr	-4,645	Stationary	-2,14	-2,26	-2,47
d_ln_rec	-4,441	Stationary	-2,14	-2,26	-2,47
d2_ln_urb	-3,583	Stationary	-2,14	-2,26	-2,47
d_ln_gdp_per_cap	-2,684	Stationary	-2,14	-2,26	-2,47

After ensuring the stationarity of our variables we look at the correlation between our variables with the correlation matrix and we find that there is no significant serial correlation. To determine whether our model is the random effect or fixed effect model, we conduct the Hausman test and conclude that we have random effects.

Moreover, when we conducted maximum likelihood estimation (MLE) random effects with multiplicative heteroscedasticity test we could not reject the null hypothesis. Thus, we also have a heteroscedasticity problem in our model.

However, even if we have heteroscedasticity and cross-section dependence problems, it will not cause inconsistency when we study with appropriate methods as in our analysis.

5.2.1. Estimation Results of the PVAR Model for Developed Countries

Before estimation, it is necessary to determine the appropriate lag length for the estimation of the Panel VAR model. Therefore, the suitable lag length will be determined by the (MBIC), (MAIC), and (MQIC) criteria. With those criteria, the appropriate lag length is determined to be one. Using the GMM method our panel VAR model with one lag length is estimated and results are elaborated in Table 5.8.

Table 5. 8. Suitable lag length results for developed countries.

lag	CD	J	J p value	MBIC	MAIC	MQIC
1	.9788247	109.4899	.4418648	-435.8945	-106.5101	-240.2918
2	.9685239	94.80761	.0143171	-243.5327	-39.19239	-122.1866
3	.9556228	47.2956	.0045243	-78.9508	-2.704402	-33.67239

After estimation, Panel VAR model (Table 5.9) must undergo a stability analysis.[4]

Table 5. 9. PVAR model estimation results for developed countries.

GMM Estimation

Final GMM Criterion Q(b) = .773
Initial weight matrix: Identity
GMM weight matrix: Robust

No. of obs = 192
No. of panels = 12
Ave. no. of T = 16.000

	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
ln_carbonpc						
ln_carbonpc L1.	1.038423	.0117263	88.56	0.000	1.01544	1.061406
d_ln_gdp_percap L1.	.4454108	.0571804	7.79	0.000	.3333393	.5574823
d_ln_envtaxpct L1.	.2336484	.0359665	6.50	0.000	.1631553	.3041416
d2_ln_urb L1.	25.30049	2.985831	8.47	0.000	19.44837	31.15261
d_ln_patent L1.	-.0197363	.0033527	-5.89	0.000	-.0263075	-.0131652
d_ln_nrr L1.	-.0246607	.0031623	-7.80	0.000	-.0308587	-.0184628
d_ln_rec L1.	-.1612123	.0101072	-15.95	0.000	-.1810222	-.1414025

As we see from Table 5.9 above, patents, natural resources rent and renewable energy have negative coefficients indicating negative impacts on CPC. Moreover, environmental tax, urbanization and GDP per capita have positive coefficients indicating positive impacts on CPC.

The model passing the stability analysis is crucial for obtaining the results of the impulse response analysis and variance decomposition. However, it is also important

[4] The results of the stability analysis are presented in the appendix part in the developed countries' section. From the table, The results of the stability test indicate that our model is stable and stationary. Since the eigenvalues associated with all the characteristic roots of the Panel VAR model are smaller than one.

for the results to be supported by the information about the existence and direction of the relationships among the variables.

When we do the Granger causality test, we can see bilateral causality between carbon per capita and environmental tax, natural resources rent, renewable energy consumption and urbanization. Moreover, unilaterally, GDP per capita and patents related with environmental technologies are Granger causes of carbon per capita. Hypothesis and p values of the analysis are revealed in the appendix.

The causal relationships obtained from our model demonstrate the significance of structural shocks. Following VAR analysis, IRFs are used to determine the dynamic relationships among the variables. Impulse-response analyses help to identify the effect of a 1% standard error shock in one of the error terms of our independent variables on the current and future values of our dependent variable carbon per capita.

The results of the analyses are revealed in Figure 5.2 below. IRF confidence intervals are estimated via 200 Monte Carlo Simulations based on our estimated model.

The shock of CPC over itself has a positive but decreasing effect from the first period till the end of the tenth period. Moreover, the effect of one standard deviation shock of patents related with environmental technologies on CPC has a strong decreasing effect until the fourth period. In the fifth period and afterwards, environmental technologies' strong negative effect decreases slightly but it preserves its negative impact over the CPC. In addition, when we consider the shock in environmental tax over CPC, we could see that it has a positive increasing effect in the first three periods. In the fourth and fifth periods, the effect reaches its peak point but afterwards, at the consecutive periods, the shock loses its strength slightly over CPC but still its positive impact remains. When we examine the effect of natural resources rent over the CPC, the shock has a drastic negative decreasing impact in the first period. Afterwards that negative effect is reversed from that minimum point and starts to increase, while preserving its negative effect, until the fifth period. Then, after slightly increasing in the sixth period its negative effect is compensated considerably and the shock over CPC fades over ensuing periods.

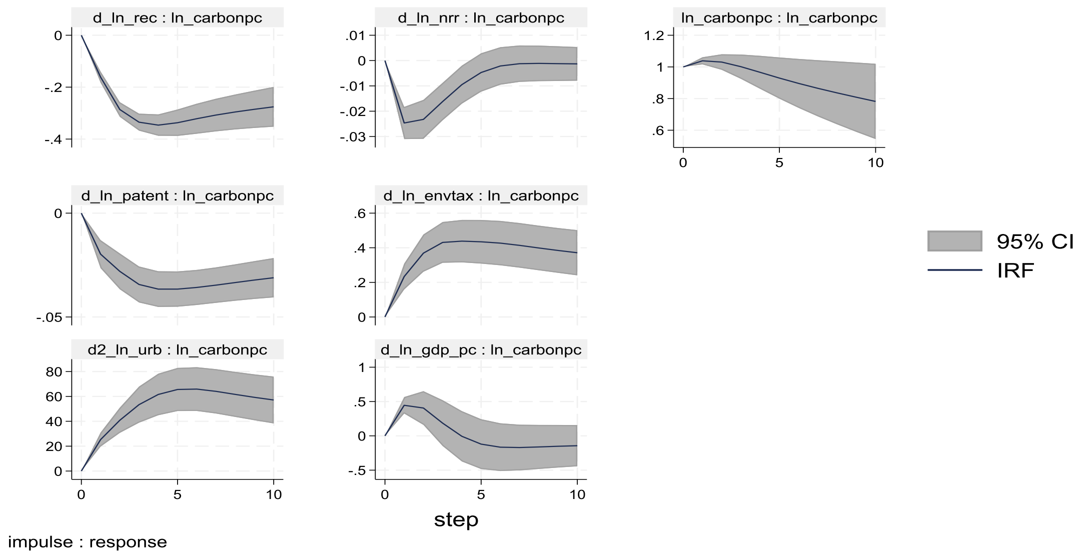

Figure 5. 2. Impulse- Response analysis graphs for developed countries[5].

From Figure 5.2, it is observed that one standard deviation shock occurring in renewable energy consumption exerts its impact on CPC strongly and negatively until the fourth period. After the fourth period till the tenth period that effect increases CPC slightly but still renewable energy consumption sustains its decreasing effect on CPC. Furthermore, when we ponder the one standard deviation shock of urbanization over CPC, we recognize that it has an enormous increasingly positive effect in the first five periods. Then, continuing its positive effect on the CPC, at consecutive periods magnitude of the shock weakens but remains high and positive. Lastly, when we look upon the effect of the one standard deviation shock of GDP per capita on the CPC in the first period it has an increasingly positive impact but from the second period to the fifth that impact begins to weaken and in fact, after the fourth period its effect becomes negative over the CPC. After the fifth period and onwards its effect flattens and remains negative.

Following the findings obtained from the impulse-response analysis, an analysis for variance decomposition is conducted for each variable individually to examine how

[5] At figure 5.2, "ln" stands for the natural logarithm and "d" stands for the first difference. carbon_pc: carbon emissions, patent: Patents related with environmental technologies, envtax: Environmental Tax, nrr: natural resources rent, rec: renewable energy consumption, urb: urbanization, gdp_percap: GDP per capita.

much of the forecast error variance "p" periods ahead originates from itself and how much from other variables in the system. The results are presented in Table 5.10. From the table, we observe that forecast error variance in CPC is explained mostly by itself.

When we consider the table as a whole, it is clear that the explanation of forecast error variance in CPC by itself decreases from 93% to 66% while other independent variables' explanatory power on the forecast error variance of CPC increases. To exemplify, patents related environmental technologies are increased from 0.3% to 1%, environmental tax is increased from 1% to 4.8%, renewable energy is increased from 2% to 9%, urbanization increased from 2% to 15% and GDP per capita is increased from 0.1% to 3.3%, in their explanatory capacities over the forecast error variance of CPC. Meanwhile explanatory capacity for natural resources rent has decreased from 1.1% to 0.3%. In summary, except for natural resources rent, we can observe that the influence of the independent variables in our model on the variation in our dependent variable CPC generally increases over time towards future periods.

Table 5. 10. Variance decomposition results for developed countries.

Forecast-error variance decomposition

Response variable and Forecast horizon	Impulse variable ln_carbon_pc	d_ln_gdp_pc	d_ln_envtax	d_ln_nrr	d2_ln_urb	Impulse variable d_ln_patent	d_ln_rec
ln_carbon_pc							
0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0
2	.9320724	.0004011	.0108108	.0107847	.0221642	.0032483	.0205184
3	.8652312	.0016638	.0221349	.0119709	.0455575	.0050956	.048346
4	.8077009	.0074442	.0308756	.0099073	.0700165	.0068985	.067157
5	.761515	.0149496	.0363975	.0078661	.0926675	.0082077	.0783966
6	.7265558	.0213874	.0401824	.0064047	.1117992	.0090987	.084572
7	.7014403	.0260048	.0429505	.0054273	.1264373	.0097366	.0880032
8	.683778	.0291686	.0449609	.0047538	.1369984	.0102033	.090137
9	.6711441	.0313892	.0464209	.004263	.1445992	.0105465	.0916371
10	.6617487	.0330229	.0475125	.0038886	.150247	.0108044	.0927759

5.3. Analysis of Developing Countries in the EU

Before starting the analysis we estimate the summary statistics for developing countries in EU which is elaborated below Table 5.11.

Table 5. 11. Summary statistics for the developing countries in EU.

Variable	Observations	Mean	Standard Deviation	Min	Max
CPC	260	6.531852	2.679546	2.926895	14.74312
patent	260	157.8115	243.376	1	1379
envtax_pct	260	7.598418	2.314058	.6851241	11.75
nrr	260	.8622753	.8150986	.0375407	5.695609
rec	260	18.58362	9.079702	3.73	42.6
urb	260	63.91345	7.968418	50.754	79.388
lgdp_per_cap	260	13616.8	4879.934	3721.051	24125.39

Similar to the analysis for developed countries, the Peseran and Yamagata's heterogeneity test is conducted for our panel data for developing countries. Since we reject the null hypothesis like in the analysis of developed countries, we conclude that our data set is heterogeneous.[6]

After conducting Peseran's (2004) cross section dependency test we find that there is cross section dependency. Thus, we decided to use 2nd generation panel unit root test for our variables. Peserans' panel unit root test (2007) is utilized, and the stationarity of our variables is elaborated in Table 5.12 below.

Table 5. 12. Unit root test results for developing countries.

Unit root tests at level	H0: (homogeneous non-stationary)				
N,T = (13, 20)	CIPS Value	Stationarity at % 1 level	Critical values at %10	Critical values at %5	Critical values at %1
d_ln_carbon_per_cap	-4.609	Stationary	-2.14	-2.26	-2.47
d_ln_patent	-3.751	Stationary	-2.14	-2.26	-2.47
d_ln_envtax_pct	-4.058	Stationary	-2.14	-2.26	-2.47
ln_nrr	-2.509	Stationary	-2.14	-2.26	-2.47
ln_rec	-2.786	Stationary	-2.14	-2.26	-2.47
d2_ln_urb	-4.657	Stationary	-2.14	-2.26	-2.47
d_ln_gdp_per_cap	-2.759	Stationary	-2.14	-2.26	-2.47

Different from developed countries, here dependent variable carbon per capita (ln_carbon_per_cap) is stationary at its first difference I (1). Moreover, our independent variables patents related with environmental technologies (ln_patent), environmental tax (ln_envtax_pct) and GDP per capita (ln_gdp_percap), are

[6] Test results are elaborated in the appendix part in the developing countries section.

stationary at their first differences I (1) like in our analysis of developed countries. Likewise urbanization (ln_urb) variable became stationary at its second difference I (2) in both developed and developing country data sets. Different from the developed countries, independent variables, natural resources rent (ln_nrr) and renewable energy consumption (ln_rec) are stationary at their level I (0).

After ensuring the stationarity of the variables we look at the correlation between our variables with the correlation matrix and the results indicate that there is no serial correlation between our variables which is the same result we get for the developed countries' analysis. Moreover, as we do in the previous section, to determine whether our model is the random effect or fixed effect model, we utilize the Hausman test and conclude that we have random effects which is the same as in the developed countries case. Moreover, we conducted MLE random effects with a multiplicative heteroscedasticity test and we could not reject the null hypothesis. Likewise in the developed countries analysis, we also have a heteroscedasticity problem in the developing countries' model. However, even if we have heteroscedasticity and cross-section dependence problems, it will not cause inconsistency when we study with appropriate methods as mentioned before.

5.3.1. Estimation Results of PVAR Model for Developing Countries

We will determine the appropriate lag length for estimation of the Panel VAR model. Therefore, the suitable lag lengths again are determined by the MBIC, MAIC, and MQIC criteria. Using the GMM and the model selection criteria, we determine the appropriate lag lengths. to be one. The results are provided in Table 5.13 below.

Table 5. 13. Suitable lag length results for developing countries.

lag	CD	J	J p value	MBIC	MAIC	MQIC
1	0.9978767	115.8003	0.5913974	-499.7875	-124.1997	-276.6203
2	0.9987796	81.23144	0.2382616	-293.2512	-64.76856	-157.4911
3	0.9935743	50.50113	0.0199354	-113.6556	-13.49887	-54.14437

The results of the stability analysis reveal that our model is stable[7]. The results of the estimated model with system GMM and one lag length are elaborated in Table 5.14

[7] The eigenvalues associated with all the characteristic roots of our Panel VAR model are smaller than one. Stability test results could be seen at the appendix in developing countries' section

below. Thus, our model is stable and stationary and it is also appropriate for Panel VAR analysis.

Table 5. 14. PVAR model estimation results for developing countries.

GMM Estimation

Final GMM Criterion Q(b) = .68
Initial weight matrix: Identity
GMM weight matrix: Robust

No. of obs = 208
No. of panels = 13
Ave. no. of T = 16.000

	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
d_ln_carbonpc						
d_ln_carbonpc						
L1.	-.3396382	.0527942	-6.43	0.000	-.443113	-.2361634
d_ln_gdp_percap						
L1.	.5779447	.079095	7.31	0.000	.4229212	.7329681
d_ln_envtax_pct						
L1.	.2498127	.0281411	8.88	0.000	.1946572	.3049682
ln_nrr						
L1.	-.0010061	.0092237	-0.11	0.913	-.0190841	.0170719
d2_ln_urb						
L1.	28.25822	3.836679	7.37	0.000	20.73847	35.77797
d_ln_patent						
L1.	-.0154087	.0048332	-3.19	0.001	-.0248816	-.0059357
ln_rec						
L1.	-.0501126	.0105134	-4.77	0.000	-.0707185	-.0295068

As we see from the table above, patents related with environmental technologies, natural resources rent, and renewable energy consumption have a negative coefficient indicating a negative effect on the CPC. Contrarily, environmental tax, urbanization and GDP per capita have positive coefficients showing a positive impact on the CPC.

