ASSESSING THE ENVIRONMENTAL IMPACT OF ENERGY IN THE EUROPEAN UNION-27 COUNTRIES: THE STIRPAT MODEL ANALYSIS FOR THE PERIOD 2000-2019

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submitted by **TAHA MERVAN DEMET** in partial fulfillment of the requirements for the degree of **Master of Science in Economics, the Graduate School of Social Sciences of Middle East Technical University** by,

Prof. Dr. Sadettin KİRAZCI
Dean
Graduate School of Social Sciences

Prof. Dr. Dürdane Şirin SARAÇOĞLU
Head of Department
Department of Economics

Prof. Dr. Gül İpek TUNÇ
Supervisor
Department of Economics

Examining Committee Members:

Prof. Dr. Elif AKBOSTANCI ÖZKAZANÇ (Head of the Examining Committee)
Middle East Technical University
Department of Economics

Prof. Dr. Gül İpek TUNÇ (Supervisor)
Middle East Technical University
Department of Economics

Prof. Dr. Ayşen SİVRİKAYA
Hacettepe University
Department of Economics

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Taha Mervan DEMET

Signature:

ABSTRACT

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DEMET, Taha Mervan
M.S., The Department of Economics
Supervisor: Prof. Dr. Gül İpek TUNÇ

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As a global leader in environmental protection policies, the European Union has placed great emphasis on reducing CO_2 emissions, which is the primary contributor to climate change. To achieve this, it has made a strong effort to align its energy policies with its environmental policies. Focusing on the EU's directives in its energy policy, this study attempts to reveal the factors contributing to CO_2 emissions in the EU-27 for the period 2000-2019 within the framework of STIRPAT model. Employing the fixed effects model with Driscoll and Kraay standard errors, this study reveals that the impacts of population growth, financial development, and energy intensity on CO_2 emissions are positive while the impacts of renewable energy consumption and energy-related tax revenue on CO_2 emissions are negative in the EU-27.

Keywords: CO_2 emissions, Energy, Environment, Environmental Impact Analysis, STIRPAT Model

ÖZ

AVRUPA BİRLİĞİ-27 ÜLKELERİNDE ENERJİNİN ÇEVRESEL ETKİLERİNİN DEĞERLENDİRİLMESİ: 2000-2019 DÖNEMİ İÇİN STIRPAT MODEL ANALİZİ

DEMET, Taha Mervan
Yüksek Lisans, İktisat Bölümü
Tez Yöneticisi: Prof. Dr. Gül İpek TUNÇ

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Çevre koruma politikalarında küresel bir lider olan Avrupa Birliği (AB), iklim değişikliğinin başlıca nedeni olan CO_2 emisyonlarının azaltılmasına büyük önem vermektedir. Bu doğrultuda enerji politikalarını çevre politikalarıyla uyumlu hale getirmek için yoğun çaba sarf etmektedir. AB'nin enerji politikasındaki direktiflerine odaklanan bu çalışma, STIRPAT modeli çerçevesinde 2000-2019 dönemi için AB-27'de CO_2 emisyonlarına katkıda bulunan faktörleri ortaya koymaya çalışmaktadır. Driscoll ve Kraay standart hatalar ile sabit etkiler modelinin kullanıldığı bu çalışma, AB-27'de nüfus artışı, finansal gelişme ve enerji yoğunluğunun CO_2 emisyonları üzerindeki etkilerinin pozitif, yenilenebilir enerji tüketimi ve enerji vergisi gelirlerinin CO_2 emisyonları üzerindeki etkilerinin ise negatif olduğunu ortaya koymaktadır.

Anahtar Kelimeler: CO_2 emisyonu, Enerji, Çevre, Çevresel Etki Analizi, STIRPAT Modeli

To My Family

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LIST OF ABBREVIATIONS

CO_2	Carbon Dioxide
ECSC	European Coal and Steel Community
EEC	European Economic Community
ETS	European Emissions Trading Scheme
EU	European Union
FEM	Fixed Effects Model
GHG	Greenhouse Gas
GLS	Generalized Least Squares
IPAT	Impacts, Population, Affluence and Technology
IPCC	Intergovernmental Panel on Climate Change
NDCs	Nationally Determined Contributions
POLS	Pooled Ordinary Least Squares
REM	Random Effects Model
SEA	Single European Act
STIRPAT	Stochastic Impacts by Regression on Population, Affluence, and Technology
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change
VIF	Variance Inflation Factor

CHAPTER 1

INTRODUCTION

There has been a growing concern about climate change and global warming resulting from environmental degradation by human activities since their impacts have increasingly threatened the world and humanity. For this reason, a thorough understanding of the factors causing environmental degradation is necessary. Among these factors, carbon dioxide (CO_2) emissions are the major contributor to environmental degradation and, consequently, climate change and global warming. Therefore, CO_2 emissions have become a critical environmental investigation issue. According to the latest IPCC’s Synthesis Report: Climate Change (2023), limiting human-caused global warming requires net zero CO_2 emissions arising from anthropogenic activities since global surface temperature in the first two decades of the 21st century was 0.99°C higher than 1850-1900. In this sense, analyzing the determinants of CO_2 emissions, has vital importance as it will enable the development of effective strategies and policies to address the main drivers of CO_2 emissions.

The European Union (EU) has historically been a global leader in international environmental efforts. It has exhibited a steadfast commitment to implementing various policies and regulations to address environmental challenges. Reducing CO_2 emissions has been a paramount objective of its environmental agenda, and it has made a strong effort to achieve this. Since the energy sector plays a pivotal role in driving CO_2 emissions the EU has prioritized the energy policies to realize this objective. Three key directives have emerged as the guiding principles for the EU member countries within the framework of the EU’s energy policies. These directives, namely the Renewable Energy Directive, Energy Efficiency Directive, and Energy Taxation Directive, have essential roles in harmonizing energy and environmental policies in the EU. In this context, this study focuses mainly on examining the impact of energy related variables namely renewable energy consumption, energy intensity, and energy-related tax revenue on CO_2 emissions to investigate the environmental impact of the three energy-related directives in the EU. For this purpose, the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model, which is widely used in environmental impact analysis studies, is employed in this study.

Specifically, the main objective of this thesis is to analyze the impact of factors that are subject to the Renewable Energy Directive, Energy Efficiency Directive, and Energy Taxation Directive on the CO_2 emissions in the EU-27[1] over the period 2000-2019 by using the STIRPAT model framework. This thesis aims to contribute to the literature on environmental impact analysis in a few ways. First, this thesis is significant for evaluating the progress made in the EU's energy policies to reduce CO_2 emissions since, to our knowledge, there is no study addressing the impact of the EU's energy policies on carbon emissions through these three directives together. Second, this study is creditable since the application of the STIRPAT model for environmental impact analysis in the EU is limited to a few studies. Third and last, energy related tax is included in the environment impact analysis applying the STIRPAT model for the first time with this study.

The remainder of this thesis is organized as follows: After the introduction, the second chapter examines the environment and energy policies of the EU from a historical perspective. In this chapter, the historical development of the EU's environmental policies to reduce CO_2 emissions is discussed by providing information about the initiatives, agreements, and milestones chronologically. In the next section the energy policies, which have been shaped in line with environmental policies, are discussed mainly by focusing on the Renewable Energy Directives, Energy Efficiency Directives, and Energy Taxation Directives.

The third chapter provides a literature review to give background about the findings of the previous studies. In the first section of this chapter, studies employing the

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[1] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden

STIRPAT model are analyzed. In the second section, the studies using renewable energy, energy intensity or energy-related tax variables in their models are reviewed. In addition, the literature gap is addressed and the contribution of this thesis to the literature is highlighted at the end of this chapter. The fourth chapter expounds the data and the model used in this study. This chapter first focuses on the STIRPAT model, which constitutes the theoretical framework of this study. Development of the STIRPAT model and its components are indicated. Afterwards, the selection of the variables in the model and the reasons are explained. Finally, in this chapter, the data set, model specification, and econometric methodology used in this study are explained.

The fifth chapter presents the empirical results of our analysis with the STIRPAT model framework. This chapter reveals the environmental impact of the population, affluence and technology in the EU-27 over the period 2000-2019. Subsequently, the findings obtained from the analysis is evaluated and interpreted in this chapter.

The sixth and final chapter concludes this study. This chapter overviews this study and makes an overall assessment on the findings of the study.

CHAPTER 2

ENVIRONMENT AND ENERGY POLICIES OF THE EUROPEAN UNION IN A HISTORICAL PERSPECTIVE

This chapter examines critical historical periods, showing how the EU environmental policies, and energy policies within environment considerations have gone from their initial stages to an advanced framework today. Initially established as an economic cooperation in the wake of the devastating war, the formation of the European Union marked the beginning of a transformative era characterized by cooperation, integration, and shared responsibility for economic growth. Over the decades, in view of a growing awareness of the environment, the EU's environmental policies have evolved into systematic strategies. Looking back on history, we encounter many important milestones that shaped the EU policy frameworks for environmental protection and emissions reduction. This chapter looks at transformation process in the EU's environmental and energy policies with a particular focus on emissions reduction.

This chapter is divided into two distinct but interconnected sections. In the first section, the historical process of the EU’s environmental policy and its efforts to reduce emissions is explored by looking at the initiatives, agreements, and milestones that define the EU's path to tackle climate change on a global scale. Subsequently, the second section analyzes how the EU’s energy policies have been affected by the EU's changing environmental policies and the changing international agreements.

2.1. Overview of the EU’s Historical Environmental Policy and Emission Reduction Initiatives

After the World War II, boosting economic growth was prioritized in Europe because of the need for reconstruction and economic recovery. The European Coal and Steel Community (ECSC), the first European Community, was established in 1951 to regulate the supply and use of coal, which was Europe’s most important energy source, and steel. In the ECSC, the focus was energy policies, and the environmental cost of these products was not considered. Similarly, the Treaty of the European Economic Community (EEC), which came into force with the Treaty of Rome in 1958, was based on economic cooperation and competitiveness and did not include any environmental regulation. These treaties, which formed the basis of the EU, did not contain any provisions regulating environmental issues since environmental concerns did not gain much attention at that time. Furthermore, during this period, Europe's rapid expansion of industrialization further increased oil demand, and it caused Europe’s oil imports from Middle Eastern countries to rise. Due to the predominant use of coal and oil as energy sources during the 1950s and 1960s, the environment was significantly damaged.

Recognizing the severe consequences of neglecting the environmental impact of economic growth, awareness regarding the environmental costs of economic growth increased in the 1970s. The questioning of the approach based on economic growth with the use of fossil energy resources at high levels, led to the issue being addressed at the international diplomacy level. The United Nations (UN) held the Conference on the Human Environment in Stockholm in 1972, bringing together many countries for the first time with an environmental agenda. This was the first conference of the UN's on international environmental issues that emphasized the necessity of environmentally sustainable development policies. This conference was a turning point in the development of international environmental politics. As a result, "the environment" became one of the key topics on the global agenda from that time onwards. The Conference brought attention to the need to harmonize development with environmental considerations, setting the stage for increased worldwide awareness and action on environmental issues.

Environmental issues coming to the fore with the Stockholm Conference became the focus of controversies in the 1970s and 1980s. Adopting the Single European Act was the starting point for the legal environment policies of the EEC with a comprehensive approach. Afterward, from that time to present, there have been many agreements, treaties, initiatives, etc., within Europe and internationally that have shaped the environmental policies of the EU. In the following part of this section, we examine the milestones that have shaped the EU's environmental and emission reduction policies.

2.1.1. The Single European Act

As a turning point in the environmental policy in Europe, the Single European Act (SEA) was signed on February 17, 1986, and it entered into force on July 1, 1987. The SEA aimed to seek to revise the Treaty of Rome by giving a new impetus to European integration and establishing the internal market with the free movement of goods, people, services, and capital (EUR-Lex, 2018). Although the main aim of SEA was to set up an internal market and improve Europe's integration, it was of great importance as it was the first Treaty that determined the EEC’s environmental policies. The SEA marked that environmental policy was included in the primary legislation of the EEC for the first time. To establish an explicit legal basis on which the approach was based, SEA included environmental policies within the Treaty structure of the EEC (Damro et al., 2008). With Article 25 of the SEA, a new chapter on “environment” was added to Article 130 of the EEC Treaty. The EEC’s environmental policy was regulated under Title VII of the Single European Act. In the related article under this title, it was stated that the objective of the Community is to preserve, protect and improve the quality of the environment, to contribute towards protecting human health, and to ensure prudent and rational utilization of natural resources. To achieve these objectives, it was stated that environmental protection requirements should be a component of the Community’s other policies (Single European Act, 1986). Thus, the environment was included in the common policies and legislation of the Community as a critical element.

2.1.2. The Maastricht Treaty

Providing for the transition from the Community to the European Union, The Maastricht Treaty was signed on February 7, 1992, and entered into force on November 1, 1993. One of the objectives of this Treaty was to strengthen environmental policies. With this Treaty, which was the instituter of the European Union, it was stated that all policies under the Union should integrate environmental protection (Treaty on European Union, 1992). The importance of this Treaty for the environment was that it incorporated the environmental objectives into the EU’s common policy area. It was envisaged that the environment must be considered in the decisions taken by the EU on different issues. Considering environmental values and concerns in all sectoral policies, such as energy, trade, industry, etc., was emphasized as an essential aspect of the Union's environmental policies. Also, emphasizing environmentally sensitive economic growth, the concept of "sustainability" was introduced for the first time in the context of the Union’s environmental policies.

2.1.3. The United Nations Framework Convention on Climate Change

At the international level during this period, the United Nations conducted studies to analyze climate change and evaluate the measures to be taken. As a result of these studies, United Nations Framework Convention on Climate Change (UNFCCC) was ratified by 196 countries, including the European Union countries. It was adopted on May 9, 1992, and entered into force on March 21, 1994. It was the first significant international step against the impacts of global warming caused by human activities. The ultimate objective of this Convention, as stated in Article 2 of the Convention, was to achieve stabilization of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (UNFCCC, 1992). The Convention has played a crucial role in shaping international discussions on climate change and supporting global corporations in accordance with the principle of "common but differentiated responsibilities and respective capabilities,” based on the premise that it would be appropriate for countries to participate in the global effort to reduce GHG emissions within their socio-economic conditions. Thus, some countries, including most of the EU countries, were made to take more responsibility since they emitted more greenhouse gases into the atmosphere than other countries, which caused climate change after the Industrial Revolution.

This Convention has provided a framework for member countries to cooperate on reducing GHG emissions and adapting to the effects of climate change. It has served as a guiding principle for other negotiations. The EU has a strong and influential role in the UNFCCC. It is the most important decision-maker within the framework of the UN Framework Convention. The UNFCCC has two implementation instruments: the Kyoto Protocol, signed at the 3rd Session of the Conference of the Parties (COP 3), and the Paris Agreement, signed at the 21st Session of the Conference of the Parties (COP 21).

2.1.4. Kyoto Protocol

As a result of negotiations among countries in response to the continued increase in GHG emissions on a global scale and concerns about climate change, the Kyoto Protocol was adopted on December 11, 1997, and entered into force on February 16, 2005. It served as the first implementation agreement under the UNFCCC, and it was a major achievement in the international negotiations on climate change, opening the way for subsequent agreements.

The Kyoto Protocol was divided into two commitment periods. The first period of the Protocol covered years 2008- 2012 and the second period covered years 2013-2020. However, the second commitment period was only formally accepted since it came into force on December 31, 2020, after the Paris Agreement came into effect. Therefore, it could be argued that the Kyoto Protocol fulfilled its function.

With Kyoto Protocol, countries agreed to reduce emissions of six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). It set legally binding specific emissions reduction targets for countries in the commitment for these greenhouse gases. When setting targets in the Treaty, countries were divided into two classes: developed countries and developing countries. Only developed countries, referred to as Annex 1 Countries in the UNFCC, had been obliged to reduce the rate of these gases they emit into the atmosphere by at least 5% below 1990 levels between 2008 and 2012 since it was accepted that developed countries are largely responsible for high GHG emissions in the atmosphere historically. Therefore, a heavier burden was placed on these countries under the principle of "common but differentiated responsibility and related capabilities." Having a historical responsibility for the emissions in the atmosphere due to their industrialization and economic development, the European Union committed to a target of reducing its emissions by 8% compared to 1990 levels during the first period. However, this target was not for each member of the EU. The EU set different targets for each of its member states based on a burden-sharing agreement, with an average of 8% target for emission reduction. In the following years, the EU expanded with the joining of Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia in 2004; Bulgaria and Romania in 2007; and Croatia in 2013. For these countries, independent emission reduction targets were set. Also, some countries, including Bulgaria, Hungary, Poland, and Romania, had a base year that was different from 1990. The emission reduction targets of countries were summarized in Table 1 below:

Table 1. Individual Targets of the EU Countries for the Period of 2008-2012

EU-15 Member States (EU pre-2004)	Targets (% change from 1990)	EU Member States that joined in 2004, 2007, 2013	Targets (% change from 1990 unless individual base years)
Austria	-13	Bulgaria (base year 1988)	-8
Belgium	-7.5	Croatia	-5
Denmark	-21	Cyprus	no target
Finland	0	Czech Republic	-8
France	0	Estonia	-8
Germany	-21	Hungary (base year 1987)	-8
Greece	+25	Latvia	-8
Ireland	+13	Lithuania	-8
Italy	-6.5	Malta	no target
Luxembourg	-28	Poland (base year 1988)	-6
Netherlands	-6	Romania (base year 1989)	-8
Portugal	+27	Slovakia	-8
Spain	+15	Slovenia	-8
Sweden	+4		
United Kingdom	-12.5		
EU-15	**-8**		

Source: Climate Policy Info Hub

To achieve the reduction commitments and to promote sustainable development, it was asserted in Article 2 of the Treaty that policies should be implemented and elaborated in accordance with the national circumstances of countries such as enhancement of energy efficiency; promotion of sustainable forest management; promotion of sustainable forms of agriculture; research and development; increased use of renewable energy; progressive reduction in fiscal incentives, tax and duty exemptions and subsidies in all GHG emitting sectors; encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures that limit or reduce emissions of GHG; limitation and/or reduction of emissions in the transportation sector; limitation and/or reduction of emissions through recovery and use in waste management, as well as in the production, transport, and distribution of energy (Kyoto Protocol,1997).

2.1.5. The Lisbon Strategy

Mainly, as a result of the awareness of the EU to keep up with the process of globalization with constantly developing technological advances and increasing competition, the EU adopted the Lisbon Strategy on March 23-24, 2000. With this strategy, the EU aimed “to become the most dynamic and competitive knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the environment.” (Rodriguez et al., 2010). This Strategy was founded on economic, social, and environmental pillars. The environmental pillar stressed that economic growth must be based on the balanced use of natural resources. For the goal of a more environmentally sustainable future, the Lisbon Strategy addressed climate change, ensuring sustainable use of natural resources and progress in achieving targets of the Kyoto Protocol. Also, the Lisbon Strategy stipulated that the EU could cooperate with other states or international organizations to address environmental problems since the fact that environmental problems could not be solved by a single international organization.

2.1.6. European Climate Change Programme

Another development in the year 2000, the European Climate Change Programme was launched with the aim of developing a common and coordinated strategy to achieve the targets of the Kyoto Protocol and examining a broad range of policy areas and instruments that could provide reduction in GHG emissions. This Program, which aimed a very inclusive climate change, focused on a wide range of issues such as energy demand management, renewable energy, and GHG emission reduction. It was emphasized that the environment and energy resources must be protected, and sustainable development must be ensured to prevent climate change. With this program, European Emissions Trading Scheme (ETS) was introduced. As the most cost-effective solution for reducing emissions, ETS has been a crucial tool in the implementation of the EU's environmental policy strategy. ETS is based on the “cap and trade system.” According to this system, each country sets the maximum amount of certain emissions for the enterprises operating on its territory during a certain period within the limits set by the European Commission. If the enterprises do not exceed this maximum amount, they can sell their remaining rights to others. The basic logic of the system is to limit emissions and control this process through a market at the EU level.

2.1.7. Europe 2020 Strategy

Facing the global financial crisis in 2007-2008, the EU arranged a policy called “The Europe 2020 Strategy” to help the EU recover from the crisis and overcome the structural weaknesses that emerged from the crisis. This strategy had three priorities: smart growth, with developing an economy based on knowledge and innovation; sustainable growth, with promoting a more resource-efficient, greener, and more competitive economy; inclusive growth, fostering a high-employment economy delivering social and territorial cohesion (European Commission, 2010).

In this Strategy, the leading role of the EU in international climate protection was underlined. It stressed the requirement of international collective action for the implementation of effective, efficient, and equitable responses to address climate change issues (Council of the European Union, 2007).

One of the ambitious targets in this Strategy was related to the environment, and a major step forward was made for the climate policy of the EU. The EU adopted a new environmental target which is even more ambitious than the targets of the Kyoto Protocol. This Strategy set a target for reduction of GHG emissions by at least 20% compared to 1990 emissions.

