CHARLES UNIVERSITY

FACULTY OF SOCIAL SCIENCES

Institute of International Studies

Department of Political Science

Master's Thesis

2024 **Shuangning Cao**

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FACULTY OF SOCIAL SCIENCES

Institute of International Studies

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UNIVERSITY COLLEGE LONDON

SCHOOL OF SLAVONIC AND EAST EUROPEAN STUDIES

IMESS

Carbon Emissions, Economic Growth and Sustainable Development in Central and Eastern Europe

Master's Thesis

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Study programme: International Masters in Economy, State and Society

Supervisor: PhDr. Jaromír Baxa, Ph.D.

Year of the defence: 2024

Declaration

1. I hereby declare that I have compiled this thesis using the listed literature and resources only.
2. I hereby declare that my thesis has not been used to gain any other academic title.
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In Prague July 2024 Shuangning Cao

References

CAO, Shuangning. *Carbon Emissions, Economic Growth and Sustainable Development in Central and Eastern Europe.* Praha, 2024. Master's thesis. Charles University, Faculty of Social Sciences, Institute of International Studies, Department of Political Science. Supervisor PhDr. Jaromír Baxa, Ph.D.

Length of the Thesis:19686

Abstract

This study examines the relationship between economic growth, sustainable development, and carbon dioxide emissions in 12 Central and Eastern European countries over a 25-year period from 1995 to 2019. Utilizing both production-based and consumption-based CO_2 emissions as dependent variables, the research aims to elucidate the impact of various economic indicators on environmental sustainability. Fixed effects and Prais-Winsten regression models with Panel-Corrected Standard Errors (PCSE) are employed. The findings reveal three critical insights. First, all CEE countries are positioned in the pre-turning point phase of the Environmental Kuznets Curve (EKC), with the Visegrád Group countries being the closest to reaching the EKC turning point compared to other countries. This suggests that these countries may experience increasing CO_2 emissions until they reach a higher level of economic development, after which emissions are expected to decline.Temporal analysis method further to examine two distinct periods, indicating that while economic growth and human development initially drove significant increases in emissions, recent trends suggest a decoupling effect. Second, significant relationships are identified between economic growth, industrial sector contributions, urbanization, and the adoption of renewable energy with both production-based and consumption-based CO_2 emissions. However, the effects of service sector employment and imports on CO_2 emissions are not consistently significant. Third, the study finds a stronger correlation between the Human Development Index and CO_2 emissions compared to GDP. This indicates that policies focusing solely on GDP growth may underestimate environmental impacts. In conclusion, this study provides valuable insights into the complex interactions between economic growth and environmental sustainability in the CEE region.

Abstrakt

Tato studie zkoumá vztah mezi hospodářským růstem, udržitelným rozvojem a emisemi oxidu uhličitého ve 12 zemích střední a východní Evropy v období 25 let od roku 1995 do roku 2019. Využívá jak emise CO_2 založené na produkci, tak i na spotřebě jako závislé proměnné, a jejím cílem je objasnit vliv různých ekonomických ukazatelů na environmentální udržitelnost. Jsou použity modely fixních efektů a Prais-Winstenovy regresní modely s panelově korigovanými standardními chybami (PCSE). Zjištění odhalují tři klíčové poznatky. Za prvé, všechny země střední a východní Evropy se nacházejí v předbodovém stádiu environmentální Kuznetsovy křivky (EKC), přičemž země Visegrádské skupiny jsou nejblíže dosažení bodu obratu EKC ve srovnání s ostatními zeměmi. To naznačuje, že tyto země mohou zaznamenávat rostoucí emise CO_2, dokud nedosáhnou vyšší úrovně hospodářského rozvoje, po které by měly emise klesat. Metoda časové analýzy dále zkoumá dvě odlišná období, což naznačuje, že zatímco hospodářský růst a lidský rozvoj zpočátku vedly k významnému nárůstu emisí, nedávné trendy naznačují efekt oddělení. Za druhé, jsou identifikovány významné vztahy mezi hospodářským růstem, příspěvky průmyslového sektoru, urbanizací a přijetím obnovitelné energie s emisemi CO_2 založenými na produkci i spotřebě. Nicméně, vliv zaměstnanosti v sektoru služeb a dovozu na emise CO_2 není konzistentně významný. Za třetí, studie nachází silnější korelaci mezi indexem lidského rozvoje a emisemi CO_2 ve srovnání s HDP. To naznačuje, že politiky zaměřené pouze na růst HDP mohou podceňovat dopady na životní prostředí. Závěrem tato studie poskytuje cenné poznatky o složitých interakcích mezi hospodářským růstem a environmentální udržitelností v regionu střední a východní Evropy.

Keywords

Sustainable Development, Carbon Dioxide Emissions, Central and Eastern European Countries, Environmental Kuznets Curve, Human Development Index, Economic Growth

Klíčová slova

Udržitelný rozvoj, emise oxidu uhličitého, země střední a východní Evropy, environmentální Kuznetsova křivka, index lidského rozvoje, hospodářský růst

Title

Carbon Emissions, Economic Growth and Sustainable Development in Central and Eastern Europe

Název práce

Emise oxidu uhličitého, hospodářský růst a udržitelný rozvoj ve střední a východní Evropě

Acknowledgement

I would like to express my sincere gratitude to PhDr. Jaromír Baxa, Ph.D. for his guidance and time on my thesis.

I express my heartfelt gratitude to my parents for their support and love.

Lastly, I am thankful for the past two years in the beautiful cities of Prague, Bangkok, and London, where growth and change have painted my journey with hues of wonder and discovery.

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Introduction

Global climate change has emerged as one of the most pressing environmental challenges facing the international community, with extensive and profound impacts on all sectors worldwide (Abbass et al., 2022). Carbon emissions, especially from the burning of fossil fuels, are the main drivers of climate change. The combustion of fossil fuels, such as coal, oil, and natural gas, releases large amounts of carbon dioxide and other greenhouse gases into the atmosphere. These gases accumulate and enhance the greenhouse effect, leading to global warming (Haiqing et al., 2013).

The consequences of climate change are multifaceted. The increased frequency and intensity of extreme weather events, such as more frequent heat waves, heavy rains, and hurricanes, not only endanger human life but also cause significant damage to agriculture, infrastructure, and economic activities. Furthermore, rising sea levels put coastal areas at risk of flooding and land loss, forcing large populations to migrate and resulting in social and economic instability (Xu et al., 2020). Therefore, it is crucial to prioritize environmental issues while pursuing economic growth. Achieving a balance between economic development and environmental protection is essential to ensure the sustainability of the economy and long-term societal well-being. Ignoring environmental issues can lead to resource depletion, ecosystem destruction, and various negative impacts of climate change, all of which have profound economic consequences. Thus, implementing green economic policies, promoting clean energy and low-carbon technologies, and encouraging the sustainable use of resources are key to achieving a win-win situation for both the economy and the environment.

As early as 1992, the EU demonstrated its commitment to addressing climate change by developing a comprehensive strategy. By 1996, it set an ambitious target to limit global

warming to less than 2 degrees Celsius above pre-industrial levels, establishing the foundation for its long-term leadership in climate change policy. The Kyoto Protocol, an international agreement under the United Nations Framework Convention on Climate Change (UNFCCC) aimed at reducing greenhouse gas emissions, was adopted in 1997 by representatives from around the world (Oberthür & Ott, 1999).

In 2005, the EU launched the world's most significant greenhouse gas emissions trading system (ETS), a cornerstone of its climate policy. Despite the international community's failure to reach a global agreement on limiting greenhouse gas emissions at the 2009 Copenhagen United Nations Climate Change Conference, the EU continued to pursue its domestic climate goals and set new targets for 2030. The December 2015 Paris Climate Agreement marked a significant victory for EU diplomacy, prompting the EU to further enhance its goals for emission reductions, renewable energy, and energy efficiency (Siddi,2020). To further address the complex issue of climate change, the European Union introduced the European Green Deal in 2019, demonstrating its commitment to green transformation and achieving climate neutrality. The deal aims to transform the EU's economy and society to make them more sustainable, including decarbonizing industries, promoting renewable energy, and enhancing energy efficiency(Claeys et al., 2019; Fetting,2020).

The promotion of economic prosperity while protecting the environment is a critical area of study for scholars globally. Researchers have extensively examined the relationship between economic growth and environmental issues across various regions and countries (Gürlük, 2009; Kais & Sami, 2016; Kasman & Duman, 2015; Narayan et al., 2016; Omri et al., 2014; Saidi & Ben Mbarek, 2016; Wolde-Rufael & Idowu, 2017; Yang et al., 2015; Zhu et al.,

2016). However, the literature focusing on Central and Eastern Europe (CEE) remains relatively scarce. Building on existing research, this study provides innovative insights into carbon emissions in CEE, particularly in the following three key areas.

First, existing literature often does not fully distinguish between production-based and consumption-based emissions when exploring carbon emissions related to the CEE region. Most studies focus on production-based carbon emissions (typically direct emissions from GDP) (Simionescu, 2021; Lazăr et al., 2019). This study also addresses consumption-based carbon emissions. By adopting this dual perspective, it provides a more comprehensive evaluation of the economic drivers of carbon emissions and more accurately reveals the actual impact of economic activities on the environment. This approach allows for the more effective identification of potential economic strategies to reduce carbon footprints.

Second, most economic analyses of carbon emissions rely on traditional economic growth indicators, such as gross domestic product (GDP), which are limited in capturing the full breadth and depth of socioeconomic development. The Human Development Index (HDI), a comprehensive indicator measuring a country's achievements in health, education, and living standards, offers a broader perspective on the quality of economic development. This study incorporates HDI into the regression analysis of carbon emissions to uncover more complex interactions between the quality of economic development and environmental quality. By conducting separate regressions, the study explores the differing impacts of economic development and sustainable economic development on carbon emissions, providing new insights for promoting sustainable development in the CEE region.

Third, this study estimates the positions of 12 CEE countries on the Environmental Kuznets

Curve (EKC) by analyzing the relationship between GDP and both production-based and consumption-based carbon emissions. Through this analysis, the study reveals the environmental performance of countries at various stages of economic development. Specifically, by comparing carbon emission data from both production and consumption perspectives, this study identifies not only the direct impact of economic activities on the environment but also the indirect impact of consumption patterns. This dual perspective analysis method helps to elucidate the evolution of different types of carbon emissions throughout the economic development process in the CEE region.

The overall regression and subsequent group analysis and temporal analysis provide substantial evidence supporting the Environmental Kuznets Curve hypothesis in the context of Central and Eastern European countries. To further dissect these findings, the CEE countries were grouped into the Visegrad Group, Baltic Countries, and Other CEE Countries. This stratification revealed nuanced insights into how economic development stages influence emissions. The group analysis demonstrated that while all groups exhibited increased emissions with economic growth, the impact was most pronounced in the early stages of development, particularly for the Other CEE Countries. The Baltic Countries showed the highest coefficients for HDI and GDP, indicating a stronger link between development and emissions. In contrast, the Visegrad Group, which has relatively more advanced economies, showed signs of decoupling, with a less pronounced relationship between GDP and emissions, especially in the later period.

The temporal analysis, segmented into the periods 1995-2000 and 2001-2019, offers additional evidence supporting the EKC hypothesis. During the earlier period (1995-2000), the regression results indicated a strong positive relationship between GDP per capita and

CO_2 emissions, with coefficients of 0.404 and 0.399 for production-based and consumption-based emissions, respectively. This period reflects the initial phase of economic growth where emissions rise sharply with increasing income. In the later period (2001-2019), the positive relationship between economic growth and emissions persisted, but the coefficients decreased to 0.181 for production-based and 0.169 for consumption-based emissions. This decline in coefficients suggests that as these economies continued to develop, the rate of increase in emissions began to slow down, indicating a potential decoupling effect.

This study examines 12 CEE countries, specifically focusing on Albania, Bulgaria, Croatia, the Czech Republic, Hungary, Poland, Romania, the Slovak Republic, Slovenia, and the three Baltic States: Estonia, Latvia, and Lithuania. The analysis covers a 25-year period from 1995 to 2019, aiming to provide a comprehensive understanding of the relationship between sustainable economic growth and both consumption-based and production-based carbon emissions in these countries.

The structure of this study is as follows:The first section provides an extensive literature review, offering a comprehensive examination and synthesis of existing research related to carbon emissions and economic variables pertinent to this study. By reviewing relevant literature, the current state of research and the main viewpoints in the academic community on this topic are established, laying the theoretical foundation for this study.

The second section details the data specifications and methodologies used in the analysis, including data sources, data processing procedures, and the statistical and econometric methods employed. This section aims to provide a clear methodological framework to ensure the transparency and reproducibility of the research process.

The third section presents the data results, providing a detailed analysis of the trends and relationships revealed by the data. Through in-depth analysis, the complex interactions between economic growth and carbon emissions in the CEE countries are elucidated.

The fourth section discusses these empirical results, interpreting their economic and environmental significance, and contextualizing them within a broader academic and policy framework. The results are compared with theories and findings from the literature review to highlight consistencies and discrepancies.

Finally, the fifth section addresses the limitations of this study, including data constraints, methodological limitations, and other factors that may affect the results. The background of the research findings is explained, emphasizing aspects that require cautious interpretation. Additionally, this section proposes areas for future research, suggesting how to further explore and address unresolved issues from the current study to advance the field.

These innovative research perspectives not only fill gaps in the existing literature but also provide crucial decision-making support for policymakers in the CEE region and globally. This study aims to offer a more refined analytical framework to explore how socioeconomic progress and environmental sustainability interact, thereby providing scientific support for achieving a green economic transition and more effectively integrating the dual goals of economic development and environmental protection.

1. Background and Literature Review

1.1 Background information in CEE region

In the context of globalization and rapid economic development, understanding the impact of various types of economic growth on carbon emissions and environmental sustainability has become a critical academic issue. With the acceleration of industrialization and urbanization processes, carbon emissions continue to increase, significantly affecting global climate change and environmental degradation. Therefore, exploring the relationship between economic growth and carbon emissions within the framework of sustainable development is of great significance for formulating effective environmental policies and promoting sustainable development.

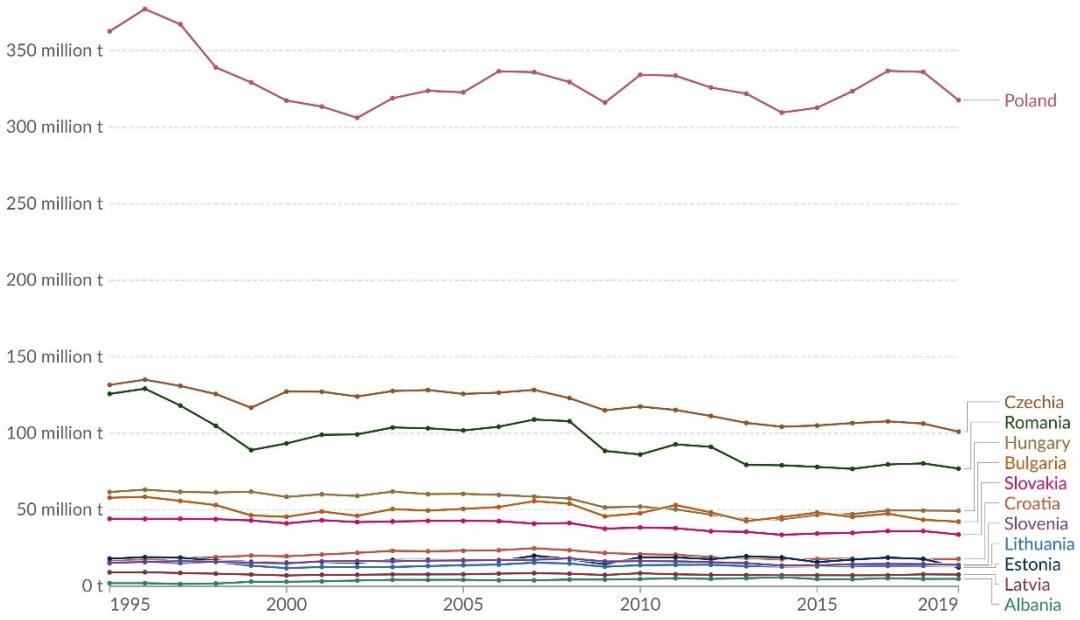
Central and Eastern European countries have undergone significant economic and political transformations since the early 1990s. Following the collapse of the Soviet Union and the subsequent shift from centrally planned economies to market-oriented systems, these countries have experienced rapid economic growth and development (Gorzelak,2019) The Organization for Economic Co-operation and Development (OECD) defines the CEE region to include Albania, Bulgaria, Croatia, the Czech Republic, Hungary, Poland, Romania, the Slovak Republic, Slovenia, and the three Baltic States: Estonia, Latvia, and Lithuania(OECD,2001).