When we do the Granger causality test, we find bilateral causality between CPC and environmental tax, GDP per capita, patents related with environmental technologies and urbanization. On the other hand, natural resources rent is not a Granger cause of CPC but there is unilateral causality from CPC toward natural resources rent and renewable energy consumption is also a Granger cause of CPC but there is no causality from CPC to renewable energy consumption. Thus, there are unilateral causal relationship between these two independent and the dependent variables. The hypothesis and p values of the analysis are shown in the appendix part to save some space.

In impulse response analysis with developing countries in the EU, the effect of the one per cent standard deviation shock of our independent variables on our dependent variable CPC is revealed in Figure 5.3 below. Moreover, IRF confidence intervals are estimated via 200 Monte Carlo Simulations based on our estimated model.

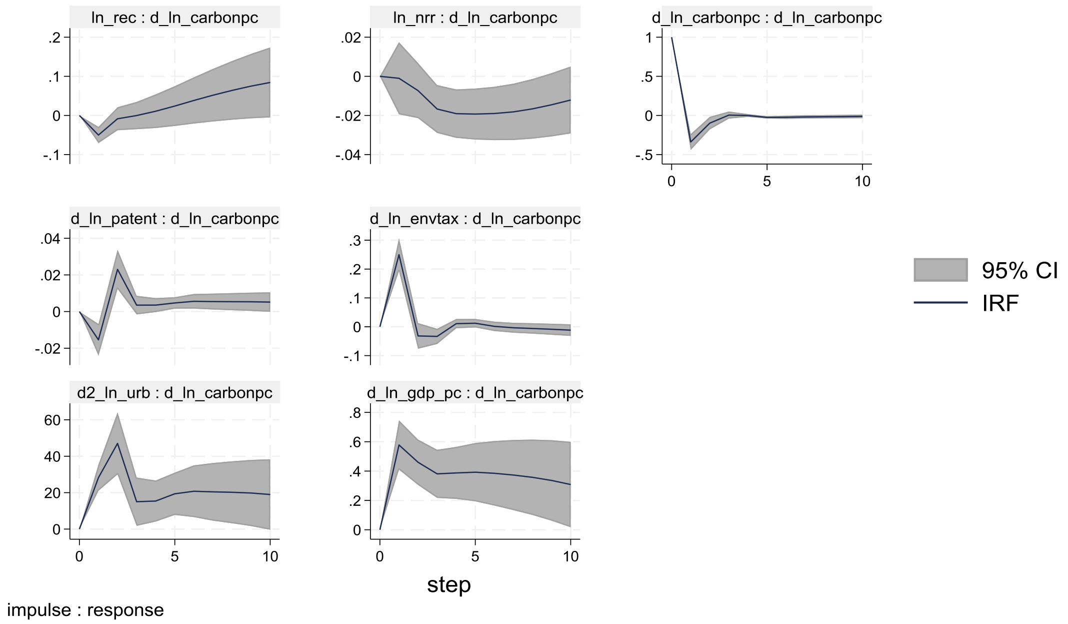

Figure 5. 3. Impulse- Response analysis graphs[8] for developing countries.

When we look at Figure 5.3 it can be observed that the effect of a one per cent standard deviation shock of CPC over itself leads to a drastic decrease so that it has even reversed the effect from positive to negative in the first period. Following the second and third periods the negative effect diminishes and from the fourth period onward it reaches its equilibrium and the effect of the shock fades away. Furthermore, the shock of patents related with environmental technologies on CPC has a decreasing negative effect in the first period. Following the second and third periods it has an increasing effect on CPC, even reversing negative impact to positive. Following the fourth period it starts to decrease and from the fifth period onward its effect perishes and reaches equilibrium. The shock of environmental tax on CPC firstly has increasing but then a decreasing effect on CPC. After this

[8] In Figure 5.3, "ln" stands for the natural logarithm and "d" stands for the first difference and "d2" stands for the second difference. carbon_pc: Carbon emissions, patent: Patents related with environmental technologies, envtax: Environmental Tax, nrr: Natural resources rent, rec: Renewable energy consumption, urb: Urbanization, gdp_percap: GDP per capita.

volatility, it reaches its equilibrium and diminishes its effect on CPC after the fourth period. Further, one standard deviation shock of natural resources rent on CPC has a decreasing effect in the initial period and following periods. After the fifth period that negative effect halts to decrease and preserves approximately its same negative level over the CPC in the following periods.

The shock taking place in renewable energy consumption has a decreasing effect over CPC in the first period but from the second period onwards that effect is reversed. It begins to increase CPC from the third period and consecutive periods. One standard deviation shock of urbanization over CPC has an increasing positive effect in the first three periods then at the fourth and fifth periods that effect decreases but remains positive. When we gaze upon the following periods, we can still see the steady positive continuing effect over the CPC. Lastly, the concussion occurring in the GDP per capita has an increasingly positive impact on CPC at the first two periods and in the third and fourth periods that effect diminishes slightly but remains positive. In the following periods, the effect remains positive and steady, but it begins to diminish towards the tenth period slightly preserving its positive impact.

Following the findings obtained from the impulse-response analysis, an analysis for variance decomposition was conducted for each variable individually to examine how much of the forecast error variance "p" periods ahead originates from itself and how much from other variables in the system. The results are presented in Table 5.15.

Table 5. 15. Variance decomposition results for developing countries.

Forecast-error variance decomposition

Response variable and Forecast horizon	Impulse variable d_ln_carbonpc	d_ln_gdp_pc	d_ln_envtax	ln_nrr	d2_ln_urb	d_ln_patent	ln_rec
d_ln_carbonpc							
0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0
2	.6692229	.0770863	.1758323	.0017138	.0659909	.0082612	.0018927
3	.5803909	.0928751	.1533686	.0019209	.1439123	.0258484	.0016839
4	.5632142	.1107959	.1463934	.005479	.1474491	.0250625	.0016059
5	.5445899	.1278026	.1411674	.0098395	.1508088	.0241945	.0015973
6	.5217279	.1433846	.13638	.0141153	.1590697	.0234858	.0018367
7	.4998548	.1567247	.1311631	.0179918	.1687541	.022982	.0025294
8	.4801416	.1681964	.1263881	.0213723	.1776792	.0224476	.0037748
9	.462293	.1777949	.1221637	.0240757	.1861349	.021926	.0056118
10	.4464233	.1854847	.1184381	.0260522	.1941199	.0214474	.0080343

After examining the responses to unexpected shocks, how big these responses stem from GDP per capita, environmental tax, natural resources rent, urbanization, patents related with environmental technologies and renewable energy consumption is searched. From Table 5.15 we observe that forecast error variance in CPC is explained by itself decreases from 67% to 44%. When we consider the table as a whole, it is clear that other independent variables' explanatory power on the forecast error variance of CPC increases over consecutive periods. To illustrate, the explanatory power of patents related with environmental technologies is increased from 1% to 2.1%, natural resources rent is increased from 0.2% to 2.6%, renewable energy is increased from 0.2% to 0.8%, likewise urbanization is increased from 6.6% to 19.4%, and GDP per capita is increased from 7,7% to 18,5%, in their explanatory capacities over the forecast error variance of CPC. Meanwhile, the capacity for environmental tax is decreased from 17.6% to 12%.

5.4. Conclusion for Analysis of Developed and Developing Countries in the EU

As expected, the characteristics of the data are identical for both developing and developed countries in terms of heterogeneity, cross-section dependency, heteroscedasticity, and random effects. However, they have different empirical results for future implications and policy recommendations.

The impulse response analyses yield different results for both groups. When we consider the shock of CPC over itself, it reaches its equilibrium in developing countries, but this is not the case for developed ones. Even if it loses its strength it preserves a positive increasing impact on itself. Moreover, patents related with environmental technologies which symbolize innovation in environmental technologies, have a decreasing impact in developed countries while in developing countries firstly it has a decreasing then increasing effect. Then, it loses its strength over the CPC in the long run. In addition, explaining the variation in CPC, it has a 1% role in developed countries whereas it has a 2% role in developing countries. Therefore it can be argued that even if it can not be a strong policy tool in general, it has a stronger impact on developing countries. Moreover, environmental tax has an increasing effect in developed countries both in the short and the long run. In addition, environmental tax has an initially increasing and then decreasing effect in developing countries. However, that effect comes to a halt in developing countries and loses its impact on CPC in the medium run. In contrast, in developed countries, it continues its positive impact on CPC in the medium and long run. This policy tool is not an effective instrument for both country groups especially for the developed ones. When we delve into variance decomposition analysis in developed countries it explains 4.7% of the total variation in CPC and in developing countries that explanatory power is nearly 12%. Further, in developed countries natural resources rent has initially a decreasing then increasing impact and in developing countries, it has a decreasing impact. For both groups, it has a slightly decreasing impact over CPC. Natural resources rent can be used effectively to decrease CPC considerably but it has a minor impact on the variation in CPC. It explains 0.4% and 2.6% of the total variation in CPC in developed countries and developing countries, respectively. Comparatively, it can be inferred that as a policy tool natural resources rent is more advantageous in developing countries. Moreover, interestingly renewable energy consumption has a decreasing role over the CPC in developed countries. However, it increases the CPC in developing countries when we analyze the future projections. For this reason, it is important to choose the right policy tools to combat the increase in carbon per capita emissions. However, when we consider the variance decomposition analysis of renewable energy consumption for developing and developed countries it weighs approximately %1 in explaining the variance in CPC. It is an important tool but to combat CPC effectively with scarce resources we need more effective tools. Moreover, urbanization has a positive impact on CPC in both developed and developing countries and it explains the 15% and 19.4% of the variation in CPC, respectively. Therefore, it is a significant determinant of CPC in both country groups. To control the increase in CPC, policies of urbanization should be considered and scrutinized seriously in the future. Lastly, GDP per capita has a decreasing effect in developed countries and it is responsible for 3.3% of the variation in CPC. The growth of countries with sustainable economic policies has a decreasing impact on CPC over time. Moreover, GDP per capita has a significant role over the CPC especially in developing countries. It explains 18.5% of the variation in CPC and it has an increasing effect on CPC. At the expense of the growth and development of developing countries, sustainable economic policies should not be neglected. Towards more sustainable development there should be used more policy tools which have a decreasing effect on CPC. In that way, they could compensate for the troublesome consequences of economic growth and development as in the case of developed countries in which GDP per capita has a decreasing impact on CPC.

CHAPTER 6

CONCLUSION

This thesis aimed to explore the determinants of pollution in the European Union (EU) within the framework of EKC theory, focusing on both developed and developing member states. The core objective is centered around understanding how various factors such as environmental technologies, environmental taxes, natural resources rent, renewable energy consumption, urbanization, and GDP per capita affect carbon emissions per capita (CPC). The study employed Panel Vector Autoregression (PVAR) to analyze data from EU countries between 2000 and 2019, for dependent variable CPC and the study also analyzes the data of developed and developing countries in the EU distinguished according to EU Cohesion Policy. Moreover, initially we conduct the analysis for the 25 EU countries and then we conduct an analysis for 12 developed countries and 13 developing countries in the EU separately with the same data set. In the conclusion part, in accordance with our impulse response and variance decomposition analysis, we will talk about suitable policy tools and policy recommendations for the EU, developed and developing countries in the EU. Moreover, the differences between the developed and developing countries in the EU within the context of EKC theory will be explained.

In the EU patents related with environmental technologies have a decreasing impact on CPC. However, this decreasing impact is effective only in the short run for CPC its impact diminishes in the long run. Thus, it is effective for decreasing pollution levels in the short run. This effectiveness is also supported by the study of Bigerna et al. (2023), thanks to environmental technologies, the production of goods needs fewer resources as a result it contributes the environmental sustainability by decreasing carbon emissions. Our analysis contributes to that result by also revealing that environmental technologies are effective tools to decrease pollution levels in the short run. Patents demonstrated varying impacts across developed and developing

EU countries. In developed nations, they effectively reduced CPC, whereas, in developing countries, their impact was initially increasing but later it began to decrease and in the long run turned to neutral. Moreover, while patents in environmental technologies were seen as crucial in developed countries, their effectiveness in developing countries was less pronounced. The effectiveness of patents on environmental technologies in developed countries could be supported by Mensah et al. (2019), and Bigerna et al. (2023). However, contrary to Ahmad et al. (2020) and Jahanger et al. (2022), claiming that there is a decreasing effect of environmental patents, we found in our analysis that in the short run, patents related with environmental technologies have an increasing effect on the EU developing countries. The result of our analysis could be supported by the study of Cheng et al. (2019) which claims that high utilization fees of patents inhibit the scattering of the environmental technologies. In addition to that, the study of Usman and Hammar (2021) says that since investors are protective of sharing their innovative ideas, technological developments depend on previously established technologies. Therefore, it fosters the traditional production techniques which results in more carbon emissions and an increase in pollution levels. Our analysis contributes to these studies by revealing these repercussions are valid in the short run. Moreover, in our analysis, we see a decreasing effect in the medium run, and in the long run, the impact becomes neutralized. As a policy recommendation, in order to combat carbon emissions and pollution levels effectively barriers regarding the diffusion of environmental technologies should be alleviated in the EU.

In our analysis, environmental taxes have an initially increasing effect on CPC in the short run. Then it begins to decrease and it neutralizes in the long run. Those results are also valid for developing countries in the EU. However, in developed countries environmental taxes have an increasing effect on CPC both in the short and the long run. Our result of the increasing effect of environmental taxes on CPC could be supported by the arguments of Fredriksson (2001) which says that since taxes are decided by governments, the decisions regarding taxation policy could be influenced by industry and environmental interest groups, which could lead to undesired policies increasing both pollution levels and CPC. Moreover, Rakpho et al. (2023) state that if the tax rate is above the optimal level firms lose their motivation to invest in emission-reducing technologies and they continue to pollute the environment. Our analysis contributes to the literature by revealing the short-run and long-run analysis. Moreover, in order to have an effective solution for reducing CPC, in accordance with Xu et al. (2023), channelization of revenues generated from environmental taxes into research and development studies of green technologies, and construction of environmental protection infrastructures is recommended for the policymakers in the EU including developed and developing countries of the union. Moreover, with studies showing various impacts on emissions, the effectiveness of environmental taxes also largely contingent on the optimal taxation strategy and the political-economic context.

