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MASTER’S THESIS

THE IMPACT OF RENEWABLE ENERGY CONSUMPTION ON ECONOMIC GROWTH: EVIDENCE FROM CENTRAL AND EASTERN EUROPEAN COUNTRIES

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ABSTRACT

This master’s thesis investigates the relationship between renewable energy consumption and economic growth in eleven Central and Eastern European countries from 2000 to 2021. These countries are Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. The key variable of interest is renewable energy consumption, measured as the share of renewable energy in total energy consumption. Control variables include energy intensity, labor force participation rate, gross capital formation, foreign direct investment, and exports of goods and services. The study employs a Time-series cross-sectional Prais–Winsten regression model with panel-corrected standard errors to estimate the econometric model. The results indicate that renewable energy consumption does not significantly contribute to economic growth, supporting the neutrality hypothesis. This outcome reflects structural and policy challenges, such as low initial adoption rates of renewables, continued reliance on fossil fuels, high infrastructure costs, outdated energy systems, and regulatory barriers. Energy intensity exhibits a positive relationship with economic growth, potentially driven by the prevalence of energy-intensive industries. In addition, gross capital formation and exports emerge as key contributors to GDP growth. The findings emphasize the need for strategic policies to increase Renewable Energy Consumption’s economic impact through investment, infrastructure modernization, innovation, and regulatory improvements. Recommendations are provided for fostering renewable energy adoption, reducing energy intensity, and ensuring sustainable economic growth in this region. Future research should address endogeneity issues, explore sectoral energy consumption, and analyze the role of political and market structures to support effective energy transitions.

KEY WORDS: Renewable energy consumption, economic growth, Central and Eastern Europe, sustainable development, transition economies, energy efficiency

SUSTAINABLE DEVELOPMENT GOALS

POZVETEK

To magistarsko delo raziskuje razmerje med porabo obnovljivih virov energije in gospodarsko rastjo v enajstih državah Srednje in Vzhodne Evrope v obdobju od leta 2000 do 2021. Te države so Bolgarija, Hrvaška, Češka, Estonija, Madžarska, Latvija, Litva, Poljska, Romunija, Slovaška in Slovenija. Ključna spremenljivka zanimanja je poraba obnovljivih virov energije, merjena kot delež obnovljivih virov energije v skupni porabi energije. Kontrolne spremenljivke vključujejo energetsko intenzivnost, stopnjo participacije delovne sile, bruto oblikovanje osnovnega kapitala, neposredne tuje naložbe in izvoz blaga in storitev.

Študija uporablja časovno-serijski presečni Prais–Winsten regresijski model s panelno korigiranimi standardnimi napakami za oceno ekonometričnega modela. Rezultati kažejo, da poraba obnovljivih virov energije nima pomembnega vpliva na gospodarsko rast, kar podpira hipotezo nevtralnosti. Ta izid odraža strukturne in politične izzive, kot so nizke začetne stopnje uporabe obnovljivih virov, nadaljnja odvisnost od fosilnih goriv, visoki stroški infrastrukture, zastareli energetski sistemi in regulativne ovire. Energetska intenzivnost kaže pozitivno povezavo z gospodarsko rastjo, kar je lahko posledica prevlade energetsko intenzivnih industrij. Poleg tega se bruto oblikovanje kapitala in izvoz izkazujeta kot ključna dejavnika rasti BDP. Ugotovitve poudarjajo potrebo po strateških politikah za povečanje gospodarskega vpliva porabe obnovljivih virov energije prek naložb, modernizacije infrastrukture, inovacij in izboljšav regulative. Podana so priporočila za spodbujanje uporabe obnovljivih virov energije, zmanjšanje energetske intenzivnosti in zagotavljanje trajnostne gospodarske rasti v tej regiji. Prihodnje raziskave naj bi naslovile vprašanja endogenosti, raziskale sektorsko porabo energije ter analizirale vlogo političnih in tržnih struktur za podporo učinkovitim energetskim prehodom.

KLJUČNE BESEDE: Poraba obnovljivih virov energije, gospodarska rast, Srednja in Vzhodna Evropa, trajnostni razvoj, prehodna gospodarstva, energetska učinkovitost

CILJI TRAJNOSTNEGA RAZVOJA

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LIST OF ABBREVIATIONS

AI – Artificial Intelligence

ARDL – Auto Regressive Distributed Lag

CEE – Central and Eastern European

CO2 – Carbon Dioxide

DOLS – Dynamic Ordinary Least Squares

ECI – Economic Complexity Indicator

EI – Energy Intensity

EKC – Environmental Kuznets Curve

EU – European Union

EU ETS - EU Emissions Trading System

EXP – Exports of Goods and Services

FMOLS - Fully Modified Ordinary Least Squares

FDI – Foreign Direct Investment

GDA – Grade Data Analysis

GDP – Gross Domestic Product

GFCF - Gross Capital Formation

GGE – Greenhouse Gas Emissions

ICT - Information and Communication Technology

LF - Labor Force Participation Rate

Non-OECD – non-Organization for Economic Cooperation and Development

Non-RES – non-Renewable Energy Sources

OECD – Organization for Economic Cooperation and Development

PCSEs - Panel-Corrected Standard Errors

PQR – Panel Quantile Regression

PV – Photovoltaic

R&D – Research and Development

REC – Renewable Energy Consumption

RES – Renewable Energy Sources

1 INTRODUCTION

One of the most severe problems of the modern world is climate change and its negative environmental consequences (IPCC, 2007). The most important factor for climate change in recent years is human activity and energy consumption. To address the changes in the environment, specific measures must be undertaken, and one of these measures is the dire change of technologies for energy production, which is imperative. Unfortunately, current predominant technologies (coal-based power plants), have detrimental, if not catastrophic impacts on the environment. Therefore, many countries have switched to greener alternatives in context of energy generation technologies, such as solar and wind.

We can say that prompt and decisive global action is needed and essential to mitigate the challenges that are posed by climate change. To respond to these challenges effectively, it is important to implement a range of measures and transition fundamentally from traditional energy generation technologies to more sustainable alternatives. Traditional methods of energy production, such as coal-burning power plants, contribute significantly to atmospheric pollution and pose serious threats to public health and ecosystems.

Furthermore, addressing these issues has initiated a global movement towards adopting greener and more sustainable energy generation techniques, emphasizing renewable energy sources such as geothermal, hydro, wind, and solar power. Unlike fossil fuels, renewable energy sources (hereinafter: RES) offer significant advantages regarding environmental sustainability, as they produce little to no greenhouse gas emissions (hereinafter: GGE) during operation and have minimal adverse impacts on air and water quality.

The transition towards renewable energy represents a paradigm shift in energy production and consumption patterns driven by technological innovation, market forces, and increasingly stringent environmental regulations. In recent years, significant advancements in renewable energy technologies, declining costs, and growing economies of scale have made the usage of renewable energy increasingly competitive with conventional fossil fuels.

The importance of renewable energy in the energy mix has been increasingly appreciated. The advantages of using renewable energy for the world's energy security and the environment are indisputable and much discussed in the literature. However, its effects on the economic welfare of countries are yet to be examined fully and described quantitatively.

Adopting renewable energy is thought to have the potential to boost employment and economic growth, especially in industries such as manufacturing, installation, and maintenance of renewable energy.

If we look back, energy consumption was mainly based on traditional biofuels and coal until the beginning of the 20th century. Their use increased over time with the growth of world energy consumption, reaching its maximum in the last few years. Since the 1950s, the use of fossil fuels and natural gas has grown, and together, they account for almost all the world's consumption.

According to U.S. Energy Information Administration (2019) predictions, world energy consumption will grow by almost 50% between 2018 and 2050. Energy consumption in non-Organization for Economic Cooperation and Development (hereinafter: non-OECD) countries will increase by approximately 70% between 2018 and 2050 and by approximately 15% in Organization for Economic Cooperation and Development (hereinafter: OECD) countries.

A significant number of countries have been shifting from conventional energy sources to unconventional alternatives in recent decades. The negative environmental effects of conventional energy sources and their scarcity are the main causes of the increase in demand for renewable energy sources. There are good examples of countries that are choosing more and more, cleaner energy initiatives, and expansion of RES. As an illustration of the broad commitment to moving towards sustainable energy solutions, the European Union (hereinafter: EU) has set a goal to increase its reliance on renewables from 32% to 42.5% by 2030.