From Figure 1, Poland stands out consistently registering the highest emissions among all CEE countries, around 300 million tonnes per year. This level suggests a substantial industrial base and stable energy consumption over the years. Poland's economic development has heavily relied on its abundant hard coal and lignite resources. To ensure national energy security, the Council of Ministers approved the "Poland's Energy Policy until

2030" document on November 10, 2009, which clearly states that coal will continue to be the primary fuel source for the electricity and heating industries (Sobczyk & Sobczyk, 2021).

Czechia and Romania also show significant emissions, with Czechia typically maintaining steady levels just over 100 million tonnes. In contrast, Romania's emissions exhibit some fluctuations, particularly a rise post-2000, which later stabilizes.

Figure 1 Production-based annual CO_2 emissions from 1995-2019



Source:Global Carbon Budget (2023)

The decline in Romania's carbon emissions around 2000 and 2008 is linked to its adherence to carbon-related laws and regulations, as well as its accession to the European Union in 2004. Following the implementation of the Kyoto Protocol, Romania developed specialized GHG services. Additionally, to fulfill its annual reporting obligations to the UNFCCC and the EU, Romania adheres to conformity verification under the international standard ISO 14065. This standard provides credibility for various local, regional, and global emissions schemes. Companies that offer these services typically have experience with the EU ETS.

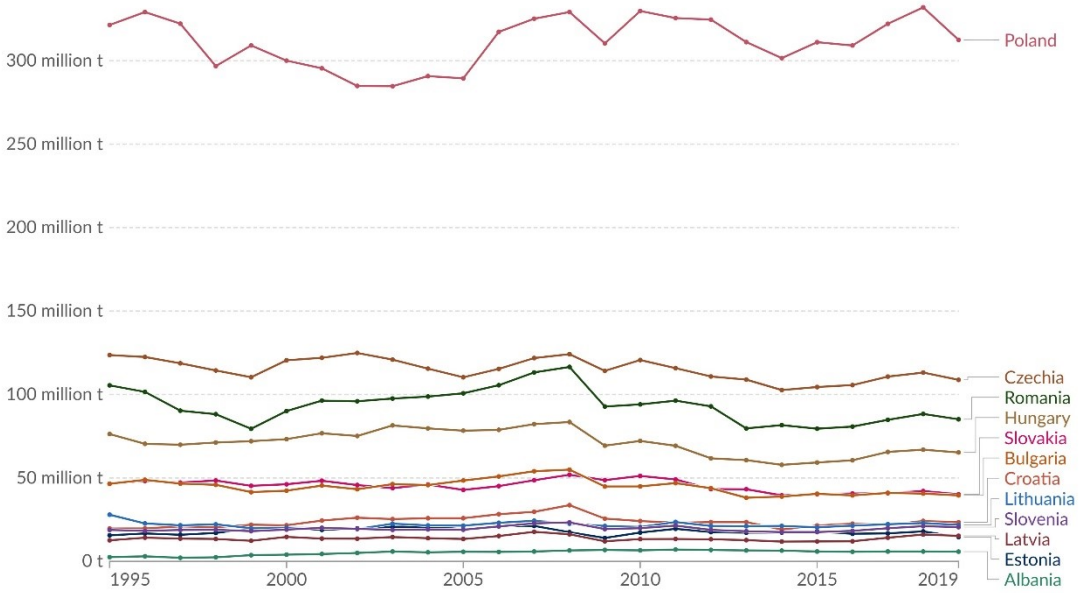
Romania’s efforts also include the establishment of GHG emissions inventories and product verification according to internationally accepted standards (Moiceanu & Dinca, 2021).

Hungary and Bulgaria are depicted with moderate emission levels. Hungary's emissions gradually decline over the years, potentially reflecting effective energy efficiency measures or a transition to less carbon-intensive energy sources. Bulgaria's emissions, while showing slight variability, generally maintain a consistent output, indicative of a stable level of industrial activity.

The figure also highlights lower emissions from Slovakia, Croatia, Slovenia, Lithuania, Estonia, Latvia, and Albania, all reporting under 50 million tonnes annually. Estonia and Latvia, in particular, show a relatively lower and stable emissions profile. Albania consistently reports the lowest emissions, underscoring its smaller scale of industrial activities. This overview provides a clear picture of the varying scales of industrialization and energy consumption patterns across these countries.

Figure 2 illustrates the consumption-based carbon dioxide emissions for various CEE countries from 1995 to 2019. The pattern of consumption-based emissions closely mirrors that of production-based emissions, with Poland consistently exhibiting the highest levels, around 300 million tons. This similarity in trends indicates that both domestic production and the consumption of imported goods significantly contribute to the carbon footprint. Other countries like Czechia, Romania, and Hungary show substantial emissions but at lower levels, while Estonia, Latvia, and Albania have the lowest emissions. The alignment of trends highlights the interconnected nature of production and consumption in influencing overall carbon emissions.

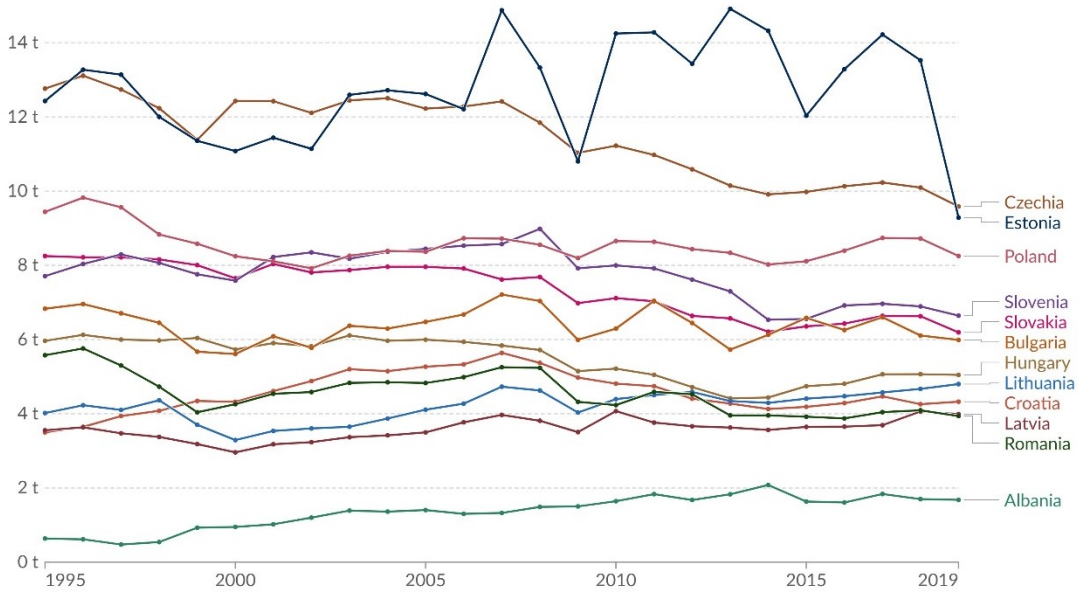
Figure 2 Consumption-based annual CO_2 emissions from 1995-2019



Source:Global Carbon Budget (2023)

Figure 3 shows per capita production-based carbon dioxide emissions from selected CEE countries from 1995 to 2019, with each line representing the average annual emissions in tonnes per person.

Figure 3 Production-based per capita CO_2 emissions from 1995-2019



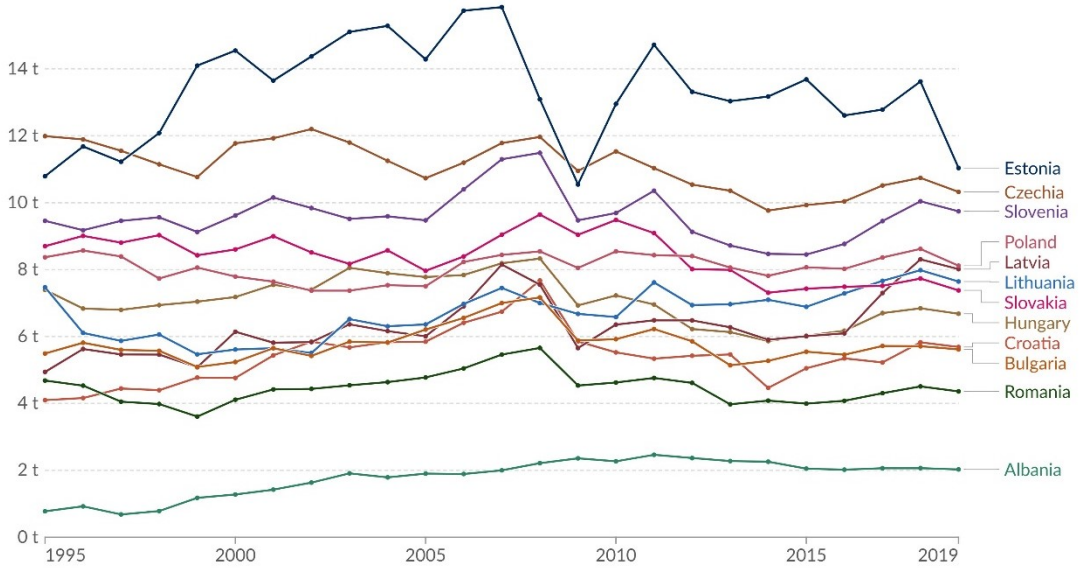
Source:Global Carbon Budget (2023)

Although Estonia’s total annual emissions are relatively small, its per capita emissions are high among all selected countries. Estonia and Czechia consistently exhibit the highest per capita emissions, with Estonia's emissions peaking around 2009 before declining sharply. Czechia’s emissions, while slightly fluctuating, generally maintain a steady level. Poland's emissions remain relatively high, though there is a gradual decrease towards the end of the period.

During this period, Estonia experienced significant fluctuations in its energy market, closely linked to its unique national energy infrastructure and EU regulations. Estonia, home to the world's largest reserves of oil shale, developed its electricity production system around this resource. The country's power stations primarily use locally mined oil shale as fuel, which is not only the main source of Estonia's energy supply but also a significant cause of environmental pollution. In accordance with the EU's 2008 directive on limiting air emissions from large combustion plants, Estonian power facilities had to comply with these regulations. During its accession to the EU, Estonia negotiated a transitional period but committed to shutting down all existing oil shale burning units by the end of 2015 (Agabus et al., 2007).

Countries such as Slovenia, Slovakia, Bulgaria, Hungary, Lithuania, Croatia, Latvia, and Romania display moderate emissions levels, ranging from 4 to 8 tonnes per person. In contrast, Albania presents a distinctly lower emission profile, with levels persistently below 2 tonnes per person, although it has been gradually increasing, making it the country with the lowest emissions among those charted.

Figure 4 Consumption-based per capita CO_2 emissions from 1995-2019



Source:Global Carbon Budget (2023)

Figure 4 shows that the pattern of per capita consumption-based CO_2 emissions in various countries is similar to the pattern of per capita production-based CO_2 emissions depicted in Figure 3. Estonia and Czechia still exhibit the highest per capita emissions. Poland and Slovenia also have relatively high emissions, although they show a decrease towards the end of the period. Hungary, Bulgaria, Slovakia, and Croatia maintain moderate emissions levels. In contrast, Albania has the lowest emissions, albeit with an increasing trend. Additionally, even within the scope of the European Union, Estonia is considered one of the countries with the highest per capita carbon emissions. This means that among the EU member states, Estonia's carbon emission level is relatively high compared to its population size (Jóźwik et al.,2021)

Figure 5 and Figure 6 compare the Augmented Human Development Index (AHDI) against GDP per capita for selected 12 Central and Eastern European countries in 1995 and 2020.

Figure 5 Augmented Human Development Index vs. GDP per Capita for 1995

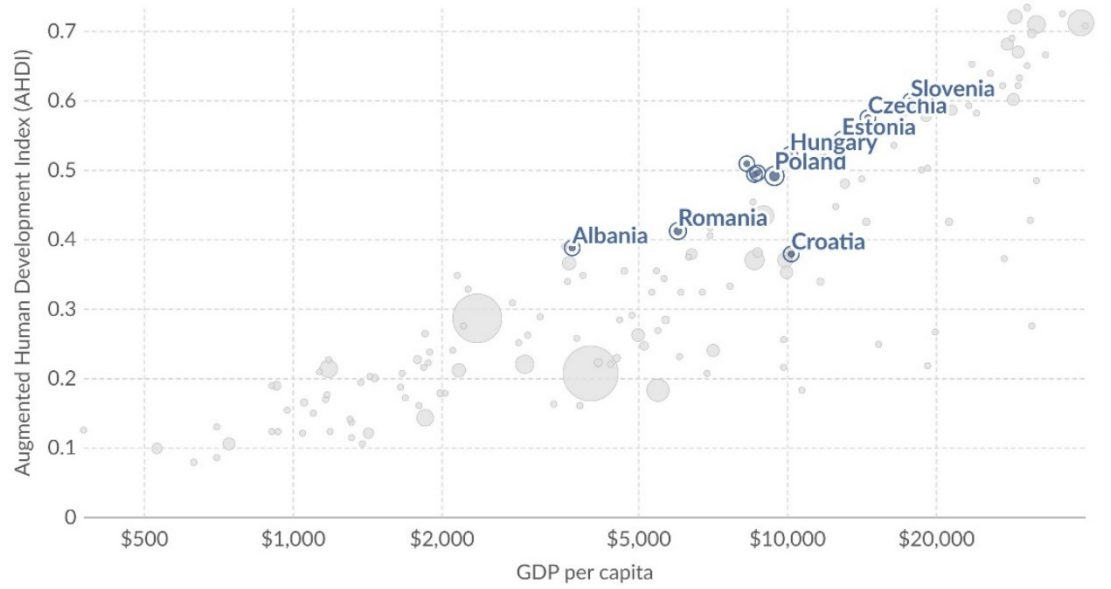
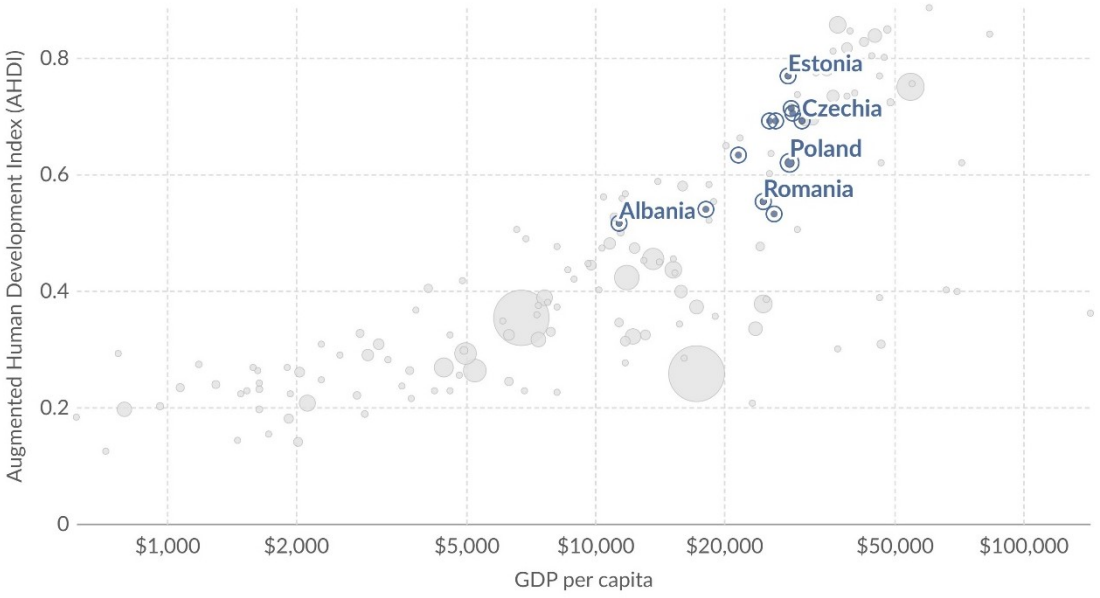


Figure 6 Augmented Human Development Index vs. GDP per Capita for 2000



GDP per capita figures are adjusted for inflation and differences in the cost of living between countries, providing a clear picture of economic performance in terms of the average income of citizens. The Augmented Human Development Index (AHDI) is a comprehensive measure of human development, expanding on the traditional Human Development Index. It includes four key dimensions of human development: a long and healthy life, being

knowledgeable, being free, and having a decent standard of living. The AHDI aims to provide a more holistic view of development by incorporating additional factors such as freedom and overall well-being, which are crucial for understanding the quality of life beyond mere economic output.

As shown in Figure 5, in 1995, the scatter plot reveals that CEE countries such as Albania, Romania, and Croatia had relatively lower GDP per capita and lower AHDI values. Albania, in particular, had one of the lowest positions on both scales, indicating significant economic and developmental challenges at that time. Slovenia and Czechia, on the other hand, were positioned higher on both GDP per capita and AHDI, reflecting their relatively better economic conditions and human development status even at the onset of their post-socialist transitions. Hungary, Poland, and Estonia also displayed moderate AHDI values relative to their GDP per capita, illustrating a middle-ground status in terms of both economic and human development.