Subsequently, the EU published a resolution on climate change called “Limiting Global Climate Change to 2 degrees Celsius: The way ahead for 2020 and Beyond” in 2007. With this resolution, it was proposed that the EU could pursue a 30 % reduction in GHG emissions by developed countries by 2020 compared to 1990 levels in the context of international negotiations. It stressed the necessity of emission reduction to limit the global temperature increase to 2°C compared to the pre-industrial revolution period. Therefore, it emphasized that global emissions must be decreased up to 50 % compared to 1990, and to achieve this, 60-80 % of emissions reduction in developed countries and significant emissions reduction in many developing countries must be realized (Commission of the European Communities, 2007).

2.1.8. European Union long-term emission reduction targets for 2030 and 2050

In 2011, the EU published “A Roadmap for Moving to a Competitive Low Carbon Economy in 2050” to set a comprehensive guide for the EU's efforts to achieve a sustainable, low-carbon economy over the long term. With this document, the EU committed the reduce emissions to 80-95% below 1990 levels by 2050 to keep climate change below 2ºC. Also, in this roadmap, the intermediate target was set for emission reduction. According to this, 40% domestic reduction of emissions compared to 1990 as a milestone for 2030 would be necessary to reach 2050 goals (European Commission, 2011a). In line with this target, the EU adopted a “2030 Climate and Energy Framework” in 2014. This framework set a target of at least 40% cut in emissions from 1990 levels for the year 2030.

2.1.9. Paris Agreement

After, the 1997 Kyoto Protocol, efforts to reach a global consensus on climate change prevention continued. As a result of these efforts, Paris Agreement was adopted at the 21st Conference of the Parties of UNFCCC held in Paris, France, on December 12, 2015, and entered into force on November 4, 2016. The EU's commitment to ambitious climate action contributed to the negotiation of this agreement, which formed the framework for the international climate change regime after 2020.

The Paris Agreement aimed to strengthen the global response to the threat of climate change in the context of sustainable development and set targets in the Article 2 as holding the increase in global warming to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels; increasing the mitigation of climate change and encouraging low GHG emissions; making financial flows towards low GHG emissions and climate-resilient development (Paris Agreement, 2015). According to the Agreement, climate change and its negative impacts could be significantly reduced if the temperature increase is kept at targeted levels. In line with this target, for the first time, all countries on a global scale have agreed to make plans to reduce their emissions of greenhouse gasses after 2020.

According to Paris Agreement, the legally binding global climate change agreement, each participating country must submit its voluntary climate action plan, known as the Nationally Determined Contributions (NDCs). NDCs are key components of the Paris Agreement and the path of its long-term goals. These contributions are determined by each country based on their own national circumstances and capabilities based on the principle of "common but differentiated responsibilities and respective capabilities." NDCs outline countries' specific targets and lay out the nations' efforts to cut GHG emissions. According to this agreement, NDCs should be revised and submitted every five years to UNFCC. In this way, the activities of countries could be monitored to check whether the parties to the agreement fulfill their obligations fully.

The EU committed to reduce CO_2 by at least 40% by 2030, compared to 1990 levels. The member states of the EU did not commit their NDCs individually since they collectively submitted their NDCs in Paris Agreement.

2.1.10. The European Green Deal

On November 28, 2019, the European Parliament declared a climate emergency in Europe and emphasized the urgent need to counteract the climate crisis globally. This declaration emphasized the severity of the situation and the impending danger the world is facing. It was a call as a response to growing concerns about the escalating catastrophic effects of climate change and the requirement for immediate and more ambitious measures to mitigate its effects. With this declaration, the EU updated its goal to limit global warming levels from 2° C determined previously in the Paris Agreement to under 1.5° C. The declaration also stressed the significance of international cooperation to solve the climate crisis emergency. It asked other countries to mobilize support for stronger climate policies and measures and quick action to decrease GHG emissions. After the announcement of climate emergency, the EU announced a comprehensive policy framework known as the European Green Deal on December 11, 2019, as the new roadmap of the Paris Climate Agreement. It aimed to transform the EU into a fair and prosperous society with a modern, resource-efficient, and competitive economy where there would be no net emissions of greenhouse gases in 2050 (European Commission, 2019). With the Green Deal, the European Commission updated its target of reducing GHG emissions by raising from 40% to 55% by 2030 compared to 1990 levels.

European Green Deal has served as a roadmap for the EU strategy for a green transition, i.e., the transformation of Europe to become the first climate-neutral continent by 2050. The roadmap has set out an EU strategy for attaining climate neutrality and transform into a sustainable economy. To achieve this, Green Deal has brought together different sectors and policy areas. European Green Deal is the most ambitious European effort yet, promising to completely transform the EU market and society over the next 30 years (Mihalakas & Hyde, 2020).

To put the Green Deal on a legal basis, the European Climate Law was proposed by the Commission. It was officially adopted by the European Parliament and the Council of the EU and entered into force on July 29, 2021. The European Climate Law legalizes the EU's climate objectives and obligations. It is a landmark legislation that further strengthens the EU's commitment to address climate change. It creates a strong legislative framework for action on climate change through enshrinement in the law of carbon neutrality and significant emission reduction targets. It legally binds the EU to achieve climate neutrality by the year 2050, with a minimum intermediate goal of a 55% decrease in GHG emissions by 2030 compared to 1990 levels.

To conclude, in this section, the evolution of the EU's environmental policies was examined by outlining crucial milestones that shaped these policies. The EU's policy transformed from an era of economic growth-based, which took precedence over environmental considerations, to sustainable growth-based considering the environment with a strong commitment to global leadership to reduce emissions. As a result of these policies, the EU has managed to significantly reduce its emissions as we can see in Figure 1.

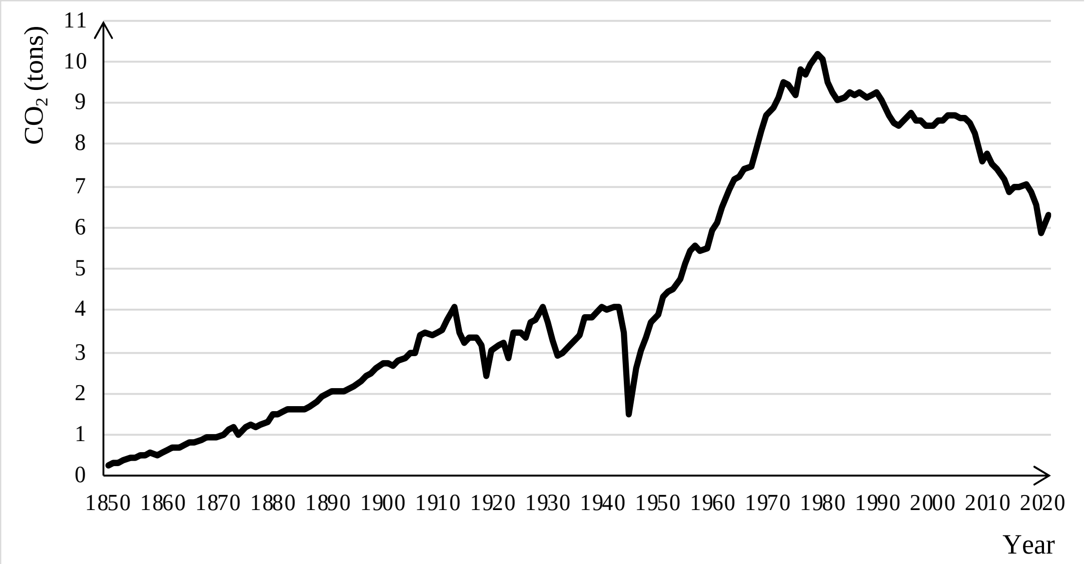

Figure 1. Annual CO_2 emissions per capita in the EU

Source: Our World in Data

This graph shows the annual CO_2 emissions per capita in tons in the EU-27 countries from 1850 to 2020. The amount of CO_2 emissions shows a steady increase from 1850 until World War II, with occasional decreases. However, after the War, from the 1950s to the 1980s, carbon emissions per capita started to increase dramatically.

This is an indication that the EU policies during this period did not consider the environment. As a result, the environment suffered a significant damage during this period. Since the 1980s, when the EU's environmentally conscious policies put into force, its emissions have been on a downward trend.

Especially since the 2000s, this downward trend has become more pronounced by achieving a greater reduction in carbon emissions compared to previous years. Even if carbon emissions per capita are still high, this downward trend can be interpreted as a success of the EU's environment and carbon emission reduction policies.

The following section examines the EU's energy policy in the historical nexus with its environment policy. As a matter of fact, while implementing its environmental policies, the EU has given great importance to the energy field by prioritizing it. The following section will aim to shed light on how environmental and energy policies have complemented each other over time by examining their historical development and interconnections. In this study, we employed the energy-related variables as key factors to explain the carbon emissions. Therefore, we address changes in the energy policies of the EU as well as its environmental policies.

2.2. Overview of the EU's Energy Policy in the Historical Nexus with Environment Policy

There are many sectors that cause environmental degradation by increasing emissions. However, energy ranks first among them. The amount of GHG released into the atmosphere during energy production and consumption is very high. 75% of the total emissions in the EU are attributed to the energy sector (European Commission, 2019). In this sense, energy and climate change policies have an integrated structure, and a common regulation in both areas makes sense because of the significant contribution of the energy sector to emissions.

The environmental aspect was not a priority in the EU's energy policies before the 1990s. In this period, the EU's energy policies focused more on factors such as energy security, competitiveness, and economic growth. The EU started to adopt environmental issues in its energy policies more prominently towards the end of the 1990s. In 1995, “The Green Paper on Energy Policy for the European Union” and “The White Paper on Energy Policy for the European Union”, of great importance regarding energy and environment policies for the EU, were published by the European Commission. The Green Paper was published with the aim of determining the new targets of the EU in energy policies and preparing a road map by gathering opinions and suggestions from stakeholders and the public. It was an instrument of consultation, which the European Commission released for public debate on specific policy issues. Its objectives were to describe the EU's energy policy goals and deal with industry challenges while taking environmental issues into account. It emphasized the significance of making the shift to a more ecologically friendly and sustainable energy system. Based on the input provided during the consultation phase of the Green Paper, White Paper was a comprehensive policy document that outlines the long-term energy strategy of the EU within the frame of concrete proposals and political recommendations. These documents contributed significantly to the formulation of the EU’s energy policies, support sustainable energy practices, and reduce GHG emissions in the EU.

Especially since the beginning of the 2000s, the EU has started to adopt environmental-based approaches in its energy policies more strongly, and it has taken important steps by placing environmental sustainability at the center of energy policies. During this period, the EU has issued directives on energy efficiency, renewable energy, and energy taxation to implement energy policies by setting concrete targets, which have facilitated an accelerated energy transformation process. Targets set on issues such as increasing energy efficiency, promoting renewable energy sources, and reducing emissions have become the main pillars of the EU's environmental and energy policies. Within this framework, the European Union's efforts towards a new energy future are marked by its role as a global leader on climate change.

In 2001, the EU adopted a directive (Directive 2001/77/EC) with the purpose of promoting an increase in the contribution of renewable energy sources to electricity production in the internal market for electricity and to create a basis for a future

Community framework (European Parliament, 2001). This Directive set a target of 12% share of renewable energy in gross domestic energy consumption of the EU by 2010, in line with the White Paper. According to this Directive, member states of the EU were required to establish their national targets and implement measures to promote the use of renewable energy sources. In 2003, the EU adopted two more directives on energy. The first one (Directive 2003/30/EC) was about the promotion of use of biofuels or other renewable fuels for transportation. This directive emphasized that the transportation sector accounted for more than 30% of final energy consumption, with an upward trend resulting in increasing CO_2 emissions. The directive set an initial target as 2% share of biofuels in the overall fuel consumption in transportation of each member state by the end of 2005; and 5% by the end of 2010 (European Parliament, 2003a). The second directive (Directive 2003/96/EC) was on a framework for the taxation of energy products. This Directive had two main objectives, which were the harmonization of energy taxation across the EU members and the achievement of environmental protection. In this direction, this Directive stated that exemptions or reductions in the level of taxation to environmentally friendly energy products and renewable energy should be implemented (European Parliament, 2003b). In 2006, the EU adopted a directive (Directive 2006/32/EC) on energy end-use efficiency and energy services. The main objective of this Directive was to promote energy efficiency across the EU. This Directive highlighted the difficulty of realization of Kyoto commitments under the increasing trend of carbon emissions and announced the need for improved energy efficiency and promotion of the production of renewable energy for the prevention of dangerous climate change resulting from emissions. According to this Directive, each member state was obliged to draw up programs and measures to improve energy efficiency to achieve UNFCCC's long-term objective of stabilizing the emissions in the atmosphere at a level that prevents climate change danger (European Parliament, 2006). The Directive set 9% indicative target for energy efficiency improvement by 2016 compared to the business-as-usual scenario for the member states.

The Treaty of Lisbon was signed on December 13, 2007, and entered into force on December 1, 2009. This Treaty had an important place in the field of energy in the

EU since the founding treaties of the EU did not provide any specific provision on EU energy intervention before the Lisbon Treaty. Henceforth, this Treaty introduced a specific legal basis in the field of energy (EUR-Lex, 2010). In Article 194/1 of the Treaty, the goals and objectives of the EU's energy policy were outlined to ensure the functioning of the energy market, security of energy supply, promotion of energy efficiency and energy saving, the interconnection of energy networks with regards to the need to preserve and improve the environment and development of new and renewable forms of energy (Treaty of Lisbon, 2007). These goals and objectives are binding on member countries of the EU.

In the Climate and Energy Package introduced in 2008, known as the 20-20-20 package, in addition to the 20% carbon emissions reduction target, there were also two targets: 20% improvement in energy efficiency and 20% share of renewable energy in the total energy consumption by 2020. This package showed that the EU has been addressing energy and climate change policies within an integrated structure. Based on the Climate and Energy Package, Renewable Energy Directive (Directive 2009/28/EC), repealing Directive 2001/77/EC and Directive 2003/30/EC was adopted in 2009. This Directive laid emphasis on the use of energy from renewable sources, together with increased energy efficiency, which constituted an important part of the package to reduce emissions. Complying with the Kyoto Protocol and the UNFCCC, the EU established a mandatory national target for the share of renewable energy in the final energy consumption of the EU. According to this Directive, in line with the strategy, 20% share of the EU’s final energy consumption must have come from renewable energy sources by 2020 (European Parliament, 2009).

In 2011, the European Commission published the "Energy Roadmap 2050" in line with the “A Roadmap for Moving to a Competitive Low Carbon Economy in 2050” published in 2011 for the EU’s low-carbon economy target over the long term. It set out in detail the EU’s long-term goals for energy and climate policy until 2050. With a view of ensuring the sustainability, safety, and affordability of energy systems within the EU, this roadmap intended to tackle climate change. In this document, it was stated that if Energy 2020 goals in the climate and energy package in 2007 were to continue at the same pace, it would just help to reduce emissions by about 40% by

2050, and this would not be sufficient to achieve emissions reductions in the long run. With this document, the EU committed to reduce emissions to 80-95% below 1990 levels by 2050. It emphasized the importance of energy-related emissions' share in the total emissions and described the energy sector as the lion's share of man-made emissions (European Commission, 2011b). In accordance with the Energy Roadmap 2050, Energy Efficiency Directive (Directive 2012/27/EU), repealing Directive 2006/32/EC, was adopted in 2012. This Directive aimed to promote energy efficiency across various sectors of the EU economy, considering climate change mitigation. The EU established a legal framework to promote energy efficiency to reduce emissions from the energy sector by setting a binding energy efficiency target of saving 20% of the EU's energy consumption by 2020. According to this Directive, member states were required to develop their national energy efficiency plans in various energy sectors (European Parliament, 2012).

With the "2030 Climate and Energy Framework" released in 2014, in addition to the target of at least 40% cuts in emissions from 1990 levels, 27% share for renewable energy, and 27% improvement in energy efficiency for the year 2030, targets were set.

Aiming for a low-carbon, sustainable and climate-friendly economy, the EU published "A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy" on February 25, 2015. The Energy Union aimed to bring energy and climate actions in relevant policy areas together across Europe. It focused on five main aims of the energy policy, which were ensuring energy security, solidarity, and trust through cooperation among the EU countries; ensuring the internal energy market; improving energy efficiency; decarbonizing the economy and moving towards a low-carbon economy in line with the Paris Agreement; promoting research and innovation for transition into low-carbon and clean energy technologies (European Parliament, 2015). The current European energy policy is based on the Energy Union strategy (Ciucci, 2023). One of the notable outcomes of the Energy Union was the announcement of the "Clean Energy for All Europeans" package. This package aimed for the EU to lead the global energy transition. To meet its NDCs under the Paris Agreement, this significant legislative package was adopted by the EU in 2018. Also, the EU revised the targets set in Climate and Energy Framework in 2014. As part of the "Clean Energy for all Europeans" package, both the Renewable Energy Efficiency Directive and Energy Intensity Directive were revised in 2018 to accelerate the transition towards a sustainable and decarbonized energy system. In the revised Renewable Energy Directive (Directive 2018/2001), it was stated that increased use of renewable energies constituted a significant part of this package to reduce emissions and comply with the EU's commitment under the Paris Agreement. Thus, it set a binding target for the EU to achieve at least 32% share of renewable energy in its final energy consumption by 2030 (European Parliament, 2018a). Besides, the revised Energy Efficiency Directive (Directive 2018/2002) set a target of 32.5% improvement in energy efficiency for the year 2030 (European Parliament, 2018b).

In the Green Deal in 2019, it was emphasized that the energy system is critical to reach the target of reducing GHG emissions by 55% by 2030 compared to 1990 levels. For further decarbonizing energy efficiency, renewable energy, and energy taxation must be prioritized. Therefore, it was declared that focusing on environmental issues; the Renewable Energy Directive, Energy Efficiency Directive, and Energy Taxation Directive to reach climate objectives in 2030 and 2050 would be revised (European Commission, 2019).

In 2021, the EU published a legislative package on energy known as “Fit for 55: delivering the EU's 2030 Climate Target on the Way to Climate Neutrality”. With this Package, it was highlighted that supporting renewable energy use and more energy saving and focusing on taxing energy sources in line with climate goals and environmental objectives play a significant role (European Commission, 2021). Concordantly, the Renewable Energy Directive, the Energy Efficiency Directive, and the Energy Taxation Directive as part of this package were revised. According to these revisions in the Directives, the targets were increased to at least a 40% share of renewable energy in its final energy consumption by 2030 and a 32.5% improvement in energy efficiency for the year 2030.

In March 2023, the EU reinforced the Renewable Energy Directive by raising the EU's binding share of renewable energy target for 2030 to at least 42.5%, aiming for

45%. This deal brought the EU one step closer to complete the “Fit for 55” legislation to deliver the European Green Deal (European Commission, 2023).

In conclusion, this chapter shows that the EU's energy policies have been shaped by environmental concerns and emission reduction targets since the 1990s and especially since the 2000s. This is an indication of the EU's approach to the energy sector as the most important factor affecting emissions. Therefore, they have made a special effort to set and realize targets in energy sector considering environment.

CHAPTER 3

LITERATURE REVIEW

This chapter examines existing literature, specifically focusing on CO_2 emissions as an indicator of environmental degradation, to enlighten factors influencing the environment. There is a variety of driving forces affecting CO_2 emissions that scholars worldwide have tried to explain in their studies. A selection of studies investigating the determinants of CO_2 emissions for different countries and periods are presented with their findings in this chapter.

This chapter is organized into two sections. In the first section, the studies that employ the STIRPAT model framework to investigate the drivers of CO_2 emissions will be examined comprehensively. The second section broadens the scope of the literature survey. In this section, the studies that do not employ the STIRPAT model but the ones that investigate the effect of the variables used in our model as the explanatory variables on CO_2 emissions are discussed. At the end of the chapter, the reviewed literature is presented as a summary table including the author, period, country/country group, model/method used, and main results obtained.

3.1. Literature Review Based on the STIRPAT Model

Environmental impact analysis is essential in understanding the complex relationship between human activities and the environment. To accurately obtain information about the drivers of environmental change, there is a growing need for robust analytical tools. A significant and well-known analytical framework that has acquired recognition in environmental studies is the STIRPAT model. This model aims to quantitatively assess human activities' effects on the environment by examining relationships between environmental outcomes and a set of crucial variables.

As the world population continues to grow, concerns about the resulting increase in CO_2 emissions have increased. Therefore, a key element in environmental studies has been the impact of population on CO_2 emissions. The first study conducted within the STIRPAT model framework was by York et al. (2003). They use the Ordinary Least Squares (OLS) model with 146 countries for the year 1996. They show that population is the major driver of CO_2 emissions, and a 1% increase in population increases CO_2 emissions by approximately 1%. On the other hand, a 1% increase in affluence increases the CO_2 emissions by approximately 0.9%. However, a 1% increase in the square of affluence decreases the CO_2 emissions by approximately 1.16%. They find that the turning point level where affluence starts to decrease CO_2 emissions is $61.000 per capita GDP. As a major variable in the STIRPAT model, most researchers have viewed population as the key driver of environmental impact, and its effect on CO_2 emissions is generally accepted as positive and significant. However, Fan et al. (2006) reveal different findings. They test the model for 208 countries at different income levels (55 high-income, 40 upper-middle income, 54 lower-middle income, 59 low-income) between 1975 and 2000 by employing the partial least squares method. According to their results, the effects of population, affluence, and technology on CO_2 differ according to countries' income levels. They find that the percentage of the population aged between 15-64 has a negative impact in high-income countries but a positive impact in low-income countries on CO_2 emissions. They reveal that a 1% increase in the percentage of the population aged between 15-64 provides a 0.70% reduction in CO_2 emissions in high-income countries while it increases CO_2 emissions by 0.17% in upper-middle income countries, 0.57% in lower-middle income countries, 0.23% in low-income countries. Also, the findings obtained on the global scale in this study reveal that affluence and energy intensity make the most significant contribution to CO_2 emissions. A 1% increase in affluence and energy intensity leads to a 1% increase in CO_2 emissions by 0.57% and 0.20% in high-income countries, 0.33% and 0.13% in upper-middle income countries, 0.44% and 0.71% in lower-middle income countries, 0.26% and 0.13% in low-income countries, respectively.