Globally, just a few years ago, it was projected that renewable energy sources would account for around 30% of total energy consumption and production by 2021. When looking at the statistics, we can say that the world is on a good path to add more renewable capacity in the following years, and one of the forecasts and milestones that are expected to be achieved is that in 2028, renewable energy sources will account for over 42% of global electricity generation with the share of wind and solar photovoltaic (hereinafter: PV) doubling to 25%. (IEA, 2023)

However, intermittency, grid integration, storage constraints, and policy uncertainty are some of the obstacles in the line. Governments, business partners, and civil society organizations must work together to address these issues by promoting innovation, enhancing infrastructure, and developing robust legislative frameworks that will encourage investments in renewable energy.

It is clear and well know that the relationship between RES consumption and economic growth has become a subject of substantial academic inquiry and policy discourse. Of course, this relationship between renewable energy consumption and economic growth is rather complex, and it encompasses various economic, environmental, and social dimensions. The pursuit of renewable energy represents a strategic investment in transitions towards low-carbon economy, thus mitigating the adverse impacts of greenhouse gas emissions on climate change. Moreover, renewable energy deployment has the potential to enhance energy security by reducing dependence on imported fossil fuels, and consequently bolstering national energy resilience.

Energy, along with, for example, labor and capital, is vital input and a condition for socio-economic development. Additionally, energy also plays a significant role in contributing to sustainable economic growth (World Economic Forum, 2012). It is known that the rapid pace of economic growth in most countries has been accompanied by high energy consumption. Unfortunately, the use of energy, especially fossil fuels as the main energy source has a series of harmful effects on the environment. The energy consumption obtained from non-renewable sources significantly contributes to greenhouse gas emissions that cause global warming. Global warming is causing climate change and climate change threatens to undermine the wellbeing of the society, slow down economic development and change the natural environment. This is one of the key challenges facing the world globally. If we talk about possible solutions to reduce and mitigate climate change, it is the use of energy from renewable energy sources that generate lower greenhouse gas emissions in comparison to fossil fuels. Concerns about continued dependence on non-renewable energy sources have attracted the attention of governments to consider and adopt a wide range of Carbon dioxide (hereinafter: CO2) reduction policies and to identify specific policies and mechanisms that can respond to climate change.

The significant economic debate goes around in the energy economics literature when it comes to the interaction between economic growth and energy consumption. The link between energy variables and growth has been the subject of research into the often conflicting and paradoxical goals desired by policymakers. Of course, it is important to understand the dynamic link between economic growth, energy consumption and environmental quality, which is crucial for understanding energy and environmental policy, which is again a cornerstone for creating sustainable environmental and economic policies. There are numerous previous empirical works on the connection between economic growth and renewable energy consumption.

In the literature there is no agreement on the links between energy consumption and economic growth due to differences in the structural features of the analyzed countries, their development stages, econometric methods used, and the time frames analyzed. However, some researchers have synthesized the main results, highlighting four different hypotheses that have been tested and confirmed and will be further elaborated in this paper.

The first is the "non-causality hypothesis" or "neutrality hypothesis," which suggests there is no significant relationship between energy consumption and economic growth. This is observed in countries whose real Gross Domestic Product (hereinafter: GDP) growth relies more on the low energy-consuming service sector. Validating this hypothesis implies that reducing energy consumption to lower greenhouse gas emissions will not negatively affect domestic output, indicating the economy is decoupled from energy consumption dynamics.

The second is the "uni-directional causality from economic growth" or "conservation hypothesis," which posits that real GDP growth influences energy consumption. Here, decisions to reduce energy consumption will only marginally impact economic dynamics. This hypothesis can be analyzed in contexts where economic activity either leads to higher energy consumption or results in lower consumption due to resource constraints and reduced demand for high-energy-consuming products.

The third hypothesis is the "uni-directional causality from energy consumption" or "growth hypothesis," which states that energy consumption significantly influences economic growth. A positive relationship between these variables means pollution reduction measures could negatively affect domestic output. However, a negative relationship might suggest that reducing energy consumption can boost domestic output if the economy is more service-oriented and less energy-intensive.

The last hypothesis is the "bi-directional causality" or "feedback hypothesis," which suggests that energy consumption and economic growth are interdependent. Increased energy consumption leads to higher real GDP, which in turn increases energy consumption. In this scenario, environmental policies would reduce both consumption and GDP, while economic stimulus measures would boost both GDP and energy consumption.

It is believed that when one country increases share of renewable energy it can help meet the growing future demand for energy and have influence on the economic development at the same time. It is well known and proved that RES consumption can improve and enhance development and that it can be used in less developed areas and consequently reduce costs that are associated with climate change. Piralogea & Cicea (2012) claim that increase in exploitation of renewable energies play great role in economic growth and increasing of renewable energies is beneficial to economy of one country. The awareness of the influence on RES consumption on growth can help decision makers to define measures for developing the needed infrastructure to produce green energy.

The prediction for the future periods is that many countries will benefit with economic growth as a direct result of doubling the share of renewables in their energy mix. However, this is not that simple because to achieve economic growth through RES consumption, it is advisable for countries to create different policies that will promote and enhance the development of RES sector. Countries should also work on the acceleration of investments made in the RES field, for the economic growth to be achieved by increased domestic production, job creation, etc. It is advisable for the policies to be made in a way that they support the coexistence of renewable and non-renewable energy sources to create economic growth. These policies could allow for careful, step-by-step adoption of new energy sources.

There is relatively small number of research related to Central and Eastern European (hereinafter: CEE) countries and in this regard this thesis will try to shed some light on better understanding of the relationship between economic growth and renewable energy consumption in transition countries to promote both sustainable economic development and renewable energy development. The results of this analysis will have implications for the implementation of future policies on promoting renewable energies in combination with macroeconomic policies in CEE region. Additionally, it will fill the research gap and make it a collection of systematic reviews in this field.

In this context, the purpose of this thesis is to determine quantitatively the impact of renewable energy consumption to the economic growth in a panel data framework for eleven Central and Eastern European countries (Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia) for the period from 2000 to 2021.

This thesis will try to answer the following research question:

Is there a relationship between renewable energy consumption and economic growth in Central and Eastern European Countries?

Hypothesis is set as follows: *There is no significant and positive effect of renewable energy consumption on economic growth in Central and Eastern European Countries.*

This master's thesis aims to achieve the following objectives:

- To present the appropriate conceptual framework used to explore relationship between REC and economic growth.
- To give the literature review about the relationship between REC and economic growth.
- To analyze the impact of REC on economic growth in the countries of CEE.
- To provide strategic recommendations for advancing the development and efficient utilization of renewable energy sources.

This master's thesis will employ methods such as literature review to examine previous studies on the relationship between renewable energy sources consumption and economic growth. The insights gained from the literature review will form the basis for further analysis and discussion of the research findings presented in the thesis.

Based on the literature review, the independent influencing variables in this research will be selected from the most frequently mentioned determinants of economic growth. The variable of interest in this research will be renewable energy consumption, which will be measured as total consumption of renewable energy and share of renewable consumption in the energy mix. Further, we will incorporate a set of control variables. In our model we will include energy intensity level of primary energy, labor force participation rate, gross capital formation, foreign direct investment, inwards stock and exports of goods and services, which proved to be relevant in several previous empirical studies on economic growth.

As said above, the research will be based on panel data, and an adequate method for analyzing panel data will be used to estimate the econometric model. Based on the obtained research results, adequate recommendations will be given for the improvement of policies to promote renewable energies in the CEE region.

This thesis is organized into six main chapters, each addressing a specific aspect of renewable energy consumption and its relationship with economic growth, with a focus on Central and Eastern European countries.

Chapter one, outlines the background, significance, and objectives of the study, along with the research questions and hypotheses. It discusses the challenges and opportunities faced by CEE countries in transitioning toward renewable energy and highlights the role of renewable energy in fostering sustainable economic growth.

Chapter two provides an overview of relevant empirical studies on the relationship between renewable energy consumption and economic growth. It explores theoretical frameworks and empirical findings from global and regional perspectives, categorizing studies based on whether they show a positive, negative, or insignificant impact of renewable energy on economic growth. Key hypotheses, such as the growth, feedback, conservation, and neutrality hypotheses, are introduced and contextualized within the scope of this research.