By 2020, there is a marked improvement across most countries shown in Figure 6. Estonia, Czechia, and Slovenia show significant upward movements on both GDP per capita and AHDI scales, indicating substantial progress in economic growth and human development. Poland and Hungary also demonstrate notable advancements, with increased AHDI values corresponding to higher GDP per capita. Albania, while still lower relative to other countries, has made visible progress in both dimensions, reflecting its ongoing efforts in economic and human development.

Furthermore, understanding the relationship between these 12 countries and the European Union is crucial for comprehending their development trajectories. EU membership

typically brings significant economic and social benefits, including access to structural funds that finance infrastructure projects, market integration that opens up trade opportunities, and the adoption of regulatory frameworks that promote economic growth and human development. These benefits foster a stable economic environment, attract foreign investment, and improve overall living standards.

EU membership not only provides direct economic support but also sets in motion a series of social and economic reforms that are necessary for meeting EU standards. These reforms often lead to enhanced governance, increased transparency, and better public services. Consequently, these changes contribute to the improvement of the Human Development Index and GDP per capita, reflecting better health, education, and income levels.

Poland, Czechia, Hungary, Slovakia, Slovenia, Lithuania, Latvia, and Estonia all joined the EU in 2004, marking a significant expansion of the EU into Central and Eastern Europe. Bulgaria and Romania followed in 2007, benefiting from similar economic and social reforms. Croatia, the most recent entrant, joined the EU in 2013, continuing the trend of integration and development in the region. Albania is currently a candidate for EU membership, and while not yet a member (Schweiger,2015).

1.2 Literature Review

This section aims to systematically review the existing literature to delve into the mechanisms and effects of economic growth on carbon dioxide emissions. These factors exhibit complex and diverse influence pathways across different economies and stages of development. Understanding their interrelationships is crucial for devising effective environmental and economic policies. The literature review will cover various related

studies, including those on economic growth and sustainable economic growth, employment in the service sector, imports, industry value added, urbanization, and the proportion of renewable energy, comprehensively revealing their interactions with carbon emissions.

1.2.1 Economic and Sustainable Growth Factors

The interplay between economic growth and carbon dioxide emissions has been a focal point of environmental economics. This section discusses key literature on GDP as a measure of economic development and the Human Development Index as a measure of sustainable economic variables in relation to their impact on carbon emissions.

Economic growth has long been considered a significant factor in carbon dioxide emissions. Grossman and Krueger (1991) were the pioneers in exploring the relationship between the environment and per capita income. This relationship is not linear but varies across different stages of development. At lower income levels, increases in per capita GDP lead to greater environmental pollution. However, as income levels rise, pollution tends to decrease.
Tucker (1995), through an empirical analysis of data from 137 economies between 1971 and 1991, concluded that increases in per capita income significantly raise carbon dioxide emissions. Yet, this trend tends to decelerate with further income growth. Similar conclusions were reached in Shafik and Bandyopadhyay's (1992) study on economic growth and environmental quality. Their empirical analysis, based on data from 149 countries from 1960 to 1990, also identified an inverted U-shaped curve.

Subsequently, an increasing number of studies have adopted this curve as a theoretical foundation. This curve, known as the Environmental Kuznets Curve (EKC), hypothesizes a relationship between economic growth and environmental degradation. The hypothesis

outlines three dynamic processes related to economic growth. Before an economy reaches industrialization, economic growth is positively correlated with increased pollution and emissions due to the depletion of natural resources driven by industrialization and urbanization, a phenomenon referred to as the scale effect.

As industrialization progresses, structural changes in the economy gradually mitigate environmental degradation, reflecting the structural effect. This trend continues until economic growth reaches a specific threshold. Beyond this turning point, the relationship between economic growth and environmental degradation reverses. Higher income levels lead to increased attention to environmental issues, and the economic structure shifts towards sectors that use fewer natural resources. The technology effect further supports this transition, resulting in reduced pollution as per capita income increases. The EKC suggests that economies can "grow now, clean later" (Panayotou, 1993; Gill et al., 2018; Bilgili et al.,2016)

A substantial body of research supports the EKC hypothesis. Ren et al. (2014) demonstrated the EKC pattern in China's industrial sector by analyzing FDI and trade data across 18 industries from 2000 to 2010. Narayan et al. (2016) found that in their study of 181 countries, over 42% of high-income countries provided empirical evidence supporting the EKC hypothesis. Xu and Lin (2015), using nonparametric additive regression models, identified a nonlinear, inverted U-shaped relationship between industrialization and carbon emissions in China from 1990 to 2011. Similarly, Bilgili et al. (2016) examined panel data from 1977 to 2010 in 17 OECD countries, their findings indicate that the selected countries conform to the EKC hypothesis.

However, the EKC hypothesis has also faced criticism. A study on Malaysia's carbon

emissions, energy consumption, and economic growth using ARDL-DOLS methods with data from 1970 to 2009 (Begum et al., 2015) indicated that per capita GDP growth significantly increased per capita carbon emissions in the long run, failing to support the EKC hypothesis for Malaysia. Similarly, Akpan and Akpan (2012) found a unidirectional Granger causality between electricity consumption, carbon emissions, and economic growth in Nigeria from 1970 to 2008, but no empirical evidence for the EKC hypothesis. Azerbaijan also did not fit the EKC hypothesis (Mikayilov et al., 2018).

Numerous studies have focused on the causal relationship between carbon emissions and economic growth. Ang (2007) investigated France from 1960 to 2000 using a Vector Error Correction Model (VECM), finding that economic growth increases carbon emissions in the long term. Similar conclusions were reached by other scholars. For instance, Mikayilov et al. (2018) provided empirical evidence from a co-integration analysis of Azerbaijan's economic growth and carbon emissions from 1992 to 2013. Long et al. (2015) used co-integration analysis to show that economic growth was the primary driver of China's carbon emissions from 1996 to 2010. Chen et al. (2016), studying 188 countries from 1993 to 2010, found that higher GDP leads to higher carbon emissions in both developing and developed countries in the long term.

Additionally, Abid (2015) examined the informal economic growth and carbon emissions in Tunisia from 1980 to 2009, finding empirical evidence of a monotonically increasing linear relationship. Both formal and informal economic growth contributed to increased carbon emissions in both the short and long term.

The Human Development Index, introduced by the United Nations Development

Programme (UNDP) in 1990, is a composite measure widely used in global research to evaluate achievements in three key dimensions: health, education, and income. These dimensions are specifically defined as a long and healthy life, knowledge, and a decent standard of living (Klasen, 2018).

Akbar et al. (2021) conducted a study using panel data from 33 OECD countries covering the period from 2006 to 2016. Their empirical results indicate that an increase in carbon dioxide emissions significantly lowers the HDI of the evaluated countries, adversely affecting multiple dimensions, including health, education, and income. Similarly, Banday and Kocoglu (2023) analyzed panel data from emerging economies for the period 1990-2014, finding that carbon emissions negatively impact HDI. These conclusions are consistent with findings from other scholars (Li & Chen, 2021).

However, Balsamo et al. (2023) examined the relationship between socioeconomic indicators, carbon dioxide emissions, and energy consumption across 193 United Nations member states. Their findings suggest that both carbon dioxide emissions and energy consumption tend to increase with rising HDI.

Given the complexity of the HDI as an indicator, the relationship between HDI and carbon emissions can be nuanced and multifaceted. For instance, a study on Bangladesh using data from 1990 to 2018 explored this relationship, revealing a decoupling effect between HDI and carbon emissions (Afzal et al., 2021). Similar findings have been confirmed in other studies (Li et al., 2022).

1.2.1 Related Factors

A higher proportion of employment in the service sector typically indicates a transition from

more carbon-intensive industrial activities to less carbon-intensive service activities. This transition is anticipated to result in lower CO_2 emissions, as the service sector generally produces fewer emissions compared to industrial sectors. Service activities typically have a lower carbon footprint than manufacturing and heavy industries, so increased employment in services can contribute to a more sustainable economy. (Grove et al., 1996, Oliver-Solà et al., 2007).

Friedl and Getzner (2003), in their study of Austria from 1960 to 1999, found that the growth of the service sector helped mitigate CO_2 emissions, assuming other conditions remained constant. Mulder et al. (2014) conducted a detailed analysis of the energy intensity of the service sector in 18 OECD countries from 1980 to 2005, concluding that an increase in the service economy significantly reduced overall energy intensity levels in these countries. Rüstemoğlu and Andrés (2016) examined the factors influencing carbon emissions in Brazil and Russia from 1992 to 2011. Their study highlighted that economic activity in the service sector significantly impacts carbon emissions. In Brazil, the increase in service sector employment correlated with higher CO_2 emissions. In Russia, the impact varied over time, with economic activity reducing emissions initially but increasing them later, alongside an accelerating effect from sectoral employment shifts. This underscores the role of employment changes in influencing carbon emissions in the service sector.

Furthermore, the expansion of the service sector is often accompanied by technological advancements and increased efficiency, further enhancing the potential for reducing emissions. Martínez and Silveira (2012) analyzed data from 19 sub-sectors in Sweden from 1993 to 2008 using Data Envelopment Analysis (DEA). Their empirical results indicate that the service sector not only reduced Sweden's carbon emissions but also improved energy and

technological efficiency.

However, Simon et al. (2021) found that the service sector has contributed a substantial proportion of greenhouse gas emissions in the evaluated countries. This is primarily attributed to the carbon footprint of offshore manufacturing activities associated with the service sector, warranting careful consideration. This finding is also supported by empirical evidence on the impact of the service sector on carbon emissions in Spain (Alcántara and Padilla, 2009).

The relationship between trade and the environment has been a significant topic of academic research. Economic systems are deeply interconnected with ecological systems, and environmental degradation can undermine the sustainability of economies. While some countries may gain environmental advantages through international trade, others might experience adverse effects from environmental degradation (Nordström and Vaughan, 1999; Machado, 2001).

Safi et al. (2021) studied consumption-based carbon emissions in the Emerging Seven countries from 1995 to 2018, finding that imports substantially increase carbon emissions, whereas exports lead to significant reductions in carbon emissions.

Hasanov et al. (2018) examined the specific dynamics of oil-exporting and oil-importing countries through a cointegration analysis of nine oil-exporting nations. Their findings indicate that both imports and exports have a significant impact on consumption-based CO_2 emissions, although no similar effects were observed for production-based CO_2 emissions.

Trade does not always result in environmental degradation. Jebli (2016) analyzed data from 25 OECD countries between 1980 and 2010 and discovered that increased trade can reduce CO_2 emissions. Similarly, Wang et al. (2020) explored the link between eco-innovation and export diversification in G7 countries from 1990 to 2017. They found that while export diversification significantly raised CO_2 emissions, this effect was lessened by higher levels of environmental innovation.

A substantial body of economic literature indicates that industrial value addition is a significant driver of increased carbon dioxide emissions. For instance, Samargandi (2017) conducted an extensive study using data from Saudi Arabia spanning 1970-2014 and identified a positive correlation between the growth of industrial value addition and the rise in carbon dioxide emissions. In a similar vein, Dong et al. (2020) analyzed data from China between 2000 and 2017, focusing on the value addition of six sectors as a proportion of GDP. They found that a reduction in the share of industrial value addition relative to GDP significantly decreases carbon dioxide emissions. This inverse relationship between industrial value added and carbon dioxide emissions is further substantiated by the research of other scholars (Okere et al., 2021; Liu et al., 2015; Jebli et al., 2020).

Contrarily, some researchers have identified a decoupling relationship between industrial growth and carbon emissions. Wu et al. (2018) investigated this decoupling phenomenon at both national and provincial levels in China from 2005 to 2015. Their findings reveal that most provinces exhibit a decoupling relationship, with Shanghai demonstrating the most effective decoupling performance.

Urbanization can significantly influence energy consumption patterns and CO_2 emissions

through increased industrial activity and higher energy demands in urban areas. As cities expand, the concentration of population and economic activities leads to greater energy consumption and higher emissions, posing substantial challenges for sustainable development (Glaeser and Kahn, 2004).

Dogan and Turkekul (2016) investigated the determinants of CO_2 emissions in the United States from 1960 to 2010 and concluded that urbanization exacerbates environmental degradation over the long term. Similarly, Wang et al. (2015), through a case study of Shandong Province in China from 2005 to 2009, identified urbanization as a significant factor influencing energy consumption, with profound implications for the sustainability of the local air environment. Numerous other studies corroborate the positive correlation between urbanization and increased carbon emissions, as well as environmental degradation (Zhou et al., 2019; Zhang et al., 2021; Wang, 2016; Dong, 2020)

Conversely, urban areas can benefit from more efficient infrastructure and economies of scale. Haseeb et al. (2018) employed the Environmental Kuznets Curve hypothesis and panel data from BRICS countries between 1995 and 2014 to assert that the impact of urbanization on CO_2 emissions is negligible. Sharma (2011), through an analysis of dynamic panel data from 69 global economies between 1985 and 2005, discovered a significant negative correlation between urbanization and CO_2 emissions, regardless of the income level of the economies. Al-Mulali et al. (2012) found no relationship between urbanization and CO_2 emissions in low-income countries after examining urbanization trends in seven global regions. Empirical evidence from Austria further supports this perspective. Muñoz et al. (2020) conducted a study on the carbon footprint of 8,000 Austrian households, categorized into urban, semi-urban, and rural groups, and concluded that urban residents had the lowest

carbon footprint, whereas semi-urban residents exhibited the highest carbon footprint.

The European Union has prioritized the advancement of renewable energy to decrease greenhouse gas emissions. The EU's Renewable Energy Directive mandates that by 2030, renewable sources should comprise 27% of the total energy mix (European Union, 2018). Achieving the long-term climate goals of the 2015 Paris Agreement requires a reduction in energy-related carbon emissions. Projections of the global energy mix indicate that renewable energy is expected to experience significant growth across almost all scenarios. (Newell et al.,2021)

Bilgili et al. (2016) investigated the impact of renewable energy consumption on carbon emissions in 17 OECD countries, finding that increased renewable energy consumption significantly reduces carbon dioxide emissions. Haldar and Sethi (2021) studied the relationship between energy consumption, institutional quality, and carbon emissions in 39 selected developing countries, discovering a significant negative long-term correlation between renewable energy use and carbon emissions. Similarly, Mukhtarov (2022), using data from 1993 to 2019 and employing the Dynamic Ordinary Least Squares Method (DOLS), found that renewable energy consumption reduces carbon emissions in Azerbaijan. Sharif et al. (2019) examined the relationship between renewable and non-renewable energy consumption and carbon dioxide emissions. By analyzing panel data from 74 economies between 1990 and 2015, the authors found that renewable energy has a significantly positive impact on mitigating environmental degradation.

However, Zaidi et al. (2014) conducted a study on Pakistan's data from 1970 to 2016 using the auto-regressive distributive lag (ARDL) model and found that renewable energy

consumption did not significantly impact the reduction of carbon emissions. Menyah and Wolde-Rufael (2010) examined the relationship between carbon emissions, renewable energy, nuclear energy consumption, and economic growth in the United States from 1960 to 2007. Their results indicated that while renewable energy consumption did not significantly contribute to reducing carbon emissions, nuclear energy consumption did help mitigate carbon emissions to some extent.

In summary, the existing literature provides a wealth of theoretical and empirical research findings, revealing the complex relationships between economic growth, and carbon emissions. However, variations in specific variables, methodologies, and regional contexts across different studies indicate the necessity for further research. Building on this foundation, the present study proposes models based on production and consumption carbon emissions, introducing the HDI as a substitute variable for GDP. This approach aims to provide a more comprehensive understanding of the relationship between economic development and environmental sustainability. By systematically analyzing data from the CEE region, this study not only deepens the understanding of the interaction mechanisms between the economy and the environment in this area but also offers scientific evidence to inform policy-making, supporting the achievement of global sustainable development goals.

Drawing from an extensive review of existing research and scholarly literature, this study formulates the following hypotheses to investigate the relationship between economic growth and CO_2 emissions in CEE countries:

H1: Economic growth, measured by both GDP per capita, and sustainable economic growth, measured by the Human Development Index, significantly increase CO_2 emissions in CEE

countries.

H2: The share of the industrial sector in GDP is a significant driver of CO_2 emissions, attributable to the energy-intensive nature of industrial activities.

H3: Urbanization contributes to higher CO_2 emissions, as urban areas have increased demand for energy and resources.

H4: The increased adoption of renewable energy sources leads to a reduction in CO_2 emissions.

H5: Higher employment in the service sector correlates with lower CO_2 emissions, due to the lower energy intensity of services compared to industrial activities.

H6: Imports affect CO_2 emissions, reflecting the carbon footprint associated with the production and transportation of imported goods.

These hypotheses will be tested in the following study, examining both production-based and consumption-based CO_2 emissions.

2. Data and Methodology

2.1 Data Source

This study focuses on dada from 12 Central and Eastern European countries: Albania, Bulgaria, Croatia, the Czech Republic, Hungary, Poland, Romania, the Slovak Republic, Slovenia, Estonia, Latvia, and Lithuania.