Bargaoui et al. (2014) use the data of 214 countries spanning the period of 1980-2010 and find that population growth and affluence positively and significantly affect CO_2 emissions for all countries with different geographical and income level groups by employing the fixed effects model. They find that a 1% increase in population growth and affluence increase CO_2 emissions by approximately 0.97% and 1.15%, respectively. Also, they find that energy efficiency contributes to the reduction of emissions for all countries in their sample. Their findings reveal that a 1% increase in energy efficiency decreases CO_2 emissions by approximately 0.82%.

Another main impact factor in the STIRPAT model studies is affluence, and its impact on the environment varies across studies. Shuai et al. (2017) use the STIRPAT model framework to identify the key impact factors influencing CO_2 emissions for 125 countries with different income levels from 1990 to 2011 by applying the OLS technique. Their results show that affluence is the key impact factor worldwide, followed by technology and population taking priority regarding their effect on CO_2 emissions. They find that affluence, technology, and population are the key impact factors, and their impacts on total CO_2 emissions are 55%, 28%, and 17%, respectively, for countries at the global level. However, they find that this situation varies according to the income status of countries. According to their findings, technology has the greatest impact on CO_2 emissions, while affluence has a lower impact for high-income countries. On the other hand, affluence has the greatest impact on CO_2 emissions, while technology has the least impact for countries at low-income levels. The impacts of population, affluence, and technology on total CO_2 emissions are 16%, 23%, and 61%, respectively, for high-income countries, while 22%, 67%, and 11%, respectively, for low-income countries.

Financial development is broadly recognized as a key element for economic growth, with its mobilization of savings, improving information on investment decisions, and an integral part of capital allocation (Bashir et al., 2020). In this respect, financial development could be evaluated as an indicator of affluence in the STIRPAT model. Studies on the impact of financial development on CO_2 emissions imply different results. Acar et al. (2021) conduct a cross-sectional analysis of 154 countries in 2016 using the quantile regression approach. They reveal that a 1% increase in the financial development index increases ecological footprint by approximately 0.79% at only 0.25 quantile value. On the other hand, Tao et al. (2023) reach the opposite finding that financial development significantly reduces the CO_2 emissions in OECD countries during 2004–2018 in their study by employing a dynamic panel threshold model incorporating the generalized method of moments based on the STIRPAT model. They showed that a 1% increase in financial deepening, financial size, and financial efficiency decreases CO_2 emissions by approximately 0.05%, 0.06%, and 0.04, respectively.

Following studies on the literature that we review below include renewable energy, energy intensity, and energy-related taxes in the STIRPAT model.

Shafiei and Salim (2014) try to explain the role of renewable and non-renewable energy in CO_2 emissions of OECD countries for the years 1980-2011 using the augmented mean group (AMG) estimation technique. According to the study, it is determined that renewable energy consumption decreases CO_2 emissions, while non-renewable energy consumption increases CO_2 emissions. They reveal that a 1% increase in renewable energy consumption leads to a reduction in CO_2 emissions by 0.004% in the long run, while a 1% increase in non-renewable energy consumption increases CO_2 emissions by 1.038%. The authors emphasize that renewable energy consumption should be increased for sustainability and stability.

Wu et al. (2021) examine the drivers of CO_2 emissions for the period 1990-2016 for 18 developed countries by using the fixed-effects model. They find that renewable energy consumption share is the primary factor contributing to the decrease of CO_2 emissions, while population, GDP per capita, and energy intensity increase CO_2 emissions levels. Their result reveals that a 1% increase in renewable energy consumption decreases CO_2 emissions by 0.013%, while a 1% increase in population, GDP per capita, and energy intensity increases CO_2 emissions by 0.25%, 0.27%, and 0.48%, respectively. They emphasize the importance of the increase in energy efficiency and renewable energy use to reduce CO_2 emissions.

Voumik and Mimi (2023) investigate the impact of population, affluence, renewable energy, nuclear energy, research, and development on CO_2 emissions for 30 European Nations over the period 1990-2021 by using the cross-section autoregressive distributed lags method. The study identifies major causes of environmental damage as population growth and continuing fossil fuel use. They find that a 1% increase in population growth and fossil fuel use leads to an increase in CO_2 emissions by approximately 0.03% and 0.27% in the short run and 0.11% and 0.39% in the long run, respectively. The authors state that renewable energy and R&D investments are the best way to stop environmental degradation, while nuclear energy is insignificant. Their results show that a 1% increase in renewable energy consumption and R&D investments lead to decrease in CO_2 emissions by 0.35% and 0.01% in the short run and 0.11% and 0.06% in the long run, respectively.

Unlike these studies, Sun (2023) argues that renewable energy does not always have a negative impact on CO_2 emissions. He evaluates the impacts of renewable resource deployment and green finance on CO_2 emissions in 5 Asian countries for the period 2010 to 2021 using the fixed effects - Driscoll and Kraay technique in his research. He highlights that the impacts of these variables on CO_2 dioxide emissions differ in regions. The expansion of renewable energies does not significantly affect CO_2 emissions in South Asia and Southeast Asia, while it reduces CO_2 emissions in Central Asia, East Asia, and West Asia. This study reveals that a 1% increase in renewable energy consumption decreases CO_2 emissions by 0.19%, 0.14%, and 0.19% in the Central, East, and West Asia regions, respectively.

Lin et al. (2009) measure the impact of population, urbanization, GDP per capita, industrialization rate, and energy intensity variables on the environment in China between 1978 and 2006 using the OLS method. According to the results of the study, the population has the greatest impact on the environment. The population is followed by urbanization, industrialization, GDP per capita, and energy intensity. They reveal that a 1% increase in population, urbanization, industrialization level, GDP per capita, and energy intensity increases CO_2 emissions by 1.50%, 0.47%, 0.44%, 0.23%, and 0.11%, respectively. Also, they conclude that the rapid decline in energy intensity was the main factor restraining the increase in China's environmental impact.

Rasoulinezhad and Taghizadeh-Hesary (2022) use the STIRPAT model to investigate the factors affecting the CO_2 emissions in the top 10 economies (Canada, Denmark, Hong Kong, Japan, New Zealand, Norway, Sweden, Switzerland, the UK, the USA) that support green finance between 2002 and 2018 with the augmented mean group estimation technique. They find that population, affluence, and energy intensity increase CO_2 emissions, while the issuance of green bonds and green energy index consisting of nuclear, hydro, solar, wind, biofuels consumptions contribute to decrease in CO_2 emissions. Their results show that a 1% increase in population, affluence, and energy intensity increases CO2 emissions by 0.04%, 0.11%, and 0.09%, respectively, while a 1% increase in green bonds and green energy index lead to a reduction in CO_2 emissions by 1% and 0.92%, respectively in the long run.

Sun et al. (2022) analyze the driving factors of CO_2 emissions for 62 Belt and Road Initiative (B&R) countries over the period of 1990-2018. Their results show that population, GDP per capita, and energy intensity are the key driving factors of CO_2 emissions in high-income and upper-middle-income countries. A 1% increase in these variables increases CO_2 emissions by 0.37%, 0.26%, and 0.35% in case of high-income countries and 0.15%, 0.34% and 0.27% in case of upper-middle-income countries respectively. Population, GDP per capita, energy intensity, and renewable energy are the key driving factors of CO_2 emissions in low-middle-income and low-income. A 1% increase in population, GDP per capita, and energy intensity increase CO_2 emissions by 0.32%, 0.35%, and 0.26% in case of low-middle-income and 0.35%, 0.36% and 0.23% in case of low-income countries, respectively. On the other hand, a 1% increase in renewable energy consumption decreases CO_2 emissions by 0.37% in low-middle-income countries and 0.28% in low-middle-income countries. They emphasize that the impact of energy intensity on CO_2 emissions increases with the income level of countries.

From the above discussion, it can be understood that energy intensity generally increases the CO_2 emissions according to empirical research. However, Wang and Zhao (2015) find that energy intensity does not increase CO_2 emissions, i.e., energy efficiency does not decrease CO_2 emissions in their studies. Wang and Zhao (2015) investigate the impacts of energy-related CO_2 emissions in China for the period of 1997-2012 by employing the partial least square method. Their results indicate that a 1% increase in population, affluence, urbanization, and industrial structure increases

CO_2 emissions by 0.01%, 0.28%, 0.24%, and 0.30%, respectively, while a 1% increase in energy intensity decreases CO_2 emissions by 0.05%, showing that energy intensity has a negative influence on CO_2 emissions. They state that energy efficiency savings are offset by new energy demand, leading to increase in CO_2 emissions.

Although there are many studies on energy-related taxes in the literature, there is no study that includes the energy-related tax variable in the STIRPAT model to our knowledge. Therefore, we review the literature on environmental taxes instead of energy-related taxes used in the STIRPAT model. Sharif et al. (2023) examine the environmental impact on CO_2 emissions in 5 sovereign Nordic countries for the period 1995–2020 by using the cross-sectional augmented autoregressive distributed lag model. Their results indicate that a 1% increase in environmental taxes, green technology, and green energy contribute to decrease in CO_2 emissions by 0.33%, 0.28%, and 0.24%, respectively, in the long run. On the contrary, a 1% increase in population and income lead to an increase in CO_2 emissions by 0.17% and 0.26%, respectively, in the long run. In a similar manner, Ofori et al. (2023) analyze the factors impacting CO_2 emission in E7 economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) by using the Driscoll-Kraay's fixed-effect OLS technique and data from 2000 to 2020. They reveal that environmental tax has a significant negative connection with CO_2 emissions. A 1% increase in environmental tax reduces CO_2 emission by 0.09%. They suggest enhancing environmental tax in these economies. Also, Hashmi and Alam (2019) study the effects of environmental regulation on CO_2 emissions reduction of OECD countries over the period 1999-2014 by employing the fixed effects model and generalized methods of moments. Their results show that a 1% increase in environmental tax revenue decreases CO_2 emissions by 0.03%. Contrary to the studies that obtain a positive impact of environmental tax on the environment, Aziz et al. (2023) reach a different result in their study. They investigate the drivers of ecological footprint in East Asian countries (Japan, North Korea, South Korea, Mongolia, and China) over the period 1999-2019 by using the method of moments quantile regression. They find that environmental tax and renewable energy have insignificant impacts on ecological footprints in their study.

3.2. Further Studies on the Energy-Related Drivers of CO_2 Emissions

3.2.1. Renewable Energy Consumption and CO_2 Emissions

There are numerous studies that analyze the impact of renewable energy on CO_2 emissions with different results. Many scholars show that renewable energy is an efficient tool to mitigate CO_2 emissions in their study.

Jebli et al. (2016) reveal that a 1% increase in renewable energy consumption reduces CO_2 emissions by 0.03%, while a 1% increase in non-renewable energy consumption increases CO_2 emissions by 0.43% in the long run by using the OLS method in their empirical study for a panel of 25 OECD countries for the period of 1980-2010. Similarly, Bekun et al. (2019) investigate the impact of renewable and nonrenewable energy consumption on CO_2 emissions in 16 EU countries (Austria, Belgium, Bulgaria, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom) for the period of 1996-2014 by using the panel pooled mean group technique. They find that renewable energy consumption improves the environmental quality by mitigating the CO_2 emissions in the studied countries. They reveal that a 1% increase in renewable energy consumption leads to a 0.13% reduction in CO_2 emissions, and a 1% increase in nonrenewable energy consumption increases CO_2 emissions by 1.12%.

Anwar et al. (2021) find 1% increase in non-renewable energy consumption increases CO_2 emission by 0.29%, 0.26%, and 0.30%, whereas a 1% increase in the usage of renewable energy reduces CO_2 emission by 0.17%, 0.15% and 0.17% in case of fully modified-OLS, dynamic-OLS and fixed effects-OLS, respectively in their empirical study for the ASEAN countries for the time period of 1990-2018. Likewise, Fan and Hajiyeva (2022) find that every 2% increase in renewable energy consumption contributes to the reduction of CO_2 emission by 0.07%, 0.27%, and 0.09% in the case of fully modified-OLS, dynamic-OLS, and OLS, respectively in their empirical study for the Group of Seven (G7) countries over the period 2005-2019. In the same way, Aziz et al. (2021) examine the impact of renewable energy consumption on CO_2 in MINT (Mexico, Indonesia, Nigeria, and Turkey) economies for the period of 1995-2018. They reveal that a 1 % increase in renewable energy consumption mitigates the CO_2 emissions by 0.37%, 0.31%, and 0.35% in the case of fully modified-OLS, dynamic-OLS, and fixed effects-OLS, respectively.

Hasanov et al. (2021) reveal that the impact of renewable energy consumption on CO_2 emissions in BRICS (Brazil, Russia, India, China, South Africa) countries is negative over the 1990-2017 period by using the cross-sectional augmented autoregressive distributed lags technique. They find that a 1% increase in renewable energy consumption decreases CO_2 emissions by approximately 0.56% in the short run and 0.65% in the long run, respectively.

Although the majority of studies conclude that renewable energy could help to reduce CO_2 emissions, some of the studies show conflicting results. Apergis et al. (2010) study the effect of renewable energy consumption on CO_2 emissions for a group of 19 developed and developing countries covering the years 1984-2017 by employing a panel error correction model. They find that renewable energy consumption does not contribute to reduce emissions.

By using OLS, fully modified-OLS, and dynamic-OLS techniques for 5 North African countries over the period 1980-2011, Jebli and Youssef (2017) discover that renewable energy increases emissions. Their result shows that a 1 % increase in renewable energy consumption increases the CO_2 emissions by 0.16%, 0.18%, and 0.16% in the case of OLS, fully modified-OLS, and dynamic-OLS, respectively. Similarly, Hasnisah et al. (2019) examine the impact of renewable energy consumption on CO_2 emissions in 13 developing countries in Asia for the period of 1980-2014 by employing fully modified OLS and dynamic-OLS to test for cointegration in the long run. Their results suggest that renewable energy consumption is insignificant in contributing to less pollution regarding CO_2 emissions. Nathaniel and Iheonu (2019) examine the role of renewable and non-renewable energy consumption on CO_2 emissions for 19 African countries from 1990 to 2014 by employing the augmented mean group estimation technique. Their results assert that while renewable energy inhibits CO_2 emissions insignificantly, a 1% increase in non-renewable energy significantly increases CO_2 emissions by 1.02%.

Finally, Nguyen and Kakinaka (2019) investigate the relationship between renewable energy consumption and CO_2 emissions based on the development stages of the countries. They use data for 41 low-income, 31 middle-income, and 35 high-income countries spanning the period of 1990-2013. According to their panel cointegration analysis results, the long-run relationship between renewable energy consumption and CO_2 emissions relates to the development stages. They indicate that renewable energy consumption has a positive association with emissions in the case of low-income countries while it has a negative association with emissions in the case of middle and high-income countries. They show that a 1% increase in renewable energy consumption decreases CO_2 emissions by 0.35% in middle-income countries and 0.47% in high-income countries while it increases CO_2 emissions by 0.33% in low-income countries.

3.2.2. Energy Intensity and CO_2 Emissions

Most scholars express that energy intensity has a positive effect on CO_2 emissions. Shahbaz et al. (2015) investigate the dynamic relationship between CO_2 emissions and energy intensity for Sub-Saharan African countries over the period of 1980-2012 by employing panel cointegration. Their results show that energy intensity has a positive and statistically significant impact on CO_2 emissions. They reveal that a 1% increase in energy intensity leads to an increase in CO_2 emissions by approximately 1.29% in the short run and 1.09% in the long run.

Li et al. (2016) analyze the main drivers of CO_2 emissions in the agricultural sector of 18 selected European countries for the periods of 1995-2009 by using index decomposition analysis. They indicate that energy intensity is the main factor of CO_2 emissions, while the share of renewables in final energy consumption in agriculture does not affect the CO_2 emissions significantly. They emphasize the importance of energy efficiency policies in Europe to achieve CO_2 emissions reduction targets. Chen et al. (2018) find that energy intensity is one of the main factors influencing CO_2 emissions in their study by using the Logarithmic Mean Divisia Index (LMDI) decomposition method for the OECD countries for the period 2001-2015. Their results show that the decrease in energy intensity leads to a reduction in CO_2

emissions by 7.139 billion tons from 2001 to 2015, while the increase in per capita GDP and population increase CO_2 emissions by 6.174 billion tons and 1.224 billion tons, respectively. Similarly, Li et al. (2023) analyze the factors that influence the CO_2 emissions in Beijing from 2010 to 2020 by applying the LMDI decomposition method. Their results show that the main driver of CO_2 emissions reduction in Beijing is the effect of energy intensity. They find that a 1% decrease in energy intensity decreases CO_2 emissions by approximately 1.29% in the short run and 1.55% in the long run. They conclude that reduction of energy intensity is crucial to achieve CO_2 neutrality.

Liu and Bae (2018) consider energy intensity as the main determinant of CO_2 emissions. The authors find that a 1% rise in energy intensity leads to an increase in CO_2 emissions by 1.1% in China over the period from 1970 to 2015 by employing the autoregressive distributed lag.

Even though the literature generally suggests that energy intensity is a positive driver of CO_2 emissions, Wang and Feng (2017) reach the opposite finding as Wang and Zhao (2015). They study the driving factors of CO_2 emissions in China over the period 2000-2014 by using the LMDI decomposition method. They find that the energy intensity has a dominant negative effect on CO_2 emissions. According to their findings, it contributes to a cumulative reduction in CO_2 emissions by 80.07% from 2000 to 2014, while economic output and population growth contribute to a cumulative increase in CO_2 emissions by 154.85% and 10.71%, respectively.

3.2.3. Energy-Related Tax and CO_2 Emissions

As a fiscal tool, energy-related tax in mitigating the environmental impact of energy sources has been tested by scholars to crystallize whether it has desired effects on the environment. Miller and Vela (2013) find that higher energy tax revenue contributes to the decrease in CO_2 emissions in their study by applying generalized methods of moments for 50 countries from all regions of the world for the period between 1995 and 2010. They find that a 1% increase in energy taxation decreases CO_2 emissions by 0.06%.

Jeffrey and Perkins (2015) investigate the association between energy taxes and CO_2 emissions for EU-27 countries over the period 1996-2009 by using seemingly unrelated regression (SUR) analysis in their study. They find that a 1% increase in energy tax results in a 0.11% decrease in CO_2 emissions. Also, they reveal that energy taxation is more efficient for CO_2 emissions reduction than the emission trading system.

Tekin and Şaşmaz (2016) argue that energy taxes have a negative impact on CO_2 emissions, while environment and transportation taxes have no impact in 25 EU countries during the period 1995-2012 by employing fully modified OLS in their study. They find that €1000 increase in energy tax revenues leads to a 1-ton reduction in CO_2. Similarly, Lapinskienė et al. (2017) claim that the increase in energy taxes contributes to the decrease in the GHG level by applying the fixed effect panel model for the 20 EU countries over the years 2006-2013. They find that a 1% increase in tax revenue decreases CO_2 emissions by approximately 0.09%. Also, they point out that the impact of energy taxes on emissions is more direct than overall environmental taxes.

Contrary to the above-mentioned studies, Liobikienė et al. (2019) find that energy tax policy in the EU is ineffective since energy taxes do not influence GHG emissions in their study in which they analyze the contribution of energy taxes to climate change policy in the EU-28 countries (including England) over the period 1995-2012 by using Granger causality method. Similarly, Wolde-Rufael and Mulat-Weldemeskel (2021) find no causality between energy taxes and CO_2 emissions in their study, in which they analyze the effectiveness of policy instruments for combating environmental degradation in 7 emerging economies (Czech Republic, Greece, Hungary, Korea, Poland, South Africa, and Turkey) for the period 1994–2015 by using panel Granger causality test.

To conclude, it can be argued that even though the STIRPAT model has been extensively used in numerous studies for various countries or country groups in the existing literature, the application of this model for the environmental impact analysis in the European Union is limited to a few studies. This study aims to enrich the literature by applying the STIRPAT model to analyze the environmental impact of population, affluence and technology on the EU-27. Furthermore, this study is creditable since one of the influencing factors on CO_2 emission energy-related tax is comprehended. The energy related tax has not been included in the environment impact analysis applying the STIRPAT model in previous studies in the literature. Therefore, addressing this variable in the STIRPAT model could enrich the literature.