Chapter three, examines the context of renewable energy in CEE countries, including their energy dependence, economic structures, and adoption of renewable energy sources. It explores how regional trends in renewable energy use are shaped by historical, economic, and policy factors. Additionally, it discusses the impact of the European Union's renewable energy policies, such as the Green Deal, on the region's energy transition efforts.

Chapter four describes the data sources and variables used in the empirical analysis. It explains the econometric techniques employed to examine both short and long term relationships between renewable energy consumption and economic growth in CEE countries. The chapter also details the construction of the models and the rationale behind the selection of variables.

Chapter five presents the findings of the empirical analysis, including descriptive statistics, correlation matrices, and regression outputs. The results are discussed in relation to the growth, feedback, conservation, and neutrality hypotheses. Cross-country comparisons within the CEE region are included to highlight variations in the impact of renewable energy consumption on economic growth. Tables and charts are used to visually support the analysis and facilitate interpretation.

Finally, Chapter 6 summarizes the main findings of the research and discuss its policy implications. It provides recommendations for promoting renewable energy adoption in CEE countries to achieve sustainable economic growth while aligning with environmental objectives. The chapter also addresses the limitations of the study and suggests directions for future research, emphasizing the need for continued exploration of renewable energy's role in economic development.

2 LITERATURE REVIEW

The relationship between energy consumption and economic growth is one of the main topics when it comes to academic discussions, due to its significant policy implications. Although energy is a vital component of economic growth, its use frequently has negative environmental effects. The widespread reliance on fossil fuels has resulted in many environmental challenges, such as resource depletion and rising carbon emissions, especially in the last 20 to 30 years.

Transitioning towards renewable energy production and consumption has become increasingly important for several reasons. Fossil fuel price volatility poses risks of energy insecurity and cost fluctuations, which are especially troublesome for countries that rely on oil imports. Furthermore, the widespread use of non-renewable resources worsens environmental deterioration, impacting vital resources like forests, water, and air, which can eventually jeopardize the stability of the world economy.

For countries that rely on energy imports, energy security is a critical issue because it creates vulnerabilities that renewable energy can help to mitigate. Renewable energy sources offer a solution to these problems by reducing carbon emissions and enhancing energy security. In addition, countries need to lower their carbon footprints to adhere to global frameworks for addressing climate change, such as the Kyoto Protocol and the Paris Agreement. Usage of RES is becoming more acknowledged as efficient tool for sustainable economic growth and environmentally friendly societies. Renewable energy is increasingly recognized as the best means of achieving environmental goals, enhancing energy security, and fostering sustainable economic growth.

The following sections will explore the key theories of economic growth, with a particular focus on the role of energy consumption as a pivotal factor in driving economic progress.

2.1 Growth theories

There are several growth theories that can offer valuable insights when exploring the relationship between renewable energy consumption and economic growth. Amongst the theories that are explaining the phenomenon of long-term economic growth, there are neoclassical theory and theory of endogenous growth. The neoclassical theory first appeared in the middle of the previous century, and it basically points to the three well known elements that need to be kept in mind when we are talking about long-term economic growth, namely: technology, capital, and labor. This theory points out that, besides the change in the amount of the engaged capital and labor, it is the result of technological progress that is exogenously determined. It is considered that the modern theory of economic growth begins with neoclassical Solow model, whose main drawback is that technological progress in considered exogenous category. The founder of this model, Robert Solow was aware of this drawback, however, at the time, it was not possible overcome it due to the analytical tools that he had on disposal.

2.1.1 Solow Growth Model

The Solow Growth Model, developed by Robert Solow in 1956, is a foundational theoretical framework in economics for understanding and analyzing economic growth and has become known as the neoclassical growth model. This model is based on a production function that shows how capital and labor influence total economic output, with an emphasis on technological progress as the primary driver of long-term economic growth. The standard production function often used is the Cobb-Douglas function, where output is determined by a combination of capital, labor, and technology (Cobb & Douglas, 1928). Technological progress in this context is considered an exogenous factor, meaning it originates outside the economic system itself. Solow's model demonstrates that increasing capital and labor can lead to economic growth in the short term, but only technological advancement can enable continuous long-term growth by mitigating the diminishing returns to capital (Solow, 1956).

According to Solow's model, capital accumulation is essential for short-term growth, but after a certain amount of capital per worker is reached, diminishing returns set in, meaning that more units of capital contribute less and less to total production. According to the theory of diminishing returns, economic growth might be constrained in the absence of technological advancement. The significance of saving, which permits capital accumulation and thereby fosters short-term economic growth, was also underlined by Solow. However, without ongoing technological advancement, a higher savings rate alone is insufficient to sustain long-term growth (Solow, 1956). Additionally, Solow's model predicts convergence between richer and poorer economies. Poorer countries, with lower capital per worker, can grow faster than wealthier nations due to a higher marginal product of capital. Under the assumption that countries have similar savings rates and technological progress, nations with lower levels of capital per worker tend to catch up to wealthier countries, a process known as convergence (Solow, 1956; Barro & Sala-i-Martin, 1992).

The Solow Growth Model laid the foundation for further development of modern growth theories and inspired endogenous growth theories, which aim to explain technological progress because of internal economic factors rather than as an exogenous factor, as proposed in Solow's approach (Romer, 1990). In this sense, Solow advanced our knowledge of the main drivers of economic expansion and offered a precise framework for examining different growth-promoting policies.

Energy is not specifically mentioned as a factor of production in Solow's initial growth model. The model emphasizes labor, capital, and technological advancement as the primary drivers of growth. Later models, however, expanded Solow's approach by adding energy as a separate factor because it is an essential production factor and plays a major role in economic growth processes (Stiglitz, 1974; Dasgupta & Heal, 1979).

Exogenous growth models, such as Solow's, face criticism for their limited ability to explain income differences among countries. Mankiw et al. (1992) demonstrated that this model can explain income differences by a factor of two at most, while actual differences are considerably larger, indicating bias due to omitted variables. The Solow residual, representing total factor productivity, is criticized by endogenous theorists for overlooking critical efficiency factors, such as stable inflation, competitive exchange rates, and a developed financial system, all of which encourage savings and investments (World Bank, 1990). Researchers have sought to improve the Solow model by including factors such as human capital (Mankiw et al. 1992) and outward market orientation (Knight et al. 1993), which enhances growth explanations through greater technology and knowledge transfer.

As explained by Asanovic (2018), the Solow growth model emphasizes the idea of convergence, where developing countries experience faster economic growth than more developed ones, helping them to close the gap. This occurs because of the diminishing returns on capital, which means that capital accumulation in less developed countries can yield higher marginal returns. However, endogenous growth theories dispute the automatic convergence posited by neoclassical models. In endogenous models, convergence is not inevitable, meaning that poorer countries may not necessarily catch up with wealthier nations. This lack of guaranteed convergence often stems from challenges in empirically proving the presence of externalities, and there is often a lack of reliable data on research and development (hereinafter: R&D) investments (Asanovic, 2018).

Solow also developed a long-term growth model to address the limitations of the Harrod-Domar model, which failed to explain sustainable growth. Around the same time, Trevor Swan proposed a similar model, leading to the Solow-Swan growth model. The key objective of this model was to demonstrate that economies can achieve long-term sustainable growth, where income per capita grows at the same rate as the population. By introducing the concept of substitutability between production factors, the Solow-Swan model corrected two major flaws of the Harrod-Domar model: economic instability and the inability to fully utilize labor (Pietak, 2014).

Additionally, Pietak (2014) explains that another neoclassical growth model originated from Frank Ramsey’s work on determining the optimal savings rate. This was later extended by David Cass and Tjalling Koopmans, forming what is known as the Ramsey-Cass-Koopmans model. In this model, the savings rate is an endogenous variable, determined by consumer behavior. Despite this difference, the Ramsey-Cass-Koopmans model’s conclusions on steady-state growth align with those of the Solow-Swan model.

Neoclassical models, of course, stress the idea of convergence and claim that economies typically achieve long-term equilibrium. According to this theory, because the main difference between less developed and wealthier nations is in their capital-to-labor ratios, the former will grow faster than the latter. In the end, these economies ought to converge to a common steady-state equilibrium, which would enable lower-income countries to grow more quickly until they catch up to more developed ones (Pietak, 2014).