Natural resources rent has a decreasing impact in the short run and it loses its effect on CPC in the long run in the EU. In accordance with and Balsalobre-Lorente et al. (2018) and Zafar et al. (2019), we find that natural resources rent has a decreasing effect on CPC in our analysis. Moreover, the exploitation of natural resources had mixed effects on emissions, with the impact varying based on economic, social, and environmental governance structures. Our analysis reveals that both in the short run and the long run, natural resources rent has a minor yet slightly decreasing impact on CPC in both developed and developing countries in the EU, hinting at its potential as a policy tool when managed sustainably. Moreover, specifically, it is more effective for developed countries in the short run according to our analysis. Our analysis regarding the developed countries in the EU could be supported by the study of Tufail et al. (2021) which states that developed countries with high fiscal decentralization have higher accountability as a result, proper use of natural resources rent decreases carbon emissions. Moreover, Danish et al. (2019) say that in emerging market economies with abundant natural resources, natural resources rent also has a decreasing effect on carbon emissions due to less dependency on the import of fossil fuels. Furthermore, according to Zafar et al. (2019), giving education to people to increase their environmental awareness is also effective for the prevention of unsustainable use of natural resources which also results in a reduction in emissions and pollution levels. Both for developed and developing countries, fiscal decentralization and educated citizens make natural resources rent as an effective policy tool for policymakers in the combat for CPC and pollution levels.

The results of our analysis of developed countries and developing countries also support those policy recommendations.

In the EU, renewable energy consumption has a positive impact on CPC in the long run. For developed and developing countries, renewable energy consumption showed divergent effects; it reduced CPC in developed countries but, intriguingly, increased CPC in developing nations, indicating the need for tailored policy approaches in promoting renewable energy. The increasing effect on CPC in our analysis could be supported by the studies of Kaygusuz (2009) and Owusu and Asumadu-Sarkodie (2016). According to the former, materials used in the production of equipment of renewable energy have serious implications on carbon emissions and natural habitat pollution. Moreover, the latter also acknowledges the mentioned arguments and adds to them by stating the dependence of renewable energy production on climate conditions which creates discontinuities in the production and increases consumption of other energy resources. As a result, emission levels increase. Moreover, in our analysis, the decreasing effect of renewable energy consumption in developed countries could be the effects of technology on renewable energy structure as Doğan et al. (2020) mentioned in their study. Moreover, according to Soukiazis et al (2019), the decreasing effect of renewable energy occurs mainly through the development of human capital since escalated skills of human capital play a pivotal role in the advancement of renewable energy technologies. In short, the shift towards renewable energy is identified as a key driver in reducing carbon emissions, though its effectiveness varied across sectors and regions. Studies suggested that while renewable energy consumption had a significant potential to mitigate emissions, its impact in real-world scenarios was often limited by existing energy structures, technology level, and quality of human capital. Our study contributes to literature by revealing the limitations and differences between developed and developing countries in the EU. As a policy recommendation investing in human capital and merging high-level technologies to the structure of renewable energy consumption could make it an effective policy tool in the future.

Urbanization has an increasing effect on CPC in the short run and in the long run, its effect diminishes. Moreover, Urbanization positively influenced CPC in both developed and developing countries in the short run and the long run, indicating its significant role in shaping carbon emissions. Studies by Mensah et al. (2019), Anwar et al. (2020), Musah et al. (2021), and Huang et al. (2023) support the findings in our analysis. The expansion of urban areas creates more carbon emissions and increases the pollution level. Migration of people to urban areas for better life standards, construction of infrastructures, public transportation, and demand-driven goods and services production by industries are some of the main reasons behind the increasing impact of urbanization on CPC and pollution levels. According to Wu et al (2016), the geographical scattering of population and economic activities across the cities is important in solving the mentioned side effects of urbanization. In accordance with the study by Fan et al (2023), the construction of smart cities is also offered as a policy recommendation for curbing emissions and pollution levels. Moreover, in regions with low carbon efficiency, making efficiency-increasing investments could also be an effective policy tool in decreasing CPC and pollution levels. In short, urbanization was generally associated with increased emissions due to higher energy consumption, infrastructure development, and lifestyle changes. Therefore, planning of urbanization and the construction of smart cities are the optimal policy recommendations for it. Moreover, the migration of people and transfer of production facilities should be planned in accordance with the carbon efficiency of the cities. If the flow occurs from cities with high carbon efficiency to cities with low carbon efficiency, it increases emissions and pollution levels.

In the EU, GDP per capita has an increasing effect on CPC in the short run. However, in the long run, that effect begins to decrease end becomes neutral. That result is a strong evidence for the validation of EKC theory. Moreover, GDP per capita had a decreasing effect on CPC in developed countries, reflecting a transition towards more sustainable growth models. On the other hand, in developing countries, GDP growth increased CPC, underlining the challenges of balancing economic development with environmental sustainability. The relationship between GDP per capita and emissions was complex. While economic growth initially led to higher emissions, the trend could reverse in more advanced stages of economic development which is in accordance with the EKC hypothesis. According to Cheng et al. (2019), in the process from developing countries to developed countries, economic expansion increases emissions in the initial phase, and then in the phase of post-industrial development emissions tend to decline. Moreover, according to Ulucak et al. (2020) increasing income enhances countries' capacity to invest in clean technologies and throughout that phase, information technologies raise the awareness regarding environmental degradation. Rakpho et al. (2023) and Soukiazis et al. (2019) also support these notions. Furthermore, we have also revealed the development process of the effect of GDP per capita on CPC in our developed and developing countries' analysis. In fact, our analysis, by verifying that GDP per capita has an increasing effect on CPC in developing countries and a decreasing effect on CPC in developed countries, confirms the development process that is mentioned in the EKC literature. In order to be an effective policy tool, an increase in the GDP per capita should be combined with advancements in environmental technologies with investments which have an improving effect on human capital.

Considering all of the analysis and our literature review, rather than offering a single policy set to the EU, different policies for developed and developing countries should be adopted in their combat with the CPC and pollution levels due to their intrinsic economic and structural differences. In accordance with our variance decomposition analysis, we offer developed countries that they should give priority to urbanization and renewable energy consumption policies combined with the application of environmental technological advancements. Moreover, for developing countries, the priority should be their urbanization policy and optimal environmental taxation system together with environmental technologies.

In our empirical findings chapter, results reveals significant evidences to validate the Environmental Kuznets Curve (EKC) theory, which proposes a relationship between environmental quality and economic development. According to the EKC theory, as GDP increases, emissions and pollution initially increase, but after reaching a certain level of GDP per capita, the trend reverses, leading to decrease in emissions and in general pollution levels. Our study assesses the validity of the EKC hypothesis in the context of the EU, taking into account the differences between developed and developing member states. Our findings indicate that in developed countries, higher GDP per capita is associated with a reduction in CPC, consistent with the EKC's post-industrial phase with technique effect. Conversely, in developing EU countries, the initial economic growth stage aligns with increased emissions, suggesting they are in the preindustrial and industrial phase of the EKC with scale effect. This differentiation indicates the importance of considering the stage of economic development when implementing environmental policies within the EU.

This study also contributes to the understanding of how various factors influence carbon emissions per capita and pollution levels in the EU. By analyzing both developed and developing countries separately, it offers beneficial insights into region-specific challenges and policy needs. The use of the PVAR model in this context is also a methodological contribution, adding depth to the existing literature on environmental economics and policy. The findings underscore the importance of tailored policy approaches and highlight the need for continued research and collaborative efforts in addressing environmental challenges at both national and EU levels.

Moreover, the methodological contribution of our study, particularly the choice of a Panel Vector Autoregression (PVAR) model with random effects for Carbon Per Capita (CPC), plays a crucial role in the depth and accuracy of our findings. This approach is particularly significant given the diverse environmental and economic contexts of EU countries. By accommodating unobserved heterogeneity and cross-sectional dependencies, the model effectively captures the impacts of various independent variables, as evidenced in the empirical results. The impulse response analysis further improves our understanding, revealing that while certain policy measures may yield immediate effects on carbon emissions, their long-term efficacy can vary significantly. This insight aligns with and extends the literature's discussion on the sustained effectiveness of environmental policies. These findings emphasize the importance of continuous monitoring and adaptive policy frameworks that can respond to evolving environmental challenges. Such an adaptive and forward-looking perspective is essential for developing robust strategies that not only address current environmental concerns but are also resilient to future changes. This study, therefore, not only contributes to the current understanding of environmental policy impacts within the EU but also sets a foundation for future research and policy development that can dynamically adapt to changing environmental and economic conditions.

Furthermore, our study emphasizes the divergent approaches required for developed and developing member states. In developed EU countries, policies are increasingly geared towards innovation in green technology and enforcing stringent environmental standards, reflects their postindustrial stage with technique effect in the EKC. This includes initiatives like the European Green Deal, aiming for climate neutrality by 2050. For developing member states, the EU's focus is on balancing economic development with environmental sustainability, offering support for the transition to renewable energy sources and implementing gradual environmental regulations. These differentiated approaches align with the EKC theory, acknowledging the different stages of economic development and corresponding environmental impacts. The EU's policy framework demonstrates understanding of the varying needs of its member countries, aiming to collectively reduce emissions while supporting individual economic development trajectories.

In the broader context of global environmental initiatives, this study's findings resonate significantly with the objectives of the Paris Agreement and the Sustainable Development Goals (SDGs). The Paris Agreement's emphasis on individualized national commitments to reduce greenhouse gas emissions aligns with our study's recommendation for tailored environmental policies in EU member states. Specifically, our analysis underlines the need for differentiated strategies in developed and developing countries, echoing the Agreement's principle of 'common but differentiated responsibilities.' Furthermore, the study's focus on sustainable economic development, technological innovation, and effective urbanization policies directly contributes to several SDGs, including SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). The empirical results and the literature review suggest that achieving these goals requires a multifaceted approach. Our analysis highlights the importance of considering both short-term impacts and long-term sustainability, as evidenced in the varied effects of policies like environmental taxes and renewable energy consumption. This aligns with the SDGs' vision of sustainable development that balances economic growth with environmental stewardship. Furthermore, the study's emphasis on the effective utilization of natural resources and the promotion of innovative environmental technologies supports SDG 9 (Industry, Innovation, and Infrastructure), reinforcing the need for a comprehensive understanding of environmental issues. The findings also suggest that future policies should be dynamic, adapting to evolving economic structures and technological advancements to remain effective. This study, therefore, not only contributes to academic literature but also offers practical insights for policymakers striving to align national and regional policies with global environmental commitments.

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APPENDICES

A. ANALYSIS OF THE EU COUNTRIES BETWEEN 2000 AND 2019

Table A.1 Heterogeneity test results for EU countries.

(Pesaran, Yamagata. 2008. Journal of Econometrics) H0: slope coefficients are homogenous		
	Delta	p-value
	13.031	0.000
Adj	16.822	0.000

Table A.2 Correlation matrix of the model variables.

	d_ln_cpc	d_ln_g~c	d_ln_e~x	d_ln_nrr	d2_ln_~b	d_ln_p~t	ln_rec
d_ln_cpc	1.0000						
d_ln_gdp_pc	0.3859	1.0000					
d_ln_envtax	-0.0756	-0.2491	1.0000				
d_ln_nrr	0.1380	0.1264	-0.0355	1.0000			
d2_ln_urb	0.0065	0.0659	-0.0191	-0.0556	1.0000		
d_ln_patent	-0.0574	-0.0865	0.0051	-0.0013	-0.0934	1.0000	
ln_rec	-0.0594	0.0240	-0.0047	-0.0391	0.1077	-0.0068	1.0000

Table A.3 Hausman test results for EU countries.

	Coefficients (b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) Std. err.
d_ln_gdp_pc	.62043	.6293711	-.0089411	.0411329
d_ln_envtax	.0105586	.0228688	-.0123102	.0162677
d_ln_nrr	.0132917	.0144426	-.001151	.0013018
d2_ln_urb	-1.63786	-.7306748	-.9071848	1.016765
d_ln_patent	-.0047918	-.0037637	-.0010282	.0012962
ln_rec	-.0223508	-.0052143	-.0171366	.0068377

b = Consistent under H0 and Ha; obtained from **xtreg**.
B = Inconsistent under Ha, efficient under H0; obtained from **xtreg**.

Test of H0: Difference in coefficients not systematic

chi2(6) = (b-B)'[(V_b-V_B)^(-1)](b-B)
= 7.33
Prob > chi2 = 0.2916

Table A.4 Heterosedasticity test for EU countries.

```
==============================================================================
* MLE Random-Effects Panel Data Regression (Normal Distribution)
* Multiplicative Heteroscedasticity
==============================================================================
  d_ln_cpc = d_ln_gdp_pc + d_ln_envtax + d_ln_nrr + d2_ln_urb + d_ln_patent + ln_rec
------------------------------------------------------------------------------
  Sample Size       =         450   |   Cross Sections Number   =          25
  Wald Test         =     82.6933   |   P-Value > Chi2(6)       =      0.0000
  F-Test            =     13.7822   |   P-Value > F(6 , 419)    =      0.0000
 (Buse 1973) R2     =      0.1573   |   Raw Moments R2          =      0.1979
 (Buse 1973) R2 Adj =      0.0970   |   Raw Moments R2 Adj      =      0.1405
  Root MSE (Sigma)  =      0.0579   |   Log Likelihood Function =    719.6362
------------------------------------------------------------------------------
- R2h= 0.1598   R2h Adj= 0.0996  F-Test =   14.04 P-Value > F(6 , 419) 0.0000
- R2v= 0.1250   R2v Adj= 0.0624  F-Test =   10.55 P-Value > F(6 , 419) 0.0000
------------------------------------------------------------------------------
    d_ln_cpc | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
d_ln_cpc     |
 d_ln_gdp_pc |    .5431907   .0635237     8.55   0.000     .4186864    .6676949
 d_ln_envtax |    .0072756   .0405476     0.18   0.858    -.0721962    .0867473
    d_ln_nrr |     .016079   .0052493     3.06   0.002     .0057906    .0263674
   d2_ln_urb |   -.7436178   3.029692    -0.25   0.806    -6.681705    5.194469
 d_ln_patent |    .0018747   .0056704     0.33   0.741    -.0092392    .0129885
      ln_rec |   -.0035356   .0030933    -1.14   0.253    -.0095984    .0025273
       _cons |   -.0162496   .0077937    -2.08   0.037     -.031525   -.0009741
-------------+----------------------------------------------------------------
Hetero       |
 d_ln_gdp_pc |    6.628451   3.230798     2.05   0.040     .2962029     12.9607
 d_ln_envtax |    .9517605    .629402     1.51   0.130    -.2818447    2.185366
    d_ln_nrr |    .1722832   .0917375     1.88   0.060    -.0075191    .3520854
   d2_ln_urb |    -691.955   220.3552    -3.14   0.002    -1123.843   -260.0666
 d_ln_patent |     .139468   .0743953     1.87   0.061    -.0063442    .2852801
      ln_rec |     .563225   .0750219     7.51   0.000     .4161847    .7102652
-------------+----------------------------------------------------------------
       /Sigu |    2.70e-09   .0007795     0.00   1.000    -.0015277    .0015277
       /Sige |   -.0086776   .0021761    -3.99   0.000    -.0129428   -.0044125
------------------------------------------------------------------------------

==============================================================================
* Panel Model Selection Diagnostic Criteria - Model= (xtmlh)
==============================================================================
- Log Likelihood Function                   LLF            =    719.6362
---------------------------------------------------------------------------
- Akaike Information Criterion              (1974) AIC     =      0.0033
- Akaike Information Criterion              (1973) Log AIC =     -5.7062
---------------------------------------------------------------------------
- Schwarz Criterion                         (1978) SC      =      0.0038
- Schwarz Criterion                         (1978) Log SC  =     -5.5713
---------------------------------------------------------------------------
- Amemiya Prediction Criterion              (1969) FPE     =      0.0035
- Hannan-Quinn Criterion                    (1979) HQ      =      0.0035
- Rice Criterion                            (1984) Rice    =      0.0033
- Shibata Criterion                         (1981) Shibata =      0.0033
- Craven-Wahba Generalized Cross Validation (1979) GCV     =      0.0033
------------------------------------------------------------------------------

==============================================================================
* Panel Groupwise Heteroscedasticity Tests
==============================================================================
  Ho: Panel Homoscedasticity - Ha: Panel Groupwise Heteroscedasticity

- Lagrange Multiplier LM Test     = 5.41e+04     P-Value > Chi2(24)  0.0000
- Likelihood Ratio LR Test        = -78.2328     P-Value > Chi2(24)  0.0000
- Wald Test                       = 7.63e+04     P-Value > Chi2(25)  0.0000
------------------------------------------------------------------------------
```

Table A.5 Crosssection dependency test for EU countries.