The analysis time covers a 25-year period from 1995 to 2019. This selected timeframe is particularly relevant for two main reasons. Firstly, following the dissolution of Czechoslovakia in 1993, comprehensive and consistent data for the Czech Republic and the Slovak Republic became available. This availability is crucial for a robust analysis as it

ensures the inclusion of these key countries, providing a more complete understanding of the region's economic and environmental dynamics. Secondly, this period encompasses significant political and economic transformations that occurred in the region during the early 1990s. Over the subsequent years, these nations gradually stabilized, offering a valuable context for examining the interplay between carbon emissions, economic growth, and sustainable development. The stability achieved over these years allows for a thorough analysis of the long-term trends and impacts, enhancing the study's relevance and depth.

Both production-based and consumption-based CO_2 emissions datasets are sourced from the Global Carbon Project. This comprehensive dataset integrates multiple data sources, including official reports to the UNFCCC, national official statistical agencies, CDIAC-FF, the Energy Institute, and many others. HDI data is obtained from the Human Development Report of the United Nations Development Programme. All other selected dependent variables are from the World Bank.

2.2 Data Specification

2.2.1 Dependent Variables

To investigate the relationship between carbon emissions, economic growth, and sustainable development in the Central and Eastern European region, this study distinguishes between production-based CO_2 emissions and consumption-based CO_2 emissions, treating each as a dependent variable in separate analyses. This distinction is crucial because it provides a more nuanced understanding of the sources and drivers of carbon emissions.

In this study, production-based CO_2 emissions encompass the total carbon dioxide emitted within a country’s borders, mainly stemming from the use of fossil fuels like coal, oil, gas,

and flaring, as well as direct industrial emissions from cement production. Conversely, consumption-based CO_2 emissions account for the total carbon dioxide generated by the consumption of goods and services within a country, regardless of where these emissions take place. This measure includes emissions from fossil fuel consumption and direct industrial emissions related to cement production.

Choosing these two variables is important for following reasons. First, by considering both production and consumption perspectives, the study provides a more holistic view of carbon emissions. This approach helps identify whether emissions are primarily driven by domestic production activities or by the consumption of imported goods and services. Secondly, understanding the distinction between production-based and consumption-based emissions can inform more effective policy-making. For instance, if production-based emissions are high, policies might focus on cleaner production technologies and energy efficiency. If consumption-based emissions are significant, policies could encourage sustainable consumption practices and the reduction of carbon footprints through consumer choices.

Third, from an economic growth and sustainability perspective, the relationship between carbon emissions and economic growth can vary depending on the type of emissions considered. By analyzing both types, the study can better understand how economic development impacts environmental sustainability in different ways and identify potential trade-offs or synergies.

2.2.2 Independent Variables

This section covers all the independent variables included in this study, encompassing the selection of GDP, HDI, employment in the service sector, imports, industry value added,

urbanization, and the proportion of renewable energy.

Per capita GDP measures the average economic output per person. Higher per capita GDP is often associated with increased consumption levels and heightened production activities, leading to higher CO_2 emissions. However, economic and technological advancements may also result in greater investment in clean technologies and environmental protection. As discussed in the literature review, there exists an inverted U-shaped relationship between environmental quality and economic development, known as the Environmental Kuznets Curve. This curve suggests that as an economy grows, environmental degradation increases up to a point, after which further economic growth leads to environmental improvement. By analyzing the relationship between GDP and carbon emissions, it is possible to estimate where CEE countries stands on the EKC. Utilizing this variable is crucial for further exploring how economic prosperity influences environmental outcomes across the 12 Central and Eastern European countries under study. The GDP data has been log-transformed to capture its relationship with CO_2 emissions more effectively.

In the subsequent research, the HDI replaces GDP to investigate the relationship between sustainable economic development and environmental pollution. HDI is a comprehensive indicator that not only considers economic factors but also includes education levels and life expectancy, reflecting social and health dimensions. By using HDI, this study aims to more holistically assess the impact of economic development on the environment, particularly in the context of pursuing sustainable development goals.

Compared to GDP alone, HDI provides richer contextual information, revealing the complex interplay between economic growth, social progress, and environmental protection. This

approach is expected to offer deeper insights into the challenges and opportunities faced by the 12 Central and Eastern European countries in achieving both economic prosperity and environmental sustainability. By examining the relationship between HDI and CO_2 emissions, the study further elucidates the dynamics at play in the Environmental Kuznets Curve and identifies strategies for promoting sustainable development.

Employment in services refers to the percentage of the total workforce employed in the service sector. A higher proportion of service sector employment typically indicates a shift from more carbon-intensive industrial activities to less carbon-intensive service activities. This transition is expected to result in lower CO_2 emissions, as the service sector generally produces fewer emissions compared to industrial sectors.

For the CEE region, this variable is particularly relevant due to the significant economic restructuring that has occurred since the post-socialist transition. The shift from centrally planned economies, heavily reliant on industrial production, to market economies with a growing emphasis on services, marks a profound change in the economic landscape of these countries. his structural transformation towards a service-based economy not only represents economic modernization and integration into the global market but also has important environmental implications.

As service activities typically have a lower carbon footprint compared to manufacturing and heavy industries, increased employment in services can contribute to a greener economy. Additionally, the growth of the service sector often accompanies technological advancements and increased efficiency, further enhancing the potential for reducing emissions.

Imports of goods and services, measured as a percentage of GDP, capture the extent of a country's reliance on global markets and its integration into the international economy. The impact of imports on CO_2 emissions can be analyzed from both production-based and consumption-based perspectives. Increased imports might lead to higher production-based emissions due to the transportation and production activities associated with foreign goods.

From a consumption-based perspective, imports can lead to higher emissions depending on the carbon intensity of the goods consumed. When a country imports goods and services, it is essentially outsourcing the production and associated emissions to the exporting countries. Therefore, even if domestic production emissions are lower, the overall carbon footprint could be high due to the consumption of imported goods.

The percentage of industry value added measures the contribution of the industrial sector, to a country's overall economic output. This variable is chosen because crucial for understanding the role of industrial activities in CO_2 emissions. Industrial processes, particularly in sectors such as manufacturing and construction, are energy-intensive and have significant carbon footprints. Higher industry value added is expected to correlate with increased CO_2 emissions due to the greater energy consumption associated with industrial production.

For many countries in the Central and Eastern European region, this variable is especially important because they have substantial industrial bases. By examining the share of industry in GDP, this study aims to capture the impact of industrial activities on carbon emissions and assess how shifts in industrial contributions to the economy influence overall environmental sustainability. From a production perspective, an increase in industry value

added typically leads to higher carbon emissions due to the significant energy consumption involved in industrial production. Understanding this dynamic is essential for a comprehensive analysis of the carbon footprint in the CEE region.

Urbanization can influence energy consumption patterns and CO_2 emissions through increased industrial activity and higher energy demands in cities. However, urban areas may also benefit from more efficient infrastructure and economies of scale. In the CEE region, urbanization trends are significant as these countries continue to develop and modernize their cities. Therefore, the impact of urban population on CO_2 emissions is expected to be significant, with urbanization potentially leading to higher emissions due to greater energy consumption, though efficiency gains could mitigate this effect. Higher urbanization rates bring both opportunities and challenges. Countries with high urbanization benefit from increased economic activity and innovation but face issues such as urban congestion, traffic, and environmental pollution. On the other hand, countries with lower urbanization rates might struggle with underdeveloped infrastructure and may require more investment and policy support to boost urban growth and improve living standards. This variable is chosen to explore how urbanization trends affect environmental sustainability and resource use in the CEE context.

Renewable energy consumption indicates the proportion of total energy consumption derived from renewable sources, such as wind, solar, hydro, and biomass. Increased reliance on renewable energy is expected to reduce CO_2 emissions by decreasing dependence on fossil fuels, which are major contributors to greenhouse gas emissions. As renewable energy sources produce little to no direct CO_2 emissions, a higher share of renewable energy in the energy mix is crucial for mitigating climate change.

Increased renewable energy consumption is expected to result in a significant reduction in CO_2 emissions, reflecting the environmental benefits of transitioning to cleaner energy sources. By decreasing the share of energy produced from fossil fuels, countries can lower their carbon footprints and move towards more sustainable energy practices. This transition not only helps in reducing emissions but also enhances energy security and can lead to economic benefits through the development of new industries and job creation in the renewable energy sector.

2.3 Research Model

Following the methodologies of Li et al. (2020), Sadikov et al. (2020), Mitić (2022), and Tichá (2023), this study examines the empirical relationship between CO_2 emissions, economic growth and sustainable development using a refined methodological approach. This research distinguishes between production-based and consumption-based CO_2 emissions in its models. The dependent variables are production-based CO_2 emissions and consumption-based CO_2 emissions. Both GDP and CO_2 emission variables are log-transformed to improve the data's logarithmic relationship.

To provide a comprehensive analysis, the study employs four distinct models, each designed to capture different aspects of the relationship between economic variables and CO_2 emissions. These models are structured to isolate the effects of various independent variables, thereby offering a nuanced understanding of the dynamics at play. The subsequent sections will detail the specifications and results of each model

$$In\_PCO2_{it} = \beta_0 + \beta_1 ln\_GDP_{it} + \beta_2 EIS_{it} + \beta_3 IMPORTS_{it} + \beta_4 INDUSTRY_{it} + \beta_5 URBANPP_{it} + \beta_6 RENEWE_{it} + \varepsilon_{it} \quad (1)$$

$$In\_CCO2_{it} = \beta_0 + \beta_1 ln\_GDP_{it} + \beta_2 EIS_{it} + \beta_3 IMPORTS_{it} + \beta_4 INDUSTRY_{it} + \beta_5 URBANPP_{it} + \beta_6 RENEWE_{it} + \varepsilon_{it}$$

(2)

$$In\_PCO2_{it} = \beta_0 + \beta_1 HDI_{it} + \beta_2 EIS_{it} + \beta_3 IMPORTS_{it} + \beta_4 INDUSTRY_{it} + \beta_5 URBANPP_{it} + \beta_6 RENEWE_{it} + \varepsilon_{it}$$

(3)

$$In\_CCO2_{it} = \beta_0 + \beta_1 HDI_{it} + \beta_2 EIS_{it} + \beta_3 IMPORTS_{it} + \beta_4 INDUSTRY_{it} + \beta_5 URBANPP_{it} + \beta_6 RENEWE_{it} + \varepsilon_{it}$$

(4)

$$\varepsilon_{it} = \mu_i + \lambda_j + \gamma_{it}$$

μ_i is the unobserved country-specific effects; λ_j is the unobserved time-specific effects; and γ_{it} is the idiosyncratic error.

Where:

In_PCO2_{it}: The logarithm of production-based carbon dioxide emissions for country i at time t

In_CCO2_{it}: The logarithm of consumption-based carbon dioxide emissions for country i at time t

ln_GDP_{it}: The logarithm of GDP per capita for country i at time t

HDI_{it}: Human Development Index for country i at time t

EIS_{it}: Employment in services as a share of total employment for country i at time t

$IMPORTS_{it}$: Imports of goods and services as a share of GDP for country i at time t

$INDUSTRY_{it}$: Industry value added as a share of GDP for country i at time t

$URBANPP_{it}$: Urban population as a percentage of total population for country i at time t

$RENEWE_{it}$: Renewable energy consumption as a percentage of total final energy consumption for country i at time t

3. Data Analysis

3.1 Descriptive Analysis

In this section, an overview of the main variables is provided through descriptive statistics. Descriptive statistics offer a concise summary of the data, highlighting central tendencies, dispersions, and overall patterns. By calculating and analyzing metrics such as mean, standard deviation, minimum, and maximum values, a preliminary understanding of the distribution and fundamental characteristics of each variable can be obtained. This initial analysis is crucial for understanding the basic features of the data before conducting more complex inferential analyses.

Table 1 below presents the descriptive statistics of the main variables studied. Table 2 further displays the mean values of each variable by country, providing a basis for comparing differences between CEE countries.

Table 1 Descriptive Statistics

VarName	Obs	Mean	SD	Min	Median	Max
ln_PCO_2	300	1.722	0.608	-0.746	1.790	2.703
ln_CCO_2	300	1.883	0.529	-0.382	1.964	2.763
ln_GDP	300	8.985	0.799	6.576	9.182	10.225
HDI	300	0.808	0.058	0.632	0.813	0.918
EIS	300	55.056	9.305	28.717	56.775	69.825
IMPORTS	300	55.776	15.593	20.781	53.185	93.968
INDUSTRY	299	27.024	4.464	15.347	26.809	40.212
URBANPP	300	61.878	8.509	38.911	63.181	75.347
RENEWE	300	19.456	11.276	3.030	17.675	55.930
GDP	300	10335.263	6468.169	717.380	9723.414	27595.600
PCO_2	300	6.504	3.232	0.474	5.991	14.917
CCO_2	300	7.344	3.041	0.682	7.131	15.844

From Table 1 and 2, the production-based CO_2 emissions, originally measured in tonnes per capita, have been log-transformed for this analysis to normalize the data distribution and facilitate comparative analysis. The average log of production-based CO_2 emissions across the selected countries is 1.72, with a standard deviation of 0.61. Estonia exhibits the highest

log-transformed production-based CO_2 emissions at 2.54, followed by Czechia and Poland. Conversely, Albania and Latvia show the lowest log-transformed production-based CO_2 emissions at 0.23 and 1.27, respectively. This range underscores the varying levels of industrial activity and energy consumption patterns across the region.

Consumption-based CO_2 emissions, initially quantified in tonnes per capita, have been logarithmically transformed for this study. The mean log value of consumption-based CO_2 emissions across the selected countries stands at 1.89, with a standard deviation of 0.53. Estonia exhibits the highest log-transformed consumption-based CO_2 emissions at 2.58, followed by Czechia at 2.41 and Slovenia at 2.26, reflecting elevated per capita emissions due to consumption activities. Conversely, Albania records the lowest log-transformed consumption-based CO_2 emissions at 0.52, indicating a lesser per capita impact on CO_2 emissions from consumption. This range of values highlights the diverse consumption behaviors and their corresponding environmental effects within the region.

In this analysis, the GDP of the selected countries, initially measured in US dollars, has been log-transformed. The average log-transformed GDP across these countries is 8.99, with a standard deviation of 0.80. Slovenia leads with the highest log-transformed GDP at 9.78, indicating robust economic performance. Czechia follows with a log-transformed GDP of 9.48, and Slovakia at 9.33, reflecting relatively high economic outputs in these countries. Conversely, Albania and Bulgaria have the lowest log-transformed GDP values at 7.81 and 8.35, respectively.

According to the Human Development Report, an HDI above 0.800 is considered very high, between 0.700 and 0.799 is high, 0.550 to 0.699 is medium, and below 0.550 is low. Among

the 12 selected Central and Eastern European countries in this study, 9 have HDI scores exceeding 0.8, classifying them as having very high human development. Slovenia tops the list with an HDI of 0.864. Despite having relatively lower HDI scores, Albania, Bulgaria, and Romania still fall within the high human development category, each scoring above 0.7. This classification underscores the significant strides in human development across the region, even though relative disparities persist among the countries.

Employment in services across the selected countries averages 55.056%, indicating that these economies are not predominantly service-oriented. Latvia has the highest service sector employment at 62.41%, followed closely by Estonia and Hungary, with 62.34% and 62.18% respectively. In contrast, Romania and Albania have the lowest service sector employment, at 37.98% and 38.13% respectively. This variation highlights the diverse economic structures and stages of development within the region, with some countries relying more heavily on industrial or agricultural sectors while others are more service-oriented.

The average import percentage for the selected twelve countries is 55.78%, with a standard deviation of 15.59%. Slovakia leads with the highest import percentage at 75.03%, followed by Estonia at 72.35% and Hungary at 68.89%. On the lower end, Romania has the lowest import percentage at 36.80%, indicating a relatively lower dependence on foreign goods and services compared to other CEE countries. These differences highlight the varied economic structures and degrees of global integration among these countries.

The percentage of industry value added to GDP is a vital indicator of the industrial sector's contribution to economic output. In our study, the average industry value added across the

selected countries is 27.02%. Czechia leads with the highest industry value added at 33.62%, followed closely by Romania at 33.18% and Slovakia at 30.07%. On the lower end, Latvia and Albania have the lowest industry value added percentages at 21.76% and 21.99%, respectively. This variation underscores the diverse economic structures within the region. Countries with high industry value added, such as Czechia, Romania, and Slovakia, have economies significantly driven by industrial activities, indicating robust industrial sectors. Conversely, countries like Latvia and Albania, with lower industry contributions, may rely more on services or agriculture, reflecting different stages and focuses of economic development.