The Solow growth model offers a helpful framework for comprehending the connection between economic growth and the use of renewable energy in the context of Central and Eastern European nations. According to the model, making investments in renewable energy can act to accumulate capital and hasten the process of catching up to more developed countries. Because renewable energy technologies are still relatively underdeveloped in many CEE countries, investing in them could yield high returns, like how traditional capital investments behave in economies with low initial capital stocks.

In traditional capital investment, diminishing returns mean that additional capital produces smaller increases in output. Investments in renewable energy, however, might not initially experience the same diminishing returns in CEE nations, which have traditionally relied on non-renewable sources. By switching to renewable energy, this offers CEE nations the chance to grow more quickly and increase sustainability and productivity. According to the Solow model, technological advancement is an exogenous factor that propels long-term economic growth.

2.1.2 Endogenous Growth Model

Unlike exogenous growth models, which rely on factors outside the economy to explain growth, endogenous growth models seek to explain key trends in the global economy by focusing on internal factors. One of the main questions these models address is why modern economies produce significantly more goods than they did a century ago. Romer (1990) attributes this phenomenon to increasing returns on labor and the accumulation of human capital. Human capital, defined as the knowledge, skills, and innovation capabilities of the workforce, is considered crucial for driving economic growth. Furthermore, these models seek to understand why economic disparities between nations are widening, despite the global economy's interconnectedness (Pietak, 2014).

Romer's version of the endogenous growth theory emphasizes technological progress and innovation as primary drivers of economic expansion. In the context of renewable energy, this theory suggests that investments in renewable energy sources can lead to sustained economic growth. By focusing on developing new technologies and enhancing energy efficiency, countries can improve productivity, foster innovation, and create new industries. For instance, competitiveness of the nations at the global market has a positive correlation with RES related research and development.

This view highlights the importance of energy transition as a core aspect of economic modernization. Both direct economic benefits, like increased job creation and energy security, and indirect benefits, like technological spillovers into other sectors, can result from nations investing in renewable energy infrastructure and innovation. Furthermore, investments in renewable energy can propel technological developments that promote sustained productivity increases, which are crucial for the endogenous growth framework.

According to the endogenous growth theory, which rose to prominence in the 1980s, economic growth originates internally within the system rather than from outside sources. Under this theory, different models incorporate technological advancement in different ways. One strategy focuses on externalities, such as the broader societal benefits of investments in renewable energy. A more resilient energy system, reduced healthcare costs, and improved air quality are just a few examples of the positive externalities that can arise from the adoption of clean energy technologies and promote sustainable growth.

Another set of models highlights the importance of R&D in driving technological progress, which is especially relevant for the renewable energy sector. Investments in R&D for renewable energy not only improve energy efficiency and lower production costs but also catalyze technological breakthroughs that can be adopted globally. In turn, this strengthens the role of renewable energy as a pivotal factor in achieving long-term economic growth.

A third group of models within the endogenous growth theory emphasizes constant returns on capital, meaning that investments, including those in renewable energy infrastructure, can continue to generate economic growth without the diminishing returns predicted by earlier neoclassical models. For renewable energy, this could imply that as capital is continuously invested in upgrading renewable energy systems and technologies, it could drive sustained internal growth within economies (Asanovic, 2018).

Both neoclassical and endogenous growth theories agree on the importance of capital accumulation and technological innovation as the main engines of economic growth. However, in contrast to neoclassical models, which view capital as subject to diminishing returns, endogenous growth models suggest that capital investments, especially in areas such as renewable energy, can yield continuous and lasting growth. In an ideal financial market, savings would perfectly match investments, allowing for the necessary capital to fund renewable energy projects. However, access to financing for renewable energy projects may not always be ideal due to flaws in financial markets, such as asymmetric information and transaction costs, which can restrict growth potential.

The endogenous growth model highlights the critical role that energy, specifically renewable energy, plays in fostering economic growth. Investments in RES can enhance countries productivity, improve innovation, and maintain competitiveness in a rapidly evolving global economy. In this way, renewable energy becomes both environmentally friendly technology and essential driver of sustainable, long-term economic growth.

Furthermore, endogenous growth models argue that long-term growth can be driven by internal factors such as innovation, human capital development, and R&D. In the case of renewable energy, if CEE countries invest significantly in R&D and innovation within this sector, they could foster sustained economic growth independent of external technological progress. However, empirical testing of this theory remains difficult due to the lack of reliable data on R&D investments in renewable energy in the region (Asanovic, 2018).

In endogenous growth theory, energy is a vital factor that influences long-term economic growth and productivity (Stern, 2011). It powers industrial processes and drives technological advancements, with investments in energy, particularly renewable energy development and efficiency improvements, boosting productivity by enhancing total factor productivity (hereinafter: TFP) (Sadorsky, 2012). Since energy comprises a substantial part of production costs, its availability and affordability directly impact both productivity and operating expenses. Innovations in the energy sector that provide stable, cost-effective energy sources can encourage investment and lower overall costs, supporting sustainable growth by mitigating issues linked to resource depletion and environmental damage.

Endogenous growth models highlight that technological advancements and research within the energy sector generate "spillover" effects, where the benefits of energy innovations extend to other sectors, improving overall efficiency (Jaffe et al., 2005). Furthermore, reliable energy supply contributes positively to human capital development, enabling better healthcare and education systems that cultivate a skilled workforce that is critical for continued technological progress (Bhattacharya et al., 2016). Thus, energy not only facilitates production and productivity but also fuels innovation, cuts costs, advances sustainability, and strengthens human capital, serving as an essential driver of sustainable economic growth in endogenous growth models.

2.2 Causal Relationship Between Economic Growth and Renewable Energy Consumption: A Review of Key Hypotheses

Discussions on sustainable development are significantly related to the impacts of REC on the economic growth. Understanding the link between the use of renewable energy and economic growth has become more important as countries look to reduce carbon emissions and move away from fossil fuels. When renewable energy is successfully integrated into economic systems, it not only benefits the environment but also generates financial gains like increased energy security, lower energy prices, and the encouragement of technological advancement. Notwithstanding these advantages, the precise relationship between the use of renewable energy and economic expansion is still complicated and the subject of ongoing research.

Debate centers around whether renewable energy consumption directly drives economic growth, whether economic expansion encourages greater adoption of renewable energy, or whether the relationship is bidirectional or even neutral. To address this, researchers have identified four key hypotheses that seek to clarify the direction of causality between renewable energy consumption and economic growth. Each hypothesis carries distinct implications for shaping economic policies and advancing sustainable development initiatives, as follows:

- The growth hypothesis suggests that there is a unidirectional causal relationship from energy consumption to economic growth. This implies that increased energy use can directly or indirectly stimulate economic growth by complementing other production factors, such as capital and labor, within the classical production function framework. The hypothesis holds if unidirectional causality is found, where energy consumption drives economic growth (Destek & Aslan, 2017; Kahia et al., 2017a, b). The application of the Granger causality test typically supports this hypothesis, indicating that energy consumption has a leading role in promoting economic expansion. This suggests that policies should focus on encouraging energy consumption and investments in energy infrastructure, as energy conservation measures might harm the overall health of the economy. Although energy use may contribute to economic expansion, it is important to recognize that this relationship may have both beneficial and detrimental consequences. Certain studies draw attention to the possible negative effects, where an over-reliance on energy use could lead to vulnerabilities, particularly when considering the sustainability of the environment and resources.