Correlation matrix of residuals:

	__e1	__e2	__e3	__e4	__e5	__e6	__e7	__e8	__e9	__e10
__e1	.0292741									
__e2	.0194819	.0345612								
__e3	.0073672	-.0057396	.0799635							
__e4	.0082305	-.0023031	.0142577	.017928						
__e5	.0017683	.0034567	.0042165	.0039413	.0088105					
__e6	.0125636	.0194941	-.0148222	.0095904	.0120493	.0953438				
__e7	.0225237	.0200345	.0398105	.0082468	.0343903	.0603278	.4151506			
__e8	.0188576	.022825	-.0097077	.0090357	.0213912	.1094559	.0927906	.1725217		
__e9	.0129848	.014111	-.0077861	.0038721	.0034431	.0080637	.0133549	.0041978	.0146501	
__e10	.0092884	.015341	-.0083079	-.0017759	.0049337	.0197857	.0361105	.0215445	.0101636	.0155895
__e11	-.0054972	-.0071594	.0163292	.0050724	.004094	-.0077592	.0168405	-.0193421	.0016594	-.0009389
__e12	.011001	.0101382	.0280658	.0110464	.0058911	.0053371	.026641	.0051352	.0060286	.0028595
__e13	.0039366	.0133802	-.0172664	-.0084379	-.0013029	.0077681	.0248209	-.0019714	.0068269	.010614
__e14	.0143322	.0089266	.0126506	.0065819	.0018275	.0031122	.0025823	.0068982	.0072523	.0031255
__e15	.0126473	.0230935	.0029461	-.0053492	.0060032	.0257177	.0620763	.0558328	.0013096	.0084553
__e16	.0070685	.0134419	-.0119663	-.006175	.0009439	-.0013871	.0046672	.0048457	.0075167	.0053038
__e17	.0182341	.0038265	-.0084008	-.0047395	-.0030583	-.0100342	-.0118107	-.0006051	.0062621	-.0007721
__e18	.0152256	.0188251	-.0059529	.0036224	.0063406	.0108779	.0303335	.0212604	.0112491	.0125917
__e19	.0110194	.0111348	.0057114	.0043253	.0059654	.0186291	.035464	.0233331	.0087213	.0090638
__e20	-.0034164	-.0118315	.0033201	.0082894	.001109	-.0276696	-.0050429	-.0545476	.0061208	.0011048
__e21	.0065967	-.0005362	.0415309	.0059144	.0015055	.0010645	-.0062381	.0027537	-.0008877	-.0022389
__e22	.0143276	.0145388	-.002557	.0045793	.0046835	.0131377	.0376678	.0083827	.0120417	.0094557
__e23	.0096607	.0100993	-.0086639	.0000559	.00049	.0114247	.0239301	.004151	.012075	.0097538
__e24	.0031866	-.0107566	.030204	.009912	.003463	-.0246379	.0084834	-.026694	.0018888	-.0043907
__e25	.0190733	.0157483	.0000902	.0046712	.0038301	.0162057	.0228521	.0348523	.0071715	.0097138

	__e11	__e12	__e13	__e14	__e15	__e16	__e17	__e18	__e19	__e20
__e11	.0171034									
__e12	.008381	.0289347								
__e13	-.0005992	-.0047006	.0291229							
__e14	.0031564	.0097995	.0019005	.0174588						
__e15	-.0113063	.0061385	-.0008379	.0047592	.0564639					
__e16	-.0040532	.0017889	.006761	.0076047	.0221002	.0271753				
__e17	-.0061483	-.00256	-.0028565	.0130208	.0104229	.0161587	.0464312			
__e18	-.0031783	.0059881	.0062471	.0090693	.0157668	.0112561	.0052699	.0212675		
__e19	.0014773	.0109945	.0035074	.006793	.0093346	.0064038	.0021131	.00795	.0116291	
__e20	.0158586	.0138708	-.0098024	.0012041	-.0296618	-.0025768	.0028907	.0023534	-.000266	.0649864
__e21	.0119124	.0174446	-.0044382	.0140937	-.0001902	-.003229	.0009299	-.0058075	.0069829	-.0052912
__e22	.0006945	.0148645	.0016487	.0026087	.0091099	.0069438	.0051638	.008158	.0117078	.0110217
__e23	.0028666	.0062207	.0116136	.0084152	.0027917	.0085217	.0063486	.0062068	.0091524	.0021328
__e24	.0152453	.0148463	-.010097	.0140412	-.0154814	-.0002408	.0109437	-.0003857	.003457	.0310574
__e25	-.0069169	.0077583	.0035531	.0091887	.0200444	.0068321	.0092608	.0177476	.007163	-.0078233

	__e21	__e22	__e23	__e24	__e25
__e21	.0384023				
__e22	-.0001979	.0236053			
__e23	.0050046	.0119128	.0219992		
__e24	.0183215	.0007424	-.0009355	.0412305	
__e25	.000782	.0059988	.0048675	-.0040013	.0244462

	__e1	__e2	__e3	__e4	__e5	__e6	__e7	__e8	__e9	__e10	__e11	__e12	__e13	__e14
__e1	1.0000													
__e2	0.6125	1.0000												
__e3	0.1523	-0.1092	1.0000											
__e4	0.3593	-0.0925	0.3766	1.0000										
__e5	0.1101	0.1981	0.1589	0.3136	1.0000									
__e6	0.2378	0.3396	-0.1698	0.2320	0.4157	1.0000								
__e7	0.2043	0.1673	0.2185	0.0956	0.5686	0.3032	1.0000							
__e8	0.2654	0.2956	-0.0827	0.1625	0.5487	0.8534	0.3467	1.0000						
__e9	0.6270	0.6271	-0.2275	0.2389	0.3031	0.2158	0.1712	0.0835	1.0000					
__e10	0.4348	0.6609	-0.2353	-0.1062	0.4210	0.5132	0.4489	0.4154	0.6725	1.0000				
__e11	-0.2457	-0.2945	0.4415	0.2897	0.3335	-0.1921	0.1999	-0.3561	0.1048	-0.0575	1.0000			
__e12	0.3780	0.3206	0.5835	0.4850	0.3690	0.1016	0.2431	0.0727	0.2928	0.1346	0.3767	1.0000		
__e13	0.1348	0.4217	-0.3578	-0.3693	-0.0813	0.1474	0.2257	-0.0278	0.3305	0.4981	-0.0268	-0.1619	1.0000	
__e14	0.6340	0.3634	0.3386	0.3720	0.1474	0.0763	0.0303	0.1257	0.4535	0.1895	0.1827	0.4360	0.0843	1.0000
__e15	0.3111	0.5228	0.0438	-0.1681	0.2692	0.3505	0.4055	0.5657	0.0455	0.2850	-0.3638	0.1519	-0.0207	0.1516
__e16	0.2506	0.4386	-0.2567	-0.2798	0.0610	-0.0273	0.0439	0.0708	0.3767	0.2577	-0.1880	0.0638	0.2403	0.3491
__e17	0.4946	0.0955	-0.1379	-0.1643	-0.1512	-0.1508	-0.0851	-0.0068	0.2401	-0.0287	-0.2182	-0.0698	-0.0777	0.4573
__e18	0.6102	0.6944	-0.1444	0.1855	0.4632	0.2416	0.3228	0.3510	0.6373	0.6915	-0.1666	0.2414	0.2510	0.4707
__e19	0.5972	0.5554	0.1873	0.2996	0.5893	0.5595	0.5104	0.5209	0.6682	0.6732	0.1048	0.5994	0.1906	0.4767
__e20	-0.0783	-0.2497	0.0461	0.2429	0.0463	-0.3515	-0.0307	-0.5152	0.1984	0.0347	0.4757	0.3199	-0.2253	0.0357
__e21	0.1967	-0.0147	0.7495	0.2254	0.0818	0.0176	-0.0494	0.0338	-0.0374	-0.0915	0.4648	0.5233	-0.1327	0.5443
__e22	0.5450	0.5090	-0.0589	0.2226	0.3248	0.2769	0.3805	0.1314	0.6475	0.4929	0.0346	0.5688	0.0629	0.1285
__e23	0.3807	0.3663	-0.2066	0.0028	0.0352	0.2495	0.2504	0.0674	0.6726	0.5267	0.1478	0.2466	0.4588	0.4294
__e24	0.0917	-0.2850	0.5260	0.3646	0.1817	-0.3930	0.0648	-0.3165	0.0769	-0.1732	0.5741	0.4298	-0.2914	0.5233
__e25	0.7130	0.5418	0.0020	0.2231	0.2610	0.3357	0.2268	0.5367	0.3790	0.4976	-0.3383	0.2917	0.1332	0.4448

	__e15	__e16	__e17	__e18	__e19	__e20	__e21	__e22	__e23	__e24	__e25
__e15	1.0000										
__e16	0.5642	1.0000									
__e17	0.2036	0.4549	1.0000								
__e18	0.4550	0.4682	0.1677	1.0000							
__e19	0.3643	0.3602	0.0909	0.5055	1.0000						
__e20	-0.4897	-0.0613	0.0526	0.0633	-0.0097	1.0000					
__e21	-0.0041	-0.1000	0.0220	-0.2032	0.3304	-0.1059	1.0000				
__e22	0.2495	0.2742	0.1560	0.3641	0.7066	0.2814	-0.0066	1.0000			
__e23	0.0792	0.3485	0.1986	0.2870	0.5722	0.0564	0.1722	0.5228	1.0000		
__e24	-0.3209	-0.0072	0.2501	-0.0130	0.1579	0.6000	0.4604	0.0238	-0.0311	1.0000	
__e25	0.5395	0.2651	0.2749	0.7784	0.4248	-0.1963	0.0255	0.2497	0.2099	-0.1260	1.0000

Breusch-Pagan LM test of independence: chi2(300) = 635.340, Pr = 0.0000
Based on 18 complete observations over panel units

```
Bias-adjusted LM test of error cross-section independence

H0: Cov(uit,ujt) = 0 for all t and i!=j
```

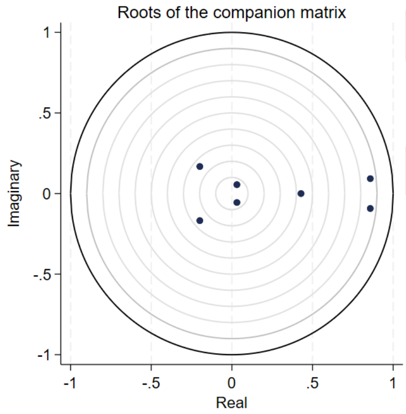
Test	Statistic	p-value
LM	435.5	0.0000
LM adj*	4.332	0.0000
LM CD*	7.92	0.0000

*two-sided test

Pr< 0.05, we fail to accept the null hypothesis and conclude that panels are correlated (cross-sectional dependence)

Table A.6 Stability analysis for EU countries.

Position of Characteristic Roots of EU Countries in Unit Circle	**Panel VAR Stability Analysis and Eigenvalue Results for EU Countries**



Eigenvalue stability condition

Eigenvalue Real	Eigenvalue Imaginary	Modulus
.8581811	-.0925453	.8631566
.8581811	.0925453	.8631566
.4285951	0	.4285951
-.1988241	.1678858	.2602242
-.1988241	-.1678858	.2602242
.0311003	.0553173	.0634605
.0311003	-.0553173	.0634605

All the eigenvalues lie inside the unit circle.
pVAR satisfies stability condition.

Table A.7 Granger causality test for EU countries.

```
panel VAR-Granger causality Wald test
  Ho: Excluded variable does not Granger-cause Equation variable
  Ha: Excluded variable Granger-causes Equation variable
```

Equation \ Excluded	chi2	df	Prob > chi2
d_ln_cpc			
d_ln_gdp_pc	84.563	1	0.000
d_ln_envtax	15.050	1	0.000
d_ln_nrr	14.698	1	0.000
d2_ln_urb	16.255	1	0.000
d_ln_patent	37.457	1	0.000
ln_rec	19.610	1	0.000
ALL	191.776	6	0.000
d_ln_gdp_pc			
d_ln_cpc	0.067	1	0.795
d_ln_envtax	66.633	1	0.000
d_ln_nrr	18.350	1	0.000
d2_ln_urb	8.206	1	0.004
d_ln_patent	0.791	1	0.374
ln_rec	2.183	1	0.140
ALL	119.409	6	0.000
d_ln_envtax			
d_ln_cpc	1.859	1	0.173
d_ln_gdp_pc	38.755	1	0.000
d_ln_nrr	1.671	1	0.196
d2_ln_urb	37.925	1	0.000
d_ln_patent	4.354	1	0.037
ln_rec	0.181	1	0.671
ALL	101.492	6	0.000
d_ln_nrr			
d_ln_cpc	53.840	1	0.000
d_ln_gdp_pc	1.269	1	0.260
d_ln_envtax	37.975	1	0.000
d2_ln_urb	54.634	1	0.000
d_ln_patent	1.987	1	0.159
ln_rec	15.233	1	0.000
ALL	179.407	6	0.000
d2_ln_urb			
d_ln_cpc	32.606	1	0.000
d_ln_gdp_pc	36.550	1	0.000
d_ln_envtax	29.987	1	0.000
d_ln_nrr	5.867	1	0.015
d_ln_patent	11.583	1	0.001
ln_rec	21.302	1	0.000
ALL	72.607	6	0.000
d_ln_patent			
d_ln_cpc	9.114	1	0.003
d_ln_gdp_pc	30.986	1	0.000
d_ln_envtax	25.820	1	0.000
d_ln_nrr	11.854	1	0.001
d2_ln_urb	54.643	1	0.000
ln_rec	16.220	1	0.000
ALL	143.536	6	0.000
ln_rec			
d_ln_cpc	18.531	1	0.000
d_ln_gdp_pc	2.988	1	0.084
d_ln_envtax	0.285	1	0.594
d_ln_nrr	0.598	1	0.439
d2_ln_urb	63.250	1	0.000
d_ln_patent	1.878	1	0.171
ALL	114.392	6	0.000

B. ANALYSIS OF DEVELOPED COUNTRIES IN THE EU BETWEEN 2000 AND 2019

Table B.1: Heterogeneity test results for developed countries in the EU.