The Table 2, presented below, provides a summary of our literature review.

Table 2. Summary of the Studies in the Literature Review

Author(s)	**Time Period**	**Model/ Method**	**Main results of the study**
	Country/ Countries		
York et al. (2003)	1996	STIRPAT, OLS	Population is the major driver of CO_2 emissions.
	146 countries		
Fan et al. (2006)	1975-2000	STIRPAT, PLS	- Population aged between 15-64 has a negative impact at high-income countries but a positive impact at low-income countries on CO_2 emissions. - The largest contribution to CO_2 emissions is made by affluence and energy intensity.
	208 countries		
Lin et al. (2009)	1978-2006	STIRPAT, OLS	Population has the greatest impact on the environment. This is followed by urbanization, industrialization, gross domestic product per capita and energy intensity.
	China		
Bargaoui et al. (2014)	1980-2010	STIRPAT, Fixed effects model	- Population growth and affluence have positive and significant effects on CO_2 emissions for all countries with different geographical and income level groups. - Energy efficiency contributes to the reduction of emissions for all countries.
	214 countries		

Table 2 (continued)

Shafiei and Salim (2014)	1980-2011	STIRPAT, AMG	-Renewable energy consumption decreases CO_2 emissions. - Non-renewable energy consumption increases CO_2 emissions.
	OECD countries		
Wang and Zhao (2015)	1997-2012	STIRPAT, PLS	- Population, affluence, and urbanization have positive influence on CO_2 emissions. - Energy intensity has a negative influence on CO_2 emissions.
	China		
Shuai et al. (2017)	1990-2011	STIRPAT, OLS	- Affluence is the key impact factor at worldwide level. - Technology has the greatest impact on CO_2 emission, while population has the lowest impact for countries at high-income level. - Affluence has the greatest impact on CO_2 emission, while technology has the least impact for countries at low-income level.
	125 countries		
Hashmi and Alam (2019)	1999-2014	STIRPAT, Fixed Effects Model, GMM	Increase in environmental tax revenue decreases CO_2 emissions.
	OECD countries		
Acar et al. (2021)	2016	STIRPAT, Cross Sectional Analysis	Financial development as the indicator of economic development of countries increases the ecological footprint.
	154 countries		
Wu et al. (2021)	1990-2016	STIRPAT, Fixed Effects Model	Renewable energy consumption decreases CO_2 emissions while population, affluence and energy intensity increase CO_2 emissions.
	18 developed countries		
Rasoulinezhad and Taghizadeh-Hesary (2022)	2002-2018	STIRPAT, AMG	- Population, affluence, and energy intensity increase CO_2 emissions. - The issuance of green bonds and renewable energy consumption decrease CO_2 emissions.
	10 countries		

Table 2 (continued)

Sun et al. (2022)	1990-2018 62 B&R countries	STIRPAT	- Population, affluence, and energy intensity have positive impacts on CO_2 emissions. - Renewable energy have negative effects on CO_2 emissions. - The impact of energy intensity on CO_2 emissions increases with the income level of countries.
Tao et al. (2023)	2004-2018 OECD countries	STIRPAT, Dynamic PTM, GMM	Financial development significantly reduces the CO_2 emissions.
Sun (2023)	2010-2021 5 Asian countries	STIRPAT, Fixed Effects Model Driscoll and Kraay Technique	Renewable energy does not have significant effect on CO_2 emissions in South Asia and Southeast Asia. On the other hand, it reduces CO_2 emissions in Central Asia, East Asia and West Asia.
Voumik and Mimi (2023)	1990-2021 30 European Nations	STIRPAT, CS-ARDL	- Major causes of environmental damage are population growth and continuing fossil fuel use. - Renewable energy and R&D investment are the best way to reduce environmental degradation. - Nuclear energy is insignificant.
Sharif et al. (2023)	1995-2020 5 Nordic countries	STIRPAT, ARDL	- Environmental taxes, green technology, and green energy contribute to decrease the CO_2 emissions. - Population and income have positive impacts on CO_2 emissions.
Ofori et al. (2023)	2000-2020 E7 countries	STIRPAT, Fixed Effects Model Driscoll and Kraay Technique	Environmental taxes decrease the CO_2 emissions.

Table 2 (continued)

Aziz et al. (2023)	1999-2019	STIRPAT, MMQR	Environmental tax and renewable energy have insignificant impacts on ecological footprints.
	East Asian countries		
Apergis et al. (2010)	1984-2017	Panel Error Correction Model	Renewable energy consumption does not contribute to reduce emissions.
	19 developed and developing countries		
Miller and Vela (2013)	1995-2010	GMM	Higher energy taxes revenue contributes to decrease in CO_2 emissions.
	50 countries		
Shahbaz et al. (2015)	1980-2012	Vector Error Correction Method	Energy intensity has positive and statistically significant impact on CO_2 emissions.
	Sub Saharan African countries		
Jeffrey and Perkins (2015)	1996-2009	SUR	- Increase in energy tax decreases CO_2 emissions. - Energy taxation is more efficient for CO_2 emissions reduction than emission trading system.
	EU-27 countries		
Jebli et al. (2016)	1980-2010	OLS	- Renewable energy consumption decreases CO_2 emissions. - Non-renewable energy consumption increases CO_2 emissions.
	25 OECD countries		
Li et al. (2016)	1995-2009	Index Decomposition Analysis	- Energy intensity is main factor to curb CO_2 emissions. - The share of renewables in final energy consumption in agriculture does not affect the CO_2 emissions significantly.
	18 European countries		

Table 2 (continued)

Tekin and Şaşmaz (2016)	1995-2012 25 EU countries	FMOLS	- Energy taxes have negative impacts on CO_2 emissions. - Environment and transportation taxes have no impact on CO_2 emissions
Ben Jebli and Ben Youssef (2017)	1980-2011 5 North Africa countries	Panel Cointegration	Renewable energy increases emissions.
Wang and Feng (2017)	2000-2014 China	LMDI Decomposition	Energy intensity has a negative effect on CO_2 emissions.
Lapinskienė et al. (2017)	2006-2013 20 EU countries	Fixed Effects Model	- Energy taxes contribute to decrease in the GHG level. - The impact of energy taxes on emissions is more direct than overall environmental taxes.
Chen et al. (2018)	2001-2015 OECD countries	LMDI Decomposition	Energy intensity is one of the main factors influencing CO_2 emissions.
Liu and Bae (2018)	1970-2015 China	ARDL	Rise of energy intensity increases CO_2 emissions.
Hasnisah et al. (2019)	1980-2014 13 developing Asian countries	FMOLS, DOLS	Renewable energy consumption is insignificant in contributing to less pollution regarding CO_2 emissions.

Table 2 (continued)

Nathaniel and Iheonu (2019)	1990-2014 19 African countries	AMG	- The impact of renewable energy on CO_2 emissions is insignificant. - Non-renewable energy increases CO_2 emissions significantly.
Bekun et al. (2019)	1996-2014 16 EU countries	PMG	Renewable energy consumption improves the environmental quality by mitigating the CO_2 emissions.
Nguyen and Kakinaka (2019)	1990-2013 107 countries	Panel Cointegration	Renewable energy consumption has positive association with emissions in the case of low-income countries while it has negative association with emissions in the case of middle and high-income countries.
Liobikienė et al. (2019)	1995-2012 EU-28 countries	Granger Causality	Energy taxes have not influence GHG emissions.
Anwar et al. (2021)	1990-2018 ASEAN countries	FMOLS, DOLS, Fixed Effects Model	Increase in non-renewable energy consumption increases CO_2 emission by whereas increase in the usage of renewable energy reduces CO_2 emission
Aziz et al. (2021)	1995-2018 MINT countries	FMOLS, DOLS, Fixed Effects Model	Renewable energy consumption mitigates the CO_2 emissions
Hasanov et al. (2021)	1990-2017 BRICS countries	CS-ARDL	The impact of renewable energy consumption on CO_2 emissions is negative.
Wolde-Rufael and Mulat-Weldemeskel (2021)	1994–2015 7 emerging economies	Granger Causality	There is no causality between energy taxes and CO_2 emissions

Table 2 (continued)

Fan and Hajiyeva (2022)	2005-2019	FMOLS, DOLS, OLS	Increase in renewable energy consumption contributes to reduction of the CO_2 emissions
	G7 countries		
Li et al. (2023)	2010-2020	LMDI Decomposition	The main driver of CO_2 emissions reduction is energy intensity.
	Beijing		

CHAPTER 4

DATA AND MODEL

This study aims to investigate the relationship between CO_2 emissions and its determinants which are population growth, financial development, energy intensity, renewable energy consumption, and energy related tax in the EU countries between 2000 and 2019. To accomplish this investigation, we use the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model, a well-known and widely used framework in environmental research and policies, to study the complex drivers of environmental impact, including CO_2 emissions.

The STIRPAT model is a reformulation of the Impacts, Population, Affluence, and Technology (IPAT) model. The IPAT model is proposed by Paul Ehrlich and John Holdren (1971) in their "Impact of Population Growth" paper to acknowledge the driving effects of environmental change. The IPAT model mathematically can be represented as:

$$I = P \times A \times T \tag{1}$$

As can be seen from the equation above, environmental impact (I) is the product of population (P), affluence (A), and technology (T). Even though the IPAT model has been widely used to examine the relationship between human activities and environmental degradation, it is criticized for oversimplifying the complex relationship between human activities and environmental impact (Dietz & Rosa, 1994). Dietz and Rosa (1994) declare that the IPAT model does not provide an adequate framework for disentangling the various driving forces of anthropogenic environmental change since it is based on an accounting equation. To overcome this problem, a modified version of the IPAT model, known as the STIRPAT model, allows for an empirical hypothesis testing developed by Dietz and Rosa (1994). The STIRPAT model can be expressed as:

$$I_{i,t} = \alpha \cdot P_{i,t}^{b} \cdot A_{i,t}^{c} \cdot T_{i,t}^{d} \cdot \mu_{i,t} \quad (2)$$

where **I** is the environmental impact, **P** is the population, **A** is the level of affluence, and **T** is the level of technology. Furthermore, $\boldsymbol{\alpha}$ is the constant term; **b**, **c**, and **d** are exponents of population, affluence, and technology factors, respectively; **μ** denotes the error term; **i** and **t** denote the countries and time periods, respectively.

This model is transformed into a natural logarithmic form to enable empirical estimation and hypothesis testing. The natural logarithmic form of the STIRPAT model can be expressed as:

$$\ln I_{i,t} = \alpha + b\left(\ln P_{i,t}\right) + c\left(\ln A_{i,t}\right) + d\left(\ln T_{i,t}\right) + \mu_{i,t} \quad (3)$$

The STIRPAT model is often expanded to include additional factors that may affect the environmental impact. In this research we modify and extend the model.

In this chapter, we provide a detailed description of our methodology. First, we introduce our variables in the model and give a justification of why the independent variables that are chosen as the determinants of the dependent variable are appropriate. Second, we describe the data that is used in our model. Third, we acknowledge the model specification by describing the modified STIRPAT model for our analysis and explaining pooled OLS, fixed effects, and random effects regression models to estimate the STIRPAT model. Overall, this chapter provide a comprehensive explanation of our methodology.

4.1. Variable Justifications

The Figure 2 below shows the components of the STIRPAT model, and the variables used in the extended STIRPAT model that we introduce.

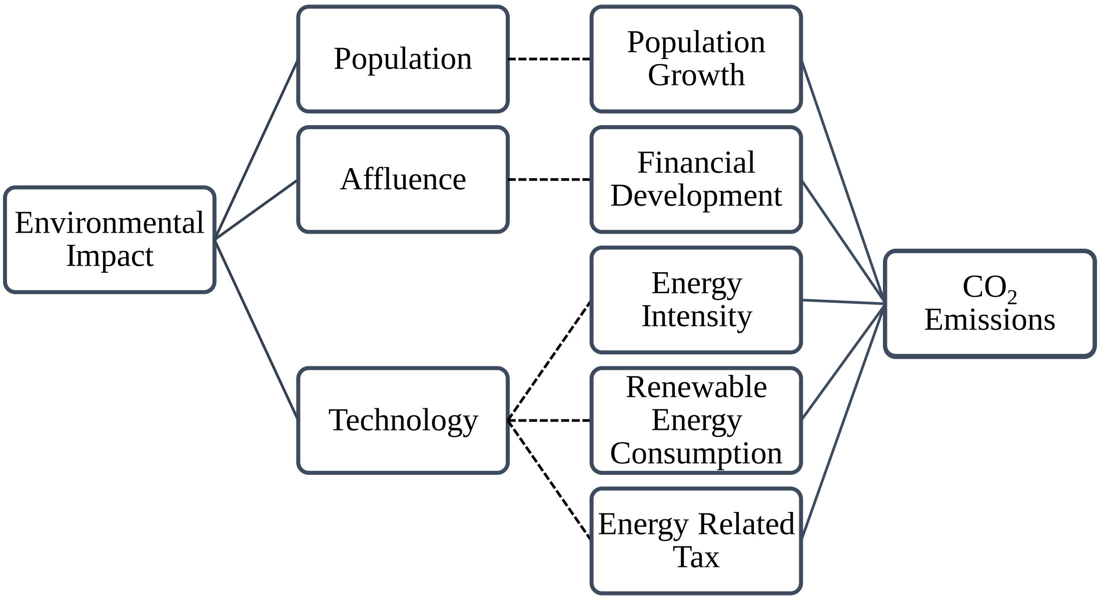

Figure 2. Components of the STIRPAT Model

4.1.1. CO_2 Emissions as a Measurement of Environmental Impact

CO_2, SO_2, CH_4, PM, and deforestation variables are often used as indicators of environmental quality in the literature to analyze the environmental impact. Especially using CO_2 emissions as an indicator of environmental quality, is widely accepted (Şahin, 2022). Therefore, CO_2 is an appropriate measure of environmental impact in the STIRPAT model, given its significant contribution to environmental change.

Following Dietz and Rosa (1997), we use CO_2 emissions in kilotons as the dependent variable to measure environmental impact in 27 European countries in our model.

The independent variables chosen to explain the carbon emissions are discussed in detail below.

4.1.2. Population and Affluence as main variables in the STIRPAT Model

In the STIRPAT model framework, population and affluence are the main drivers of environmental impact. For measurement of population, in their 1997 study Dietz and

Rosa use the population size. However, in their 1994 study, the authors argue that the pace of population growth will contribute to environmental impact more than the population size. Hence, we use population growth in annual percentage to represent population (P) in the STIRPAT model.

Dietz and Rosa (1997) state that population positively impact CO_2 emissions. A larger population generally increases the demand for goods and services, resulting in a higher requirement for energy and resources that may be the reason for higher CO_2 emissions. According to the Climate Change Report of Intergovernmental Panel on Climate Change (2023), population growth has been the strongest drivers of CO_2 emissions globally. Considering previous empirical studies, we expect a positive relationship between CO_2 emissions and population.

We use financial development as a proxy for affluence (A) in our model. To measure financial development of a country, we use the financial development index (FDI)[2], annual data obtained from the IMF.

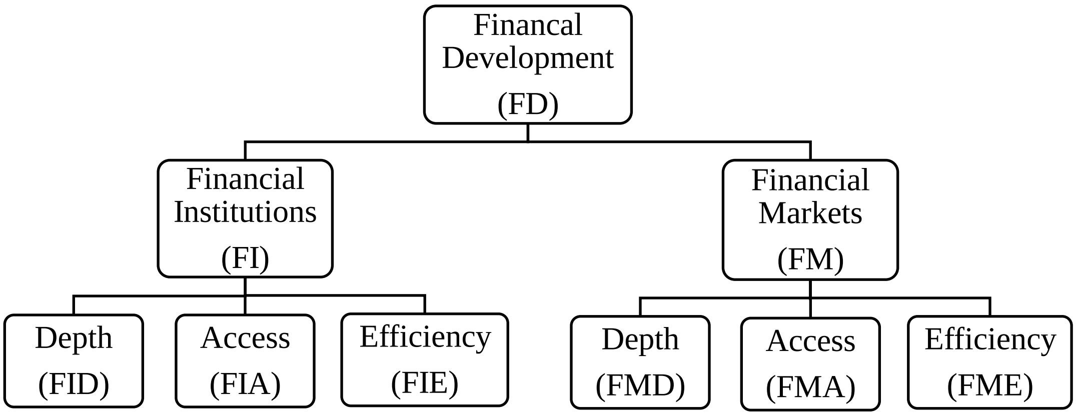

Figure 3. Financial Development Index

Source: IMF

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[2] FDI, calculated by the IMF, is a measure of a country's financial development level, comprising several key indicators related to the financial system. Each component index (FID, FIA, FIE, FMD, FMA, FME) of FDI is given a score between 0 and 1 to calculate FDI. After that, the scores for each component are weighted by using the principal component analysis (PCA) technique based on their relative importance in explaining financial development. Calculated FDI takes a value between 0 and 1, where 0 represents the lowest level of development, and 1 represents the highest level of development.

The FDI is an aggregate of the depth, access, and efficiency indexes of financial institutions and the financial markets index. The selection of FDI as the variable representing affluence, rather than the conventional use of GDP in the model, is due to its ability to provide a more comprehensive view of affluence compared to GDP. Financial development is highly correlated by economic growth, especially in the developed countries. In addition, the financial sector's depth, ease of access, and efficiency affect the consumption and investment behavior of economic agents that influence the environment. In this context, FDI encompasses not only the total economic output but also captures the effects of consumption and saving patterns and investment strategies in the economy.

The impact of the financial development variable on CO_2 emissions is somewhat more complex than the population growth. It is uncertain in which direction the financial development variable will affect CO_2 emissions. Financial development can lead to increased investment to reduce CO_2 emissions. On the other hand, financial development can also stimulate economic growth, leading to increased industrial activities and energy consumption, which can result in higher CO_2 emissions. This variable may have either a positive or a negative effect on CO_2 emissions in the EU.

4.1.3. Variables as a proxy for Technology (T) in the STIRPAT Model

Technology (T) can be disaggregated by including additional factors in the STIRPAT model that are theorized to influence the impact (Dietz & Rosa, 2003). In this regard, we disaggregate T by including energy intensity, renewable energy consumption, and energy related tax variables in our study.

4.1.3.1. Energy Intensity

Energy intensity is one of the main drivers of CO_2 emissions. According to the European Commission, the production and consumption of energy account for more than 75 % of GHG emissions. The Energy Efficiency Directive (2012/27/EU) states that improving energy efficiency will benefit the environment, enhance air quality, and reduce GHG emissions. Therefore, one of the main strategies of the EU to achieve carbon neutrality is to increase energy efficiency. Energy intensity measures the amount of energy necessary to produce one unit of economic output. In other words, it is used as a proxy for the economy's energy efficiency. We use the energy intensity level of primary energy, which is calculated by dividing the total primary energy supply by gross domestic product measured in constant 2017 US$ at purchasing power parity (World Bank). The lower (higher) the ratio the higher (lower) the energy efficiency. It is expressed in units of megajoules (MJ) per dollar of GDP, where GDP is measured in purchasing power parity (PPP) terms to account for differences in the cost of living across countries. Measuring energy intensity in MJ-$2017 PPP GDP normalizes the differences in purchasing power across countries and time periods. Energy intensity is expected to have a positive relationship with CO_2 emissions since the increase in energy intensity means that more energy is needed to produce one unit of economic output, i.e., energy efficiency decreases. As countries become more energy-efficient, they can reduce their energy consumption and subsequently reduce their CO_2 emissions.

4.1.3.2. Renewable Energy Consumption

Renewable energy consumption is a significant contributor for reduction of CO_2 emissions. The Renewable Energy Directive of the European Commission states that increased energy use from renewable sources or ‘renewable energy’ is vital to reduce greenhouse gas emissions. Thereby, the EU has a particular focus on renewable energy to be the first carbon-neutral continent in 2050 in the world. The study by European Commission about the EU’s global leadership in renewables states that the EU has a leading position in renewable developments (European Commission, 2022). European Commission first introduced Renewable Energy Directive in 2009 and set a target of 20% renewables in gross final energy consumption by 2020. In 2018, the Directive was revised and put 32% renewables target for 2030. In 2021, the target was updated, which was raised to 40% for 2030. In 2023, this target was again increased, and the institutions of the EU have reached an agreement to increase renewable energy usage targets to 45% as part of their plans to combat climate change. This shows the EU’s commitment to reduce CO_2 emissions by strengthening efforts to raise renewable energy consumption. In this context, we take the renewable energy consumption as one of our independent variables.

We express the renewable energy consumption as a percentage of final energy consumption by end users (households, industry, transportation, etc.).

Renewable energy consumption is expected to have a negative effect on CO_2 emissions since its enhancement reduces the consumption of fossil fuels, a significant CO_2 emissions source.

4.1.3.3. Energy Related Tax Revenue

Energy related tax revenue is another independent variable we include as a determinant of CO_2 emissions. The EU has emphasized environmental tax regulations for the protection of the environment. The EU environmental taxes are subdivided into four categories. These are taxes on energy, transport, pollution, and resources. Energy taxes with 75-80%, have the highest share in environmental taxes. They are based on taxing energy products such as coal, oil products, natural gas, and electricity consumed in physical units.