Urbanization rates vary significantly worldwide, influenced by economic, political, and cultural factors. Generally, in most high-income countries, approximately 80% of the population resides in urban areas. In Eastern Europe, among most upper-middle-income countries, this percentage ranges from 50% to 80% (Hannah et al., 2024). In our selected countries, the urbanization rate averages 61.88%. The Czech Republic exhibits the highest urbanization rate at 73.72%, followed by Bulgaria at 71.34%. In contrast, Albania has the lowest urbanization rate at 49.24%. The urbanization rates of other countries in the study fall within the 50% to 70% range.

Renewable energy consumption varies significantly across the selected countries. On average, renewable energy accounts for 19.46% of the total energy consumption in these countries. Albania leads with the highest renewable energy consumption at 39.80%, followed by Latvia and Croatia at 36.44% and 28.70%, respectively. In contrast, Slovakia and Poland have the lowest renewable energy consumption percentages at 8.32% and 8.99%, respectively. This wide range highlights the diverse stages of energy transition within the

region, reflecting different levels of commitment and investment in renewable energy infrastructure and policies.

Table 2 Mean Values of Variables by Country

	ln PCO2	ln CCO 2	ln GDP	HDI	EIS	IMPO RTS	INDU STRY	URBA NPP	RENE WE
Albania	.228	.518	7.814	.732	38.133	44.989	21.988	49.238	39.797
Bulgaria	1.85	1.753	8.346	.767	57.456	53.345	23.31	71.338	11.426
Croatia	1.512	1.678	9.184	.804	57.643	42.774	22.704	54.679	28.699
Czechia	2.435	2.406	9.477	.849	56.519	58.832	33.621	73.722	9.774
Estonia	2.539	2.584	9.226	.839	62.336	72.351	25.23	68.865	22.447
Hungary	1.695	1.952	9.169	.808	62.181	68.886	26.147	67.641	9.878
Latvia	1.274	1.837	8.970	.807	62.414	54.819	21.755	68.067	36.439
Lithuania	1.432	1.897	8.983	.817	59.654	61.581	27.328	67.034	20.971
Poland	2.146	2.088	9.046	.826	53.704	38.689	29.561	61.059	8.992
Romania	1.513	1.493	8.490	.77	37.977	36.8	33.179	53.54	19.043
Slovakia	1.992	2.127	9.330	.807	57.15	75.032	30.072	55.152	8.319
Slovenia	2.047	2.261	9.782	.864	55.508	61.217	29.19	52.202	17.692

3.2 Pre-Analysis Testing

This section will conduct three pre-analysis tests to ensure the data is suitable for subsequent econometric analysis. These tests include the Multicollinearity Test, Stationary Test, and Cointegration Test.

3.2.1 Multicollinearity Test

In regression analysis, ensuring that there is no severe multicollinearity among the

independent variables is crucial because multicollinearity can lead to unstable regression coefficients, which in turn affects the explanatory power and predictive capability of the regression model. According to Kennedy (2008), a severe multicollinearity issue is indicated by a correlation coefficient exceeding 0.8, which could compromise the validity of the regression outcomes. In the correlation analysis of the main economic variables across 12 Central and Eastern European countries, we observed significant correlations among these variables. Specifically, as shown in Table 3, ln_PCO2 showed significant positive correlations with ln_GDP, EIS, IMPORTS, INDUSTRY, and URBANPP, with correlation coefficients of 0.495, 0.450, 0.319, 0.488, and 0.485, respectively, all with p-values less than 0.0001. Additionally, ln_PCO2 had a significant negative correlation with RENEWE, with a correlation coefficient of -0.697 ($p < 0.0001$).

Table 3 Pairwise Correlations with GDP as Indicator (Production-based CO_2)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) ln_PCO2	1.000						
(2) ln_GDP	0.495	1.000					
	(0.000)						
(3) EIS	0.450	0.681	1.000				
	(0.000)	(0.000)					
(4) IMPORTS	0.319	0.600	0.650	1.000			
	(0.000)	(0.000)	(0.000)				
(5) INDUSTRY	0.488	0.182	-0.254	0.008	1.000		
	(0.000)	(0.002)	(0.000)	(0.885)			
(6) URBANPP	0.485	0.205	0.589	0.325	-0.017	1.000	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.768)		
(7) RENEWE	-0.697	-0.095	-0.076	-0.090	-0.606	-0.287	1.000
	(0.000)	(0.102)	(0.188)	(0.118)	(0.000)	(0.000)	

Table 4 Pairwise Correlations with GDP as Indicator (Consummption-based CO_2)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) ln_CCO2	1.000						
(2) ln_GDP	0.614	1.000					
	(0.000)						
(3) EIS	0.623	0.681	1.000				

	(0.000)	(0.000)					
(4) IMPORTS	0.462	0.600	0.650	1.000			
	(0.000)	(0.000)	(0.000)				
(5) INDUSTRY	0.391	0.182	-0.254	0.008	1.000		
	(0.000)	(0.002)	(0.000)	(0.885)			
(6) URBANPP	0.532	0.205	0.589	0.325	-0.017	1.000	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.768)		
(7) RENEWE	-0.573	-0.095	-0.076	-0.090	-0.606	-0.287	1.000
	(0.000)	(0.102)	(0.188)	(0.118)	(0.000)	(0.000)	

For ln_CCO2, the analysis from Table 4 revealed significant positive correlations with ln_GDP, EIS, IMPORTS, INDUSTRY, and URBANPP, with correlation coefficients of 0.614, 0.623, 0.462,0.391, and 0.532, respectively. ln_CCO2 also showed a significant negative correlation with RENEWE, with a correlation coefficient of -0.573 ($p < 0.0001$). A similar analysis was conducted by replacing ln_GDP with HDI, yielding consistent results from pairwise correlations analysis.

For all four models, all correlation coefficients between the variables were below 0.8, indicating that multicollinearity is not a severe issue in this analysis. This suggests that the regression results are likely to be valid and reliable, providing a solid foundation for further investigation into the causal relationships among these variables.

According to the multicollinearity test results (VIF) shown as Table 5 and Table 6 , the average VIF values for the the regression models using GDP as indicator and HDI in this study are 3.24 and 2.81, respectively. These values are well below the commonly accepted threshold of 10, indicating that multicollinearity is not a serious issue. Therefore, we can confidently conclude that multicollinearity among the independent variables does not significantly interfere with the regression results.

Table 5 Variance inflation factor (using GDP as variable)

	VIF	1/VIF
EIS	6.376	.157
ln GDP	3.776	.265
INDUSTRY	3.204	.312
URBANPP	2.086	.479
RENEWE	2.075	.482
IMPORTS	1.906	.525
Mean VIF	3.237	.

Table 6 Variance inflation factor (using HDI as variable)

	VIF	1/VIF
EIS	5.163	.194
HDI	2.99	.334
INDUSTRY	2.915	.343
RENEWE	2.165	.462
IMPORTS	1.893	.528
URBANPP	1.759	.569
Mean VIF	2.814	.

In summary, the results of these regression models indicate significant relationships between all independent variables and the dependent variables, and the models demonstrate strong explanatory power and robustness, providing a reliable foundation for further analysis of the causal relationships among thes variables.

3.2.2 Stationary Test

Stationarity implies that the statistical properties of the series are constant over time. Non-stationary data can lead to spurious regression results, making it imperative to test for unit roots. In this study, We employed the Im-Pesaran-Shin (IPS) unit root test to assess the stationarity of the panel data. The IPS test was conducted with both trend and demeaning options included. The IPS test's null hypothesis states that all panels contain unit roots, indicating non-stationarity, while the alternative hypothesi suggests that some panels are stationary.

Table 7 Stationary Test Result

Variable Name	Original Data Stationary	First-Order Difference	Second-Order Difference
ln_PCO2	Yes	Yes	Yes
ln_CCO2	Yes	Yes	Yes
ln_GDP	Yes	Yes	Yes
HDI	No	Yes	Yes
EIS	Yes	Yes	Yes
URBANPP	No	No	Yes
IMPORTS	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes
RENEWE	Yes	Yes	Yes

As shown in Table 7, the IPS unit root test results indicate that while most of the variables are stationary, URBANPP and HDI were initially non-stationary. Specifically, the IPS test for ln_PCO2, ln_CCO2, ln_GDP, EIS, IMPORTS, INDUSTRY, and RENEWE all resulted in p-values less than the 0.05 significance level, leading us to reject the null hypothesis of unit roots and conclude that these variables are stationary.

However, the test for URBANPP and HDI yielded p-values greater than 0.05, indicating non-stationarity as we failed to reject the null hypothesis for these variables. To address this issue and transform these non-stationary variables into stationary ones, we applied differencing. For HDI, a single differencing was sufficient to achieve stationarity, as evidenced by the significantly low p-value following the first difference. Conversely, URBANPP required a second differencing to become stationary, with the p-value indicating strong stationarity after the second difference.

3.2.2 Cointegration Test

To further validate the long-term equilibrium relationships among the variables, this study

conducted cointegration tests. Cointegration tests help identify whether non-stationary time series have stable long-term relationships. If cointegration exists, we can use the original data for analysis even if the individual series are non-stationary as discussed above. This test employed both Westerlund and Pedroni cointegration tests for different sets of variables, using models as we strctured above.

Table 8 Cointegration Test Table

Westerlund test for cointegration for Model 1		
	Statistic	p-value
Variance ratio	-1.8477	0.0323
Westerlund test for cointegration for Model 2		
Variance ratio	-1.7753	0.0379
Pedroni test for cointegration for Model 3		
	Statistic	p-value
Modified Phillips–Perron t	4.0525	0.0000
Phillips–Perron t	-7.8742	0.0000
Augmented Dickey–Fuller t	-3.4249	0.0003
Pedroni test for cointegration for Model 4		
	Statistic	p-value
Modified Phillips–Perron t	3.4637	0.0003
Phillips–Perron t	-4.9995	0.0000
Augmented Dickey–Fuller t	-4.0356	0.0000

The results of cointegration shows in Table 8. First, the Westerlund cointegration test was applied, using ln_GDP as the reference variable. The null hypothesis of the Westerlund test states that there is no cointegration among the panel data, while the alternative hypothesis suggests that some panels are cointegrated. The results for the cointegration tests between ln_PCO2, ln_CCO2, and ln_GDP are as follows:

For the ln_PCO2 and ln_GDP pair, the test statistic was -1.8477, with a p-value of 0.0323.

Since the p-value is less than the significance level of 0.05, we reject the null hypothesis and conclude that there is a cointegration relationship between ln_PCO2 and ln_GDP.

Similarly, for the ln_CCO2 and ln_GDP pair, the test statistic was -1.7753, with a p-value of 0.0379. Again, since the p-value is less than 0.05, we reject the null hypothesis and conclude that there is a cointegration relationship between ln_CCO2 and ln_GDP.

Next, the Pedroni cointegration test was conducted using HDI as the reference variable. The null hypothesis of the Pedroni test states that there is no cointegration among the panel data, while the alternative hypothesis suggests that all panels are cointegrated. The results for the cointegration tests between ln_PCO2, ln_CCO2, and HDI are as follows:

For the ln_PCO2 and HDI pair, the Modified Phillips-Perron t-statistic was 4.0525 with a p-value of 0.0000; the Phillips-Perron t-statistic was -7.8742 with a p-value of 0.0000; and the Augmented Dickey-Fuller t-statistic was -3.4249 with a p-value of 0.0003. Since all p-values are significantly less than 0.05, we reject the null hypothesis and conclude that there is a cointegration relationship between ln_PCO2 and HDI.

Similarly, for the ln_CCO2 and HDI pair, the Modified Phillips-Perron t-statistic was 3.4637 with a p-value of 0.0003; the Phillips-Perron t-statistic was -4.9995 with a p-value of 0.0000; and the Augmented Dickey-Fuller t-statistic was -4.0356 with a p-value of 0.0000. Again, since all p-values are significantly less than 0.05, we reject the null hypothesis and conclude that there is a cointegration relationship between ln_CCO2 and HDI.

In summary, the results from both Westerlund and Pedroni cointegration tests indicate that

ln_PCO2 and ln_CCO2 are cointegrated with ln_GDP and HDI, respectively. This finding implies that, despite some variables failing the stationarity test, there are stable long-term relationships among these non-stationary time series. Consequently, the original data can be used for subsequent empirical analysis without the need for differencing.

3.3 Model Choice

In this analysis, we opted for the fixed effects (FE) model to estimate the relationship between producation-based and consumption-based carbon dioxide emissions and various economic indicators, as well as the Human Development Index, although the Hausman test suggests using the random effects model. The primary reason for choosing the fixed effects model is its ability to control for time-invariant unobserved heterogeneity across different panels. This is crucial because panel data often contain individual-specific characteristics that, if not accounted for, can bias the results. The fixed effects model effectively isolates the impact of the variables of interest by removing these unobserved, constant factors within each panel.

The significant F-tests for the fixed effects in all models confirm that these unobserved individual effects are indeed present and important, justifying their inclusion. Additionally, the within R-squared values indicate a substantial portion of the variance is explained within each panel, further validating the choice of the FE model.

Furthermore, the Wald tests were conducted to assess the joint significance of the explanatory variables. The null hypothesis for the Wald test states that all the coefficients of the explanatory variables are equal to zero, implying that the variables do not jointly affect the dependent variable. The alternative hypothesis suggests that at least one of the

coefficients is not equal to zero, indicating joint significance. In our models, the Wald tests yielded F-statistics with p-values well below 0.05, leading to the rejection of the null hypothesis and confirming that the included variables are collectively significant predictors of ln_PCO2 and ln_CCO2.

By using fixed effects, the analysis ensures that the estimated relationships between the economic indicators, HDI, and CO2 emissions are robust and not confounded by omitted variable bias. This approach provides reliable and meaningful insights into the factors driving emissions, confirming that fixed effects models are well-suited for analyzing panel data where controlling for unobserved heterogeneity is critical.

3.4 Post-analysis Testing

Next, a series of essential tests following the regression analysis will be examined to ensure the robustness and validity of the regression models. These tests include the Autocorrelation Test, the Heteroskedasticity Test, and the Cross-sectional Independence Test. These diagnostic tests systematically identify potential issues within the models and facilitate appropriate corrective measures, thereby enhancing the precision of estimates and the reliability of conclusions. Conducting these tests provides comprehensive tools to evaluate and enhance the quality of the regression analysis before proceeding to more complex inferences and predictions.

3.4.1 Autocorrelation Test

The Wooldridge test for autocorrelation in panel data was conducted to assess the presence of first-order autocorrelation in the residuals for four regression models. These models included ln_PCO2 and ln_CCO2 with ln_GDP, as well as ln_PCO2 and ln_CCO2 with HDI，

respectively. The Wooldridge test is a robust method for detecting autocorrelation, which, if present, can compromise the efficiency of the estimates and the validity of standard errors. The null hypothesis posits no first-order autocorrelation, while the alternative hypothesis indicates the presence of such autocorrelation.

From Table 9, the results indicated significant first-order autocorrelation in all four models, as the p-values were below the 0.05 threshold. Consequently, the null hypothesis was rejected for each model.

Table 9 Autocorrelation Test Result

Wooldridge test for autocorrelation in panel data for Model 1
F(1, 11) = 97.144
Prob > F = 0.0000
Wooldridge test for autocorrelation in panel data for Model 2
F(1, 11) = 37.028
Prob > F = 0.0001
Wooldridge test for autocorrelation in panel data for Model 3
F(1, 11) = 94.659
Prob > F = 0.0000
Wooldridge test for autocorrelation in panel data for Model 4
F(1, 11) = 38.270
Prob > F = 0.0001

3.4.2 Heteroskedasticity Test

To further validate the robustness of the regression models, the Modified Wald test for groupwise heteroskedasticity was conducted on each model. The null hypothesis of the Modified Wald test posits homoskedasticity, indicating constant variances of the errors across groups, while the alternative hypothesis suggests the presence of heteroskedasticity,

implying differing error variances across groups. The results shown in Table 10 for the four models—ln_PCO2 and ln_CCO2 with In_GDP, and ln_PCO2 and ln_CCO2 with HDI—revealed chi-squared statistics with p-values significantly below the 0.05 threshold. These results led to the consistent rejection of the null hypothesis for all models, thereby confirming the presence of heteroskedasticity.

Table 10 Heteroskedasticity Test

Modified Wald test for heteroskedasticity in fixed effect regression model 1
chi2 (12) = 291.99
Prob>chi2 = 0.0000
Modified Wald test for heteroskedasticity in fixed effect regression model 2
chi2 (12) = 133.13
Prob>chi2 = 0.0000
Modified Wald test for heteroskedasticity in fixed effect regression model 3
chi2 (12) = 495.99
Prob>chi2 = 0.0000
Modified Wald test for heteroskedasticity in fixed effect regression model 4
chi2 (12) = 113.24
Prob>chi2 = 0.0000

3.4.3 Cross-sectional Independence Test

The results from Pesaran's test for cross-sectional independence shown as Table 11 provide important insights into the relationships captured by the panel data models. For the fixed effects estimation of ln_PCO2 with ln_GDP (Model 1), Pesaran's test yielded a test statistic of 1.064 with a p-value of 0.2873. This indicates that we fail to reject the null hypothesis of no cross-sectional dependence, suggesting that CO2 emissions in response to economic indicators such as GDP, EIS, imports, industry, urban population, and renewable energy, are relatively independent across the countries studied. In contrast, the fixed effects estimation

for ln_CCO2 with ln_GDP (Model 2) shows significant cross-sectional dependence. Similarly, significant cross-sectional dependence was detected in the fixed effects estimation of ln_PCO2 with HDI and ln_CCO2 with HDI(Model 3 and Model 4).