(Pesaran, Yamagata. 2008. Journal of Econometrics) H0: slope coefficients are homogenous		
	Delta	p-value
	8,957	0,000
Adj	11,563	0,000

Table B.2 Correlation matrix of the model variables.

	ln_car~p	D. ln_gdp~p	D. ln_env~t	D. ln_nrr	D2. ln_urb	D. ln_pat~t	D. ln_rec
ln_carbon_~p	1.0000						
ln_gdp_per~p D1.	0.0271	1.0000					
ln_envtax_~t D1.	-0.0659	-0.1610	1.0000				
ln_nrr D1.	0.0585	0.1892	-0.0702	1.0000			
ln_urb D2.	-0.1339	-0.0094	0.0722	0.0137	1.0000		
ln_patent D1.	0.0804	-0.0901	-0.0190	-0.0750	-0.0027	1.0000	
ln_rec D1.	0.1400	-0.0055	-0.0949	-0.0052	0.0778	0.0711	1.0000

Table B.3 Hausman test results for developed countries in the EU.

	Coefficients (b) fixed	Coefficients (B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) Std. err.
d_ln_gdp_pc	.1966081	.1976924	-.0010843	.0294559
d_ln_envtax	.4714219	.4643001	.0071219	.0180892
d_ln_nrr	.0821791	.0819792	.0001998	.0018287
d2_ln_urb	7.898152	7.032606	.8655452	1.135995
d_ln_patent	.0611605	.0613942	-.0002337	.0019817
d_ln_rec	-.0131648	-.0081944	-.0049704	.0068744

```
                    b = Consistent under H0 and Ha; obtained from xtreg.
     B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

    chi2(6) = (b-B)'[(V_b-V_B)^(-1)](b-B)
            =   1.13
Prob > chi2 = 0.9801
```

Table B.4 Heteroscedasticity test for developed countries in the EU.

```
  ln_carbon_percap = d_ln_gdp_percap + d_ln_envtax_pct + d_ln_nrr +
                     d2_ln_urb + d_ln_patent + d_ln_rec
------------------------------------------------------------------------------
  Sample Size       =         216   |   Cross Sections Number   =          12
  Wald Test         =      1.4848   |   P-Value > Chi2(6)       =      0.9605
  F-Test            =      0.2475   |   P-Value > F(6 , 198)    =      0.9599
 (Buse 1973) R2     =      0.0071   |   Raw Moments R2          =      0.9665
 (Buse 1973) R2 Adj =     -0.0782   |   Raw Moments R2 Adj      =      0.9637
  Root MSE (Sigma)  =      0.4091   |   Log Likelihood Function =     96.1296
------------------------------------------------------------------------------
- R2h= 0.0071   R2h Adj=-0.0782  F-Test =    0.25 P-Value > F(6 , 198) 0.9599
- R2v= 0.0066   R2v Adj=-0.0787  F-Test =    0.23 P-Value > F(6 , 198) 0.9665
--------------------------------------------------------------------------------
ln_carbon_pe~p | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
---------------+----------------------------------------------------------------
ln_carbon_pe~p |
d_ln_gdp_per~p |   .0784392   .3532017     0.22   0.824    -.6138234    .7707019
d_ln_envtax_~t |   .3470755   .2403519     1.44   0.149    -.1240056    .8181565
      d_ln_nrr |   .0563871   .0244813     2.30   0.021     .0084045    .1043696
     d2_ln_urb |  -.9486338   11.41523    -0.08   0.934    -23.32207     21.4248
   d_ln_patent |   .0562319   .0312809     1.80   0.072    -.0050775    .1175413
      d_ln_rec |   .0351105   .0863364     0.41   0.684    -.1341057    .2043267
         _cons |   2.168866   .0794823    27.29   0.000     2.013083    2.324648
---------------+----------------------------------------------------------------
Hetero         |
d_ln_gdp_per~p |   13.91418   9.557434     1.46   0.145    -4.818047    32.64641
d_ln_envtax_~t |  -10.28572   1.848285    -5.57   0.000    -13.90829   -6.663144
      d_ln_nrr |  -.9365786    .252962    -3.70   0.000    -1.432375   -.4407823
     d2_ln_urb |  -841.7991   577.5085    -1.46   0.145    -1973.695    290.0968
   d_ln_patent |   .7894112   .2537321     3.11   0.002     .2921055    1.286717
      d_ln_rec |  -6.567253   1.449088    -4.53   0.000    -9.407414   -3.727093
---------------+----------------------------------------------------------------
         /Sigu |   .2183156   .0520023     4.20   0.000      .116393    .3202381
         /Sige |    .093668   .0106734     8.78   0.000     .0727486    .1145874
--------------------------------------------------------------------------------

==============================================================================
* Panel Model Selection Diagnostic Criteria - Model= (xtmlh)
==============================================================================
- Log Likelihood Function                   LLF            =     96.1296
---------------------------------------------------------------------------
- Akaike Information Criterion              (1974) AIC     =      0.1753
- Akaike Information Criterion              (1973) Log AIC =     -1.7411
---------------------------------------------------------------------------
- Schwarz Criterion                         (1978) SC      =      0.2211
- Schwarz Criterion                         (1978) Log SC  =     -1.5091
---------------------------------------------------------------------------
- Amemiya Prediction Criterion              (1969) FPE     =      0.1785
- Hannan-Quinn Criterion                    (1979) HQ      =      0.1925
- Rice Criterion                            (1984) Rice    =      0.1770
- Shibata Criterion                         (1981) Shibata =      0.1739
- Craven-Wahba Generalized Cross Validation (1979) GCV     =      0.1761
------------------------------------------------------------------------------

==============================================================================
* Panel Groupwise Heteroscedasticity Tests
==============================================================================
  Ho: Panel Homoscedasticity - Ha: Panel Groupwise Heteroscedasticity

- Lagrange Multiplier LM Test     = 2.58e+04     P-Value > Chi2(11)  0.0000
- Likelihood Ratio LR Test        = 120.4087     P-Value > Chi2(11)  0.0000
- Wald Test                       = 2.08e+05     P-Value > Chi2(12)  0.0000
```

Table B.5 Cross-section dependency test for developed countries in the EU.

Correlation matrix of residuals:

	__e1	__e2	__e3	__e4	__e5	__e6	__e7	__e8	__e9	__e10
__e1	.1309011									
__e2	.1614102	.2320796								
__e3	.116713	.1766402	.1607325							
__e4	.3125563	.4421464	.3703912	.9756296						
__e5	.0195408	.0578193	.063952	.1244679	.4210967					
__e6	.2438807	.3439536	.274114	.7454524	.1001912	.6035339				
__e7	.1435123	.2041373	.1601029	.4039333	.0461687	.316849	.1899871			
__e8	.0473666	.0905708	.0775643	.1877263	.0849391	.1472364	.0854076	.0718778		
__e9	.2223688	.3122491	.2659006	.6760638	.0975123	.496475	.2859956	.1289595	.5078669	
__e10	.1057185	.1353655	.1000659	.2382172	-.047455	.183683	.1221409	.0209269	.1800974	.1421131
__e11	.2185538	.3111003	.2383746	.5979669	.0480824	.4564067	.2767282	.1124115	.4455237	.2111806
__e12	.2377032	.3188612	.2534786	.6508672	.0634795	.499557	.2912214	.1168029	.4706769	.2007148
__e13	.2155259	.300809	.2487861	.6229041	.1473942	.4848289	.2847671	.1384838	.4482402	.1453464
__e14	.0763817	.1106999	.0904855	.2247206	.051727	.1752197	.0989216	.0525042	.1491659	.0523639
__e15	-.0125945	-.0275525	-.0249962	-.0609579	-.0380849	-.0463377	-.0168306	-.0181156	-.0376266	.012832
__e16	.1362508	.1989152	.170011	.380715	.0297081	.2880654	.1779182	.0726784	.2818326	.1335588
__e17	.1073687	.1465399	.1160104	.2896038	.0306433	.2206207	.1291753	.0422868	.2127913	.1075819
__e18	.0773696	.1087042	.1004773	.242983	.0532794	.1677864	.1003804	.0399558	.1965364	.0685001
__e19	.2162818	.2865599	.2310287	.5557665	.0333752	.4237686	.2638546	.0980583	.4146137	.2103114
__e20	.2279103	.3323892	.2556265	.6616921	.0824185	.5246022	.300164	.1466698	.4651613	.1735301

	__e11	__e12	__e13	__e14	__e15	__e16	__e17	__e18	__e19	__e20
__e11	.4799746									
__e12	.4480644	.4812492								
__e13	.3804288	.4394832	.5157855							
__e14	.1348544	.1554578	.1611899	.0707478						
__e15	-.0281031	-.0338412	-.032352	-.0184312	.03633					
__e16	.2849182	.2833242	.2363855	.0869698	-.0303724	.2224286				
__e17	.2193405	.2099288	.1783064	.0595518	-.0137435	.1414261	.1173932			
__e18	.1614789	.1722285	.1733634	.04449	-.0039967	.0936642	.0810888	.106001		
__e19	.4209143	.4323125	.3809219	.1263799	-.0169119	.2792117	.2005895	.150754	.4333298	
__e20	.4341338	.4637741	.4497761	.1650258	-.049531	.2858573	.1974108	.1468158	.4051006	.518883

	__e1	__e2	__e3	__e4	__e5	__e6	__e7	__e8	__e9	__e10	__e11	__e12	__e13	__e14
__e1	1.0000													
__e2	0.9261	1.0000												
__e3	0.8046	0.9146	1.0000											
__e4	0.8746	0.9292	0.9353	1.0000										
__e5	0.0832	0.1850	0.2458	0.1942	1.0000									
__e6	0.8677	0.9190	0.8801	0.9715	0.1987	1.0000								
__e7	0.9100	0.9722	0.9162	0.9382	0.1632	0.9357	1.0000							
__e8	0.4883	0.7012	0.7216	0.7089	0.4882	0.7069	0.7309	1.0000						
__e9	0.8624	0.9095	0.9307	0.9604	0.2109	0.8968	0.9207	0.6750	1.0000					
__e10	0.7751	0.7454	0.6621	0.6398	-0.1940	0.6272	0.7433	0.2071	0.6704	1.0000				
__e11	0.8719	0.9321	0.8582	0.8738	0.1070	0.8480	0.9164	0.6052	0.9024	0.8086	1.0000			
__e12	0.9471	0.9541	0.9114	0.9499	0.1410	0.9269	0.9631	0.6280	0.9521	0.7675	0.9323	1.0000		
__e13	0.8295	0.8694	0.8641	0.8781	0.3163	0.8690	0.9097	0.7192	0.8758	0.5368	0.7646	0.8821	1.0000	
__e14	0.7937	0.8639	0.8485	0.8554	0.2997	0.8480	0.8532	0.7363	0.7869	0.5222	0.7318	0.8425	0.8438	1.0000
__e15	-0.1826	-0.3001	-0.3271	-0.3238	-0.3079	-0.3129	-0.2026	-0.3545	-0.2770	0.1786	-0.2128	-0.2559	-0.2363	-0.3635
__e16	0.7985	0.8755	0.8991	0.8173	0.0971	0.7862	0.8655	0.5748	0.8385	0.7512	0.8720	0.8660	0.6979	0.6933
__e17	0.8661	0.8878	0.8445	0.8557	0.1378	0.8288	0.8650	0.4603	0.8715	0.8329	0.9240	0.8832	0.7246	0.6535
__e18	0.6568	0.6931	0.7698	0.7556	0.2522	0.6634	0.7073	0.4577	0.8471	0.5581	0.7159	0.7625	0.7414	0.5137
__e19	0.9081	0.9036	0.8754	0.8548	0.0781	0.8286	0.9196	0.5556	0.8838	0.8475	0.9229	0.9467	0.8057	0.7218
__e20	0.8745	0.9578	0.8852	0.9300	0.1763	0.9374	0.9560	0.7595	0.9061	0.6390	0.8699	0.9281	0.8694	0.8613

	__e15	__e16	__e17	__e18	__e19	__e20
__e15	1.0000					
__e16	-0.3379	1.0000				
__e17	-0.2104	0.8752	1.0000			
__e18	-0.0644	0.6100	0.7269	1.0000		
__e19	-0.1348	0.8994	0.8894	0.7034	1.0000	
__e20	-0.3608	0.8414	0.7999	0.6260	0.8543	1.0000

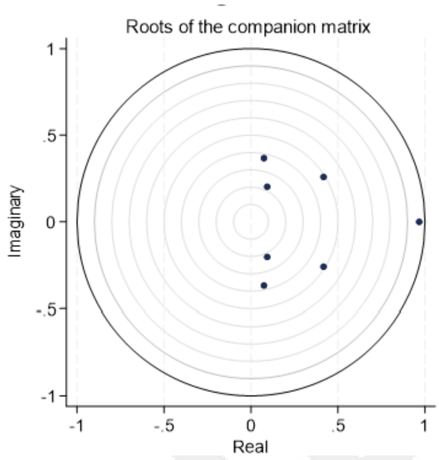
Breusch-Pagan LM test of independence: chi2(190) = 1891.751, Pr = 0.0000
Based on 18 complete observations over panel units

Pr< 0.05, we fail to accept the null hypothesis and conclude that panels are correlated (cross-sectional dependence).

Table B.6 Stability analysis for developed countries in the EU.

Position of Characteristic Roots of Developed Countries in Unit Circle

Panel VAR Stability Analysis and Eigenvalue Results for Developed Countries



Eigenvalue stability condition

Eigenvalue Real	Eigenvalue Imaginary	Modulus
.9670452	0	.9670452
.4172874	-.2590859	.4911764
.4172874	.2590859	.4911764
.0745333	.3677015	.3751794
.0745333	-.3677015	.3751794
.0931911	-.2027684	.2231583
.0931911	.2027684	.2231583

All the eigenvalues lie inside the unit circle.
pVAR satisfies stability condition.

Table B.7 Granger causality test for developed countries in the EU

panel VAR-Granger causality Wald test
Ho: Excluded variable does not Granger-cause Equation variable
Ha: Excluded variable Granger-causes Equation variable

Equation \ Excluded	chi2	df	Prob > chi2
ln_carbon_pc			
d_ln_gdp_pc	60.677	1	0.000
d_ln_envtax	42.202	1	0.000
d_ln_nrr	60.815	1	0.000
d2_ln_urb	71.800	1	0.000
d_ln_patent	34.653	1	0.000
d_ln_rec	254.408	1	0.000
ALL	838.575	6	0.000
d_ln_gdp_pc			
ln_carbon_pc	0.925	1	0.336
d_ln_envtax	35.377	1	0.000
d_ln_nrr	41.222	1	0.000
d2_ln_urb	149.228	1	0.000
d_ln_patent	5.403	1	0.020
d_ln_rec	6.279	1	0.012
ALL	339.067	6	0.000
d_ln_envtax			
ln_carbon_pc	12.812	1	0.000
d_ln_gdp_pc	196.519	1	0.000
d_ln_nrr	0.978	1	0.323
d2_ln_urb	1.005	1	0.316
d_ln_patent	150.035	1	0.000
d_ln_rec	160.454	1	0.000
ALL	711.399	6	0.000
d_ln_nrr			
ln_carbon_pc	53.741	1	0.000
d_ln_gdp_pc	192.087	1	0.000
d_ln_envtax	3.157	1	0.076
d2_ln_urb	125.078	1	0.000
d_ln_patent	9.593	1	0.002
d_ln_rec	33.170	1	0.000
ALL	514.289	6	0.000
d2_ln_urb			
ln_carbon_pc	11.701	1	0.001
d_ln_gdp_pc	24.948	1	0.000
d_ln_envtax	233.414	1	0.000
d_ln_nrr	35.987	1	0.000
d_ln_patent	0.642	1	0.423
d_ln_rec	9.314	1	0.002
ALL	483.755	6	0.000
d_ln_patent			
ln_carbon_pc	1.382	1	0.240
d_ln_gdp_pc	31.017	1	0.000
d_ln_envtax	228.239	1	0.000
d_ln_nrr	17.590	1	0.000
d2_ln_urb	84.150	1	0.000
d_ln_rec	351.009	1	0.000
ALL	828.231	6	0.000
d_ln_rec			
ln_carbon_pc	107.260	1	0.000
d_ln_gdp_pc	263.596	1	0.000
d_ln_envtax	19.333	1	0.000
d_ln_nrr	33.460	1	0.000
d2_ln_urb	113.932	1	0.000
d_ln_patent	28.037	1	0.000
ALL	695.273	6	0.000

C. ANALYSIS OF DEVELOPING COUNTRIES IN THE EU BETWEEN 2000 AND 2019

Table C.1 Heterogeneity test results for developing countries in the EU.