The provisions and goals described in the Energy Taxation Directive (Directive 2003/96/EC) established by the EU provide justification for the inclusion of energy-related tax revenue as an independent variable in our model. This Directive is a crucial resource for comprehending the function of energy related taxes in encouraging renewable energy sources and reducing CO_2 emissions. Aiming to standardize energy taxation practices among member states and to establish a framework for promoting environmentally sustainable energy consumption, the EU established the Energy Taxation Directive in 2003. The Directive acknowledges the potential for fiscal policies to have an impact on energy use and encourage the shift to a low-carbon economy. The Energy Taxation Directive highlights the significance of environmental concerns and encourages member states to use energy taxation as a tool for attaining environmental goals. Comparability and cross-country analysis are made easier and possible by the Energy Taxation Directive's goal of standardizing energy taxation practices among member nations. We establish a unified framework for assessing the effect of energy taxation on CO_2 emissions across the EU countries throughout the predetermined time period by taking energy-related tax income into account as an independent variable.

The data for energy related tax revenue is obtained from the OECD. It is measured as a percentage of GDP. The data provides a valuable basis for comparing the energy-related tax revenue performance among the EU countries. It provides an assess to the effectiveness of energy-related tax policies and to understand variations in tax burdens across countries. Overall, the energy-related tax revenue data presented in terms of percentage of GDP provides a valuable resource for studying the fiscal aspects of energy policies. The relationship between energy-related tax revenue and CO_2 emissions is expected to be negative. Higher energy-related tax revenues are often associated with increased taxation on carbon-intensive energy sources, which creates financial disincentives for energy consumption. This, in turn, can lead to a decrease in CO_2 emissions as individuals and businesses are required to seek cleaner and more sustainable energy alternatives.

4.2. Data

The definitions of variables used in the model and their sources of data are shown in Table 3 below:

Table 3. Definition of Variables

Variable	Symbol	Definition	Unit	Source
CO_2 emissions	CO	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	kiloton	World Bank
Population growth	POP	Annual population growth rate. Population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship.	%	World Bank

Table 3 (continued)

Financial development index	FD	A relative ranking of countries on the depth, access, and efficiency of their financial institutions and financial markets	index (0-1)	International Monetary Fund
Energy intensity	EI	Energy intensity is the ratio of energy supply to GDP measured at purchasing power parity.	MJ-$2017 PPP GDP	World Bank
Renewable energy consumption	REC	The share of renewable energy in total final energy consumption	%	World Bank
Energy-related tax revenue	ET	The share of energy-related tax revenue to GDP	%	OECD

The observations of the variables in the table were collected in annual frequency between 2000 and 2019 for 27 European countries. The choice of this period was motivated by the availability of data on the relevant variables for this period. We have balanced panel data with all its observations for 27 countries at 20 different time periods (N=27, T=20).

4.3. Model Specification

In this section, we acknowledge the model specification by presenting a modified version of the STIRPAT model for our analysis and try to explain the reasons of the choice of using pooled OLS, fixed effects, and random effects regression models to estimate the model. Later, we show how the estimation of each model works and how we select the appropriate model for our study.

4.3.1. Model

The modified and extended STIRPAT model utilized in this study can be expressed as follows:

$$\ln(\mathrm{CO}_{i,t}) = \alpha + \beta_1 \ln(\mathrm{POP}_{i,t}) + \beta_2 \ln(\mathrm{FD}_{i,t}) + \beta_3 \ln(\mathrm{EI}_{i,t}) + \beta_4 \ln(\mathrm{REC}_{i,t}) + \beta_5 \ln(\mathrm{ET}_{i,t}) + \varepsilon_{i,t} \quad (4)$$

where CO, POP, FD, EI, REC, and ET represent CO_2 emissions, population growth, financial development, energy intensity, renewable energy consumption, and energy related tax revenue, respectively. The **i** subscript in the equation represents the unit (country) dimension of the panel data, while the **t** subscript represents the time (year) dimension. **α** is the constant term in the equation, and **ε** represents the error term assumed to be white noise with zero mean and constant variance. The **β_i** terms in the model represent the coefficients to be estimated that express the effects of the independent variables on the dependent variable.

In the estimation of the STIRPAT model, all variables are in logarithmic form. (York et al., 2003). Hence, we follow this process by using the log-log model, and **ln** prefixes of variables in the model indicate that the variables are included in the model logarithmically.

4.3.2. Cross-Sectional Dependence (CD) Test

We begin our econometric analysis with identifying cross-sectional dependency among panel data estimation. We want to find out if there exists correlation between cross section units. Cross-sectional dependence can emerge from a variety of factors, leading to interconnections among different entities or units within a dataset. This phenomenon may occur due to shared disturbances that impact multiple units simultaneously, economic integration of countries, geographical influences that affect neighboring units similarly, or unexpected elements specific to individual countries that introduce interdependencies among units. These causes contribute to the presence of cross-sectional dependence, highlighting the importance of considering and analyzing the potential sources of interdependence when examining panel data.

In this research, we apply the Pesaran (2004) CD test, which is one of the most frequently used tests in the panel data literature, to check cross-sectional dependency.

Examining the cross-sectional dependency is important to select appropriate panel unit root tests because the type of panel unit root tests we use depends on this.

4.3.3. Panel Unit Root Test

In the second stage, it is necessary to determine whether the variables contain unit roots and to identify their stationary levels. In this context, if there is correlation among the units (cross-sectional dependency), second-generation panel unit root test is recommended since the first-generation unit root tests do not consider the cross-sectional dependence and give inefficient results (Bình, 2020).

We conduct Pesaran (2007) cross-sectional augmented IPS unit root test in the presence of cross-section dependence, so that we can obtain more consistent and reliable results since it can control the problem of cross-sectional dependence.

The presence of unit roots indicates that the variables being examined are non-stationary, implying that they exhibit persistent and long-term trends. On the other hand, stationary variables exhibit stability over time, without any substantial long-term trends. Therefore, identifying the stationary levels of the variables is crucial in order to obtain accurate and meaningful results in panel data analysis.

4.3.4. Analysis of the Model

In the scope of the research, the panel data econometric method is utilized by combining unit and time dimensions.[3]

Given that the unit dimension consists of 27 countries and the time dimension covers a 20-year period, analyses are carried out using Pooled OLS, Fixed Effects, and Random Effects regression models that are suitable for short panel data by conducting necessary specification tests.

The panel data model can be expressed as shown in equation 5:

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[3] All econometric analyses are conducted using the Stata 17.0 package program.

$$\mathrm{Y_{i,t} = \mu + \beta X'_{i,t} + \alpha_{i,t} + \varepsilon_{i,t}} \tag{5}$$

where the ***i*** and ***t*** subscripts refer to the cross-sectional unit being observed and the time period at which it is observed, respectively. $\boldsymbol{\varepsilon_{i,t}}$ is the error term. $\mathbf{X_{i,t}}$ represents the vector of K-dimensional independent variables, and the term $\boldsymbol{\mu}$ represents intercept, indicating that all units have a common value. $\boldsymbol{\alpha_{\mathrm{i,t}}}$ represents heterogeneity and/or unit effects. There are four possible cases for $\alpha_{i,t}$:

1. $\alpha_{\mathrm{i,t}} = 0$
2. $\alpha_{\mathrm{i,t}} = \alpha_{\mathrm{i}}$
3. $\alpha_{\mathrm{i,t}} = \gamma_{\mathrm{t}}$
4. $\alpha_{\mathrm{i,t}} = \alpha_{\mathrm{i}} + \gamma_{\mathrm{t}}$

As seen in the four different forms, panel data models can vary according to time and/or units. If the $\alpha_{\mathrm{i,t}}$ parameter changes only with unit or time, as in the second and third cases; we have a one-way panel data model. If it changes with both units and time, as in the fourth case, then we have a two-way panel data model.

4.3.4.1. Pooled Ordinary Least Squares Model (POLS)

If $\alpha_{\mathrm{i,t}} = 0$, it means that there is no unit effect in the model. In other words, the intercept is constant across units, and the error term, $\varepsilon_{\mathrm{i,t}}$, captures differences over individuals. This model is known as the “pooled model”, and it is shown as follows:

$$\mathrm{Y_{i,t} = \mu + \beta X'_{i,t} + \varepsilon_{i,t}} \tag{6}$$

As we can see in equation 6, cross-sectional units have no individuality (heterogeneity) since the intercept does not vary across individuals. Thus, we can assume that all the EU countries have the same intercept parameter, i.e., there is no heterogeneity among them. In this model, we consider the unit effect (heterogeneity), if it exists, is relatively small, i.e., there could be some unobserved heterogeneity among the EU countries, but its effect is negligibly small.

Since the constant term is the same for all units, i.e., there is no heterogeneity, it is known that estimating the pooled model by Ordinary Least Square (OLS) method is efficient and consistent.

If there exists heterogeneity, unobserved entity-specific characteristics will be subsumed in the error term, $\varepsilon_{i,t}$,. This would lead to an endogeneity problem in which the error term is correlated with one or more of the independent variables ($\mathrm{cov}(\varepsilon_{i,t}, X_{i,t}) \neq 0$). This situation leads to biased and inconsistent estimators in the model. In the model in equation 5, if $\alpha_{i,t} = \alpha_i$, $\alpha_{i,t} = \gamma_t$ and $\alpha_{i,t} = \alpha_i + \gamma_t$ cases are present, the pooled OLS would be inappropriate because parameter estimates will be biased and inconsistent. In this case, as a remedy, we use the fixed effects model or random effects model, which both consider unobserved heterogeneity.

4.3.4.2. Fixed Effects Model (FEM)

If $\alpha_{i,t} \neq 0$, it is possible that $\alpha_{i,t}$ includes unobserved and non-random effects. In such a case, we use the "fixed effects model," which is a method for controlling for omitted variables in panel data when the omitted variables vary across entities but do not change over time (Stock & Watson, 2020).

The representation can be used for a one-way entity-fixed effects model.

$$Y_{i,t} = \mu + \beta X'_{i,t} + \alpha_i + \varepsilon_{i,t} \tag{7}$$

In this representation, $\boldsymbol{\alpha_i}$ represents entity-specific intercept value, with a different and constant non-random value for each entity. FEM explicitly accounts for heterogeneity by allowing different intercepts, one for each entity. Here, α_i stands for the unobserved variable that varies for each country to account for the heterogeneity of the EU countries but is fixed through time (time-invariant) and, as a result, has no subscript of **t**. For each of the 27 countries, the intercept will be different due to some unique features of countries, such as geography, demographics, culture, etc. If non-negligible heterogeneity exists among countries in our model, FEM would be appropriate to estimate our model.

If heterogeneity exists, $\alpha_{i,t}$ is unobserved and correlated with $X_{i,t}$, $\mathrm{cov}(\alpha_i, X_i) \neq 0$, and thereby the OLS estimators will be inconsistent and biased. The fixed effects model is estimated using the Within-Group Estimation method. First, within-group means are calculated, and entity fixed effect (heterogeneity) is removed from the model by using the differencing method.

If $\mathrm{cov}(X_{i,t}, \varepsilon_{i,t}) = 0$ is assumed in equation 7, the within-group mean can be expressed as in equation 8:

$$\overline{Y}_i = \alpha_i + \beta\overline{X}_i + \bar{\varepsilon}_i \tag{8}$$

The following definitions for time-mean are made in equation 8:

$$\overline{Y}_i = \frac{\sum_t Y_{i,t}}{T} \qquad \overline{X}_i = \frac{\sum_t X_{i,t}}{T} \quad \text{ve} \quad \bar{\varepsilon}_i = \frac{\sum_t \varepsilon_{i,t}}{T}$$

By taking the difference between equation 7 and equation 8, i.e., by subtracting time-mean from each variable, we removed the unobserved unit effect α_i, and we obtained:

$$Y_{i,t} - \overline{Y}_{i,t} = \mu + \beta\left(X_{i,t} - \overline{X}_{i,t}\right) + \left(\varepsilon_{i,t} - \bar{\varepsilon}_{i,t}\right) \tag{9}$$

This transformation is called the within transformation. By this transformation, we eliminate α_i, which could be correlated with $X_{i,t}$, which could result in inefficient estimators. After eliminating α_i, it is known that the OLS estimator of equation 9 is efficient and consistent.

4.3.4.3. Random Effects Model (REM)

In the random effects model, we assume that differences between countries are not constant, but they can randomly vary. The parameters are treated as part of a stochastic process. In other words, $\alpha_i \sim \mathrm{IID}(0, \sigma_\alpha^2)$ and $\gamma_t \sim \mathrm{IID}(0, \sigma_\gamma^2)$ are defined. α_i represents unit-specific random effects, while γ_t represents time-specific random effects. Unlike the FEM, REM assumes that the unobserved effect, $\alpha_{i,t}$, is uncorrelated with all the independent variables. The random effects model is expressed as in equation 10:

$$\mathrm{Y_{i,t}} = \mu + \beta \mathrm{X'_{i,t}} + \mathrm{u_{i,t}} \tag{10}$$

Unlike the FEM, where each country has its own intercept value, in the REM, the common intercept (μ) is the average of all countries' intercepts. In the REM, it is assumed that the error term $\mathrm{u_{i,t}}$ contains the random effects of $\alpha_{\mathrm{i,t}}$. In other words, unit and/or time effects are considered as components of the error term, $\mathrm{u_{i,t}}$. In this case, the composite error term can be defined as in equation 11:

$$\mu_{\mathrm{i,t}} = \alpha_{\mathrm{i,t}} + \varepsilon_{\mathrm{i,t}} \tag{11}$$

The estimators of OLS for the REM are not unbiased and efficient. Therefore, the random effects model is estimated using the Generalized Least Squares (GLS) method.

In the case of entity-specific random effects, $\mathrm{E}(\mathrm{u_{i,t}}) = 0$ and $\mathrm{var}(\mathrm{u_{i,t}}) = \sigma_\alpha^2 + \sigma_\varepsilon^2$. In other words, the composite error term has a zero mean, and the variance of the composite error term equals the sum of the variance of the unit effect and the variance of the error term. In this case, the variance is constant, and therefore, the error term is homogeneous for all units and time, but the composite error term, $u_{i,t}$, is serially correlated across time since it includes $\alpha_{i,t}$ at each time period. In this case, the error covariance is defined by equation 12:

$$\mathrm{Cov}(\mathrm{u_{i,t}}, \mathrm{u_{j,s}}) = \begin{cases} \sigma_\alpha^2 + \sigma_\varepsilon^2, & \mathrm{i = j, t = s} \\ \sigma_\alpha^2, & \mathrm{i = j, t \neq s} \\ 0, & \text{other cases} \end{cases} \tag{12}$$

For the GLS method, the weighted within-group means are subtracted from equation 10 to obtain the model in equation 13:

$$\left(Y_{i,t} - \overline{\theta Y}_i\right) = (1-\theta)\mu + \beta\left(X_{i,t} - \theta\overline{X}_i\right) + ((1-\theta)\alpha_i + (\varepsilon_{i,t} - \theta\overline{\varepsilon}_i) \qquad (13)$$

where $\theta = 1 - \sqrt{\frac{\sigma_u^2}{\sigma_u^2 + T\sigma_\alpha^2}}$

4.3.5. Specification Tests for Selection of Suitable Panel Data Model

To choose the appropriate model for our study, we should first test whether heterogeneity exists among the countries in our model or not. For this purpose, the test for unit effects is examined using the Breusch-Pagan Lagrange Multiplier approach. Breusch-Pagan (1980) test provides us to detect the presence of heterogeneity. With this, we test whether the pooled OLS model is appropriate or not.

The null and alternative hypotheses for Breusch-Pagan test is as follows:

H_0: The variance of the unit effect is zero. ($\sigma_u^2 = 0$)
H_A: The variance of the unit effect differs from zero. ($\sigma_u^2 \neq 0$)

If the null hypothesis is rejected, it is concluded that there is a unit effect, which requires determining the type of unit effect (Breusch & Pagan, 1980). The Hausman (1978) approach is used to determine the type of unit effect. The Hausman test is a statistical test used to determine whether a model with fixed effects or random effects is more appropriate.

The choice between fixed effects and random effects models depends on whether the unobserved unit effect is correlated with the observed explanatory variables. According to this assumption, if there is no correlation between the independent variable and the unit effect, both estimators are consistent, but the random effects estimator is more efficient. On the other hand, if there is a correlation between the independent variable and the unit effect, the random effects estimator is biased, while the fixed effects estimator is consistent.

In brief, the null and alternative hypotheses for Hausman test are as follows:

H_0: Both Fixed Effects and Random Effects estimates are consistent, but Random Effects estimates are more efficient.

H_A: Fixed Effects estimates are consistent, and Random Effects estimates are inconsistent.

The Hausman test statistic is obtained using the difference between the fixed and random effects estimators.

Considering the theoretical information above, the most appropriate model among the Pooled OLS, Fixed Effects Model and Random Effects Model is selected by using the Breusch-Pagan Lagrange Multiplier Test (1980) and the Hausman Test (1978). According to the results obtained from these specification tests, the most appropriate model is determined to be the Fixed Effects Model. The post-estimation tests were performed to validate the robustness of this model. Modified Wald Test (Greene, 2000) to detect the heteroscedasticity, Modified Bhargava, Franzini and Narendranathan Durbin-Watson Test (Bhargava et al., 1982) and Baltagi-Wu Locally Best Invariant (LBI) Test (Baltagi & Wu, 1999) to detect autocorrelation, Pesaran Test (2004) to detect cross-sectional dependency are applied on the Fixed Effects Model. Considering the problems of heteroscedasticity, autocorrelation and cross-sectional dependency, the Driscoll Kraay robust standard errors model (Driscoll & Kraay, 1998) is preferred, and the estimation results were obtained with this model. In the following chapter, we will present the empirical results of this study.

CHAPTER 5

EMPIRICAL RESULTS

This chapter presents the empirical results obtained from the panel data analysis for this study. This chapter is structured into six sections: Section 1 presents the descriptive statistics of our panel dataset. Section 2 shows the correlation analysis between the variables in the model. Section 3 contains a critical step to ensure the validity of the empirical model, the panel stationarity. Section 4 explains the application of the specification tests to choose the most appropriate model among the pooled OLS, fixed effects model, and random effect model. After the selection and estimation of the model, the post-estimation tests are conducted to validate the robustness of the chosen model in Section 5. Lastly, according to the results of the post-estimation tests, Section 6 presents the model estimation results.

5.1. Descriptive Statistics

The data presented in Table 4 shows descriptive statistics, for each variable in our model.

Table 4. Descriptive Statistics of Variables

	CO	**POP**	**FD**	**REC**	**EI**	**ET**
Mean	117920.5	0.229	0.547	16.739	4.049	1.976
Median	50085	0.241	0.563	14.395	3.755	1.91
Min	1350	-3.847	0.103	0.000	1.320	0.650
Max	847680	3.931	0.901	52.880	9.380	3.790
Std. Dev.	169237.3	0.856	0.197	11.655	1.368	0.526
Skewness	-0.094	-0.841	-0.990	-0.756	-0.039	-0.081
Kurtosis	2.639	4.364	3.410	3.566	3.449	3.169
Observation	540	540	540	540	540	540

-CO: CO_2 emissions, POP: population growth rate, FD: financial development index, REC: renewable energy consumption, EI: energy intensity, ET: energy related tax

-Skewness and kurtosis tests are calculated for the logarithmic form of variables.

5.2. Correlation Analysis

The correlation matrix table presented in Table 5 below examines the correlational relationships between variables to see whether the relationship between independent variables causes multicollinearity problems.

Table 5. Correlation Matrix

	lco	**lpop**	**lfd**	**lei**	**lrec**	**let**
lco	1.0000					
lpop	-0.0041	1.0000				
lfd	0.3821	0.5949	1.0000			
lei	-0.0211	-0.3650	-0.2048	1.0000		
lrec	0.0769	-0.3778	-0.4589	0.0964	1.0000	
let	-0.0612	-0.3444	-0.2046	0.3268	0.2425	1.0000

l means log of variable

When the table is examined, it appears that the highest correlation between independent variables is 0.5949, between lpop and lfd variables. In this case, it can be said that no perfect multicollinearity problem resulting from the relationships between independent variables is expected in the model since all correlation levels between variables is under 0.80 (Gujarati & Porter, 2009).

Additionally, Variance Inflation Factor (VIF) values are presented in Table 6 below. The results of the VIF test show that all values are lower than 5, indicating that there is no presence of a multicollinearity problem.

Table 6. Variance Inflation Factor

Variable	**VIF**	**1/VIF**
lpop	1.01	0.994695
lfd	1.29	0.777775
lei	1.25	0.798228
lrec	1.04	0.957214
let	1.01	0.988849
Mean VIF	1.12	

After examining the correlation matrix and VIF values, it can be concluded that there is no problem with the higher correlation between variables and, thus, multicollinearity.

5.3. Panel Stationarity

Before performing model estimation with panel data, the stationarity of variables should be achieved. A cross-sectional dependency test and, subsequently, a unit root test are applied to variables in the model to assess stationarity in panel data.