Table 11 Cross-sectional Independence Test Result

Pesaran's test for cross-sectional independence for regression model 1
Pesaran's test of cross sectional independence = 1.064, Pr = 0.2873
Average absolute value of the off-diagonal elements = 0.393
Pesaran's test for cross-sectional independence for regression model 2
Pesaran's test of cross sectional independence = 4.135, Pr = 0.0000
Average absolute value of the off-diagonal elements = 0.291
Pesaran's test for cross-sectional independence for regression model 3
Pesaran's test of cross sectional independence = 2.446, Pr = 0.0144
Average absolute value of the off-diagonal elements = 0.441
Pesaran's test for cross-sectional independence for regression model 4
Pesaran's test of cross sectional independence = 5.739, Pr = 0.0000
Average absolute value of the off-diagonal elements = 0.299

3.5 Revised Regression Model Analysis

To ensure the robustness and reliability of the regression models in this study, the Prais-Winsten regression with Panel-Corrected Standard Errors (PCSE) has been employed. This methodological choice addresses three critical issues inherent in panel data analysis: autocorrelation, heteroskedasticity, and cross-sectional dependence. The PCSE method is considered highly effective because it corrects for these issues, providing more accurate standard errors and more reliable coefficient estimates (Beck & Katz, 1996; Doku et al.,2019). Also, Hoechle (2007) indicates the PCSE estimator is highly regarded for its ability to address cross-sectional dependence issues, thereby expanding the array of methodologies available for panel data analysis.

Autocorrelation in panel data can lead to inefficient estimates and invalid statistical inference, while heteroskedasticity can distort standard errors, making hypothesis tests unreliable. Cross-sectional dependence can result in underestimated standard errors and biased parameter estimates. The Prais-Winsten regression, in conjunction with PCSE, adjusts for these problems, thereby enhancing the accuracy and credibility of the regression results (Wolf & Best, 2013).

The PCSE approach is particularly advantageous in addressing the complex nature of panel data, where each unit may exhibit unique characteristics over time. By incorporating corrections for autocorrelation within panels, heteroskedasticity across panels, and cross-sectional dependence, the method ensures that the standard errors are not only accurate but also robust to various data irregularities. This leads to more reliable inference about the relationships between variables under study.

4. Empirical Results and Discussion

4.1 Overall PCSE Regression for 12 CEE countires

First, the regression analysis investigates the determinants of both per capita production-based CO_2 emissions (ln_PCO2) in Model 1 and per capita consumption-based CO_2 emissions (ln_CCO2) in Model 2 across 12 selected Central and Eastern European countries, revealing key insights into the factors influencing carbon emissions shown in Table 12.

Table 12 PCSE estimation Result for Model 1 and Model 2

VARIABLES	(1) ln_PCO2	(2) ln_CCO2
ln_GDP	0.164*** (5.41)	0.202*** (5.54)

EIS	0.003	0.003
	(0.70)	(0.73)
IMPORTS	0.001	0.003**
	(0.90)	(2.47)
INDUSTRY	0.013***	0.005
	(4.06)	(1.49)
URBANPP	0.017***	0.018***
	(5.48)	(4.79)
RENEWE	-0.027***	-0.018***
	(-13.93)	(-8.79)
Constant	-0.854**	-1.046***
	(-2.54)	(-2.85)
Observations	299	299
R-squared	0.898	0.883
Number of code	12	12

z-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Model 1: Production-Based CO_2 Emissions with GDP

For production-based CO_2 emissions, GDP per capita (ln_GDP) has a significant positive impact, with a coefficient of 0.164 and a high level of statistical significance ($p<0.01$). This indicates that a 1% increase in GDP per capita is associated with a 0.164% increase in emissions, underscoring the relationship between economic growth and higher emissions due to increased energy consumption and industrial activity. The industrial sector's share of GDP (INDUSTRY) also significantly raises production-based emissions, with a coefficient of 0.013 ($p<0.01$), reflecting the high energy intensity of industrial processes. Urbanization (URBANPP) is another significant driver, with a coefficient of 0.017 ($p<0.01$), indicating that higher urban population percentages are linked to increased emissions due to higher energy demands in urban areas. Conversely, the share of renewable energy (RENEWE) significantly reduces production-based emissions, with a coefficient of -0.027 ($p<0.01$), demonstrating the effectiveness of renewable energy in mitigating emissions. Employment in services (EIS) does not show a significant impact, with a coefficient of 0.003, suggesting that the service sector's employment does not heavily influence production-based emissions.

The constant term is significant ($p<0.05$) and negative, indicating baseline emissions levels when all explanatory variables are zero. The model explains a high proportion of the variance in emissions, with an R-squared value of 0.898.

Model 2: Consumption-Based CO_2 Emissions with GDP

In the consumption-based CO_2 emissions model, GDP per capita (ln_GDP) remains a significant positive factor, with a coefficient of 0.202 ($p<0.01$), indicating that economic growth leads to greater consumption and thus higher emissions. Imports (IMPORTS) significantly increase consumption-based emissions, with a coefficient of 0.003 ($p<0.05$), highlighting the carbon footprint of imported goods and the role of international trade in shaping a country's overall emissions profile. The industrial sector's share of GDP (INDUSTRY) shows a positive but not statistically significant impact. Urbanization (URBANPP) continues to positively affect consumption-based emissions, with a coefficient of 0.018 ($p<0.01$), consistent with the increased energy demands associated with urban areas. The share of renewable energy (RENEWE) remains a significant negative factor, with a coefficient of -0.018 ($p<0.01$), reinforcing the importance of renewable energy in reducing emissions. Employment in services (EIS) again does not show a significant impact, with a coefficient of 0.003. The constant term is significant ($p<0.01$) and negative, indicating baseline emissions levels when all explanatory variables are zero. The model has a slightly lower R-squared value of 0.883 compared to the production-based emissions model, but still explains a substantial proportion of the variance in emissions.

Based on the positive and statistically significant coefficients for GDP per capita in both Model 1 (production-based CO_2 emissions) and Model 2 (consumption-based CO_2 emissions), we can infer that the 12 Central and Eastern European countries are currently situated on the upward-sloping portion of the Environmental Kuznets Curv. Specifically, the

regression results indicate that a 1% increase in GDP per capita is associated with a 0.164% increase in production-based CO_2 emissions and a 0.202% increase in consumption-based CO_2 emissions, both of which are statistically significant at the 1% level. This positive relationship demonstrates that as these countries' economies grow, their CO_2 emissions are also rising. Given the transitional and developing nature of these economies, it is reasonable to estimate that they are in the early to middle stages of the EKC. During this phase, economic growth is closely linked to increased energy consumption and industrial activity, which drive up emissions. This conclusion is further supported by other research, which also indicates that CEE countries are generally in the early to middle stages of economic development, where economic growth is still driving up emissions (Lazăr et al.,2019). Therefore, these countries have not yet reached the turning point of the EKC, where further economic development would lead to a reduction in CO_2 emissions. Another study also further confirmed the validity of the EKC in Central and Eastern Europe, supporting the applicability of the EKC theory in this region (Atici, 2009).

Table 13 PCSE estimation Result for Model 3 and Model 4

VARIABLES	(3) ln_PCO2	(4) ln_CCO2
HDI	2.257***	2.247***
	(4.89)	(3.97)
EIS	0.001	0.003
	(0.21)	(0.63)
IMPORTS	0.001	0.003***
	(1.10)	(2.81)
INDUSTRY	0.015***	0.007*
	(4.66)	(1.89)
URBANPP	0.014***	0.014***
	(4.87)	(4.08)
RENEWE	-0.027***	-0.019***
	(-16.08)	(-8.42)
Constant	-0.953**	-0.879**
	(-2.50)	(-2.02)
Observations	299	299

R-squared	0.918	0.852
Number of code	12	12

z-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Secondly, the Human Development Index is substituted for GDP as the variable representing sustainable economic growth in the model. The regression results incorporating HDI are presented in Table 13. This analysis aims to investigate whether HDI provides a better explanation of the variations in the dependent variables compared to GDP, thereby offering deeper insights into the impact of sustainable development on the studied outcomes. The use of HDI as a measure reflects a holistic approach to economic growth, acknowledging that human well-being extends beyond mere financial metrics.

Model 3: Production-Based CO_2 Emissions with HDI

The regression analysis in Model 3 examines the determinants of per capita production-based CO_2 emissions (ln_PCO2) using the Human Development Index as a key explanatory variable, alongside other factors, across 12 selected Central and Eastern European countries. The results show that HDI has a significant positive impact on production-based CO_2 emissions, with a coefficient of 2.257 ($p<0.01$). This suggests that higher human development levels, which often correlate with increased economic activity and energy consumption, lead to higher emissions. The industrial sector's share of GDP (INDUSTRY) also significantly increases emissions, with a coefficient of 0.015 ($p<0.01$), indicating the high energy intensity of industrial processes. Urbanization (URBANPP) is another significant driver, with a coefficient of 0.014 ($p<0.01$), reflecting the higher energy demands of urban areas. Conversely, the share of renewable energy (RENEWE) significantly reduces emissions, with a coefficient of -0.027 ($p<0.01$), demonstrating the effectiveness of renewable energy in mitigating emissions. Employment in services (EIS) and imports (IMPORTS) do not show significant impacts on production-based emissions. The model's

constant term is significant and negative ($p<0.05$), indicating baseline emissions levels when all explanatory variables are zero. The model explains a substantial proportion of the variance in emissions, with an R-squared value of 0.918.

Model 4: Consumption-Based CO_2 Emissions with HDI

In Model 4, the regression analysis explores the determinants of per capita consumption-based CO_2 emissions (ln_CCO2), again using HDI as a key explanatory variable. The results indicate that HDI remains a significant positive factor, with a coefficient of 2.247 ($p<0.01$), implying that higher human development levels lead to greater consumption and thus higher emissions. Imports (IMPORTS) significantly increase consumption-based emissions, with a coefficient of 0.003 ($p<0.01$), highlighting the carbon footprint of imported goods and the importance of international trade in shaping emissions. The industrial sector's share of GDP (INDUSTRY) shows a positive impact on consumption-based emissions, with a coefficient of 0.007 ($p<0.1$), suggesting a moderate influence of domestic industrial activities. Urbanization (URBANPP) continues to positively affect emissions, with a coefficient of 0.014 ($p<0.01$), consistent with increased energy demands in urban areas. The share of renewable energy (RENEWE) significantly reduces consumption-based emissions, with a coefficient of -0.019 ($p<0.01$), reinforcing the role of renewable energy in emission reduction. Employment in services (EIS) does not show a significant impact. The model's constant term is significant and negative ($p<0.05$), indicating baseline emissions levels when all explanatory variables are zero. This model has an R-squared value of 0.852, explaining a substantial proportion of the variance in emissions.

Based on the comprehensive analysis of all the regression results presented in this section, we can now thoroughly evaluate each of the hypotheses that we initially proposed.

H1: Economic growth, measured by both GDP per capita and sustainable economic growth, measured by the Human Development Index (HDI), significantly increases CO_2 emissions in CEE countries. The regression results indicate that GDP per capita has a positive and highly significant coefficient in both Model 1 and Model 2. Similarly, HDI exhibits a positive and highly significant coefficient in Model 3 and Model 4. These findings support the hypothesis that both economic growth and sustainable economic growth lead to an increase in CO_2 emissions in CEE countries. Therefore, H1 is supported by the data.

H2: The share of the industrial sector in GDP is a significant driver of CO_2 emissions, attributable to the energy-intensive nature of industrial activities. The coefficient for the industrial sector is positive and significant in Model 1, but its significance is less pronounced in Models 2 and 4, with Model 2 not showing statistical significance. In Model 3, the industrial sector's coefficient is also significant. This suggests that the industrial sector's impact on CO_2 emissions is significant in some models but not consistently across all models. Thus, H2 is partially supported.

H3: Urbanization contributes to higher CO_2 emissions, as urban areas have increased demand for energy and resources. Urbanization shows a positive and highly significant coefficient across all models. These results support the hypothesis that urbanization leads to higher CO_2 emissions due to increased demand for energy and resources in urban areas. Consequently, H3 is supported.

H4: The increased adoption of renewable energy sources leads to a reduction in CO_2 emissions. The coefficient for renewable energy is negative and highly significant in all models. This provides strong evidence that the adoption of renewable energy sources reduces CO_2 emissions, thereby supporting H4.

H5: Higher employment in the service sector correlates with lower CO_2 emissions, due to the lower energy intensity of services compared to industrial activities. The coefficient for employment in the service sector is not significant in any of the models. This does not support the hypothesis that higher employment in the service sector correlates with lower CO_2 emissions. Hence, H5 is not supported by the data.

H6: Imports affect CO_2 emissions, reflecting the carbon footprint associated with the production and transportation of imported goods. The coefficient for imports is positive and significant in Models 2 and 4, but it is not significant in Models 1 and 3. This indicates that imports impact CO_2 emissions in some models but not consistently across all models. Therefore, H6 is partially supported.

In summary, the regression results largely support the hypotheses related to economic growth, the industrial sector's contribution, urbanization, and the adoption of renewable energy on CO_2 emissions. However, the effects of service sector employment and imports on CO_2 emissions are not consistently significant across all models.

4.2 Grouped PCSE Regression for 12 CEE countires

4.2.1Grouped Regression Result with GDP

In this section, a grouped regression analysis is conducted to further explore the determinants of CO_2 emissions across different clusters of Central and Eastern European countries.

Table 14 Classification of CEE countries

Country Group	Visegrad Group Countries	Baltic Countries	Other CEE Countries
Country Name	Czechia, Hungary, Poland, Slovakia	Estonia, Latvia, Lithuania	Albania, Bulgaria, Croatia, Romania, Slovenia

The 12 countries in this study are divided into three groups shown in Table 14: the Visegrad Group Countries, the Baltic Countries, and Other CEE Countries, which include Albania, Bulgaria, Croatia, Romania, and Slovenia. This categorization allows for a detailed examination of how various economic and social factors impact CO_2 emissions in distinct regional contexts.

Table 15 presents the results of the grouped regression analysis with GDP as indicator. For the Visegrad Group, GDP per capita is a strong positive driver for both production-based and consumption-based CO_2 emissions, with coefficients of 0.152 and 0.154, respectively, both significant at the 1% level. This indicates that economic growth in these countries leads to higher emissions. Employment in services significantly reduces CO_2 emissions in this group, suggesting a transition towards a less carbon-intensive service sector. Imports have a slight negative impact on production-based emissions, while the industrial sector and urbanization significantly increase emissions. Renewable energy adoption effectively reduces emissions, highlighting its role in mitigating environmental impact.

Table 15 PCSE estimation Result for Grouped Countries with GDP

	Visegrad Group Countries		Baltic Countries		Other CEE Countries	
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln_PCO2	ln_CCO2	ln_PCO2	ln_CCO2	ln_PCO2	ln_CCO2
ln_GDP	0.152***	0.154***	0.217***	0.261***	0.258***	0.277***
	(4.12)	(3.81)	(3.27)	(4.02)	(7.77)	(10.11)
EIS	-0.026***	-0.014***	0.011	-0.003	0.013***	0.011***
	(-4.71)	(-2.72)	(1.29)	(-0.35)	(3.08)	(3.13)
IMPORTS	-0.002**	0.000	0.004*	0.003	-0.003	0.000
	(-2.15)	(0.33)	(1.79)	(1.36)	(-1.56)	(0.01)
INDUSTRY	0.027***	0.018***	0.014	-0.006	0.008*	0.007*
	(5.25)	(3.54)	(1.43)	(-0.56)	(1.65)	(1.71)
URBANPP	0.010***	0.009***	0.356***	0.248***	-0.000	-0.015***
	(4.66)	(4.66)	(6.50)	(6.95)	(-0.11)	(-6.22)
RENEWE	-0.011***	-0.016***	-0.030***	-0.021***	-0.038***	-0.034***
	(-2.58)	(-3.51)	(-6.42)	(-5.68)	(-16.65)	(-18.26)
Constant	0.928**	0.578	-24.953***	-16.505***	-0.631**	0.107
	(2.46)	(1.52)	(-6.37)	(-6.33)	(-2.08)	(0.46)

Observations	100	100	75	75	124	124
R-squared	0.945	0.934	0.768	0.886	0.966	0.982
Number of code	4	4	3	3	5	5

z-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In contrast, the Baltic Countries exhibit a stronger positive relationship between GDP per capita and CO_2 emissions, with coefficients of 0.217 for production-based and 0.261 for consumption-based emissions, both highly significant. This suggests a robust link between economic growth and increased emissions. Unlike the Visegrad Group, employment in services does not significantly affect emissions, indicating a less pronounced shift towards the service sector. Imports show a marginal positive impact on production-based emissions but are not significant for consumption-based emissions. The industrial sector's share of GDP is not a significant factor, while urbanization has a substantial positive impact on emissions. Renewable energy again plays a crucial role in reducing emissions in this group.