(Pesaran, Yamagata. 2008. Journal of Econometrics) H0: slope coefficients are homogenous		
	Delta	p-value
	7.423	0.000
Adj	9.584	0.000

Table C.2 Correlation matrix of the model variables.

	D. ln_car~c	D. ln_gdp~p	D. ln_env~t	ln_nrr	D2. ln_urb	D. ln_pat~t	ln_rec
ln_carbonpc							
D1.	1.0000						
ln_gdp_per~p							
D1.	0.4196	1.0000					
ln_envtax_~t							
D1.	-0.1324	-0.2393	1.0000				
ln_nrr	0.0649	0.2274	0.0079	1.0000			
ln_urb							
D2.	0.0348	0.0802	-0.0729	0.0278	1.0000		
ln_patent							
D1.	-0.0984	-0.0737	-0.0223	0.0847	-0.2334	1.0000	
ln_rec	-0.0370	-0.0686	-0.0296	0.1029	-0.0311	0.0914	1.0000

Table C.3 Hausman test results for developing countries in the EU.

	Coefficients (b) fixed	Coefficients (B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) Std. err.
ln_gdp_per~p				
D1.	.6078931	.6524209	-.0445277	.0441126
ln_envtax_~t				
D1.	-.0362596	-.0286564	-.0076032	.0127019
ln_nrr	-.0021675	-.0015808	-.0005868	.0092567
ln_urb				
D2.	-2.401133	-1.524813	-.8763206	1.486355
ln_patent				
D1.	-.0115111	-.0099395	-.0015716	.001967
ln_rec	-.0269131	-.0002124	-.0267007	.0150177

```
              b = Consistent under H0 and Ha; obtained from xtreg.
B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

    chi2(6) = (b-B)'[(V_b-V_B)^(-1)](b-B)
            =   3.82
Prob > chi2 = 0.7008
```

Table C.4 Heteroscedasticity test for developing countries in the EU.

```
* MLE Random-Effects Panel Data Regression (Normal Distribution)
* Multiplicative Heteroscedasticity
==============================================================================
  d_ln_carbonpc = d_ln_gdp_percap + d_ln_envtax_pct + ln_nrr + d2_ln_urb + d_ln_patent + ln_rec
------------------------------------------------------------------------------
  Sample Size       =         234   |   Cross Sections Number   =          13
  Wald Test         =     48.4494   |   P-Value > Chi2(6)       =      0.0000
  F-Test            =      8.0749   |   P-Value > F(6 , 215)    =      0.0000
 (Buse 1973) R2     =      0.1759   |   Raw Moments R2          =      0.1856
 (Buse 1973) R2 Adj =      0.1069   |   Raw Moments R2 Adj      =      0.1175
  Root MSE (Sigma)  =      0.0626   |   Log Likelihood Function =    384.6521
------------------------------------------------------------------------------
- R2h= 0.1781   R2h Adj= 0.1093  F-Test =    8.20 P-Value > F(6 , 215) 0.0000
- R2v= 0.1440   R2v Adj= 0.0723  F-Test =    6.36 P-Value > F(6 , 215) 0.0000

  d_ln_carbonpc | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
----------------+----------------------------------------------------------------
d_ln_carbonpc   |
d_ln_gdp_percap |    .585986   .0761612     7.69   0.000     .4367129    .7352592
d_ln_envtax_pct |  -.0162685   .0362251    -0.45   0.653    -.0872684    .0547314
         ln_nrr |   .0009697   .0028747     0.34   0.736    -.0046647    .0066041
      d2_ln_urb |  -3.082729   3.731436    -0.83   0.409    -10.39621    4.230751
    d_ln_patent |  -.0045217    .006852    -0.66   0.509    -.0179513    .0089079
         ln_rec |   .0023771   .0053955     0.44   0.660    -.0081979    .0129522
          _cons |  -.0297602   .0149924    -1.99   0.047    -.0591447   -.0003757
----------------+----------------------------------------------------------------
Hetero          |
d_ln_gdp_percap |  -6.297959   7.402347    -0.85   0.395    -20.80629    8.210373
d_ln_envtax_pct |   3.817554   .7607889     5.02   0.000     2.326435    5.308673
         ln_nrr |   .2991465   .1041299     2.87   0.004     .0950555    .5032374
      d2_ln_urb |  -463.8575   301.6109    -1.54   0.124    -1055.004     127.289
    d_ln_patent |  -.0585252   .1205431    -0.49   0.627    -.2947854     .177735
         ln_rec |    .502506    .174305     2.88   0.004     .1608746    .8441374
----------------+----------------------------------------------------------------
          /Sigu |   3.31e-12   .0013657     0.00   1.000    -.0026767    .0026767
          /Sige |  -.0166645   .0122038    -1.37   0.172    -.0405836    .0072546
---------------------------------------------------------------------------------

==============================================================================
* Panel Model Selection Diagnostic Criteria - Model= (xtmlh)
==============================================================================
- Log Likelihood Function                   LLF            =    384.6521
---------------------------------------------------------------------------
- Akaike Information Criterion              (1974) AIC     =      0.0041
- Akaike Information Criterion              (1973) Log AIC =     -5.5028
---------------------------------------------------------------------------
- Schwarz Criterion                         (1978) SC      =      0.0051
- Schwarz Criterion                         (1978) Log SC  =     -5.2837
---------------------------------------------------------------------------
- Amemiya Prediction Criterion              (1969) FPE     =      0.0042
- Hannan-Quinn Criterion                    (1979) HQ      =      0.0045
- Rice Criterion                            (1984) Rice    =      0.0041
- Shibata Criterion                         (1981) Shibata =      0.0040
- Craven-Wahba Generalized Cross Validation (1979) GCV     =      0.0041
------------------------------------------------------------------------------

==============================================================================
* Panel Groupwise Heteroscedasticity Tests
==============================================================================
  Ho: Panel Homoscedasticity - Ha: Panel Groupwise Heteroscedasticity

- Lagrange Multiplier LM Test     = 3.32e+04     P-Value > Chi2(12)  0.0000
- Likelihood Ratio LR Test        =  -6.4339     P-Value > Chi2(12)  0.8926
- Wald Test                       = 8.69e+04     P-Value > Chi2(13)  0.0000
```

Table C.5 Cross-section dependency test for developing countries in the EU.

Correlation matrix of residuals:

	__e1	__e2	__e3	__e4	__e5	__e6	__e7	__e8	__e9	__e10
__e1	.0763672									
__e2	.0132354	.0132413								
__e3	.0053217	.001839	.0058899							
__e4	.036445	.008269	.0303176	.3946608						
__e5	.0175158	.0031738	.0039808	.0296851	.016531					
__e6	.025518	.0098646	.0049251	.0260702	.0074775	.0273716				
__e7	.003543	-.0026205	.009073	.0644192	-.0079463	.0074463	.0610374			
__e8	-.0077415	-.0031436	.004967	.0170243	-.0007655	.00443	.0245897	.0251884		
__e9	.0061857	.002317	.0062559	.0518627	.0033972	.0120582	.0136472	.0100388	.0159812	
__e10	.0127101	.008121	.0016564	.0042876	.0151107	.0174214	-.0258552	-.0009727	.0034365	.0547532
__e11	.0371195	.0028261	.0027307	-.0097227	.0098826	.0141651	.00156	-.0013924	.0046677	-.0023053
__e12	-.0004509	.0058251	.003964	.0416528	.0014466	.0154211	.010758	.0079304	.0139396	.0120459
__e13	-.00383	.0001638	.0022628	.0286263	.004661	.0085802	.0061925	.0087125	.0123012	.0013178

	__e11	__e12	__e13
__e11	.0320705		
__e12	-.0001065	.0251664	
__e13	.0041534	.0129658	.0214221

	__e1	__e2	__e3	__e4	__e5	__e6	__e7	__e8	__e9	__e10	__e11	__e12	__e13
__e1	1.0000												
__e2	0.4162	1.0000											
__e3	0.2509	0.2082	1.0000										
__e4	0.2099	0.1144	0.6288	1.0000									
__e5	0.4930	0.2145	0.4034	0.3675	1.0000								
__e6	0.5581	0.5182	0.3879	0.2508	0.3515	1.0000							
__e7	0.0519	-0.0922	0.4785	0.4151	-0.2502	0.1822	1.0000						
__e8	-0.1765	-0.1721	0.4078	0.1707	-0.0375	0.1687	0.6271	1.0000					
__e9	0.1771	0.1593	0.6448	0.6530	0.2090	0.5765	0.4370	0.5004	1.0000				
__e10	0.1966	0.3016	0.0922	0.0292	0.5023	0.4500	-0.4472	-0.0262	0.1162	1.0000			
__e11	0.7501	0.1371	0.1987	-0.0864	0.4292	0.4781	0.0353	-0.0490	0.2062	-0.0550	1.0000		
__e12	-0.0103	0.3191	0.3256	0.4179	0.0709	0.5876	0.2745	0.3150	0.6951	0.3245	-0.0037	1.0000	
__e13	-0.0947	0.0097	0.2014	0.3113	0.2477	0.3543	0.1713	0.3751	0.6648	0.0385	0.1585	0.5584	1.0000

Breusch-Pagan LM test of independence: chi2(78) = 176.723, Pr = 0.0000
Based on 16 complete observations over panel units

Bias-adjusted LM test of error cross-section independence

H0: Cov(uit,ujt) = 0 for all t and i!=j

Test	Statistic	p-value
LM	135.3	0.0001
LM adj*	5.392	0.0000
LM CD*	5.542	0.0000

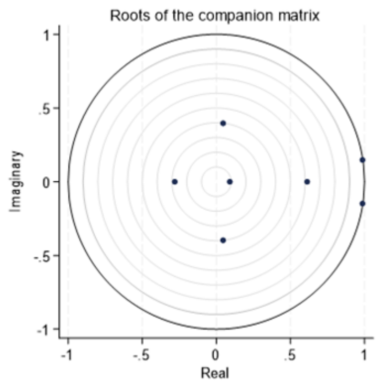
*two-sided test

Pr< 0.05, we fail to accept the null hypothesis and conclude that the panel are correlated (cross-sectional dependence).

Table C.6 Stability analysis for developing countries in the EU.

Position of Characteristic Roots of Developing Countries in Unit Circle

Panel VAR Stability Analysis and Eigenvalue Results for Developing Countries



Eigenvalue stability condition

Eigenvalue Real	Eigenvalue Imaginary	Modulus
.9862286	-.1479843	.9972694
.9862286	.1479843	.9972694
.6130681	0	.6130681
.0455617	.396479	.3990883
.0455617	-.396479	.3990883
-.2809728	0	.2809728
.0911292	0	.0911292

All the eigenvalues lie inside the unit circle.
pVAR satisfies stability condition.

Table C.7 Granger causality test for developing countries in the EU.

```
panel VAR-Granger causality Wald test
  Ho: Excluded variable does not Granger-cause Equation variable
  Ha: Excluded variable Granger-causes Equation variable
```

Equation \ Excluded	chi2	df	Prob > chi2
d_ln_carbonpc			
d_ln_gdp_percap	53.392	1	0.000
d_ln_envtax_pct	78.804	1	0.000
ln_nrr	0.012	1	0.913
d2_ln_urb	54.247	1	0.000
d_ln_patent	10.164	1	0.001
ln_rec	22.720	1	0.000
ALL	326.094	6	0.000
d_ln_gdp_percap			
d_ln_carbonpc	4.859	1	0.028
d_ln_envtax_pct	24.938	1	0.000
ln_nrr	11.952	1	0.001
d2_ln_urb	78.509	1	0.000
d_ln_patent	4.849	1	0.028
ln_rec	1.095	1	0.295
ALL	122.335	6	0.000
d_ln_envtax_pct			
d_ln_carbonpc	177.161	1	0.000
d_ln_gdp_percap	0.014	1	0.907
ln_nrr	4.641	1	0.031
d2_ln_urb	49.052	1	0.000
d_ln_patent	4.518	1	0.034
ln_rec	1.293	1	0.256
ALL	262.960	6	0.000
ln_nrr			
d_ln_carbonpc	5.477	1	0.019
d_ln_gdp_percap	127.731	1	0.000
d_ln_envtax_pct	0.418	1	0.518
d2_ln_urb	91.040	1	0.000
d_ln_patent	1.719	1	0.190
ln_rec	75.974	1	0.000
ALL	265.104	6	0.000
d2_ln_urb			
d_ln_carbonpc	104.639	1	0.000
d_ln_gdp_percap	70.922	1	0.000
d_ln_envtax_pct	9.634	1	0.002
ln_nrr	2.655	1	0.103
d_ln_patent	18.753	1	0.000
ln_rec	9.584	1	0.002
ALL	264.783	6	0.000
d_ln_patent			
d_ln_carbonpc	26.428	1	0.000
d_ln_gdp_percap	68.448	1	0.000
d_ln_envtax_pct	0.359	1	0.549
ln_nrr	0.146	1	0.702
d2_ln_urb	87.340	1	0.000
ln_rec	25.794	1	0.000
ALL	279.752	6	0.000
ln_rec			
d_ln_carbonpc	1.916	1	0.166
d_ln_gdp_percap	37.379	1	0.000
d_ln_envtax_pct	47.538	1	0.000
ln_nrr	38.608	1	0.000
d2_ln_urb	43.042	1	0.000
d_ln_patent	6.138	1	0.013
ALL	261.088	6	0.000