5.3.1. Cross-Sectional Dependency

To ensure the efficiency of the empirical analysis, firstly, it is crucial to check if the cross-sectional dependency exists among the units in the panel. In the existence of cross-sectional dependence (CD), a shock affecting one unit may also affect other units. Therefore, it is necessary to test the cross-sectional dependence among the EU-27 countries in the model. In this study, the CD test developed by Pesaran (2004) is used. Table 7 below provides the results of the CD test:

Table 7. Pesaran CD Test Result

Test	Statistics	p-value
LM CD	14.19***	0.000

*** denotes statistically significant at the (1%) level

H_0: $\mathrm{cov}(u_{it},u_{jt}) = 0$ for all t and $i \neq j$

The null hypothesis of the Pesaran CD test is that there is no cross-sectional dependency across the EU-27 countries. However, the result of this test reveals that at 1% significance level, the null hypothesis is strongly rejected, i.e., we can assert that there is indeed CD in the model. It refers to a situation where EU-27 countries in the panel dataset are not statistically independent from each other. Accordingly, the existence of correlation between units is confirmed. This result is not surprising since the model includes EU countries that are economically, socially, and legally interdependent to each other.

According to the result of this test, the unit root test to be applied is determined. After verifying the CD in the model, the next step is to perform the panel unit root test to check the level of stationarity.

5.3.2. Unit Root Test Results

In the presence of CD, first-generation unit root tests produce biased results. Therefore, second-generation unit root tests should be used to obtain reliable and consistent results from unit root tests for panel data. The cross-sectional augmented IPS (CIPS) test developed by Pesaran (2007), one of the second-generation unit root tests frequently used, can control the problem of cross-sectional dependence. Therefore, in this study, it is applied to detect the presence of unit roots. By applying the CIPS test, the stationarity level of the variables is checked. Table 8 below shows the result of the CIPS test:

Table 8. Panel Unit Root Test (CIPS Test) Results

Variables	I(0)		I(1)	
	without trend	with trend	without trend	with trend
lco	-2.245**	-2.896***		
lpop	-1.578	-1.907	-3.275***	-3.547***
lfd	-2.369***	-3.189***		
lrec	-2.635***	-3.025***		
lei	-2.456***	-2.496***		
let	-1.615	-2.473	-4.065***	-4.107***

* (10%), ** (5%) and *** (1%) denotes the level of significance accordingly.
Test of H_0: non-stationary

The result of the CIPS test indicates that the null hypothesis of non-stationarity can be rejected at the level for lco, lfd, lrec, and lei variables with trends and without trends, i.e., they are stationary at level I(0). However, it is seen that the null hypothesis of non-stationarity fails to be rejected at the level for lpop and let variables, i.e., they are not stationarity at the level. They turn out to follow the stationary property after taking their first difference I(1).

After identifying the stationarity levels of variables in the model, we choose the appropriate model in the next section.

5.4. Model Selection: Pooled OLS, Fixed Effects, Random Effects

The choice of the appropriate model framework is an important decision that must be made to carry out robust and accurate economic analysis. In the case of panel data, where the data structure calls for methodologies that effectively capture individual heterogeneity and temporal dynamics, this decision is particularly important. Pooled Ordinary Least Squares, Fixed Effect, and Random Effect models are the three most important models to be considered for this study.

The Figure 4 below shows the diagram of the process of model selection. The specification tests shown on the diagram will serve as a basis for determining which model is best compatible with the underlying data properties and assumptions made in the analysis.

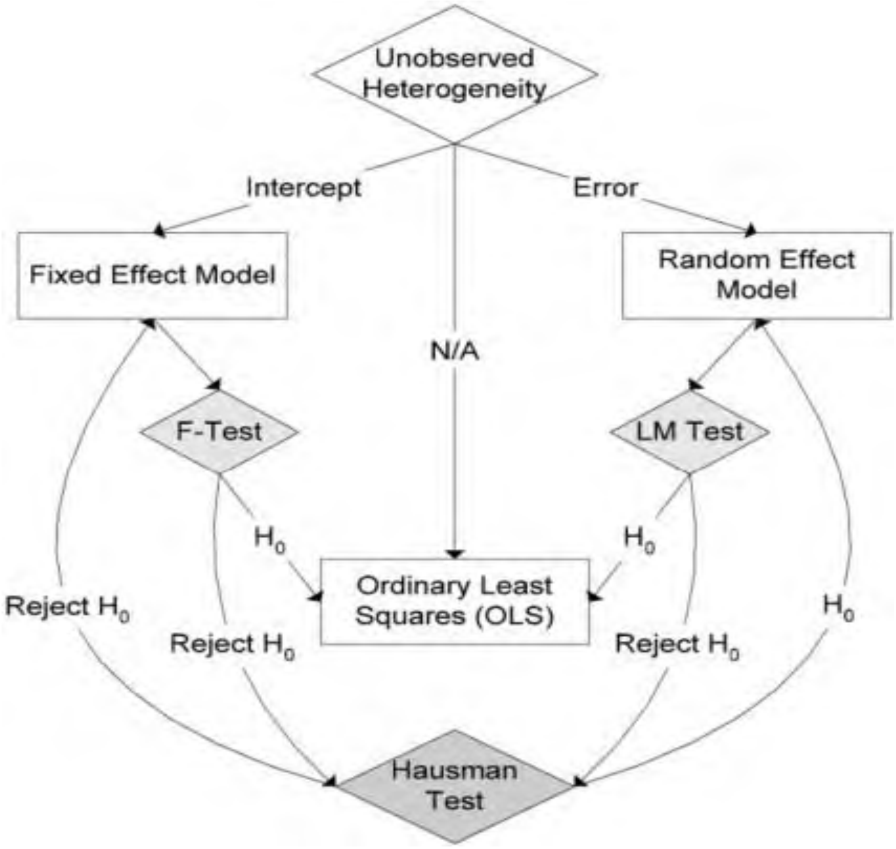

Figure 4. Diagram of the Process of Model Selection

Source: (Park, 2011)

As a result of the F Test and Breusch-Pagan LM Test it is concluded that the pooled OLS is not appropriate model and there is a unit effect[4]. Hence, we should make a choice between the fixed effect and the random effect models. Third and last, we apply the Hausman Test to determine which is more relevant and significant in the panel data. The results of this test are shown below:

Table 9. Hausman Test Results

	Coefficients			
Variables	**(b) Fixed**	**(B) Random**	**(b – B) Difference**	**sqrt(diag(V_b – V_B)) Standard error**
lpop	0.049411	0.0496422	-0.0002312	0.0001784
lfd	0.0956587	0.1008053	-0.0051466	0.0018154
lrec	-0.1642197	-0.1629287	-0.001291	0.0012167
lei	0.23735	0.2412509	-0.0039009	0.0027838
let	-0.1533312	-0.1543589	0.0010278	0.0003816
lpop	0.049411	0.0496422	-0.0002312	0.0001784

b = Consistent H_0 and H_A
B= Inconsistent under H_A, efficient under H_0
Test of H_0: Difference in coefficients not systematic
chi2(5) = (b – B)’ [(V_b – V_B) ^ (-1)] (b – B)
= 15.30
Prob > chi2 = 0.00

According to Hausman Test result, the null hypothesis of random effect being more efficient is rejected. Therefore, it can be concluded that fixed effect model (which assumes correlated individual-specific effects and regressors) is efficient and consistent unlike the random effect model (which assumes no correlation between individual-specific effects and regressors).

In conclusion, fixed effects model is utilized in our base model in this study. This result is satisfactory for this empirical analysis since all the EU countries are

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[4] See Appendix for the F Test and Breusch-Pagan LM Test results.

included in the model, i.e., the countries in the model are not randomly selected so that individual differences are expected to be non-random. The table below, shows the results of our main model estimation:

Table 10. Fixed Effects Regression Model Estimation Results

Dependent variable is lco		
Independent Variables	**Coefficient**	**p-value**
lpop	0.049411 (0.031888)	0.122
lfd	0.0956587*** (0.0330938)	0.004
lrec	-0.1642197*** (0.0168802)	0.000
lei	0.23735*** (0.0401962)	0.000
let	-0.1533312*** (0.0430179)	0.000
constant	11.01252*** (0.0877301)	0.000
Number of observations	513	
Number of groups	27	
R^2	0.5597	
F(5,481)	122.26*** Prob>F = 0.0000	

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10

After the estimation of the model, it is necessary to carry out post-estimation tests for the model since the model regression coefficients are likely to be biased, inconsistent and inefficient in the presence of heteroscedasticity, autocorrelation and cross-sectional dependency. In this case, models that produce robust standard errors should be used in order not to cause spurious relation in panel data analysis. Therefore, post-estimation tests to investigate the normality, heteroskedasticity, autocorrelation and cross-sectional dependency in our base model are applied[5]. The skewness/kurtosis tests results show the presence of normality in the model. According to the Modified Wald Test, heteroskedasticity is detected in the model. The Modified Bhargava, Franzini, and Narendranathan Durbin-Watson Test results reveal that there is autocorrelation. Similarly, the Baltagi-Wu Locally Best Invariant (LBI) Test confirms the presence of autocorrelation in the model. Finally, Pesaran Test result shows that there exists cross-sectional dependency in the model.

5.5. Fixed Effects Model Estimation with Driscoll and Kraay Standard Errors

After carrying out the post-estimation tests for our base model, the presence of heteroscedasticity, autocorrelation, and cross-sectional dependency is detected. Driscoll-Kraay standard errors are robust standard errors which are recommended for the fixed effects model in the case when the model is heteroscedastic, autocorrelated and cross-sectionally dependent. Therefore, in estimations, the fixed effects regression with Driscoll and Kraay standard errors is used.

The table 11 shows the estimation results of the fixed effects regression with Driscoll-Kraay standard errors:

Table 11. Fixed Effects Regression Model Estimation with Driscoll-Kraay Standard Errors Results

Dependent variable is lco		
Independent Variables	**Coefficient**	**p-value**
lpop	0.049411*** (0.0171157)	0.010
lfd	0.0956587* (0.0514128)	0.079
lrec	-0.1642197*** (0.0188893)	0.000

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[5] See Appendix for the post-estimation test results.

Table 11 (continued)

lei	0.23735*** (0.0442151)	0.000
let	-0.1533312*** (0.043707)	0.003
constant	11.01252*** (0.0925857)	0.000
Number of observations	513	
Number of groups	27	
R^2	0.5597	
F(5,18)	39.60 *** Prob>F = 0.0000	

Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

According to the results that are depicted in Table 11, we reach following conclusions:

The estimated coefficients reveal that variables of population and affluence affects CO_2 emissions positively. A 1% increase/decrease in population growth rate over the study period increases/decreases CO_2 emissions by approximately 0.05% in the EU-27. This result shows that population growth in the EU-27 contributes to higher CO_2 emissions, which is in line with our expectations as we mention in the previous chapter. Contrary to Fan et al. (2006) who find the effect of population on CO_2 emissions to be negative at high-income countries, our finding is consistent with the studies of York et al. (2003) for 138 countries, Lin et al. (2009) for China, Bargaoui et al. (2014) for 214 countries, Wang and Zhao (2015) for China, Rasoulinezhad and Taghizadeh-Hesary (2022) for 10 countries, Sun et al. (2022) for B&R countries and Sharif et al. (2023) for 5 Nordic countries that revealed the positive impact of population on CO_2 emissions. Also, Voumik and Mimi (2023) obtain a similar finding showing that every 1% increase in population growth rate causes by approximately %0.03 increase in CO_2 emissions for 30 European Nations. However, unlike York et al. (2003), Lin et al. (2009) and Voumik and Mimi (2023) which claim that population has the largest impact on CO_2 emissions in their studies, our results show that population growth has the least impact on CO_2 emissions among explanatory variables in the model.

The estimation results show that financial development index, a proxy for affluence, affects the CO_2 emissions positively. A 1% increase/decrease in financial development index increases/decreases CO_2 emissions by approximately 0.10% implying that financial development of the EU-27 accelerates the CO_2 emissions. Unlike Tao et al. (2023) that find financial development as a variable reducing CO_2 emissions, identifying affluence as a positive factor regarding CO_2 emissions is in parallel with prior studies of Bargaoui et al. (2014), Shuai et al. (2017), Wang and Zhao (2015), Acar et al. (2021), Rasoulinezhad and Taghizadeh-Hesary (2022) and L. Sun et al. (2022). Yet, similar to the population growth variable, the coefficient of financial development index variable shows that its impact on CO_2 emissions is not large as the impact of technology variables in our STIRPAT model.

Based on the estimation results, we can argue that the technology variables which are renewable energy consumption, energy intensity and energy-related tax revenue in the STIRPAT model, have more impact on CO_2 emissions than population and affluence variables. Renewable energy consumption has a negative impact on CO_2 emissions in line with our prediction stated in the previous chapter. A 1% increase/decrease in the share of renewable energy in total final energy consumption decreases/increases CO_2 emissions by approximately 0.16% in the EU-27. This suggests that renewable energy policies of the EU-27 are efficient to reduce CO_2 emissions. On the contrary to the studies by Nathaniel and Iheonu (2019) for 19 African countries, Hasnisah et al. (2019) for 13 developing Asian countries, Apergis et al. (2010) for 19 developed and developing countries, T.Li et al. (2016) for 18 European countries and Sun (2023) for 5 Asian countries which find that the impact of renewable energy on CO_2 emissions is positive or insignificant, our result highlights the significant role of renewable energy consumption in reducing CO_2 emissions. We obtain similar results with studies of Bekun et al. (2019) for 16 EU countries which find that a 1% increase in renewable energy consumption decreases CO_2 emissions by approximately 0.13%. Moreover, our findings align with previous studies of Shafiei and Salim (2014) for OECD countries, Anwar et al. (2021) for Asean countries, Wu et al. (2021) for 18 developed countries, Aziz et al. (2021) for MINT countries, Rasoulinezhad and Taghizadeh-Hesary (2022) for 10 countries, Fan and Hajiyeva (2022) for G7 countries and Aziz et al. (2023) for East Asian countries that emphasize the significant role of renewable energy in reducing CO_2 emissions. Also, considering that the EU-27 is generally composed of high-income countries, our findings support Nguyen and Kakinaka (2019)'s study which finds that renewable energy consumption has a negative association with emissions in case of high-income countries.

The estimation results indicate that the energy intensity positively affects the CO_2 emissions in line with the studies cited in the previous chapter. A 1% increase/decrease in energy intensity increases/decreases the CO_2 emissions by approximately 0.24% in the EU-27. The coefficient of energy intensity variable has the highest value among the explanatory variables which means that energy intensity has the greatest impact on CO_2 emissions in our model. This finding shows that high energy intensity, i.e., low energy efficiency, is detrimental to achieving the CO_2 emissions reduction targets. The result supports the outcome of Li et al. (2016) for 18 European countries which state that energy intensity is the main factor to curb CO_2 emissions. Moreover, our result is in line with outcomes of studies by Fan et al. (2006) for 208 countries, Lin et al. (2009) for China, Bargaoui et al. (2014) for 214 countries, Shahbaz et al. (2015) for Sub Saharan African countries, Liu and Bae (2018) for China, Wu et al. (2021) for 18 developed countries, Chen et al. (2018) for OECD countries, Rasoulinezhad and Taghizadeh-Hesary (2022) for 10 countries and G. Li et al. (2023) for Beijing. On the other hand, our result differs from the outcomes of studies, which find that energy efficiency leads to higher CO_2 emissions, of Sun et al. (2022) for 62 B&R countries, Wang and Zhao (2015) and Wang and Feng (2017) for China.

The empirical findings of our model indicate that energy-related tax revenue has a negative impact on CO_2 emissions. A 1% increase/decrease in the share of energy related tax revenue to GDP decreases/increases CO_2 emissions by approximately 0.15% in the EU-27. This suggest that implementing energy-related tax policies is an efficient tool to reduce CO_2 emissions. This result is similar to the findings of Jeffrey and Perkins (2015) that 1% increase in energy tax leads to 0.11% decrease in CO_2 emissions for the EU-27 countries. Considering that they find this result for the time period of 1996-2009, we can argue that the impact of energy-related tax revenue on CO_2 emissions has increased in the following years. In addition, our finding is corroborated by the studies by Miller and Vela (2013) for 50 countries, Lapinskienė et al. (2017) for 20 EU countries and Tekin and Şaşmaz (2016) for 25 EU countries. On the other hand, our result is contradicted by Liobikienė et al. (2019) for EU-28 countries, Wolde-Rufael and Mulat-Weldemeskel (2021) for 7 emerging countries.

In conclusion, the empirical evidence shows that independent variables have significant and varying degrees of impact on the dependent variable. In sum, the results indicate that population growth, financial development and energy intensity leads to higher CO_2 emissions. On the other hand, renewable energy consumption and energy-related tax revenue cause reduction of CO_2 emissions.

CHAPTER 6

CONCLUSION

Environmental degradation caused by anthropogenic factors has serious adverse effects that result in climate change and global warming. Rising temperatures, sea-level rise, ecological destruction, biodiversity loss, intense weather events, etc., are destructive consequences of environmental degradation worldwide. For this reason, environmental protection is critical to ensure a sustainable world for present and future generations. The EU has been at the forefront of protecting the environment. This study comprehensively analyzes the historical development of the EU's environmental policies, including initiatives, agreements, and milestones. It can be asserted that the EU has consistently demonstrated its commitment to address environmental protection over the decades. Looking at the EU's environmental policies historically, it can be said that CO_2 emissions, as a major contributor to environmental degradation, have been the most important issue in the EU's environmental policies. One of the main objectives of its environmental agenda has been to reduce CO_2 emissions. The EU aims to reduce emissions by at least 55% by 2030, compared to 1990 levels, and become the world's first climate-neutral continent by 2050, as outlined in the European Green Deal. To achieve the CO_2 emissions reduction target, the EU has prioritized the energy field, and its policies are driven by the understanding that environmental protection is directly linked to energy. Therefore, this study reviews how the EU's energy policies have been affected by the EU's changing environmental policies historically. From the review, it can be concluded that EU energy policies are adjusted in line with its environmental policies to reduce CO_2 emissions. In other words, the energy and environmental policies of the EU have an integrated structure. It can be observed that specifically three key directives, namely the Renewable Energy Directive, Energy Efficiency Directive, and Energy Taxation Directive, stand out within the framework of the EU's energy policies to reduce CO_2 emissions. From this point of view, we try to analyze the environmental impacts of these three energy-related directives in the EU. Based on this, renewable energy consumption, energy intensity, and energy-related tax variables are used to assess the environmental impacts of these directives. This study is worthy since there is no study that addresses the impact of the EU's three energy-related directives together on the CO_2 emissions previously. Besides, the STIRPAT model, which has very limited application for the EU, is used in this study, and thereby, this contributes to the literature on the EU's environmental studies. Also, to our knowledge, this is the first study that includes the energy-related tax revenue in the STIRPAT model. Overall, this thesis tries to present a valuable contribution to the environmental impact analysis literature.

In this study, we use the framework of the STIRPAT model, which is widely used in environmental impact analysis to investigate the effects of population, affluence, and technology on the environment. We extend the STIRPAT model to quantitatively analyze the impacts of population growth (represents population), financial development (represents affluence), renewable energy consumption, energy intensity, and energy-related tax revenue (represents technology) on CO_2 emissions (represents environmental impact). We utilize a balanced panel dataset for the EU-27 countries spanning from 2000 to 2019. The data used in our study is subjected to several statistical tests, including the Pesaran cross-sectional dependency test and second-generation CIPS unit roots test, to achieve stationarity in panel data. After that, the specification tests are applied to choose the most appropriate panel data model among the pooled OLS, fixed effects, and random effect models. As a result, the fixed effects model is selected as our base model in this study. Subsequently, applying the post-estimation tests for our base model, the fixed effects regression model with the Driscoll-Kraay technique is employed to obtain accurate estimation results.

Based on the empirical results of our econometric analysis in general, it is concluded that population growth, financial development, and energy intensity have positive impacts on CO_2 emissions while renewable energy consumption and energy-related tax revenue have negative impacts on CO_2 emissions, on EU-27 countries over the period of 2000-2019. Evaluation of empirical results is critical for providing policy implications. The empirical results reveal that a 1% increase/decrease in population growth rate within the EU-27 increases/decreases CO_2 emissions by approximately 0.05%. It is generally an expected result since a higher population growth increases the demand for goods and services, resulting in a higher requirement for energy and resources that promotes CO_2 emissions, adversely influencing the environment. However, it may be possible to reverse this situation by implementing relevant policies on public awareness. To achieve this, governments and non-governmental organizations could organize widespread educational programs to raise people's awareness and environmental consciousness because it is only possible to protect the environment with public participation in combating environmental problems. Environmental education could help people adopt an environmentally friendly lifestyle. Therefore, the promotion of higher environmental education in the society is strongly suggested for environmental protection improvement since increasing public awareness contributes to changing people’s attitudes toward their daily activities, such as minimizing waste by recycling items, saving water, using energy-efficient appliances, using public transportation instead of driving cars, planting trees or donating to an organization that will do so, supporting environmental policies, etc. In a society where such environmental awareness is achieved, population growth may not increase CO_2 emissions; on the contrary, it may even contribute to CO_2 emissions reduction.