- The conservation hypothesis, on the other hand, asserts that energy conservation measures, which are intended to lower energy consumption and waste, do not always have a negative impact on economic expansion (Vo & Le, 2019; Nasreen et al., 2020). When there is unidirectional causality between economic growth and energy consumption, this hypothesis is confirmed. To put it another way, a growing economy might not be totally dependent on rising energy consumption, and energy-saving strategies could be put in place without having a negative effect on growth. However, several variables, including trade openness, infrastructure quality, and governance, may affect how effective energy-saving measures are. According to this theory, economic expansion may result in higher energy consumption, but growth is not primarily driven by energy consumption.
- According to the feedback hypothesis, there is a reciprocal, interdependent relationship between energy consumption and economic growth, suggesting that they are complementary. The Granger causality test in this case demonstrates bidirectional causality, which means that economic growth and energy consumption reinforce each other (Kahia et al., 2019). Research backs up this theory by showing that energy use not only promotes economic expansion but also increases energy demand in expanding economies (Rasoulinezhad & Saboori, 2018; Saad & Taleb, 2018; Shahbaz et al., 2018). Because economic growth and energy efficiency are closely related, it is important to carefully design energy efficiency measures to avoid impeding economic growth.
- Lastly, according to the neutrality hypothesis, energy use has little to no impact on economic growth because it makes up a small percentage of total economic output (Orhan et al., 2020). The Granger causality test frequently reveals no causal link between energy use and economic expansion in this situation. Because the two factors are essentially unrelated to one another, energy conservation measures can be put into place without worrying about how they will affect economic growth. Studies like Apergis & Payne (2010) and Azam et al. (2015) support the neutrality hypothesis, which states that there is no clear causal link between energy consumption and economic growth.

2.3 Transition, economic growth, and its relationship with renewable energy in CEE countries

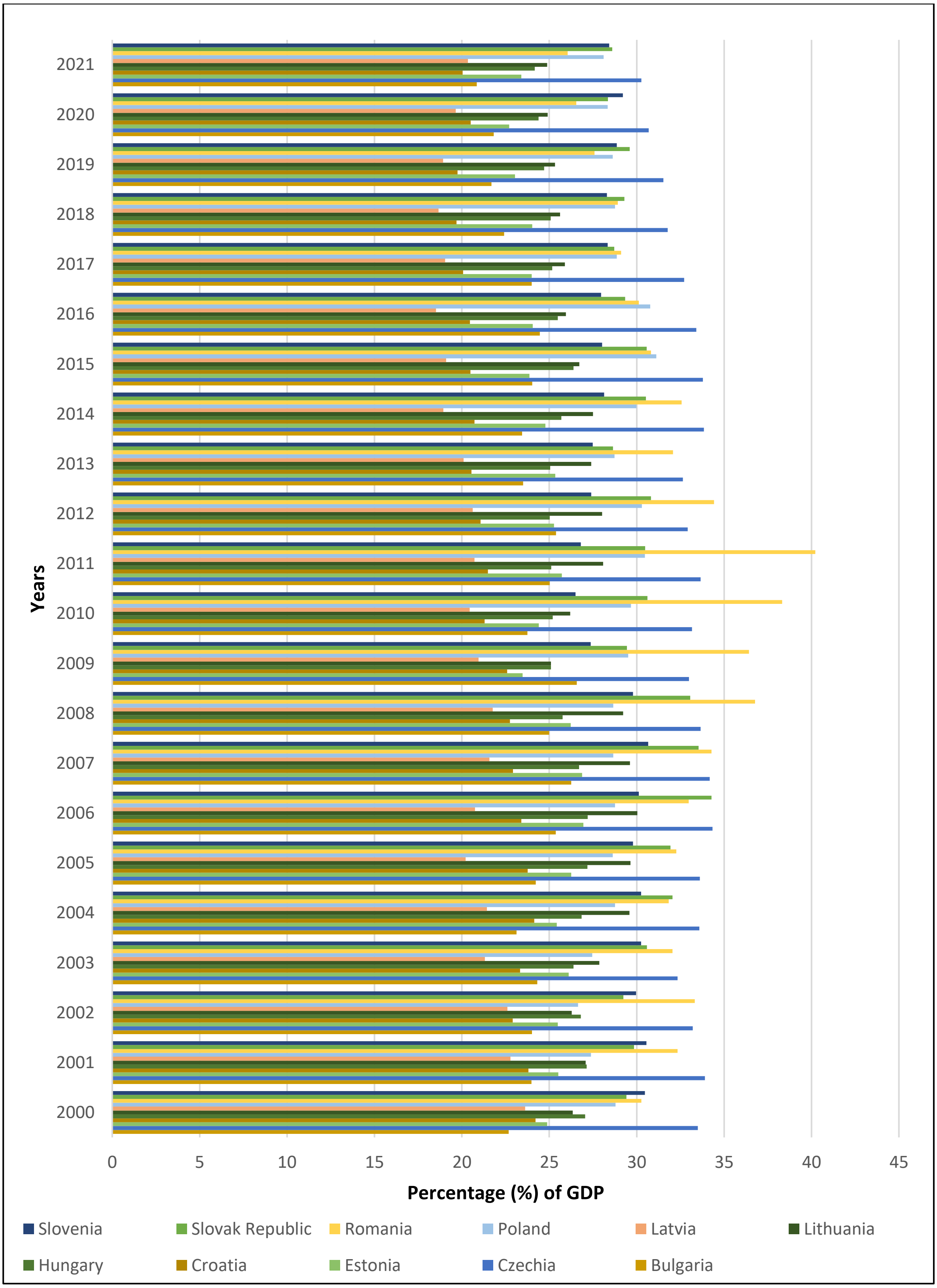
Central and Eastern European countries comprise a group of nations that transitioned from socialist systems to market-oriented economies following the fall of the Berlin Wall. These countries share a common history of economic transition, structural reforms, and the modernization of key sectors, including energy. Their development trajectories reflect both shared challenges and diverse opportunities as they integrate into the European Union and adopt sustainable practices.

Historically, many CEE economies relied heavily on energy-intensive industries and fossil fuels, which presents significant obstacles in transitioning to renewable energy while pursuing sustainable economic growth and emission reductions. Despite these challenges, numerous CEE countries have achieved notable progress in economic development and EU membership, granting them access to financial resources and technological expertise to support the shift toward renewables. However, economic conditions, infrastructure, and resource availability differ significantly across the region.

According to Grieveson et al. (2019), Central and Eastern Europe has experienced significant economic progress over the past three decades. Per capita income in the region has grown substantially in the past decade. This economic expansion has been driven by increasing integration with Western Europe, making CEE countries crucial trade partners for other developed economies.

Industrial production, especially in manufacturing, has been a major driver of economic growth in CEE nations. Compared to other regions, these countries now have a substantially higher percentage of industry contributing to their GDP. CEE nations are now essential parts of European value chains due to their industrial growth; many of them are categorized as "dependent market economies" (Hillebrand, 2022). High levels of foreign investment define these economies, especially in industrial sectors where production is driven by multinational corporations. Nonetheless, Western Europe continues to be the primary location for decision-making, with domestic businesses frequently playing a supporting role. Eleven Central and Eastern European countries' industrial production as a percentage of GDP presented in the Figure 1.