D. TURKISH SUMMARY / TÜRKÇE ÖZET

“Kirliliğin Belirleyicileri: Avrupa Birliğindeki Gelişmiş ve Gelişmekte Olan Ülkelerin Karşılaştırmalı Analizi” başlıklı tezimiz 6 ana bölümden oluşmaktadır. İlk giriş bölümünde tezimizin genel çerçevesini belirttik. Tezimiz, Çevresel Kuznet Eğrisi teorisi çerçevesinde, Avrupa Birliği'ndeki (AB) gelişmiş ve gelişmekte olan üye ülkelerle birlikte Avrupa Birliği'nde de kirliliğin belirleyicilerini araştırmayı amaçlamaktadır. Bu çalışmada, çevresel teknolojiler, çevresel vergiler, doğal kaynak kira gelirleri, yenilenebilir enerji tüketimi, kentleşme ve kişi başına düşen GSYİH gibi faktörlerin kişi başına düşen karbon emisyonunu (KBK) nasıl etkilediğini anlamaya çalışıyoruz İkinci bölüm olan teorik arka plan bölümünde, Çevresel Kuznet Eğrisi teorisi bağlamında analizimizin nasıl açıklanacağını detaylandırdık. Öncelikle Çevresel Kuznet Eğrisi (ÇKE) teorisinin tarihsel gelişiminden bahsederek ÇKE modellerinin gelişimini anlattık. Daha sonra modelimizin matematiksel gösterimini de yaparak analizimizde kullandığımız değişkenleri nasıl seçtiğimizi anlattık. Üçüncü bölümümüz olan literatür taraması bölümünde, bağımsız değişkenlerimiz hakkında farklı argümanların geniş bir özetini sunduk. Bu bölümde, her bağımsız değişkenimiz ile bağımlı değişkenimiz olan kişi başına düşen karbon emisyonları (KBK) arasındaki ilişkiyi teker teker kapsamlı bir şekilde ele alarak açıkladık. Dördüncü bölümümüz olan veri ve metodoloji bölümünde analizimizin özelliklerini, ülke setimizi, verilerimizi ve değişkenlerimizi detaylı bir şekilde açıkladık. Çalışmamız 25 Avrupa Birliği ülkesini (Avusturya, Belçika, Bulgaristan, Hırvatistan, Çekya, Danimarka, Estonya, Finlandiya, Fransa, Almanya, Yunanistan, Macaristan, İrlanda, İtalya, Letonya, Litvanya, Lüksemburg, Hollanda, Polonya, Portekiz, Romanya, Slovakya, Slovenya, İspanya, İsveç) 2000 ve 2019 yılları arasında incelemektedir. Analizimizi ilk olarak 25 AB ülkesi için yaptık daha sonra aynı analiz 12 tane gelişmiş ve 13 tane de gelişmekte olan AB ülkeleri için ayrı ayrı uyguladık. Avusturya, Belçika, Danimarka, Finlandiya, Fransa, Almanya, İrlanda, İtalya, Lüksemburg, Hollanda, İspanya ve İsveç'ten oluşan 12 AB ülkesi gelişmiş ülkeler olarak gruplandırılmıştır. Diğer 13 AB ülkesi Bulgaristan, Hırvatistan, Çekya, Estonya, Yunanistan, Macaristan, Letonya, Litvanya, Polonya, Portekiz, Romanya, Slovakya ve Slovenya gelişmekte olan ülkeler olarak gruplandırılmıştır. AB ülkelerini gelişmiş ve gelişmekte olan gruplara ayırırken, referans kriter olarak AB Uyum Politikasını kullandık. Uyum Politikası fonları, AB içindeki ekonomik, sosyal ve bölgesel farklılıkları azaltmak amacıyla daha az gelişmiş Avrupa ülkelerine ve bölgelerine yönlendirilir, böylece bu ülkelerin gelişmiş olan diğer AB üyesi ülkelere yetişebilmesi amaçlanır. Yukarıda bahsedilen 13 AB ülkesi, uyum fonunun çoğunluğunu alan ülkeler olduğu için bunları AB' deki gelişmekte olan ülkeler olarak aldık ve diğer 12 ülke AB'deki gelişmiş ülkeler olarak kabul edildi. Ayrıca Ekonometrik metodolojimizi Panel Vektör Otoregresyon modeli (PVO) olarak belirledik. Beşinci bölümümüz olan ampirik bulgular bölümünde AB, AB' deki gelişmiş olan ülkeler ve AB' deki gelişmekte olan ülkeler için ayrı ayrı genel betimleyici istatistiksel testlerimizi yaptıktan sonra belirlemiş olduğumuz metodolojimiz PVO ile analizimizi gerçekleştirdik. Bu kısım altı aşamadan oluşmaktadır. İlk aşamada modelimiz için uygun zaman gecikmesi uzunluğunun seçtik. Uygun zaman gecikmesi AB, AB' deki gelişmiş olan ülkeler ve AB' deki gelişmekte olan ülkeler için 1 zaman gecikmesi olarak bulundu. İkinci aşamada ise uygun zaman gecikmesi uzunluğu belirlendikten sonra, PVO modelimiz, her bağımlı değişkenin gecikmiş değerleri ile diğer bağımlı değişkenlerin gecikmiş değerlerini içerecek şekilde oluşturuldu. Modelimizin tahmini, GMM (genelleştirilmiş moment metodu) yaklaşımı kullanılarak gerçekleştirildi. Burada, AB, AB'deki gelişmiş olan ülkeler ve AB' deki gelişmekte olan ülkeler için GMM ile ayrı ayrı model tahminimizi yaptık. Üçüncü aşamada PVAR modeline dahil edilen değişkenler arasındaki ilişkilerin varlığına ve yönüne dair çıkarımlar kazanmak için, tahmin edilen PVAR modeli için Granger nedensellik testleri yaptık. Granger Nedensellik testi AB, AB'deki gelişmiş olan ülkeler ve AB' deki gelişmekte olan ülkeler için ayrı ayrı yapıldı. Dördüncü aşamada Panel VAR modelinin stabilitesini test etmek için, tahmin edilen modeldeki her bir eleman için özdeğerleri hesapladık ve belirtmiş olduğumuz ülke grupları için kurmuş olduğumuz modelleri stabil bularak PVO analizi için uygun olduğunu gösterdik. Daha sonra Dinamik ilişkilerin analizi için etki tepki analizi yaptık. Bu analiz belirtmiş olduğumuz ülke gruplarımız için belirlemiş olduğumuz değişkenlerin KBK üzerinde kısa ve uzun vadede ne kadar etkili olduğu konusunda bize önemli bulgular sundu. Son olarak varyans ayrıştırması analizinde, bir değişkendeki şokun ne kadarının kendisinden ve ne kadarının diğer değişkenlerden geldiğini göstererek, değişkenler arasındaki karşılıklı ilişkileri ortaya çıkardık. Yapmış olduğumuz etki tepki analizleri ve varyans ayrıştırması analizlerindeki bulgulara dayanarak öncelikli olarak Çevresel Kuznet Eğrisi teorisinin varlığını elimizdeki data seti için doğrulamış olduk. Daha sonra yine bulgulara dayanarak altıncı ve son bölümümüz olan sonuç kısmında AB, AB' deki gelişmiş olan ülkeler ve AB' deki gelişmekte olan ülkeler için kısa ve uzun vadeli analizlerimizi literatür taramamızdaki bilgiler ile sentezleyerek açıkladık ve politika önermelerinde bulunduk. Daha sonra, AB' deki gelişmiş ve gelişmekte olan ülkeleri ayrı ayrı inceliyor, aralarındaki benzerlikleri ve farklılıkları vurgulayarak kişi başına düşen karbon emisyonunu etkileyen anahtar bağımsız değişkenleri belirledik. Bu bulgular, her ülke grubunun karşılaştığı farklı problemleri ele alan özel politikalar oluşturmak için hayati öneme sahiptir. Aşağıdaki paragraflarda analizlerimizin bulgularını ve literatüre olan katkılarımızı daha ayrıntılı bir şekilde açıklıyoruz.

AB' de çevresel teknolojilerle ilgili patentlerin kişi başına düşen karbon emisyonları üzerinde azaltıcı bir etkisi vardır. Ancak, bu azaltıcı etki, KBK için kısa vadede etkili olup uzun vadede etkisi azalmaktadır. Bu nedenle patentlerin AB' de kısa vadede daha etkili bir araç olduğunu söyleyebiliriz. Bu etki, literatürde yapılan çalışmalar tarafından da desteklenmektedir; teknoloji sayesinde, malların üretimi daha az kaynak kullanılarak yapılmakta ve karbon emisyonlarını azaltarak çevresel sürdürülebilirliğe katkıda bulunmaktadır. Analizimiz de AB'de çevresel teknolojilerle ilgili patentlerin kısa vadede karbon emisyonunu ve kirlilik seviyesini azaltmak için etkili bir araç olduğunu ortaya koymaktadır. Analizimizde patentler, gelişmiş ve gelişmekte olan AB ülkeleri için farklı sonuçlar göstermiştir. Patentler gelişmiş ülkelerde KBK' yı etkili bir şekilde azaltırken, gelişmekte olan ülkelerde KBK başlangıçta artış göstermiş, ancak daha sonra azalmaya başlamış ve uzun vadede nötr hale gelmiştir. Ayrıca, bu patentlerin etkisi gelişmiş ülkelerde gelişmekte olan ülkelere kıyasla daha fazladır. Gelişmiş ülkelerde çevresel teknolojilerle ilgili patentlerin KBK üzerinde azaltıcı bir etkisi olmasına rağmen, analizimizde AB'nin gelişmekte olan ülkelerinde çevresel teknolojilerle ilgili patentlerin kısa vadede KBK üzerinde artırıcı bir etkisi olduğunu bulduk. Analizimizin bu sonucu, patentlerin yüksek kullanım ücretleri nedeniyle çevresel teknolojilerin diğer ülkelere yayılmasını engellediğini iddia eden literatür çalışmaları tarafından da desteklenmektedir. Ayrıca literatürdeki diğer çalışmalar, yatırımcıların yenilikçi fikirlerini paylaşmaktan çekinmeleri nedeniyle, teknolojik gelişmelerin daha önceki kurulmuş teknolojilere bağlı olduğunu söylemektedir. Bu durum, geleneksel üretim tekniklerini teşvik etmekte ve sonuç olarak daha fazla karbon emisyonuna ve kirlilik seviyesinin artmasına neden olmaktadır. Gelişmekte olan ülkelerle ilgili analizimizde, bu sonuçların kısa vadede geçerli olduğunu ortaya koyarak bu çalışmalara katkıda bulunmaktadır. Karbon emisyonları ve kirlilikle etkili bir şekilde mücadele etmek için, politika önerisi olarak, AB' de çevresel teknolojilerin yayılmasıyla ilgili engellerin hafifletilmesi önerilmektedir.

Analizimizde, çevresel vergilerin AB genelinde kişi başına düşen karbon emisyonları üzerinde başlangıçta kısa vadede artırıcı bir etkisi vardır. Bu etki sonra azalmaya başlayarak uzun vadede nötrleşmektedir. Bu sonuçlar, AB'nin gelişmekte olan ülkeleri için de geçerlidir. Ancak, gelişmiş ülkelerde çevresel vergilerin kişi başına düşen karbon emisyonu üzerinde hem kısa hem de uzun vadede artırıcı bir etkisi vardır. Çevresel vergilerin kişi başına düşen karbon emisyonu üzerindeki artırıcı etkisi, yaptığımız literatür çalışmasındaki argümanlarla da desteklenmektedir; vergiler hükümetler tarafından belirlendiği için, vergilendirme politikası ile ilgili kararlar endüstri ve çevresel çıkar grupları tarafından etkilenmekte ve bu da hem kirlilik seviyesini hem de KBK' yi artıran istenmeyen politikalara yol açabilmektedir. Ayrıca, literatürdeki farklı çalışmalar, vergi oranı optimal seviyenin üzerinde olduğunda, firmaların emisyon azaltıcı teknolojilere yatırım yapma motivasyonlarını kaybettiklerini ve çevreyi kirletmeye devam ettiklerini belirtmektedir. Analizimiz, kısa ve uzun vade sonuçlarını ortaya koyarak literatüre katkıda bulunmaktadır. Ayrıca, KBK' yi azaltmak için etkili bir çözüm sağlamak amacıyla, literatür çalışmamız ile de uyumlu olarak, çevresel vergilerden elde edilen gelirlerin yeşil teknolojileri araştırma ve geliştirme çalışmalarına ve çevresel koruma altyapılarının inşasına kanalize edilmesi, AB politika yapıcılarına, birliğin gelişmiş ve gelişmekte olan ülkeleri de dahil olmak üzere önerilmektedir. Ayrıca, çevresel vergilerin etkinliği büyük ölçüde optimal vergilendirme stratejisine ve siyasal-ekonomik bağlama da bağlıdır.

Doğal kaynak kira gelirlerinin AB' de kısa vadede kişi başına düşen karbon emisyonları üzerinde azaltıcı bir etkisi gözlenmekte ve uzun vadede üzerindeki etkisi kaybolmaktadır. Literatür çalışmamız ile de uyumlu olarak, analizimizde doğal kaynak kira gelirlerinin KBK üzerinde kısa vadede azaltıcı bir etkisi olduğunu bulduk. Ayrıca, doğal kaynakların sömürülmesinin emisyonlar üzerinde karmaşık etkileri vardır ve bu etki, ekonomik, sosyal ve çevresel yapılara bağlı olarak değişmektedir. Analizimiz hem kısa hem de uzun vadede, doğal kaynak kira gelirlerinin hem gelişmiş hem de gelişmekte olan AB ülkelerinde KBK üzerinde küçük ancak hafifçe azalan bir etkisi olduğunu ortaya koymaktadır ve bu, sürdürülebilir bir şekilde yönetildiğinde bir politika aracı olarak kullanılabilme potansiyelini göstermektedir. Ayrıca, özellikle analizimize göre, bu değişken kısa vadede gelişmiş ülkeler için daha etkilidir. Literatür taramamızda, maliye alanında yüksek adem-i merkeziyetçiliğe sahip olan gelişmiş ülkelerde daha fazla hesap verebilirlik olduğu ve bunun da doğal kaynak kira gelirlerinin uygun kullanımını sağlayarak karbon emisyonlarını azalttığı belirtilmektedir. Ayrıca, farklı çalışmalar geniş doğal kaynaklara sahip gelişen pazar ekonomilerinde, fosil yakıtların ithalatına daha az bağımlılık nedeniyle, doğal kaynak kira gelirlerinin de karbon emisyonlarını azaltıcı bir etkisi olduğunu belirtmektedir. Ayrıca, insanlara çevresel farkındalıklarını artırmak için eğitim vermenin, sürdürülemez doğal kaynak kullanımının önleyerek emisyon ve kirlilik seviyesinde azalma sağlamada etkili olduğunda söylenmektedir. Hem gelişmiş hem de gelişmekte olan ülkeler için, mali yapıda adem-i merkezileşme ve çevresel konularda farkındalık oluşturan eğitimlerin, KBK ile mücadelede doğal kaynak kira gelirlerinin etkili bir politika aracı olmasına katkı sağlamaktadır.