Secondly, the findings unveil that financial development has positively impacted CO_2 emissions in the EU-27. The empirical results indicate that a 1% increase/decrease in financial development index increases/decreases CO_2 emissions by approximately 0.10%. The plausible explanation for this situation may be that financial development is accompanied by economic growth. A developed financial system boosts economic growth by providing households and firms easier access to credit channels that allows them to consume and/or invest more. Expansion of credits could exert severe pressure on resources and environment and thereby causes CO_2 emissions to increase through production and consumption. Moreover, the financial sector could be reluctant to prioritize new green investments over conventional ones because of investment risk concerns. Therefore, traditional carbon-intensive sectors which are the main responsible actors of pollution, undermining environmental protection could access funding more easily from financial institutions to expand their businesses. However, harmful influences of financial development on the environment could be prevented, and could be turned into a significant advantage for the EU-27 to achieve its environmental goals. The green finance policy of the EU-27 could be strengthened to stimulate green economic growth. Increasing the availability of financing environmentally-friendly projects may reinforce the quality of the environment. In this regard, financial institutions could encourage low-carbon projects, green energy technologies investments, etc., by developing policies and strategies such as providing cheap and selective credits to investors. Promotion of the financial system of the EU-27 on environmental investments could help to achieve CO_2 emissions reduction.

Thirdly, the findings prove that higher renewable energy consumption helps to curb CO_2 emissions. The empirical results indicate that a 1% increase/decrease in the share of renewable energy in total final energy consumption decreases/increases CO_2 emissions by approximately 0.16%. This result shows the effectiveness of renewable energy in protecting the environment. We can assert that the EU-27's setting mandatory targets for a specified time period through Renewable Energy Directives has contributed significantly to reaching this conclusion. The share of renewable energy consumption in the total final energy consumption has continuously increased in the EU-27 over the years through these directives. It rose from 9% in 2000 to 19.9% in 2019. In 2020, the renewable energy consumption share reached to 22% exceeding the 20% target set in the Renewable Energy Directive 2009/29/EC. The EU is committed to reach the target of 45% renewable energy consumption by 2030, set in the latest Renewable Energy Directive. Considering the crucial role of renewable energy consumption in reducing CO_2 emissions, accelerating the transition to renewable energies for reduction of CO_2 emissions in the EU-27 further could be recommended. To achieve this, investments in renewable energy could be increased through various policies such as investment subsidies, financial support expansion, promotion of research and development on clean and low-carbon energy technology innovations, tax exemption or reduction for renewable energy, etc. Furthermore, public awareness about renewable energy consumption's significance in protecting the environment should be raised. Initiating educational campaigns could be an effective strategy for creating a society with a positive attitude toward renewable energy consumption. In addition, further regulatory policies could be implemented to incentivize individuals and corporates to increase renewable energy consumption.

Fourthly, empirical findings regarding energy intensity indicate that it has an increasing effect on CO_2 emissions. In this study, we find that a 1% increase/decrease in energy intensity increases/decreases CO_2 emissions by approximately 0.24%. The impact of energy intensity on CO_2 emissions is greater than other variables. We can claim that Energy Efficiency Directives play a crucial role in achieving this result by setting binding energy efficiency targets for member countries of the EU-27. Setting targets and employing relevant measures in a regulatory framework to maximize energy efficiency could be considered to contribute significantly to the EU-27's goals of reducing CO_2 emissions. In addition to energy efficiency targets, the EU regulates many energy efficiency policies in its Energy Directive to encourage the member states to reduce their energy consumption. The Directive aims to promote the energy efficient practices such as energy efficiency standards for products, mandatory certificates for buildings, and energy efficiency labels. These steps are essential to increase energy efficiency with mandatory applications in all sectors. The energy intensity in the EU-27 decreased from 4.1 MJ-$2017 PPP GDP in 2000 to 3 MJ-$2017 PPP GDP in 2019. In other words, it increased energy efficiency significantly in this period through its Energy Efficiency Directives. Accordingly, the EU-27 could continue to set more ambitious energy efficiency targets for its member states to strengthen its energy efficiency maximization to achieve its energy efficiency target for 2030. Enhancement in energy efficiency contributes to curbing CO_2 emissions and environmental degradation by reducing demand for conventional energy sources such as coal, oil, natural gas, etc. Considering the environmental benefits of energy efficiency, the EU-27 could focus more on improving its support to decrease energy intensity. In this regard, supportive policies could be given importance for promoting energy-efficient technology investments. This is essential for reducing CO_2 emissions without sacrificing economic growth.

Fifthly, the results show that energy-related tax revenues contribute to reduction of CO_2 emissions. The empirical results reveal that a 1% increase/decrease in the share of energy-related tax revenue to GDP decreases/increases CO_2 emissions by approximately 0.15%. This result proves the success of implementing energy tax policies of the EU-27 within the Energy Tax Directives framework to tackle environmental degradation. Energy-related taxes seem to be an ideal tool to combat CO_2 emissions since they discourage consuming carbon-intensive energy sources and excessive energy use. This is particularly significant to prevent energy waste. Also, it motivates energy investments that have the potential to reduce CO_2 emissions to avoid taxation. All of these contribute to reduce the environmental impact of energy production and consumption. Besides, it would be more efficient if the energy tax revenue were used for environmental protection efforts. It could be suggested that countries create funds with this revenue to fight against environmental problems. Environmental-related initiatives such as renewable energy investments or research and development expenditures on energy efficiency could be financed by using these funds. Simply put, developing the energy taxation policy could help reduction of CO_2 emissions and protection of the environment. The critical point here is to consider the opportunity costs of energy taxes. Indeed, it could be argued that these taxes on energy to protect the environment and generate revenue may harm economic growth by adversely affecting competition. An effective taxation policy without hindering economic growth is essential for the EU. Therefore, it is important to set policies within the scope of energy taxes by considering the economic development level of countries in setting the policies.

Considering all of these points, it could be pointed out that the EU-27 has shown a strong commitment to reduce CO_2 emissions with its comprehensive and integrated policies to tackle environmental degradation. As the EU-27 occupies an increasingly important position in the development of environmental policies in the world, it should continue developing these policies. As a global leader in environmental protection policies, the EU-27's further ambitious efforts could raise awareness and obligation of environmental responsibility for other countries in the world, thereby promising a more sustainable and greener world in the future.

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APPENDICES

A. TEST RESULTS

1. F- Test and Breusch Pagan LM Test Results

We apply the F test to choose between the fixed effects model and the pooled OLS model. The fixed effects model is tested by F-Test. The null hypothesis of this test is the value of all unit effects is equal to zero. This implies that the fixed effects are redundant and pooled OLS is valid. The result of this test is shown below:

Table Appendix A.1.: F Test Results

F test that all u_i=0: F(26, 481) = 4241.08***
Prob > F = 0.0000

Test of H_0: $u_1 = \ldots = u_{n-1} = 0$

According to the F-test result, the null hypothesis is rejected at the (1%) level, hence it can be concluded that there is a significant fixed effect in the panel data. In other words, the fixed effects model is better than the pooled OLS.

We apply the Breusch-Pagan Lagrange Multiplier Test to choose between the random effects model and the pooled OLS model. The null hypothesis is the individual specific variance components are zero, i.e., the variance of unit effect is zero. The result of this test is shown below:

Table Appendix A.2: **Breusch Pagan LM Test Results**

	Var	**SD = sqrt(Var)**
lco	1.871811	1.368142
e	0.0066199	0.0813626
u	1.33654	1.156088

Test of H_0: Var (u) = 0
Chibar2(01) = 4337.21
Prob > chibar2 = 0.0000

According to the Breusch-Pagan LM Test results, the null hypothesis is rejected hence it can be concluded that there is a significant random effect in the panel data. In other words, the random effects model is better than the pooled OLS.

2. Post-Estimation Tests for the Fixed Effects Model

2.1. Normality

We apply the skewness/kurtosis tests to verify the normality of our base model, fixed effects model. The null hypothesis of this test is the presence of normality in the model. The result of this test is shown below:

Table Appendix A.3.: Skewness/kurtosis test for normality Result

	Observation	P(skewness)	P(kurtosis)	Chi2(2)	Prob > Chi2
residual	513	0.734	0.159	2.09	0.3508

According to the result of skewness/kurtosis test for normality, the null hypothesis is failed to reject. Hence, normality is present in the model.

2.2. Heteroscedasticity

The presence of heteroscedasticity problem in the model causes wrong estimates of standard errors for regression coefficients and their t-values. To check whether there is heteroscedasticity in the model, modified Wald Test is applied. This test provides to assess the panel groupwise heteroskedasticity in the residuals of fixed effect regression model. The null hypothesis of this test is that the variances of the residuals are equal across all countries in our base model, i.e., the model is homoscedastic. The test result is shown below:

Table Appendix A.4.: Modified Wald Test Result

Chi2(27) = 2109.51***
Prob > Chi2 = 0.0000

Test of H_0: $\sigma_i^2 = \sigma^2$ for all i

According to the Modified Wald Test result, the null hypothesis is rejected at the (1%) level. This implies that there is significant groupwise heteroscedasticity in the fixed effect regression model.

2.3. Autocorrelation

Autocorrelation in panel data model causes inconsistency in the residuals and estimation results. To check whether there exists autocorrelation in the model, Modified Bhargava, Franzini and Narendranathan Durbin-Watson Test and Baltagi-Wu Locally Best Invariant (LBI) Test is performed. This test is used for serial correlation in the fixed effects model. The null hypothesis of both tests is that there is no autocorrelation. The result of autocorrelation tests is shown below:

Table Appendix A.5.: Autocorrelation Tests Result

Test	**Test Statistics**
Modified Bhargava-Franzini-Narendranathan DW Test	0.41428843 p-value = 0.0000
Baltagi-Wu LBI Test	0.62398007

Test of H_0: no first order autocorrelation

When the test statistics in both tests are close to 2, the null hypothesis cannot be rejected and, it could be argued that there is no autocorrelation. However, when the test statistics are evaluated, it is seen that they are significantly less than 2. In this case, it is concluded that the null hypothesis is rejected, hence it indicates the presence of autocorrelation problem in the model.

2.4. Cross Sectional Dependency

To assess the cross-sectional independence of residuals in the base model, Pesaran's Test is applied. The null hypothesis is no cross-sectional dependency in the model. The result of this test is shown below:

Table Appendix A.6: Pesaran's Test Result

Test	**Statistics**	**p-value**
Pesaran (2004)	11.966***	0.000

*** denotes statistically significant at the (1%) level
Test of H_0: residuals are not correlated.

The null hypothesis of Pesaran's Test is rejected at the (1%) level. Hence, it is concluded that there exists cross-sectional dependency in our base model.

B. TURKISH SUMMARY / TÜRKÇE ÖZET

İnsan faaliyetleri kaynaklı çevresel tahribat sonucu ortaya çıkan iklim değişikliği ve küresel ısınma ile ilgili endişeler giderek artmaktadır, çünkü bunların etkileri dünyayı ve insanlığı giderek daha fazla tehdit etmektedir. Artan sıcaklıklar, deniz seviyesinin yükselmesi, ekolojik yıkım, biyolojik çeşitlilik kaybı, yoğun hava olayları çevresel tahribatın yıkıcı sonuçlarıdır. Bu nedenle çevrenin korunması, şimdiki ve gelecek nesiller için sürdürülebilir bir dünyanın sağlanması açısından kritik önem taşımaktadır. Bu bağlamda, çevresel tahribata neden olan faktörlerin kapsamlı bir şekilde anlaşılması gerekmektedir. Bu faktörler arasında karbondioksit (CO_2) emisyonları çevresel tahribata ve dolayısıyla iklim değişikliği ve küresel ısınmaya en büyük katkıyı yapan faktördür. Bu nedenle, CO_2 emisyonları, kritik bir çevresel araştırma konusu haline gelmiştir. Hükümetlerarası İklim Değişikliği Paneli'nin İklim Değişikliği (2023) raporuna göre, 21. yüzyılın ilk yirmi yılında küresel yüzey sıcaklığının 1850-1900 dönemine kıyasla 0,99°C daha yüksek olması nedeniyle insan kaynaklı küresel ısınmanın sınırlandırılması için antropojenik faaliyetlerden kaynaklanan CO_2 emisyonlarının sıfırlanmasını gerekmektedir. Bu bağlamda, CO_2 emisyonlarının belirleyicilerinin analiz edilmesi, CO_2 emisyonlarının ana etkenlerine yönelik etkili strateji ve politikaların geliştirilmesini sağlayacağı için kritik bir öneme sahiptir.

Avrupa Birliği (AB) tarihsel olarak uluslararası çevre koruma politikalarında küresel bir lider olmuştur. AB çevre politikası çerçevesinde küresel ölçekte iklim değişikliğiyle mücadele etmek için tarihsel süreç boyunca çeşitli girişimler ve anlaşmalar yapmıştır. Çevresel problemleri ele almak için çeşitli politika ve düzenlemeleri uygulama konusunda kararlı bir tutum sergilemiştir. AB'nin politikası, çevresel hususların dikkate alınmadığı ekonomik büyümeye dayalı bir dönemden çevre konusunda artan farkındalıkla beraber emisyonların azaltılması için küresel liderliğe yönelik güçlü bir taahhütle çevreyi dikkate alan sürdürülebilir büyümeye dayalı bir döneme geçiş yapmıştır. AB'nin çevre politikalarına tarihsel olarak bakıldığında, çevresel tahribata sebep olan CO_2 emisyonlarının AB'nin çevre politikalarındaki en önemli konu olduğu söylenebilir. CO_2 emisyonlarının azaltılması, AB çevre gündeminin en önemli hedeflerinden biri olmuştur ve bunu başarmak için büyük bir çaba göstermektedir. AB, 2030 yılına kadar emisyonları 1990 seviyelerine kıyasla en az %55 oranında azaltmayı ve Avrupa Yeşil Mutabakatı'nda belirtildiği üzere 2050 yılına kadar dünyanın ilk iklim-nötr kıtası olmayı hedeflemektedir.

Enerji sektörü CO_2 emisyonlarının artmasında çok önemli bir rol oynadığından, AB CO_2 emisyonlarının azaltılması hedefini gerçekleştirmek için enerji politikalarına öncelik vermiştir. Enerji üretimi ve tüketimi sırasında atmosfere salınan sera gazı miktarı oldukça yüksektir. AB'deki toplam emisyonların %75'i enerji sektöründen kaynaklanmaktadır. Bu anlamda enerji ve iklim değişikliği politikaları bütünleşik bir yapıya sahiptir ve enerji sektörünün emisyonlara olan önemli katkısı nedeniyle her iki alanda da ortak bir düzenleme anlamlıdır. Nitekim, özellikle 2000'li yılların başından itibaren AB, enerji politikalarında çevre temelli yaklaşımları daha güçlü bir şekilde benimsemeye başlamış ve çevresel sürdürülebilirliği enerji politikalarının merkezine yerleştirerek önemli adımlar atmıştır. Bu dönemde AB, enerji politikalarını somut hedefler koyarak enerji dönüşüm sürecinin hızlanmasını sağlamıştır. Enerji verimliliğinin artırılması, yenilenebilir enerji kaynaklarının teşvik edilmesi ve emisyonların azaltılması gibi konularda belirlenen hedefler, AB'nin çevre ve enerji politikalarının temel dayanakları haline gelmiştir. Bu çerçevede, AB üyesi ülkeler için yol gösterici ilkeler olarak üç temel direktif ortaya çıkmıştır. Yenilenebilir Enerji Direktifi, Enerji Verimliliği Direktifi ve Enerji Vergilendirme Direktifi olarak adlandırılan bu direktifler, AB'deki enerji ve çevre politikalarının uyumlaştırılmasında önemli rol oynamaktadır. Bu noktadan hareketle bu çalışma, AB-27 ülkelerinde enerji ile ilgili üç temel direktifin çevresel etkilerini analiz etmeyi amaçlamaktadır.

Bu analizi gerçekleştirmek için bu çalışmada çevresel etki analizi çalışmalarında yaygın olarak kullanılan Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) modeli kullanılmıştır. STIRPAT modeli nüfus (P), refah (A) ve teknoloji (T) değişkenlerinin çevresel etkilerini araştırmaktadır. AB-27 ülkeleri için 2000'den 2019'a kadar olan yılları kapsayan dengeli bir panel veri seti kullanılarak yapılan bu çalışmada nüfus artış oranı, finansal gelişme, yenilenebilir enerji tüketimi, enerji yoğunluğu ve enerji vergisi geliri değişkenlerinin CO_2 emisyonları üzerindeki etkilerini analiz etmek için STIRPAT modelinin genişletilmiş hali kullanılmıştır. Çevresel etkiyi temsil etmesi için CO_2 emisyonları değişkeni bu model içerisinde bağımlı değişken olarak kullanılmıştır. CO_2 emisyonlarının çevresel tahribata ve dolayısıyla iklim değişikliği ve küresel ısınmaya olan önemli katkısı göz önüne alındığında, bu modelde çevresel etkiyi temsil etmesi açısından uygun olduğu düşünülmektedir. STIRPAT modeli çerçevesinde, nüfus ve refah değişkenleri çevresel etkinin temel faktörleridir. Nüfus (P) değişkeninin ölçümü için nüfus artış oranı değişkeni kullanılmıştır. Refah (A) değişkeninin ölçümü için ise finansal gelişmişlik endeksi değişkeni kullanılmıştır. Diğer taraftan, STIRPAT modeli çerçevesinde teknoloji (T) değişkenini temsil etmesi için teorik olarak çevresel etkisi olduğu düşünülen ek faktörler dahil edilebilmektedir. Bu bağlamda, bu çalışmada, Yenilenebilir Enerji Direktifi, Enerji Verimliliği Direktifi ve Enerji Vergilendirme Direktifi'nin çevresel etkisini değerlendirebilmek amacıyla yenilenebilir enerji tüketimi, enerji yoğunluğu ve enerji vergisi gelirleri değişkenleri teknoloji (T) değişkeninin ölçümü için dahil edilmektedir.

Bu tez, çevresel etki analizi literatürüne birkaç yönden katkıda bulunmayı amaçlamaktadır. İlk olarak, bu çalışma AB'nin CO_2 emisyonlarını azaltmaya yönelik enerji politikalarında kaydedilen ilerlemeyi değerlendirmek açısından önemlidir çünkü daha önce AB'nin enerjiyle ilgili üç direktifinin birlikte CO_2 emisyonları üzerindeki etkisini ele alan bir çalışma bulunmamaktadır. İkinci olarak, AB'de çevresel etki analizi için STIRPAT Modelinin uygulanması birkaç çalışma ile sınırlı olduğu için bu çalışmanın literatüre katkı sunması amaçlanmaktadır. Üçüncü olarak, enerji ile ilgili vergilendirme bu çalışma ile ilk kez STIRPAT Modelinin uygulandığı çevresel etki analizine dahil edilmiştir.

Çalışmamızda kullanılan veriler, panel veride durağanlığı sağlamak için Pesaran yatay kesit bağımlılık testi (2004) ve yatay kesit bağımlılığının olduğu durumda kullanılan ikinci nesil birim kök testlerinden olan CIPS birim kök testi (2007) dahil olmak üzere çeşitli istatistiksel testlere tabi tutulmuştur. Durağanlık sağlandıktan sonra, havuzlanmış OLS modeli, sabit etkiler modeli ve rassal etkiler modeli arasından en uygun panel veri modelini seçmek için spesifikasyon testleri uygulanmıştır. Breusch-Pagan Lagrange Multiplier Testi (1980) ve Hausman Testi (1978) kullanılarak elde edilen test istatistikleri sonuçlarına göre en uygun modelin Sabit Etkiler Modeli olduğu belirlenmiştir. Ardından, değişen varyans sorununun tespiti için Değiştirilmiş Wald Testi (2000), otokorelasyon sorununun tespiti için Bhargava, Franzini ve Narendranathan Durbin-Watson Otokorelasyon Testi (1982) ve Baltagi-Wu Locally Best Invariant (LBI) Testi (1999), yatay kesit bağımlılığının tespiti için Pesaran Testi (2004) Sabit Etkiler Modeline uygulanmıştır. Bu testlerin sonucunda değişen varyans, otokorelasyon ve yatay kesit bağımlılığının varlığı tespit edilmiştir. Değişen varyans, otokorelasyon ve yatay kesit bağımlılığı göz önünde bulundurularak Driscoll Kraay (1998) tekniği ile Sabit Etkiler Modeli tercih edilmiş ve tahmin sonuçları bu model ile elde edilmiştir.

Yapılan ekonometrik analizin ampirik sonuçlarına dayanarak, 2000-2019 döneminde AB-27 ülkelerinde nüfus artış oranı, finansal gelişme ve enerji yoğunluğunun CO_2 emisyonlarını artırdığı, fakat yenilenebilir enerji tüketimi ve enerji vergisi gelirlerinin ise CO_2 emisyonlarını azalttığı sonucuna ulaşılmıştır. Ayrıca, AB-27 ülkelerinde STIRPAT modelindeki teknoloji (yenilenebilir enerji tüketimi, enerji yoğunluğu ve enerji vergisi geliri) değişkenlerinin CO_2 emisyonları üzerinde nüfus ve refah değişkenlerinden daha fazla etkiye sahip olduğu tespit edilmiştir.