For the Other CEE Countries, GDP per capita shows the strongest positive impact on both production-based and consumption-based emissions, with coefficients of 0.258 and 0.277, respectively, indicating that economic growth significantly drives emissions in these countries. Employment in services slightly increases emissions, which may reflect a lesser emphasis on the service sector compared to other groups. Imports do not significantly influence emissions in this group. The industrial sector marginally increases emissions, and urbanization does not significantly affect production-based emissions but reduces consumption-based emissions, possibly due to different urban structures and efficiencies. Renewable energy consistently reduces emissions, underscoring its effectiveness in this region.

Overall, GDP per capita is a consistent positive driver of CO_2 emissions across all groups, with the strongest effects observed in the Other CEE Countries. The impact of employment in services varies, reducing emissions in the Visegrad Group, having no significant impact in the Baltic Countries, and slightly increasing emissions in the Other CEE Countries. Imports have a mixed impact, reducing production-based emissions in the Visegrad Group, marginally increasing them in the Baltic Countries, and having no significant effect in the Other CEE Countries. The industrial sector generally increases emissions, especially in the Visegrad Group, while urbanization's impact varies, significantly increasing emissions in the Visegrad and Baltic groups but reducing consumption-based emissions in the Other CEE Countries. Renewable energy consistently reduces emissions across all groups, highlighting its critical role in mitigating CO_2 emissions.

Through the analysis of grouped regression results, it is possible to estimate which group of countries is closer to the turning point of the EKC. This estimation is based on the size and significance of the GDP coefficients. Generally, smaller coefficients indicate a weaker impact of economic growth on CO_2 emissions, suggesting a closer proximity to the EKC turning point where emissions start to decrease as income increases.

For the Visegrad Group Countries, which include Czechia, Hungary, Poland, and Slovakia, the regression results show positive and significant coefficients for ln_GDP in both production-based (ln_PCO2) and consumption-based (ln_CCO2) CO_2 emissions. Specifically, the coefficients are 0.152 and 0.154, respectively, both significant at the 1% level. These relatively small coefficients suggest that economic growth in these countries, while still leading to increased CO_2 emissions, does so at a lesser rate compared to other groups. This indicates that the Visegrad Group Countries might be closer to the EKC turning

point, where the negative environmental impact of economic growth begins to diminish, signaling a potential transition towards more sustainable development.

In contrast, the Baltic Countries, which include Estonia, Latvia, and Lithuania, show higher coefficients for ln_GDP in their regression results. The coefficients are 0.217 for production-based and 0.261 for consumption-based CO_2 emissions, both highly significant. These higher coefficients indicate a stronger positive relationship between GDP per capita and CO_2 emissions, indicating that these nations are farther from reaching the EKC turning point compared to V4 countires and need to implement more robust measures to mitigate the environmental impacts of their economic activities.

For the Other CEE Countries, which include Albania, Bulgaria, Croatia, Romania, and Slovenia, the regression analysis reveals the highest GDP coefficients among the three groups. The coefficients are 0.258 for production-based and 0.277 for consumption-based CO_2 emissions, both significant at the 1% level. These high coefficients suggest that economic growth in these countries has the most substantial impact on increasing CO_2 emissions, indicating that these countries are the furthest from the EKC turning point in the selected countries . The significant positive relationship between GDP per capita and CO_2 emissions highlights the need for these countries to adopt more aggressive strategies in green technologies and renewable energy to reduce their environmental footprint and move closer to the EKC turning point.

In conclusion, the comparison of GDP coefficients across the three groups indicates that the Visegrad Group Countries are closest to the EKC turning point, followed by the Baltic Countries and then the Other CEE Countries. This viewpoint is also consistent with research

on the Environmental Kuznets Curve in Central and Eastern Europe (Lazăr et al., 2019). The findings indicate that both the Czech Republic and Hungary, which are part of the V4 group, exhibit a pronounced inverted U-shaped curve. Additionally, Lapinskienė et al. (2013) examined the validity of the EKC for the Baltic countries, using data from 1995-2008, and confirmed its effectiveness.

4.2.2 Grouped Regression Result with HDI

In this section, a similar grouped regression analysis as above is conducted to further explore the determinants of CO_2 emissions across different clusters of Central and Eastern European countries using HDI as the indicator. Table 16 presents the results of the grouped regression analysis.

Table 16 PCSE estimation Result for Grouped Countries with GDP

	Visegrad Group Countries		Baltic Countries		Other CEE Countries	
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln_PCO2	ln_CCO2	ln_PCO2	ln_CCO2	ln_PCO2	ln_CCO2
HDI	2.446***	1.666***	4.148***	4.629***	3.146***	3.232***
	(5.27)	(3.22)	(3.73)	(5.82)	(5.24)	(5.69)
EIS	-0.029***	-0.015***	0.003	-0.013*	0.015***	0.014***
	(-5.69)	(-2.72)	(0.38)	(-1.68)	(3.14)	(3.00)
IMPORTS	-0.001	0.002	0.004	0.003	-0.002	0.001
	(-1.20)	(1.42)	(1.51)	(1.31)	(-1.24)	(0.36)
INDUSTRY	0.021***	0.017***	0.024***	-0.004	0.014***	0.012***
	(4.32)	(3.18)	(2.59)	(-0.50)	(2.73)	(2.58)
URBANPP	0.009***	0.009***	0.337***	0.271***	-0.002	-0.017***
	(4.52)	(4.95)	(5.44)	(8.79)	(-0.43)	(-4.52)
RENEWE	-0.018***	-0.018***	-0.030***	-0.019***	-0.040***	-0.034***
	(-4.09)	(-3.46)	(-6.73)	(-6.50)	(-15.51)	(-13.91)
Constant	0.782**	0.615	-24.773***	-18.909***	-0.993**	-0.250
	(2.18)	(1.52)	(-5.57)	(-8.17)	(-2.11)	(-0.54)
Observations	100	100	75	75	124	124
R-squared	0.953	0.939	0.844	0.770	0.931	0.954
Number of code	4	4	3	3	5	5

z-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For the Visegrad Group, the Human Development Index significantly increases both production-based and consumption-based CO_2 emissions, with coefficients of 2.446 and 1.666, respectively, both significant at the 1% level. This indicates that higher human development levels lead to increased emissions, reflecting greater energy consumption and industrial activity associated with economic development. Employment in services significantly reduces CO_2 emissions, suggesting that a higher share of service sector employment is associated with lower emissions. Imports do not show a significant impact on emissions. The industrial sector and urbanization significantly increase emissions, while renewable energy adoption effectively reduces emissions, highlighting its role in mitigating environmental impact.

In contrast, the Baltic Countries exhibit even stronger positive relationships between HDI and CO_2 emissions, with coefficients of 4.148 for production-based and 4.629 for consumption-based emissions, both highly significant. This suggests that human development has a substantial impact on increasing emissions in these countries. Employment in services has a mixed effect, with a slight negative impact on consumption-based emissions and no significant impact on production-based emissions. Imports do not significantly affect emissions in this group. The industrial sector significantly increases production-based emissions but has no significant effect on consumption-based emissions. Urbanization has a substantial positive impact on both production-based and consumption-based emissions. Renewable energy significantly reduces emissions, demonstrating its importance in the Baltic countries.

For the Other CEE Countries, HDI also shows a strong positive impact on both production-based and consumption-based emissions, with coefficients of 3.146 and 3.232, respectively,

indicating that higher levels of human development lead to increased emissions. Employment in services slightly increases emissions, reflecting a lesser focus on the service sector. Imports do not significantly influence emissions in this group. The industrial sector significantly increases both types of emissions, highlighting the energy-intensive nature of industrial activities. Urbanization does not significantly affect production-based emissions but reduces consumption-based emissions, possibly due to different urban structures and efficiencies. Renewable energy consistently reduces emissions, underscoring its effectiveness in this region.

Overall, HDI is a consistent and strong positive driver of CO_2 emissions across all groups, with the strongest effects observed in the Baltic Countries. The impact of employment in services varies, reducing emissions in the Visegrad Group, having mixed effects in the Baltic Countries, and slightly increasing emissions in the Other CEE Countries. Imports do not significantly affect emissions in any group. The industrial sector generally increases emissions, especially in the Baltic and Other CEE Countries. Urbanization's impact varies, significantly increasing emissions in the Visegrad and Baltic groups but reducing consumption-based emissions in the Other CEE Countries.

4.2.3 Comparion Result for Grouped Regression

In this section, we will undertake a detailed comparison of the results across different groups of countries.

The comparison of GDP with HDI reveals several new dimensions in understanding the relationship between development and environmental impact in Central and Eastern European countries. Firstly, the substantially larger coefficients for HDI compared to GDP

across all country groups suggest that the factors encompassed by HDI – health, education, and standard of living – are more closely tied to increases in CO_2 emissions. This highlights that achieving comprehensive human development has a pronounced environmental footprint in CEE countries. It implies that as these countries improve their HDI, they may be simultaneously increasing their environmental burden, necessitating a balanced approach to sustainable development.

Secondly, the stronger association between HDI and CO_2 emissions indicates that investments in human capital, such as better healthcare and education systems, while essential for improving quality of life, are currently linked with higher energy consumption and resource use. This points to a critical area where sustainable practices need to be integrated into the sectors that drive human development in CEE countries.

Thirdly, the larger HDI coefficients also suggest that economic policies focusing solely on GDP growth might underestimate the environmental impact when broader aspects of development are considered. HDI provides a more holistic measure of progress, and the findings indicate that comprehensive development strategies in CEE countries must account for environmental sustainability. Policymakers should recognize that improvements in human development metrics might require more sophisticated and integrated approaches to manage the associated environmental impacts.

The analysis of CEE countries specifically shows that while GDP primarily measures economic output and is a direct indicator of economic growth, HDI offers a broader perspective by incorporating health, education, and living standards, which are central to sustainable development. In the context of CEE countries, where rapid economic

transformation has taken place, the shift from GDP to HDI reveals the deeper environmental challenges associated with comprehensive human development.

In conclusion, the comparative analysis of GDP and HDI in CEE countries highlights the multifaceted nature of development and its implications for environmental sustainability. The findings underscore the need for integrated development policies that balance economic growth with environmental stewardship and human well-being in the CEE region. As these countries strive to enhance their HDI, it is crucial to adopt sustainable practices that mitigate the environmental costs of human development.

4.3 Temporal PCSE Regression for 12 CEE countires

The regression results for the temporal analysis with GDP and HDI as explanatory variables offer insights into the determinants of CO_2 emissions in Central and Eastern European countries over two distinct periods, 1995-2000 and 2001-2019. The analysis distinguishes between production-based (ln_PCO2) and consumption-based CO_2 emissions (ln_CCO2), revealing shifts in the impact of various factors over time.

Table 17 PCSE estimation Result for Temporal Analysis with GDP

	Time Period: 1995-2000		Time Period: 2001-2019	
	(1)	(2)	(3)	(4)
VARIABLES	ln_PCO2	ln_CCO2	ln_PCO2	ln_CCO2
ln_GDP	0.404***	0.399***	0.181***	0.169***
	(7.11)	(10.23)	(5.35)	(4.01)
EIS	-0.011**	0.004	0.010**	0.003
	(-2.17)	(1.00)	(2.53)	(0.61)
IMPORTS	0.002	-0.000	-0.000	0.004***
	(1.36)	(-0.01)	(-0.37)	(3.18)
INDUSTRY	0.016***	0.013***	0.020***	0.005
	(2.68)	(3.21)	(5.15)	(1.07)
URBANPP	0.033***	0.011**	0.012***	0.016***
	(7.59)	(2.15)	(5.55)	(5.85)
RENEWE	-0.027***	-0.024***	-0.026***	-0.015***
	(-13.64)	(-8.14)	(-12.76)	(-7.16)

Constant	-3.115***	-2.356***	-1.169***	-0.774**
	(-8.20)	(-4.54)	(-3.74)	(-2.10)
Observations	71	71	228	228
R-squared	0.981	0.996	0.952	0.924
Number of code	12	12	12	12

z-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As shown in Table 17, for the period 1995-2000, GDP per capita exhibited a significant positive impact on both production-based and consumption-based CO_2 emissions, with coefficients of 0.404 and 0.399, respectively. This strong relationship indicates that economic growth during this time was closely tied to increased emissions, underscoring the environmental costs of economic development. In contrast, from 2001-2019, the coefficients for GDP per capita decreased to 0.181 for production-based and 0.169 for consumption-based emissions, suggesting a decoupling trend where economic growth led to less pronounced increases in emissions. This shift points to a potential movement towards the peak of the EKC.

In the earlier period, employment in services significantly reduced production-based emissions but did not affect consumption-based emissions. By the 2001-2019 period, the impact of employment in services on production-based emissions became slightly positive, while it remained insignificant for consumption-based emissions. This change could reflect the increased energy use in the service sector over time.

The role of imports also evolved. During 1995-2000, imports did not significantly affect emissions, whereas in the 2001-2019 period, they had a significant positive impact on consumption-based emissions, indicating the growing carbon footprint of imported goods.

The industrial sector consistently increased emissions in both periods. The coefficients for

the industrial sector's share of GDP were 0.016 and 0.013 for production-based and consumption-based emissions, respectively, in the earlier period. These coefficients remained significant in the later period, though the impact on consumption-based emissions became insignificant, indicating a persistent yet evolving role of industrial activities in driving emissions.

Urbanization significantly increased emissions across both periods. In the earlier period, the coefficients were 0.033 for production-based and 0.011 for consumption-based emissions, reflecting high energy demands in urban areas. The impact persisted in the later period, with coefficients of 0.012 and 0.016, respectively, underscoring the continued significance of urbanization in influencing emissions.

Renewable energy consistently played a mitigating role in both periods. The adoption of renewable energy significantly reduced both production-based and consumption-based emissions, with coefficients of -0.027 and -0.024 in the earlier period and -0.026 and -0.015 in the later period. This indicates the effectiveness of renewable energy in reducing emissions over time.

As shown in Table 18, the analysis with HDI as the explanatory variable presents a similar trajectory. During 1995-2000, HDI had a strong positive impact on both production-based (3.367) and consumption-based emissions (3.640), highlighting the environmental implications of human development. In the 2001-2019 period, these impacts remained positive but were less pronounced, with coefficients of 2.685 and 2.532, respectively. This reduction suggests a beginning decoupling of human development from emissions, indicating a shift towards more sustainable development practices.

Employment in services showed a mixed impact in the earlier period, positively affecting consumption-based emissions but not production-based emissions. By the later period, its impact became insignificant for both types of emissions. Imports, which were insignificant in the earlier period, had a significant positive impact on consumption-based emissions in the later period.

Table 18 PCSE estimation Result for Temporal Analysis with HDI

	Time Period: 1995-2000		Time Period: 2001-2019	
	(1)	(2)	(3)	(4)
VARIABLES	ln_PCO2	ln_CCO2	ln_PCO2	ln_CCO2
HDI	3.367***	3.640***	2.685***	2.532***
	(3.09)	(4.14)	(4.67)	(3.64)
EIS	0.004	0.019***	0.004	-0.005
	(0.82)	(5.43)	(0.96)	(-1.18)
IMPORTS	0.002	0.001	0.002*	0.006***
	(0.69)	(0.55)	(1.89)	(4.04)
INDUSTRY	0.023***	0.023***	0.014***	0.003
	(3.37)	(3.75)	(3.59)	(0.63)
URBANPP	0.016***	0.008**	0.011***	0.012***
	(4.22)	(2.18)	(4.06)	(4.29)
RENEWE	-0.031***	-0.019***	-0.025***	-0.011***
	(-16.03)	(-7.10)	(-13.27)	(-4.69)
Constant	-2.114***	-2.671***	-1.393***	-0.742
	(-2.60)	(-3.41)	(-3.11)	(-1.34)
Observations	71	71	228	228
R-squared	0.970	0.974	0.946	0.911
Number of code	12	12	12	12

z-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Employment in services showed a mixed impact in the earlier period, positively affecting consumption-based emissions but not production-based emissions. By the later period, its impact became insignificant for both types of emissions. Imports, which were insignificant in the earlier period, had a significant positive impact on consumption-based emissions in the later period.

The industrial sector's share of GDP continued to significantly increase production-based emissions across both periods, while its impact on consumption-based emissions diminished in the later period. Urbanization maintained its positive impact on emissions throughout both periods, reflecting ongoing high energy demands. Renewable energy consistently reduced emissions in both periods, reinforcing its critical role in emission mitigation.