Figure 1: Industrial production as a share of GDP

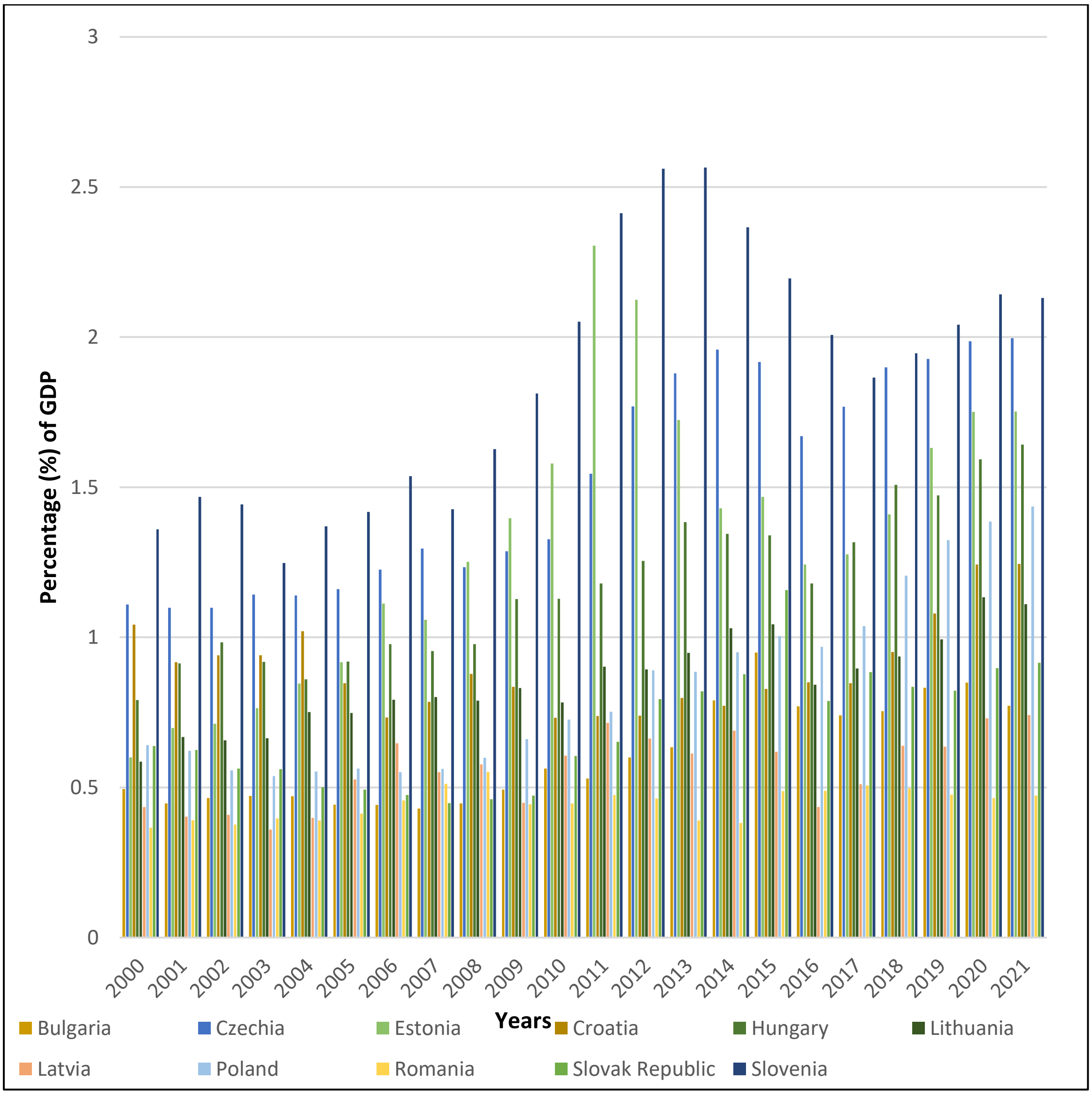


Source: World Bank Group (n.d.).

The economic model of CEE diverges from that of Southern Europe and East Asia, where national enterprises, both private and state-owned, have played a more significant role in driving growth. In CEE, foreign investors dominate, and economies specialize in producing lower cost, standardized industrial goods. This specialization has created "factory economies" in CEE countries that complement the "headquarters economies" of Western Europe, which focus on innovation and high-value-added activities.

According to Hillebrand (2022), the insignificant level of investment in research and development is a major flaw in the CEE growth model. R&D spending in these nations is lower than the EU average, even though industrial production is still high. As global economic trends move toward digitalization and green technologies, this lack of investment in innovation may pose a serious problem. The research and development expenditures as a percentage of the gross domestic product of eleven CEE countries are shown in Figure 2.

Figure 2: Research and Development as % of GDP

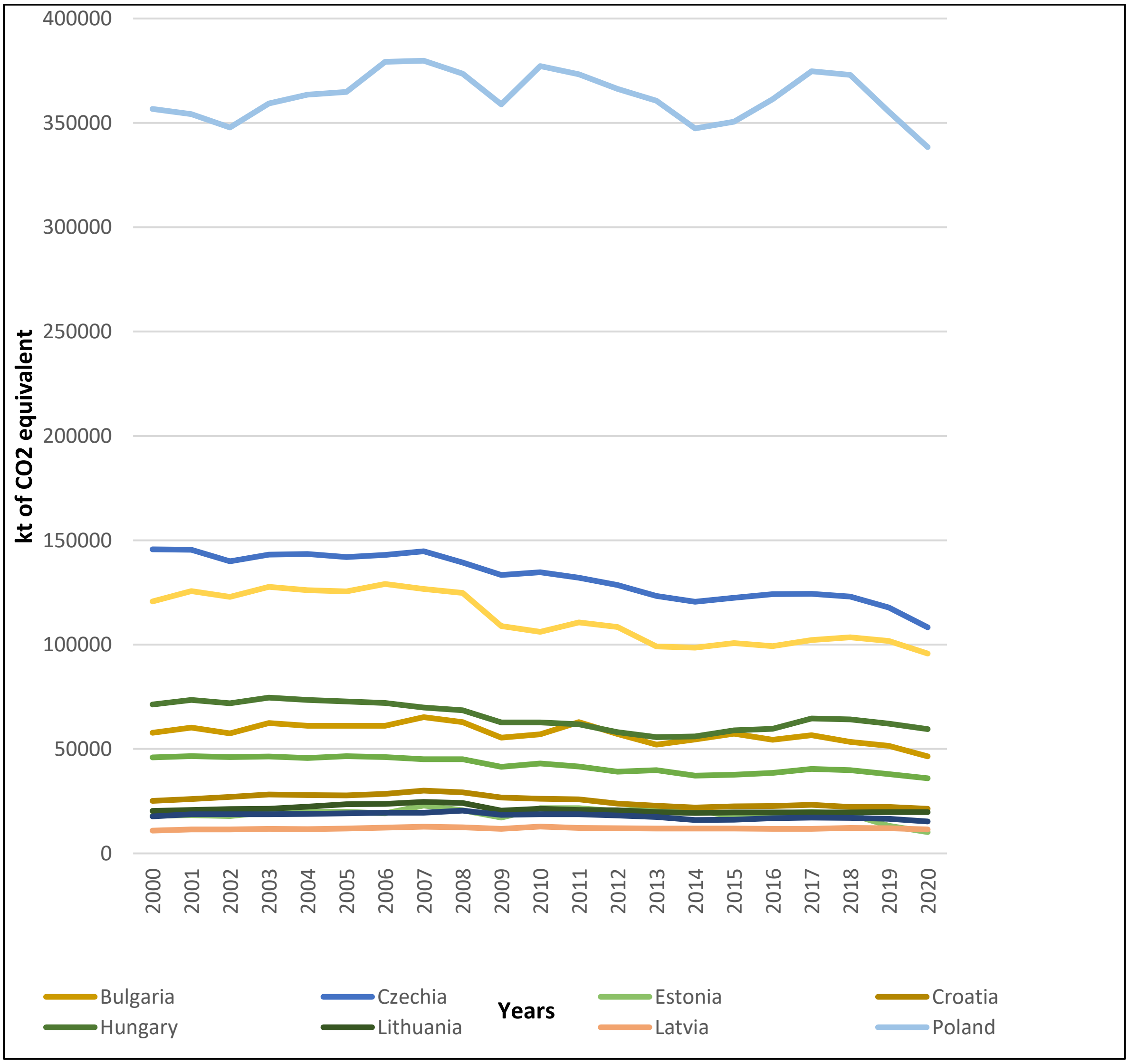


Source: World Bank Group (n.d.).

The transition to renewable energy presents another challenge for CEE economies. Many CEE countries remain heavily reliant on fossil fuels, particularly coal and natural gas. The region's high CO_2 emissions present a barrier to achieving climate neutrality, a goal central to the European Green Deal. To meet the EU's climate targets, CEE countries must make substantial investments in renewable energy infrastructure. Failure to transition could not only impact their environmental goals but also undermine their export-driven growth model, as global demand for cleaner, more sustainable goods increases.

Simionescu et al. (2021) argue that the EU's commitment to achieving climate neutrality by 2050, through the European Green Deal, will have significant implications for the economies of Central and Eastern Europe. Achieving CO_2 neutrality will require both policy shift and major investments in RES technologies, including wind, solar, and hydropower. Presented in the Figure 3, we can see greenhouse gas emission per unit of GDP of eleven Central and Eastern European countries, through the period from Year 2000 to 2020.

Figure 3: Greenhouse gas emissions per unit of GDP.



Source: World Bank Group (n.d.)

The relationship between economic growth and renewable energy in CEE countries remains complex. While renewable energy adoption has not yet significantly contributed to economic growth, the long-term advantages of transitioning to a green economy cannot be overlooked. Investments in renewable energy, though costly in the short term, offer the potential for future growth through job creation, increased energy security, and reduced dependency on fossil fuel imports.