Avrupa Birliği’ nde, yenilenebilir enerji tüketiminin uzun vadede kişi başına düşen karbon emisyonu üzerinde olumlu bir etkisi vardır. Gelişmiş ve gelişmekte olan ülkeler için yenilenebilir enerji tüketimi farklı etkiler göstermektedir. Analizlerimizde yenilenebilir enerji gelişmiş ülkelerde kişi başına düşen karbon emisyonunu azaltırken, gelişmekte olan ülkelerde ilginç bir şekilde kişi başına düşen karbon emisyonunu artırmıştır. Bu durum, yenilenebilir enerjinin teşvik edilmesinde özelleştirilmiş politika yaklaşımlarının gerekliliğine işaret etmektedir. Analizimizde yenilenebilir enerjinin KBK üzerindeki artış etkisi, literatürdeki bazı çalışmalar tarafından da desteklenmektedir. Bu çalışmalara göre yenilenebilir enerji ekipmanlarının üretiminde kullanılan malzemelerin karbon emisyonları ve doğal habitat kirliliği üzerinde ciddi sonuçları vardır. Ayrıca, yenilenebilir enerji üretiminin iklim koşullarına bağımlı olduğu ve bu durumun üretimde süreklilik sorunlarına yol açarak diğer yenilenebilir olmayan enerji kaynaklarının tüketimini artırdığını belirtilmektedir. Sonuç olarak, emisyon seviyesi ve kirlilik artmaktadır. Ayrıca, analizimizde gelişmiş ülkelerde yenilenebilir enerji tüketiminin KBK üzerindeki azaltıcı etkisi, literatürdeki çalışmalarda yenilenebilir enerji tüketiminin altyapısındaki teknolojilerle de ilgili olabileceği söylenmektedir. Ayrıca, yenilenebilir enerjinin azalan etkisinin büyük ölçüde insan sermayesinin gelişiminden kaynaklandığını belirtilmektedir, çünkü insan sermayesinin artan becerileri yenilenebilir enerji teknolojilerinin ilerlemesinde kritik bir rol oynamaktadır. Kısacası, yenilenebilir enerjiye geçiş, karbon emisyonlarını azaltmada önemli bir faktör olarak tanımlanmıştır, ancak etkinliği sektörler bölgeler ve ülkeler arasında değişiklik göstermektedir. Çalışmalar, yenilenebilir enerji tüketiminin emisyonları hafifletme potansiyeline sahip olduğunu, ancak gerçek dünya senaryolarında etkisinin genellikle mevcut enerji yapıları, teknoloji seviyesi ve insan sermayesi kalitesi tarafından sınırlı olduğunu öne sürmektedir. Çalışmamız, AB' deki gelişmiş ve gelişmekte olan ülkeler arasındaki sınırlamaları ve farklılıkları ortaya koyarak literatüre katkıda bulunmaktadır. Politika önerisi olarak, insan sermayesine yatırım yapılması ve yenilenebilir enerji tüketiminin altyapısına yüksek düzeyde teknolojilerin entegre edilmesi, yenilenebilir enerjiyi gelecekte etkili bir politika aracı haline gelebilir.

Kentleşme, kısa vadede kişi başına düşen karbon emisyonları üzerinde artırıcı bir etkiye sahiptir ve uzun vadede bu etki azalmaktadır. Ayrıca, analizimizde kentleşme hem gelişmiş hem de gelişmekte olan ülkelerde kısa ve uzun vadede kişi başına düşen karbon emisyonunu artırmaktadır. Bu durum kentleşmenin karbon emisyonlarını şekillendirmede önemli bir rolü olduğunu göstermektedir. Literatürde yapılmış olan çalışmalar analizlerimizdeki bulguları desteklemektedir. Kent alanlarının genişlemesi daha fazla karbon emisyonu yaratmakta ve kirlilik seviyesini artırmaktadır. İnsanların daha iyi yaşam standartları için kent bölgelerine göç etmesi, altyapıların inşası, toplu taşıma ve endüstriler tarafından artan talep odaklı malların ve hizmetlerin üretimi, kentleşmenin KBK ve kirlilik seviyesi üzerindeki artırıcı etkisinin başlıca nedenlerindendir. Ayrıca farklı çalışmalara göre, nüfusun ve ekonomik faaliyetlerin ilgili ülkedeki şehirler arasında coğrafi olarak nasıl dağıldığı, kentleşmenin bahsedilen yan etkilerini çözmede önemlidir. Literatür araştırmamızda, emisyon ve kirlilik seviyesini azaltmak için akıllı şehirlerin inşası da bir politika önerisi olarak sunulmuştur. Ayrıca, düşük karbon verimliliğine sahip bölgelerde, verimliliği artırıcı yatırımlar yapmak da KBK ve kirlilik seviyesini azaltmada etkili bir politika aracı olabilmektedir. Sonuç olarak, kentleşme genellikle daha yüksek enerji tüketimi, altyapı gelişimi ve yaşam tarzı değişiklikleri nedeniyle artan emisyonlarla ilişkilendirilmiştir. Bu nedenle, kentleşmenin planlanması ve akıllı şehirlerin inşası, bunun için en uygun politika önerileridir. Ayrıca, insanların göçü ve üretim tesislerinin transferi, şehirlerin karbon verimliliğine uygun olarak planlanmalıdır. Eğer göç, yüksek karbon verimliliğine sahip şehirlerden düşük karbon verimliliğine sahip şehirlere doğru gerçekleşirse, emisyon ve kirlilik seviyesini artmaktadır.

AB' de, kişi başına düşen gayri safi yurtiçi hasılanın (GSYİH' nin) kısa vadede kişi başına düşen karbon emisyonu üzerinde artırıcı bir etkisi vardır. Ancak, uzun vadede bu etki azalmaya başlayarak ve nötr hale gelmektedir. Bu sonuç çalışmamızın altyapısını oluşturan ÇKE teorisini de destekler niteliktedir. Ayrıca, gelişmiş ülkelerde kişi başına düşen GSYİH, daha sürdürülebilir büyüme modellerine geçişi yansıtarak KBK üzerinde azaltıcı bir etkiye sahiptir. Öte yandan, gelişmekte olan ülkelerde kişi başına düşen GSYİH artışı kişi başına düşen karbon emisyonunu artırmış, ekonomik gelişme ile çevresel sürdürülebilirlik arasındaki dengenin zorluklarını vurgulamıştır. Kişi başına düşen GSYİH ile emisyonlar arasındaki ilişki karmaşıktır. Ekonomik büyüme başlangıçta daha yüksek emisyonlara yol açsa da ekonomik gelişmenin daha ileri aşamalarında bu eğilim tersine dönebilmektedir. Literatürdeki çalışmalara göre, gelişmekte olan ülkelerin gelişmiş ülke statüsüne geçiş sürecinde, ekonomik genişleme başlangıç aşamasında emisyonları artırmakta ve daha sonra post-endüstriyel gelişme aşamasında emisyonlar azalmaya eğilimli olmaktadır. Ayrıca, artan GSYİH ülkelerin temiz teknolojilere yatırım yapma kapasitesini artmakta ve bu aşamada, bilgi teknolojileri de çevresel bozulma konusunda insanların farkındalığını artırmaktadır. Ayrıca, gelişmiş ve gelişmekte olan ülkelerimizin analizinde, kişi başına düşen GSYİH' nin etkisinin gelişim sürecini de ortaya çıkardık. Analizimiz, kişi başına düşen GSYİH' nin gelişmekte olan ülkelerde KBK üzerinde artırıcı bir etkiye sahip olduğunu ve gelişmiş ülkelerde ise KBK üzerinde azalan bir etkiye sahip olduğunu doğrulayarak, literatürde bahsedilen ÇKE teorisindeki gelişim sürecini de teyit etmektedir. Etkili bir politika aracı olabilmesi için, kişi başına düşen GSYİH' deki artış, çevresel teknolojilerdeki ilerleme çalışmaları ve gelişmiş insan sermayesini artıracak yatırımlar ile birleştirilmelidir.

Tüm analizlerimizi ve literatür incelememizi dikkate alarak, AB' ye tek bir politika seti sunmak yerine, içsel ekonomik ve yapısal farklılıklar nedeniyle gelişmiş ve gelişmekte olan ülkeler için farklı politikalar benimsenmesi gerektiğini düşünüyoruz. Varyans ayrıştırma analizimize uygun olarak, gelişmiş ülkelere, çevresel teknolojik gelişmelerle entegre olmuş kentleşme ve yenilenebilir enerji tüketimi politikalarına öncelik vermelerini öneriyoruz. Ayrıca, gelişmekte olan ülkeler için öncelik, çevresel teknolojilerin geliştirilmesiyle birlikte optimal çevresel vergilendirme sistemi, akıllı kentleşme politikası olmalıdır.

Ampirik bulgular bölümümüzdeki sonuçlar, çevresel kalite ile ekonomik büyüme arasında bir ilişki öneren Çevresel Kuznets Eğrisi (ÇKE) teorisini doğrulamak için önemli kanıtlar ortaya koymaktadır. ÇKE teorisine göre, GSYİH arttıkça, emisyon ve kirlilik başlangıçta artar, ancak kişi başına düşen GSYİH belirli bir seviyeye ulaştıktan sonra, eğilim tersine döner ve emisyonlarda azalmaya yol açar. Çalışmamız, AB bağlamında ÇKE hipotezinin geçerliliğini, gelişmiş ve gelişmekte olan üye devletler arasındaki farkları göz önünde bulundurarak göstermektedir. Bulgularımız, gelişmiş ülkelerde, kişi başına düşen daha yüksek GSYİH' nın, ÇKE' nin teknik etki ile post-endüstriyel aşamasına uygun olarak kişi başına düşen karbon emisyonunu azalttığını göstermektedir. Ayrıca, gelişmekte olan AB ülkelerinde ilk ekonomik büyüme aşaması artan emisyonlarla uyumlu olup gelişmekte olan ülkelerin ÇKE teorisinde bahsedilen endüstriyel aşama öncesi veya endüstriyel aşamada olduklarını ve ölçek etkisinin varlığını da göstermektedir. Bu nedenle AB içinde çevresel politikalar uygulanırken ekonomik gelişme aşamasının dikkate alınmasının önemi ortaya çıkmaktadır.

Bu çalışma AB' de çeşitli faktörlerin kişi başına düşen karbon emisyonlarını ve kirlilik seviyesini nasıl etkilediğinin anlaşılmasına katkıda bulunmaktadır. Ayrıca bu çalışmada, gelişmiş ve gelişmekte olan ülkeleri ayrı ayrı analiz ederek, ülke gruplarına özgü zorluklar ve politika ihtiyaçlarına dair faydalı öngörüler sunulmaktadır. Bu bağlamda Panel Vektör Otoregresyon (PVO) modelinin kullanılması da çevresel ekonomi ve politika üzerine mevcut literatüre metodolojik bir katkıdır. Bulgular, özelleştirilmiş politika yaklaşımlarının önemini vurgulamakta ve hem ülkesel hem de AB düzeyinde çevresel zorlukların ele alınmasında sürekli araştırma ve iş birliği çabalarının gerekliliğini göstermektedir.

Ayrıca, çalışmamızın metodolojik katkısı, özellikle kişi başına düşen karbon emisyonu için rassal etkilerle Panel Vektör Otoregresyon (PVO) modelinin seçimi, bulgularımızın derinliği ve doğruluğunda kritik bir rol oynamaktadır. Bu yaklaşım, Avrupa Birliği ülkelerinin çeşitli çevresel ve ekonomik bağlamları göz önüne alındığında özellikle önemlidir. Gözlemlenemeyen heterojenliği ve kesitsel bağımlılıkları da dikkate alarak, model çeşitli bağımsız değişkenlerin etkilerini etkili bir şekilde yakalamaktadır. Bu durum ampirik sonuçlarda da kanıtlanmıştır. Etki tepki analizi, belirli politika önlemlerinin karbon emisyonları üzerinde hemen etki yaratabileceğini ancak uzun vadeli etkilerinin önemli ölçüde değişebileceğini ortaya çıkararak anlayışımızı daha da geliştirmektedir. Bu durum, çevre politikaların sürdürülebilirliği üzerine literatürdeki tartışmayla uyumlu olup bu tartışmayı genişletmektedir. Çalışmamızdaki bulgular, sürekli gelişen çevresel sorunlara yanıt verebilen uyarlanabilir politika çerçevelerinin önemini vurgulamaktadır. Bu tür uyarlanabilir ve ileriye dönük bir perspektif, sadece mevcut çevresel sorunları ele almakla kalmayıp aynı zamanda gelecekteki değişikliklere karşı dayanıklı olacak sağlam stratejiler geliştirmek için esastır. Bu nedenle, çalışmamız sadece AB içindeki çevresel politika etkileri ile ilgili mevcut anlayışa katkıda bulunmakla kalmayıp, aynı zamanda değişen çevresel ve ekonomik koşullara da dinamik olarak uyum sağlayabilecek gelecekteki araştırma ve politika geliştirmeleri için bir temel oluşturmaktadır.

Bununla birlikte gelişmiş Avrupa Birliği ülkelerinde, politikalar giderek yeşil teknolojide yenilik ve katı çevresel standartların uygulanması yönünde ilerlemekte olup, ÇKE' nin teknik etki ile post-endüstriyel aşamasını yansıtmaktadır. Bu durum, 2050'ye kadar iklim tarafsızlığı hedefleyen Avrupa Yeşil Mutabakatı gibi girişimleri de içermektedir. Gelişmekte olan üye devletler için AB'nin odak noktası, ekonomik gelişmeyi çevresel sürdürülebilirlikle dengelemek, yenilenebilir enerji kaynaklarına geçiş için destek sunmak ve kademeli çevresel düzenlemeler uygulamak şeklinde ortaya çıkmaktadır. Bu farklılaşmış yaklaşımlar, ÇKE teorisine uygun olarak, ekonomik gelişme aşamalarının ve buna bağlı çevresel etkilerin farklı olduğunu kabul etmektedir. AB'nin politika çerçevesi, üye ülkelerinin farklı ihtiyaçlarını anlama yeteneğini göstermekte ve ekonomik kalkınma politikalarını desteklerken emisyonları kolektif olarak azaltmayı hedeflemektedir.

Genel olarak, çalışmamızın bulguları, Paris Anlaşması ve Sürdürülebilir Kalkınma Hedefleri (SKH' lar) ile de önemli ölçüde uyum içindedir. Paris Anlaşması'nın sera gazı emisyonlarını azaltmak için bireyselleştirilmiş ulusal taahhütler üzerine vurgusu, çalışmamızın Avrupa Birliği üye devletlerinde özelleştirilmiş çevresel politikalar için önerileriyle uyumluluk göstermektedir. Analizimiz gelişmiş ve gelişmekte olan ülkelerde farklılaşmış stratejilerin gerekliliğini özellikle vurgulamaktadır. Bu durum Paris Anlaşmanın ortak ancak farklılaştırılmış sorumluluklar ilkesini de yansıtmaktadır. Ayrıca, çalışmamızın sürdürülebilir ekonomik gelişme, teknolojik yenilik ve etkili kentleşme politikaları üzerine de odaklanması, SKH 7 (Uygun Fiyatlı Temiz Enerji), SKH 11 (Sürdürülebilir Şehirler ve Topluluklar) ve SKH 13 (İklim Eylemi) gibi birçok SKH' ya doğrudan katkıda bulunmaktadır. Çalışmamızın ampirik sonuçları ve literatür taraması, bu hedeflere ulaşmanın, çevresel vergiler ve yenilenebilir enerji tüketimi gibi politikaların çeşitli etkileri göz önünde bulundurularak, çok yönlü bir yaklaşım gerektirdiğini öne sürmektedir. Bu durum ekonomik büyüme ile çevresel korumayı dengeleyen sürdürülebilir kalkınma vizyonuyla uyumludur. Ayrıca, çalışmanın doğal kaynakların etkili kullanımı ve yenilikçi çevresel teknolojilerin teşvik edilmesine vurgu yapması, SKH 9 (Sanayi, Yenilik ve Altyapı) hedefini de desteklemektedir. Ayrıca, çalışmamızın sonuçları gelecekte uygulanacak politikaların, etkili olması için gelişen iktisadi yapıya ve teknolojik ilerlemelere uyum sağlayacak şekilde dinamik olması gerektiğini öne sürmektedir. Bu çalışma, bu nedenle sadece akademik literatüre katkıda bulunmakla kalmayıp aynı zamanda ülkesel ve bölgesel politikaları küresel çevresel taahhütlerle uyumlu hale getirmeye çalışan politika yapıcılar için önemli çıkarımlar sunmaktadır.

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