In summary, the temporal analysis reveals that during 1995-2000, economic growth and human development were strongly associated with increased CO_2 emissions, placing Central and Eastern European countries on the upward slope of the EKC. From 2001-2019, the relationship between economic indicators and emissions became less pronounced, suggesting a potential movement towards the EKC peak. Key factors such as the industrial sector, urbanization, and renewable energy adoption significantly influenced emissions, highlighting the need for targeted policies to promote sustainable development and decouple economic growth from environmental degradation.

5. Implication and Limitation

5.1 Policy Implication

The findings of this study have several important policy implications for Central and Eastern European countries striving to balance economic growth with environmental sustainability.

The significant relationship between renewable energy adoption and reduced CO_2 emissions underscores the need for policies that promote the development and integration of renewable energy sources. The evolution of the European Union's renewable energy policies has been primarily driven by the need to address climate change and reduce greenhouse gas emissions. Major policy developments include the Renewable Energy Directive, which sets binding targets for the share of renewable energy in the EU's energy consumption, and the 2030

Climate and Energy Framework, which further strengthens the EU's commitment to renewable energy (Solorio & Bocquillon, 2017; Musiał et al., 2021). For CEE countries, creating a favorable regulatory environment and providing financial incentives to stimulate investments in renewable energy could be effective. These incentives might include subsidies for renewable energy projects, tax breaks for companies investing in renewable technologies, and low-interest loans to mitigate the financial barriers for renewable energy initiatives. Establishing clear and long-term renewable energy targets can provide certainty for investors and encourage sustained investment in the sector. Additionally, policymakers might focus on upgrading grid infrastructure to accommodate the intermittent nature of renewable energy sources and ensure reliable energy supply.

The positive impact of urbanization on reducing CO_2 emissions highlights the importance of sustainable urban planning. Policymakers might focus on creating green infrastructure, such as parks and green roofs, that can absorb CO_2 and improve urban air quality. Enhancing public transportation systems to make them more efficient and accessible could reduce the reliance on private vehicles, thus lowering CO_2 emissions. Promoting energy-efficient buildings through stringent building codes and offering incentives for retrofitting existing buildings can significantly reduce urban energy consumption. Furthermore, implementing smart city initiatives that utilize technology to optimize energy use, traffic management, and waste disposal can create more sustainable urban environments. These initiatives could include smart grids, intelligent transportation systems, and digital platforms that provide real-time data for better urban management (Radulescu et al., 2018; Serbanica & Constantin, 2017).

The significant contribution of industrial activities to CO_2 emissions necessitates the

implementation of policies that encourage the adoption of cleaner technologies and improve energy efficiency in the industrial sector. Providing grants and tax incentives for research and development (R&D) in green technologies can foster innovation that leads to more sustainable industrial processes. Establishing stringent environmental regulations to limit emissions can drive industries to adopt cleaner technologies and practices. Additionally, creating a framework for carbon pricing, such as carbon taxes or cap-and-trade systems, can provide economic incentives for industries to reduce their carbon footprint (Pieloch-Babiarz et al., 2021; Ioan et al., 2020; Jonek-Kowalska, 2022). Policymakers might also promote collaboration between industries and academic institutions to accelerate the development and deployment of new technologies. Support for pilot projects and demonstration plants can help to showcase the feasibility and benefits of innovative green technologies, encouraging wider adoption across the industrial sector.

The stronger correlation between the Human Development Index (HDI) and CO_2 emissions compared to GDP suggests that policies should not solely focus on economic growth measured by GDP. Policymakers should adopt a more comprehensive approach that includes human development indicators such as health, education, and living standards. This approach ensures that economic policies promote overall well-being and sustainability rather than just economic output. By integrating HDI into policy frameworks, governments can develop strategies that enhance both the economic and social dimensions of development, leading to more holistic and sustainable outcomes (Bieth, 2021; Afzal & Chen, 2021). For instance, policies that improve education and healthcare can have long-term benefits for the economy and environment, fostering a society that values sustainable practices and innovation.

The inconsistent impact of service sector employment and imports on CO_2 emissions

indicates that trade policies should consider the environmental impact of both imports and exports. Policymakers should encourage the import and export of goods and services with lower carbon footprints and promote the development of green supply chains. By prioritizing environmentally friendly trade practices and environmental policies, governments can minimize the carbon footprint of their economies and support global efforts to mitigate climate change. This could involve setting stricter environmental standards for imported goods and promoting domestic production of sustainable products. Additionally, trade agreements should include environmental clauses that commit countries to reducing emissions associated with international trade. This can lead to a reduction in global CO_2 emissions and encourage countries to adopt greener technologies and practices. Furthermore, Central and Eastern European countries can benefit from regional cooperation and the sharing of best practices in sustainable development. Collaborative initiatives such as joint renewable energy projects, cross-border public transportation systems, and shared R&D programs can enhance the effectiveness of individual national policies. Regional forums and organizations should facilitate the exchange of knowledge and experiences to support the implementation of sustainable policies across the region.

In conclusion, the findings of this study indicate that integrated and forward-looking policies are crucial for CEE countries to effectively address the dual challenge of promoting economic growth while ensuring environmental sustainability. These strategies will not only help reduce CO_2 emissions but also contribute to the long-term resilience and competitiveness of the economies in the region. By promoting renewable energy, sustainable urban planning, technological innovation, comprehensive development indicators, balanced trade policies, regional cooperation, and effective monitoring, CEE countries can achieve sustainable development that benefits both their economies and the environment.

5.2 Limitation

This study, while comprehensive in its approach to analyzing the relationship between economic growth, sustainable development, and CO_2 emissions in 12 Central and Eastern European countries, has several limitations that must be acknowledged. Addressing these limitations in future research would help to advance the field and develop more robust and comprehensive strategies for sustainable development.

Firstly, each regression in this study considers only six independent variables, which may not comprehensively capture all the relevant factors influencing CO_2 emissions. The selected variables include key economic indicators, but the analysis could benefit from incorporating additional factors from social, political, and economic dimensions. For instance, variables such as technological innovation, environmental policies, income inequality, and international trade dynamics could provide deeper insights into the determinants of CO_2 emissions. Future research could incorporate these additional variables to gain a more holistic understanding of the various influences on carbon emissions. Additionally, including metrics such as political stability, regulatory quality, and institutional effectiveness could reveal how governance and policy frameworks impact environmental outcomes. By expanding the range of independent variables, researchers can develop more effective strategies for emission mitigation and sustainability.

Secondly, the study focuses solely on production-based and consumption-based CO_2 emissions, without considering other greenhouse gases and environmental pollutants that could have significant ecological impacts. This limitation means that the analysis may not fully capture the environmental sustainability of the CEE countries. Future research should aim to include a broader range of environmental indicators.Incorporating these additional

metrics would enhance the comprehensiveness of the sustainability analysis and provide a more complete picture of the environmental challenges and opportunities in the region. Furthermore, examining the impacts of land use changes, deforestation, and biodiversity loss could offer a more integrated view of environmental sustainability.

Thirdly, the regional focus on Central and Eastern Europe limits the generalizability of the findings. The economic structures, energy consumption patterns, and environmental policies of CEE countries may differ significantly from those in other regions. As a result, the findings of this study may not be directly applicable to other geographical contexts. Applying these results to other regions should be done with caution, considering the unique characteristics of each area. Future research could expand the geographical scope, allowing for comparative analyses and the development of more universally applicable insights and recommendations. Comparative studies could explore how different regional contexts influence the relationship between economic growth and environmental sustainability, helping to identify best practices and transferable strategies.

Fourthly, this study uses historical data from 1995 to 2019, which may not fully account for recent developments and emerging trends in economic growth and environmental sustainability. The rapid advancement of green technologies, shifts in global trade patterns, and the increasing urgency of climate change mitigation efforts are factors that could significantly influence the relationship between economic activities and CO_2 emissions. Future research should consider incorporating more recent data and exploring the potential impacts of these emerging trends. Additionally, scenario analysis and forecasting models could be employed to predict future trajectories of CO_2 emissions under different policy and technological scenarios, providing valuable insights for policymakers.

In conclusion, while this study provides valuable insights into the relationship between economic growth and CO_2 emissions in the CEE region, addressing these limitations in future research would help to advance the field and develop more robust and comprehensive strategies for sustainable development. By incorporating a broader range of variables, expanding the geographical scope, including more recent data, and employing advanced methodologies, future studies can enhance our understanding of the complex dynamics between economic activities and environmental sustainability, ultimately supporting the global pursuit of sustainable development goals.

Conclusion

This thesis investigates the intricate relationship between economic growth and environmental sustainability in Central and Eastern European (CEE) countries, focusing on both production-based and consumption-based CO_2 emissions. The research provides valuable insights into how various economic activities and development indicators impact environmental outcomes, employing robust econometric models and extensive data analysis over a 25-year period from 1995 to 2019.

Firstly, the study confirms the presence of the Environmental Kuznets Curve hypothesis in CEE countries, indicating that these nations are currently on the upward-sloping portion of the EKC. This suggests that economic growth in these countries is still associated with increasing CO_2 emissions, and they have not yet reached the turning point where further economic development would lead to a decline in emissions. Notably, the Visegrad Group countries are closest to this turning point, followed by the Baltic countries, while the other CEE countries are further behind in this progression.

Additionally, the temporal analysis of CO_2 emissions from 1995-2000 to 2001-2019 reveals that economic growth and human development were strongly linked to increased emissions during the earlier period, placing CEE countries on the upward slope of the EKC. However, the analysis for the more recent period shows a less pronounced relationship between economic indicators and emissions, indicating a potential transition towards the peak of the EKC. This decoupling trend suggests that these countries are beginning to achieve more sustainable development.

Secondly, the research demonstrates that both GDP per capita and the Human Development

Index significantly drive CO_2 emissions, albeit through different mechanisms. While GDP primarily measures economic output, HDI provides a more comprehensive view of development, incorporating health, education, and living standards. The findings suggest that policies focusing solely on GDP growth might underestimate the environmental impact, as improvements in HDI, which reflect broader aspects of human development, are strongly correlated with increased emissions.

Thirdly, the study identifies the industrial sector as a major contributor to CO_2 emissions across all CEE countries, highlighting the need for policies that promote cleaner technologies and improve energy efficiency in industrial processes. Urbanization shows a mixed impact, generally increasing emissions in the Visegrad and Baltic groups but reducing consumption-based emissions in the other CEE countries. The service sector and imports have varied effects, indicating the complex interplay between different economic activities and their environmental impacts.

Fourthly, the role of renewable energy consumption is emphasized, consistently showing a negative correlation with CO_2 emissions. This underscores the critical importance of policies that encourage the adoption and integration of renewable energy sources, supported by financial incentives, regulatory frameworks, and infrastructure upgrades to accommodate renewable energy technologies.

Fifthly, the findings of this study have several important policy implications for CEE countries. There is a need for integrated and forward-looking policies that address both economic growth and environmental sustainability. This includes promoting renewable energy, sustainable urban planning, and technological innovation. Policies should not only

focus on GDP growth but also consider human development indicators such as health, education, and living standards. Additionally, regional cooperation and the sharing of best practices can enhance the effectiveness of national policies and support sustainable development across the region.

Sixthly, while this study provides comprehensive insights into the relationship between economic growth and CO_2 emissions in CEE countries, it has certain limitations. The focus on six independent variables might not capture all relevant factors influencing emissions. Future research could incorporate additional variables such as technological innovation, environmental policies, income inequality, and international trade dynamics. Furthermore, expanding the geographical scope to include other regions could allow for comparative analyses and the development of more universally applicable insights and recommendations.

In conclusion, this thesis contributes to the understanding of how economic growth and sustainable development interact in the CEE region. By highlighting the complex relationships between economic indicators and environmental outcomes, it provides valuable guidance for policymakers aiming to balance economic development with environmental protection. Addressing the identified limitations and exploring the proposed future research directions could further enhance the robustness and applicability of the findings, ultimately supporting the global pursuit of sustainable development goals.

Summary

Tato diplomová práce zkoumá složitý vztah mezi hospodářským růstem a environmentální udržitelností v zemích střední a východní Evropy (CEE) se zaměřením na emise CO_2 založené jak na produkci, tak na spotřebě. Výzkum poskytuje cenné poznatky o tom, jak

různé ekonomické aktivity a ukazatele rozvoje ovlivňují environmentální výsledky, přičemž využívá robustní ekonometrické modely a rozsáhlou analýzu dat za období 25 let od roku 1995 do roku 2019.

Nejprve studie potvrzuje přítomnost hypotézy environmentální křivky Kuznets (EKC) v zemích CEE, což naznačuje, že tyto země se v současnosti nacházejí na vzestupné části EKC. To naznačuje, že hospodářský růst v těchto zemích je stále spojen s rostoucími emisemi CO_2 a že ještě nedosáhly bodu zvratu, kdy by další hospodářský rozvoj vedl k poklesu emisí. Zejména země Visegrádské skupiny jsou tomuto bodu zvratu nejblíže, následují pobaltské země, zatímco ostatní země CEE jsou v tomto vývoji dále pozadu.

Dále, časová analýza emisí CO_2 od roku 1995 do roku 2000 a od roku 2001 do roku 2019 ukazuje, že hospodářský růst a lidský rozvoj byly v dřívějším období silně spojeny se zvýšenými emisemi, což umisťuje země CEE na vzestupnou část EKC. Analýza pro novější období však ukazuje méně výrazný vztah mezi ekonomickými ukazateli a emisemi, což naznačuje potenciální přechod k vrcholu EKC. Tento trend oddělení naznačuje, že tyto země začínají dosahovat udržitelnějšího rozvoje.

Za druhé, výzkum ukazuje, že jak HDP na obyvatele, tak Index lidského rozvoje (HDI) významně ovlivňují emise CO_2, i když různými mechanismy. Zatímco HDP primárně měří ekonomický výstup, HDI poskytuje komplexnější pohled na rozvoj, zahrnující zdraví, vzdělání a životní úroveň. Zjištění naznačují, že politiky zaměřené pouze na růst HDP by mohly podceňovat environmentální dopad, protože zlepšení v HDI, která odrážejí širší aspekty lidského rozvoje, jsou silně korelována s nárůstem emisí.

Za třetí, studie identifikuje průmyslový sektor jako hlavního přispěvatele emisí CO_2 ve všech zemích CEE, což zdůrazňuje potřebu politik, které podporují čistší technologie a

zlepšují energetickou účinnost v průmyslových procesech. Urbanizace má smíšený dopad, obecně zvyšující emise ve Visegrádské a pobaltské skupině, ale snižující emise založené na spotřebě v ostatních zemích CEE. Sektor služeb a importy mají různé efekty, což naznačuje složitou interakci mezi různými ekonomickými aktivitami a jejich environmentálními dopady.

Za čtvrté, je zdůrazněna role spotřeby obnovitelných energií, která konzistentně vykazuje negativní korelaci s emisemi CO_2. To podtrhuje kritickou důležitost politik, které podporují přijetí a integraci obnovitelných zdrojů energie, podporovaných finančními pobídkami, regulačními rámci a vylepšením infrastruktury pro ubytování technologií obnovitelných zdrojů energie.

Za páté, zjištění této studie mají několik důležitých politických implikací pro země CEE. Existuje potřeba integrovaných a proaktivních politik, které se zabývají jak hospodářským růstem, tak environmentální udržitelností. To zahrnuje podporu obnovitelných energií, udržitelné městské plánování a technologické inovace. Politiky by se neměly zaměřovat pouze na růst HDP, ale také by měly zohledňovat ukazatele lidského rozvoje, jako je zdraví, vzdělání a životní úroveň. Navíc regionální spolupráce a sdílení osvědčených postupů mohou zvýšit efektivitu národních politik a podpořit udržitelný rozvoj v celém regionu.

Za šesté, ačkoli tato studie poskytuje komplexní pohled na vztah mezi hospodářským růstem a emisemi CO_2 v zemích CEE, má určité omezení. Zaměření na šest nezávislých proměnných nemusí zachytit všechny relevantní faktory ovlivňující emise. Budoucí výzkum by mohl zahrnout další proměnné, jako je technologická inovace, environmentální politiky, příjmová nerovnost a dynamika mezinárodního obchodu. Navíc, rozšíření

geografického záběru na zahrnutí dalších regionů by mohlo umožnit srovnávací analýzy a vývoj více univerzálně aplikovatelných poznatků a doporučení.

Závěrem, tato diplomová práce přispívá k porozumění, jak hospodářský růst a udržitelný rozvoj interagují v regionu CEE. Tím, že zdůrazňuje složité vztahy mezi ekonomickými ukazateli a environmentálními výsledky, poskytuje cenné pokyny pro tvůrce politik, kteří usilují o vyvážení hospodářského rozvoje s ochranou životního prostředí. Řešení identifikovaných omezení a zkoumání navržených směrů budoucího výzkumu by mohlo dále zvýšit robustnost a použitelnost zjištění, což by nakonec podpořilo globální úsilí o dosažení cílů udržitelného rozvoje.

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