While the economies of Central and Eastern Europe have advanced significantly, especially in industrial production, the region still faces difficulties in achieving sustainable growth and making the switch to renewable energy. To stay competitive in the global economy, CEE nations need to reduce their dependency on fossil fuels and increase their investments in innovation and renewable energy. Although they have not yet reached their full potential, the economic advantages of renewable energy have great potential for the region's future development.

2.4 Technological Innovation and its role in Renewable Energy Development in CEE countries

As Central and Eastern European countries make the transition to more ecologically friendly energy systems, technological advancements in renewable energy are crucial to their economic expansion and long-term viability. These nations, which have historically relied on fossil fuels and energy-intensive industries, must decarbonize to achieve environmental and economic objectives that are in line with international emission reduction agreements and European standards. The dependency on fossil fuels of these countries can be reduced, while also improving their energy security and competitiveness thanks to advancements in RES.

The declining costs of renewable energy technologies, such as photovoltaic solar systems, which saw a price reduction of nearly 89% between 2010 and 2020 (IRENA, 2021), allow CEE countries to integrate solar energy more effectively into their energy systems. Furthermore, advancements in wind turbine technology, which now allows energy generation even at lower wind speeds, provide additional opportunities for regions with less-than-ideal climate conditions for wind power (GWEC, 2020).

Energy storage is especially important for CEE countries because it stabilizes power grids and makes it easier to integrate renewable energy sources. This is especially true of advanced lithium-ion batteries. Energy security is a key concern for countries aiming to increase the share of renewable energy in their energy mix and expanding storage capacity reduces the possibility of grid instability (IEA, 2020).

Innovations in renewable energy have advantages for the environment as well as for the economic stability of CEE countries. The European Commission claims that by 2030, the European Green Deal could generate over a million new jobs, many of them in the fields of advanced technologies and renewable energy. Because they enable economic diversification and lessen reliance on fossil fuels, these job opportunities are especially beneficial for CEE nations.

Investments in research and development in CEE countries further support the transition to RES. Innovations and RES related infrastructure can help to integrate renewables more efficiently into existing infrastructure, leading to green jobs creation and enhance technological capacities (IRENA, 2020). Thus, for CEE countries, technological advancements in renewable energy are not only an environmental necessity but also a critical factor for achieving stable, long-term economic growth, energy security, and alignment with sustainable development goals.

Despite the benefits, CEE countries face several challenges in adopting advanced renewable energy technologies. One of the most significant barriers is the high investment capital cost along with building RES infrastructure and retrofitting existing grids. While RES can offer continuing economic savings, the initial investment can be prohibitive for many transition economies (European Investment Bank, 2019).

Furthermore, outdated energy infrastructure, much of which still relies heavily on coal and other fossil fuels, poses a challenge to integrating renewable technologies. Many CEE countries, such as Poland and Romania, remain dependent on coal-fired power plants, making the transition to renewables more difficult without significant upgrades to their energy grids (Corporate Leaders Group, 2021). This highlights the importance of government support in creating the financial and policy frameworks necessary to foster innovation in renewable energy technologies.

The enforcement of supportive RES policies is necessary for CEE countries to innovate the energy production and consumption technologies. Public-private partnerships that pool resources for large-scale infrastructure projects, tax incentives for renewable energy companies, and subsidies for research and development of clean energy technologies are all ways that governments can foster innovation (IRENA, 2018).

International cooperation can also be very important. Through programs like the Horizon Europe program, which provides funding for research and development in sustainable technologies and renewable energy, CEE countries can gain access to more advanced European countries for technology sharing and knowledge transfer (European Commission, 2021). By bridging the technological divide between CEE and Western Europe, these partnerships can help the latter quicken its energy transition.

Carbon pricing or emission trading schemes, which encourage businesses to use cleaner technologies and lessen their carbon footprint, are another crucial policy tool. The advantages of moving toward lower-emission technologies are already being felt by nations that have joined the EU Emissions Trading System (hereinafter: EU ETS), such as Slovakia and Hungary (European Environment Agency, 2021). Such policies can greatly increase innovation and lessen dependency on fossil fuels if they are customized to the unique economic and energy profiles of CEE nations.

Looking ahead, the CEE region stands to gain from focusing on emerging technologies such as green hydrogen and advanced bioenergy systems. Green hydrogen, produced using renewable electricity, has the potential to decarbonize sectors that are difficult to electrify, such as heavy industry and long-haul transport. Investment in hydrogen technology is growing across Europe, and CEE countries have an opportunity to position themselves as leaders in this space (IRENA, 2022).

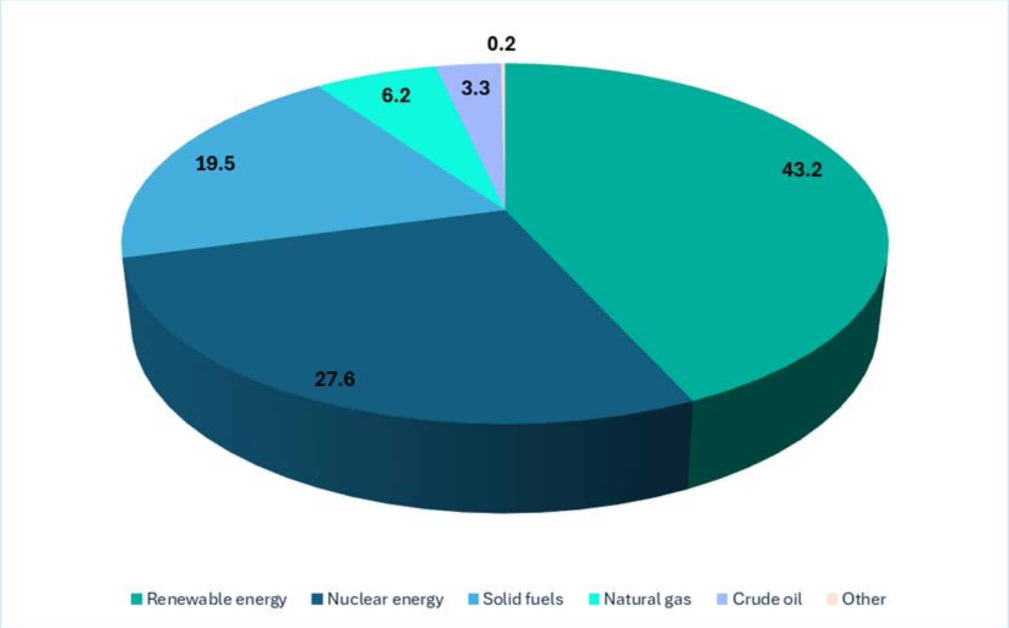
Another promising area is digitalization and the use of artificial intelligence (hereinafter: AI) in energy management. Smart energy systems, powered by AI, can optimize energy use, predict demand, and improve the efficiency of RES integration through retrofitting the existing grid (IRENA, 2021). As these technologies evolve, CEE countries can leverage them to boost energy independency, minimize costs and drive economic growth through more efficient energy use.

3 RENEWABLE ENERGY CONSUMPTION IN CENTRAL AND EASTERN EUROPEAN COUNTRIES

According to the IEA (2022), Europe hosts a diverse range of energy producers and consumers, all intricately linked to global markets. In the past several years, the region's energy landscape has undergone substantial changes since Russia's invasion of Ukraine, which triggered a crisis that pushed energy prices to unprecedented levels. In response, European nations have placed energy security at the forefront of their agendas, significantly reducing their reliance on Russian fuel imports. At the same time, they have elevated their clean energy goals, aiming to diversify their energy sources while advancing toward climate targets. Of course, despite record-breaking deployment of renewable energy, challenges remain. These include enhancing clean energy supply chains, modernizing infrastructure, and further integrating energy systems across the continent.

According to Eurostat (2022), in 2022, RES was the primary source of energy in the EU, contributing 43.2% to the region's total energy production. Nuclear energy was the second-largest source at 27.6%, followed by solid fuels (19.5%), natural gas (6.2%), crude oil (3.3%), and other sources (0.2%). Share of energy production by source in EU, in percentage, is presented in Figure 4.

Figure 4: Share of energy production by source in EU in % (2022)



Source: Eurostat (2022).