Çalışmada elde edilen tahmin sonuçlarına göre, AB-27 ülkelerinde nüfus artış oranındaki artışın daha yüksek CO_2 emisyonuna neden olduğu tespit edilmiştir. Bulgular, nüfus artış oranındaki %1'lik bir artışın/ azalışın CO_2 emisyonlarını yaklaşık %0,05 oranında artırdığını/ azalttığını ortaya koymaktadır. Nüfusun CO_2 emisyonları üzerindeki etkisini yüksek gelirli ülkelerde negatif bulan Fan ve diğerlerinin (2006) aksine, bulgumuz nüfusun CO_2 emisyonları üzerindeki artış etkisini ortaya koyan York ve diğerlerinin (2003) 138 ülke için, Lin ve diğerlerinin (2009) Çin için, Bargaoui ve diğerlerinin (2014) 214 ülke için, Wang ve Zhao (2015)'nun Çin için, Rasoulinezhad ve Taghizadeh-Hesary (2022)'nin 10 ülke için, Sun ve diğerlerinin (2022) B&R ülkeleri için ve Sharif ve diğerlerinin (2023) 5 İskandinav ülkesi için yaptığı çalışmalarla uyumludur. Özellikle, analiz sonucunda nüfus artış oranındaki her %1'lik artışın 30 Avrupa ülkesi için CO_2 emisyonlarında yaklaşık %0,03'lük bir artışa neden olduğunu gösteren Voumik ve Mimi (2023)'nin çalışmasına yakın bir sonuç elde edilmiştir. Ancak, York ve diğerleri (2003), Lin ve diğerleri (2009) ve Voumik ve Mimi (2023) çalışmalarında nüfusun CO_2 emisyonları üzerinde en büyük etkiye sahip olduğunu tespit etmişlerdir. Bizim çalışmamızda ulaşılan tahmin sonuçlarına göre nüfusun modeldeki açıklayıcı değişkenler arasında CO_2 emisyonları üzerinde en az etkiye sahip olduğunu göstermektedir. Ulaşılan sonuç, AB-27 ülkelerindeki nüfus artışının daha yüksek CO_2 emisyonlarına katkıda bulunduğunu göstermektedir. Bu genel olarak beklenen bir sonuçtur çünkü daha büyük bir nüfus mal ve hizmetlere olan talebi artırmakta, bu da CO_2 emisyonlarının artmasına yol açan enerji ve kaynaklara daha fazla ihtiyaç duyulmasına neden olarak çevreyi olumsuz yönde etkilemektedir. Ancak, kamu bilinci konusunda ilgili politikalar uygulanarak bu durumu tersine çevirmek mümkün olabilir. Bunu başarmak için hükümetler ve sivil toplum kuruluşları, insanların farkındalığını ve çevre bilincini artırmak için yaygın eğitim programları düzenleyebilirler çünkü çevreyi korumak ancak çevre sorunlarıyla mücadeleye toplumun katılımıyla mümkündür. Çevre eğitimi, insanların çevre dostu bir yaşam tarzını benimsemelerine yardımcı olabilir. Bu nedenle, toplumda daha yüksek çevre eğitiminin teşvik edilmesi, çevre korumanın iyileştirilmesi için şiddetle tavsiye edilmektedir. Kamu bilincinin artırılması, insanların geri dönüşüme önem vererek atıkları en aza indirmek, su tasarrufu yapmak, enerji tasarruflu aletler kullanmak, araba kullanmak yerine toplu taşıma araçlarını tercih etmek, ağaç dikmek veya bunu yapacak bir kuruluşa bağışta bulunmak, çevre politikalarını desteklemek vb. günlük faaliyetlerine yönelik tutumlarının değiştirilmesine katkıda bulunur. Bu tür bir çevre bilincinin sağlandığı bir toplumda, nüfus artışı CO_2 emisyonlarını artırmayabilir; aksine, CO_2 emisyonlarının azaltılmasına katkıda bulunabilir.

İkinci olarak, çalışmada elde edilen tahmin sonuçları finansal gelişmenin AB-27 ülkelerinde CO_2 emisyonlarının artışına yol açtığını ortaya koymaktadır. Ampirik sonuçlar, finansal kalkınma endeksindeki %1'lik bir artışın/ azalışın CO_2 emisyonlarını yaklaşık %0,10 oranında artırdığını/ azalttığını göstermektedir. Finansal gelişmeyi CO_2 emisyonlarını azaltan bir faktör olarak bulan Tao ve diğerlerinin (2023) aksine, refahın CO_2 emisyonlarının yükselmesine yol açan bir faktör olduğunu tespit eden Bargaoui ve diğerleri (2014), Shuai ve diğerleri (2017), Wang ve Zhao (2015), Acar ve diğerleri (2021), Rasoulinezhad ve Taghizadeh-Hesary (2022) ve L. Sun ve diğerlerinin (2022) çalışmalarıyla paraleldir. Bununla birlikte, nüfus artış oranı değişkenine benzer şekilde, finansal kalkınma endeksi değişkeninin katsayısı, CO_2 emisyonları üzerindeki etkisinin STIRPAT modelimizdeki teknoloji değişkenlerinin etkisi kadar büyük olmadığını göstermektedir.

Finansal gelişmenin AB-27 ülkelerinde CO_2 emisyonlarını artırmasının makul açıklaması, finansal gelişmeye ekonomik büyümenin eşlik etmesi olabilir. Gelişmiş bir finansal sistem, hane halkı ve firmaların kredi kanallarına daha kolay erişimini sağlayarak ekonomik büyümeyi artırmaktadır ve bu da daha fazla tüketim ve/ veya yatırım yapmalarına olanak tanımaktadır. Kredilerin genişlemesi kaynaklar ve çevre üzerinde ciddi bir baskı oluşturabilmektedir ve dolayısıyla üretim ve tüketim yoluyla CO_2 emisyonlarının artmasına neden olabilmektedir. Ayrıca, finans sektörü risk endişeleri nedeniyle yeni yeşil yatırımlara geleneksel yatırımlara kıyasla öncelik verme konusunda isteksiz olabilmektedir. Bu nedenle, çevrenin korunmasına zarar veren geleneksel karbon yoğun sektörler, işlerini büyütmek için finans kuruluşlarından daha kolay finansman sağlayabilmektedir. Bununla birlikte, finansal gelişmenin çevre üzerindeki zararlı etkileri önlenebilir ve AB-27 ülkelerinin çevresel hedeflerine ulaşması için önemli bir avantaja dönüştürülebilir. Yeşil ekonomik büyümeyi teşvik etmek için AB-27 ülkelerinin yeşil finans politikası güçlendirilmesi önemlidir. Çevre dostu projelerin finanse edilebilirliğinin arttırılması çevre politikalarına önemli katkıda bulunabilir. Bu bağlamda, finans kuruluşları yatırımcılara ucuz ve seçici krediler sağlamak gibi politika ve stratejiler geliştirerek düşük karbonlu projeleri, yeşil enerji teknolojileri yatırımlarını vb. teşvik edebilir. AB-27 ülkelerinin finansal sisteminin çevresel yatırımlar konusunda teşvik edilmesi CO_2 emisyonlarının azaltılmasına yardımcı olacaktır.

Üçüncü olarak, çalışmada elde edilen tahmin sonuçları daha yüksek yenilenebilir enerji tüketiminin CO_2 emisyonlarını azaltmaya yardımcı olduğunu kanıtlamaktadır. Ampirik sonuçlar, AB-27 ülkelerinde yenilenebilir enerjinin toplam nihai enerji tüketimindeki payında %1'lik bir artışın/ azalışın CO_2 emisyonlarını yaklaşık %0,16 oranında azalttığını/ artırdığını göstermektedir. Yenilenebilir enerjinin CO_2 emisyonlarını artırdığı veya CO_2 emisyonlarını etkilemediğini bulan Nathaniel ve

Iheonu'nun (2019) 19 Afrika ülkesi için, Hasnisah ve diğerlerinin (2019) 13 gelişmekte olan Asya ülkesi için, Apergis ve diğerlerinin (2010) 19 gelişmiş ve gelişmekte olan ülke için, T.Li ve diğerlerinin (2016) 18 Avrupa ülkesi için ve Sun'ın (2023) 5 Asya ülkesi için yaptığı çalışmaların aksine elde ettiğimiz sonuç yenilenebilir enerji tüketiminin CO_2 emisyonlarını azaltmadaki önemli rolünü vurgulamaktadır. Çalışmada elde edilen bulgular, yenilenebilir enerji tüketimindeki %1'lik bir artışın CO_2 emisyonlarını yaklaşık %0,13 oranında azalttığını tespit eden Bekun ve diğerlerinin (2019) 16 AB ülkesi için yaptığı çalışma ile benzer sonuçlar elde edildiğini göstermektedir. Ayrıca, bulgularımız yenilenebilir enerjinin CO_2 emisyonlarını azaltmadaki önemli rolünü vurgulayan Shafiei ve Salim'in (2014) OECD ülkeleri için, Anwar ve diğerlerinin (2021) Asya ülkeleri için, Wu ve diğerlerinin (2021) 18 gelişmiş ülke için, Aziz ve diğerlerinin (2021) MINT ülkeleri için, Rasoulinezhad ve Taghizadeh-Hesary (2022) 10 ülke için, Fan ve Hajiyeva (2022) G7 ülkeleri için Aziz ve diğerlerinin (2023) Doğu Asya ülkeleri için yaptıkları çalışmalarla da uyumludur. Ayrıca, AB-27 ülkelerinin genel olarak yüksek gelirli ülkelerden oluştuğu düşünüldüğünde, bulgularımız Nguyen ve Kakinaka'nın (2019) yüksek gelirli ülkelerde yenilenebilir enerji tüketiminin emisyonlarla negatif bir ilişkisi olduğunu ortaya koyan çalışmasını desteklemektedir. Ulaşılan bu sonuç, yenilenebilir enerjinin çevreyi korumadaki etkinliğini göstermektedir. AB-27 ülkelerinin Yenilenebilir Enerji Direktifleri aracılığıyla belirli bir süre için zorunlu hedefler belirlemesinin bu sonuca ulaşılmasında önemli bir katkısı olduğunu söylenebilir. AB-27 ülkelerinde yenilenebilir enerji tüketiminin toplam nihai enerji tüketimi içindeki payı bu direktifler sayesinde yıllar içinde sürekli olarak artmıştır. Bu oran 2000 yılında %9 iken 2019 yılında %19,9'a yükselmiştir. 2020 yılında yenilenebilir enerji tüketim payı, 2009/29/EC sayılı Yenilenebilir Enerji Direktifinde belirlenen %20 hedefini aşarak %22'ye ulaşmıştır. AB, en son Yenilenebilir Enerji Direktifinde belirlenen 2030 yılına kadar %45 yenilenebilir enerji tüketimi hedefine ulaşmayı taahhüt etmektedir. Yenilenebilir enerji tüketiminin CO_2 emisyonlarının azaltılmasındaki önemli rolü dikkate alındığında, AB-27 ülkelerinde CO_2 emisyonlarının azaltılması için yenilenebilir enerjilere geçişin daha da hızlandırılması önerilebilir. Bunu başarmak için, yatırım sübvansiyonları, mali desteğin genişletilmesi, temiz ve düşük karbonlu enerji teknolojisi yenilikleri üzerine araştırma ve geliştirmenin teşvik edilmesi, yenilenebilir enerji için vergi muafiyeti veya indirimi gibi çeşitli politikalar yoluyla yenilenebilir enerjiye yapılan yatırımlar artırılabilir. Ayrıca, yenilenebilir enerji tüketiminin çevrenin korunmasındaki önemi konusunda kamu bilinci artırılmalıdır. Bu konuda eğitim kampanyalarının başlatılması, yenilenebilir enerji tüketimine yönelik olumlu tutuma sahip bir toplum yaratmak için etkili bir strateji olabilir. Buna ek olarak, bireyleri ve şirketleri yenilenebilir enerji tüketimini artırmaya teşvik etmek için daha fazla düzenleyici politika uygulanabilir.

Dördüncü olarak, çalışmada elde edilen tahmin sonuçlarında yer alan enerji yoğunluğuna ilişkin ampirik bulgular, enerji yoğunluğundaki artışın CO_2 emisyonları üzerinde artırıcı bir etkisi olduğunu göstermektedir. Bu çalışmada, enerji yoğunluğundaki %1'lik bir artışın/ azalışın CO_2 emisyonlarını yaklaşık %0,24 oranında artırdığı/ azalttığı tespit edilmiştir. Enerji yoğunluğu değişkeninin katsayısı açıklayıcı değişkenler arasında en yüksek değere sahiptir, bu da enerji yoğunluğunun modelimizdeki CO_2 emisyonları üzerinde en büyük etkiye sahip olduğu anlamına gelmektedir. Bu bulgu, düşük enerji yoğunluğunun, yani yüksek enerji verimliliğinin, CO_2 emisyonlarını azaltma hedeflerine ulaşmak için ne kadar önemli olduğunu göstermektedir. Bu sonuç, enerji yoğunluğunun CO_2 emisyonlarını azaltmada ana faktör olduğunu belirten Li ve diğerlerinin (2016) 18 Avrupa ülkesi için elde ettiği sonucu desteklemektedir. Ayrıca, çalışmada elde edilen sonuç Fan ve diğerlerinin (2006) 208 ülke için, Lin ve diğerlerinin (2009) Çin için, Bargaoui ve diğerlerinin (2014) 214 ülke için, Shahbaz ve diğerlerinin (2015) Sahra Altı Afrika ülkeleri için, Liu ve Bae (2018)'nin Çin için, Wu ve diğerlerinin (2021) 18 gelişmiş ülke için, Chen ve diğerlerinin (2018) OECD ülkeleri için, Rasoulinezhad ve Taghizadeh-Hesary (2022)'nin 10 ülke için ve G. Li ve diğerlerinin (2023) Pekin için yaptıkları çalışmaların sonuçlarıyla da uyumludur. Öte yandan, elde edilen sonuç, enerji verimliliğinin daha yüksek CO_2 emisyonlarına yol açtığını tespit eden Sun ve diğerlerinin (2022) 62 B&R ülkesi için, Wang ve Zhao (2015) ve Wang ve Feng'in (2017) Çin için yaptığı çalışmaların sonuçlarından farklılık göstermektedir.

Enerji Verimliliği Direktiflerinin, AB-27 üyesi ülkeler için bağlayıcı enerji verimliliği hedefleri belirleyerek bu sonuca ulaşılmasında önemli bir rol oynadığını söyleyebiliriz. Enerji verimliliğini en üst düzeye çıkarmak için düzenleyici bir çerçevede hedefler belirlemek ve ilgili önlemleri uygulamak, AB-27 ülkelerinin CO_2 emisyonlarını azaltma hedeflerine önemli ölçüde katkıda bulunduğu söylenebilir. AB, enerji verimliliği hedeflerine ek olarak, üye devletleri enerji tüketimlerini azaltmaya teşvik etmek için direktif içerisinde birçok enerji verimliliği politikasını düzenlemektedir. Direktif, ürünler için enerji verimliliği standartları, binalar için zorunlu sertifikalar ve enerji verimliliği etiketleri gibi enerji verimliliği uygulamalarını teşvik etmeyi amaçlamaktadır. Bu adımlar, tüm sektörlerde zorunlu uygulamalarla enerji verimliliğini artırmak için gereklidir. AB-27 ülkelerindeki enerji yoğunluğu 2000 yılında 4,1 MJ-$2017 PPP GDP'den 2019 yılında 3 MJ-$2017 PPP GDP 'ye düşmüştür. Başka bir deyişle, Enerji Verimliliği Direktifleri aracılığıyla bu dönemde enerji verimliliği önemli ölçüde artırılmıştır. Bu doğrultuda AB-27 ülkeleri, enerji verimliliği maksimizasyonunu sağlamak için üye devletlerine daha iddialı enerji verimliliği hedefleri koymaya devam edebilir. Enerji verimliliğindeki artış, kömür, petrol, doğal gaz gibi geleneksel enerji kaynaklarına olan talebi azaltarak CO_2 emisyonlarının ve çevresel bozulmanın azaltılmasına katkıda bulunmaktadır. Enerji verimliliğinin çevresel faydaları göz önünde bulundurulduğunda, AB-27 ülkeleri enerji yoğunluğunu azaltmaya yönelik desteğini geliştirmeye daha fazla odaklanabilir. Bu bağlamda, enerji verimliliğinin teşvik edilmesi için destekleyici politikalara önem verilebilir. Bu, ekonomik büyümeden ödün vermeden CO_2 emisyonlarının azaltılması için gereklidir.

Beşinci olarak, çalışmada elde edilen tahmin sonuçları enerji ile ilgili vergi gelirlerinin CO_2 emisyonlarının azaltılmasına katkıda bulunduğunu göstermektedir. Ampirik sonuçlar, enerji ile ilgili vergi gelirlerindeki %1'lik bir artışın/ azalışın CO_2 emisyonlarını yaklaşık %0,15 oranında azalttığını/ artırdığını ortaya koymaktadır. Bu sonuç Jeffrey ve Perkins (2015)'in AB-27 ülkeleri için enerji vergisindeki %1'lik artışın CO_2 emisyonlarında %0,11'lik bir düşüşe yol açtığı bulgusuyla benzerlik göstermektedir. Bu sonucu 1996-2009 dönemi için buldukları göz önüne alındığında, enerji ile ilgili vergi gelirinin CO_2 emisyonları üzerindeki etkisinin sonraki yıllarda arttığını söyleyebiliriz. Ayrıca, bulgumuz Miller ve Vela'nın (2013) 50 ülke için, Lapinskienė ve diğerlerinin (2017) 20 AB ülkesi için ve Tekin ve Şaşmaz (2016)'ın 25 AB ülkesi için yaptıkları çalışmaların sonuçlarıyla da desteklenmektedir. Öte yandan, çalışmada Liobikienė ve diğerlerinin (2019) AB-28 ülkeleri için, Wolde-

Rufael ve Mulat-Weldemeskel (2021)’nin gelişmekte olan 7 ülke için yaptıkları çalışmaların aksine sonuçlar elde edilmiştir.

Bu sonuç, AB-27 ülkelerinin Enerji Vergisi Direktifleri çerçevesinde çevresel tahribat ile mücadele etmek için enerji vergisi politikalarını uygulamadaki başarısını kanıtlamaktadır. Enerji ile ilgili vergiler, karbon yoğun enerji kaynaklarının tüketimini ve aşırı enerji kullanımını caydırdığı için CO_2 emisyonlarıyla mücadelede ideal bir araç olarak görünmektedir. Bu vergiler özellikle enerji israfını önlemek için önemlidir. Ayrıca, CO_2 emisyonlarını azaltma potansiyeline sahip enerji yatırımlarını vergiden kaçınmak için teşvik eder. Tüm bunlar enerji üretimi ve tüketiminin çevresel etkilerinin azaltılmasına katkıda bulunur. Ayrıca, enerji vergisi gelirinin sadece çevre koruma çabaları için kullanılması daha verimli olacaktır. Ülkelerin bu gelirle sadece çevre sorunlarıyla mücadele için fon oluşturması önerilebilir. Yenilenebilir enerji yatırımları veya enerji verimliliğine yönelik araştırma ve geliştirme harcamaları gibi çevreyle ilgili girişimler bu fonlar kullanılarak finanse edilebilir. Basitçe ifade etmek gerekirse, enerji vergilendirme politikasının geliştirilmesi CO_2 emisyonlarının azaltılmasına ve çevrenin korunmasına yardımcı olacağı düşünülmektedir. Buradaki kritik husus, enerji vergilerinin fırsat maliyetlerini göz önünde bulundurmaktır. Gerçekten de çevreyi korumak ve gelir elde etmek için enerji üzerinden alınan bu vergilerin rekabeti olumsuz etkileyerek ekonomik büyümeye zarar verebileceği endişesi vardır. Ekonomik büyümeyi engellemeyen etkin bir vergilendirme politikası AB için elzemdir. Bu nedenle enerji vergileri kapsamındaki politikaların, politikaları belirleyen ülkenin ekonomik durumu göz önünde bulundurularak belirlenmesi önem arz etmektedir.

Tüm bu hususlar göz önünde bulundurulduğunda, AB-27 ülkelerinin çevresel bozulmayla mücadeleye yönelik kapsamlı ve bütüncül politikalarıyla CO_2 emisyonlarını azaltma konusunda güçlü bir kararlılık sergilediği söylenebilir. AB-27, dünyada çevre politikalarının geliştirilmesinde giderek daha önemli bir konuma sahip olduğundan, bu politikaları geliştirmeye devam etmelidir. Çevre koruma politikalarında küresel bir lider olan AB-27 ülkelerinin daha da iddialı çabaları, dünyadaki diğer ülkeler için çevresel sorumluluk bilincini ve yükümlülüğünü arttırabilir ve böylece gelecekte daha sürdürülebilir ve daha yeşil bir dünya vaat edebilir.

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YAZARIN / AUTHOR

Soyadı / Surname : Demet
Adı / Name : Taha Mervan
Bölümü / Department : İktisat / Economics

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