However, energy production varied significantly across EU countries (Eurostat, 2022). Malta relied entirely on renewable energy, producing no other type of energy. Moreover, renewable sources accounted for at least half of the total energy production in 15 other EU countries, with shares reaching 99.6% in Latvia, 98% in Portugal, and 96% in Cyprus. Nuclear energy dominated in France (71% of national energy production), Belgium (67%), and Slovakia (61%). Solid fuels were the main source in Poland (70%), Estonia (59%), Czechia (46%), and Bulgaria (45%). Natural gas held the largest share in the Netherlands (53%), Ireland (37%), and Romania (34%), while crude oil had the highest share in Denmark at 33%.

Ten years ago, in 2015, the share of renewable energy in the EU energy mix stood at approximately 17% (IRENA, 2018). Over the seven-year period from 2015 to 2022, this share grew to 43.2%, marking a substantial increase of 26.2 percentage points. This translates to an average annual growth rate of 3.7%, highlighting the EU's accelerated shift towards renewable energy sources. In the future, the EU intends to drastically increase the proportion of renewable energy sources in the energy mix and strives to cut greenhouse gas emissions by 80–95% by 2025 (European Commission, 2012). To achieve this goal, dramatic increase in energy efficiency is required. Simultaneously, approximately two-thirds of energy production at the regional scale should come to RES.

Despite accounting for roughly 17% of the EU's overall electricity demand, the CEE region only contributes 7% of the EU's wind capacity and 12% of its solar capacity. This discrepancy results from the region's continued reliance on fossil fuels, which raises energy prices and jeopardizes energy security. Electricity is costly in larger economies like Poland, Romania, Hungary, and the Czech Republic because they still rely largely on coal and gas (Ember, 2023).

This report suggested that by 2030, the CEE region could install up to 200 Gigawatts (hereinafter: GW) of renewable energy capacity, split between 130 GW of solar power and 65 GW of wind energy, onshore and offshore. This expansion would represent a sixfold increase from the current capacity, with renewables accounting for 63% of the region's energy generation by 2030, compared to 25% in 2022. The proposed renewable energy surge could reduce wholesale electricity prices by 29%, greatly improving the region's competitiveness and energy independence.

However, several policy and infrastructural barriers prevent renewable energy growth in the CEE region. For instance, restrictive rules around wind energy deployment in Poland and Hungary hinder its growth. Additionally, grid capacity issues in countries like Hungary and the Czech Republic delay solar energy projects. The report urges the removal of such barriers and calls for streamlined permitting processes to fully exploit renewable energy potential.

With regards to the present level of energy consumption in CEE nations, many of them still mainly rely on fossil fuels like coal and gas, which impedes the achievement of renewable energy targets. Due to its reliance on traditional energy sources, the area is also susceptible to changes in energy prices and outside geopolitical forces. Nonetheless, there is a straightforward and doable plan for CEE nations to catch up to the rest of Europe.

The region's potential for wind and solar energy can be unlocked by establishing more aggressive renewable energy targets, removing legislative obstacles, and making infrastructure investments. This will lower electricity costs and improve energy security.

In addition to being environmentally necessary, the CEE region's shift to renewable energy is also vital from an economic and political standpoint.

According to Pakulska (2021) Central and Eastern European nations have increasingly prioritized renewable energy as part of their energy strategies in recent years. This shift is motivated by both domestic initiatives and obligations under European Union climate policies. A major goal is to reduce fossil fuels dependency, which have long dominated the region’s energy mix, and transition towards RES. Historically, many CEE countries have been dependent on coal and other fossil fuels to fuel their industrial growth. This has created challenges as they seek for innovation through production and consumption of RES, given the economic and infrastructural dependencies on carbon intensive energy sources. Political changes in the CEE region in the 1990s further delayed the transition to RES.

Today, the push toward renewable energy is critical for lowering greenhouse gas emissions, improving energy efficiency, and meeting the EU’s long-term climate goals. The EU aims to achieve a climate-neutral economy by 2050, and renewable energy consumption is increasing across CEE countries as they work to align with these goals.

Pakulska (2021) investigated that CEE countries vary significantly in their adoption of renewable energy technologies. Nations like Latvia, Romania, and Bulgaria have made significant progress, especially in hydropower and biomass, while countries such as Poland and Hungary face greater challenges due to their continued reliance on coal and limited renewable energy infrastructure.

As of 2019, renewable energy sources contributed to approximately 20% of the EU's total energy consumption, with CEE nations playing a key role. Latvia led the region, with 38.5% of its total energy consumption coming from renewable sources, followed by Estonia at 28.4%. On the other hand, countries like Poland and Slovakia recorded much lower shares, with renewables accounting for only 11.4% to 13.9% of their energy use.

In some of the CEE countries, solar and wind energy are also growing quickly. Poland, for instance, saw a remarkable 421% increase in solar energy capacity and a 420% increase in wind energy capacity between 2015 and 2018. This illustrates how crucial renewable energy is becoming to supplying energy demands and lowering reliance on fossil fuels.

Despite advancements, several obstacles still stand in the way of the expansion of renewable energy in CEE nations. The sporadic nature of wind and solar energy is a major problem. Renewable energy is dependent on the weather, in contrast to fossil fuel-based power, which can offer a consistent supply. To handle variations in energy availability, better energy storage technologies and more flexible energy grids are therefore required.

Economic costs also present a major hurdle. Many CEE countries are still heavily reliant on coal, which not only contributes to significant emissions but also supports local economies. Transitioning to renewable energy, therefore, involves social and economic challenges, especially in regions where coal mining is a primary source of employment.

As said above, technological development is yet another challenge. Although there has been an increase in investments in digital and smart grid technologies, essential for integrating renewables into national grids, CEE countries still lag in this area compared to other parts of Europe. For example, Romania and Poland have increased their information and communication technology (hereinafter: ICT) spending by 95% and 55%, respectively, but additional investments are necessary to fully integrate renewable energy systems.

EU policies have been very important in driving renewable energy adoption in CEE countries. Initiatives like the European Green Deal and the Clean Energy for All Europeans package have set ambitious targets for improving energy efficiency, reducing greenhouse gas emissions, and boosting the share of renewable energy.

Moving forward, CEE nations will need to continue investing in RES infrastructure and technology, while taking care of the economic and social impacts of transitioning away from fossil fuels. Political commitment and financial support from the EU and other organizations will be critical for overcoming these obstacles.

According to Pakulska (2021) the growth of REC in CEE countries is a vital part of their efforts to meet EU climate targets and ensure long-term energy sustainability. While progress has been made, particularly in the areas of solar and wind energy, additional investment in infrastructure, technology, and policy support will be essential for a complete transition to renewable energy.

4 LITERATURE REVIEW OF THE EMPIRICAL STUDIES ON RELATIONSHIP BETWEEN RENEWABLE ENERGY CONSUMPTION AND ECONOMIC GROWTH

The link between economic growth and the use of renewable energy has become a significant focus of studies, especially considering global goals for sustainable development, and reducing emissions. RES such as solar, wind, hydropower, and biomass are viewed as essential for transitioning to a more sustainable and resilient economic framework. Research on the economic effects of renewable energy has produced diverse results, influenced by variations in analytical methods, study periods, and the unique characteristics of the countries examined, including their reliance on fossil fuels.

This review explores the findings of studies investigating the connection between renewable energy consumption and economic growth. It examines the theoretical perspectives, methodological approaches, and key factors that influence the nature and direction of this relationship, offering insights into its complexity and implications.

Numerous studies highlight the positive impact of renewable energy consumption on economic growth, particularly in countries with well-developed energy policies and infrastructure. Shafiei & Salim (2014) explained that transition economies in Central and Eastern Europe, and parts of the Soviet Union are moving towards integration of renewable energy to support economic growth. The shift towards RES is seen as a pathway to achieve sustainable development and energy security, although these countries were previously reliant on fossil fuels.

Similar as in the review of the other papers, transition economies have experiences growing investments in RES, that are driven by policy initiatives and the need to diversify energy sources. Overall, the economic benefits include job creation in the RES sector, reduced energy costs and less reliance on energy imports. It is visible that countries like Poland and Czech Republic have started to incorporate more wind, biomass and solar energy which of course supports their economic growth and overall industrial output.

However, this paper acknowledges that there are certain challenges for these countries, when it comes to RES adoption. Unfortunately, there is a legacy of old energy infrastructure, which is still largely dependent on fossil fuels and on the other hand the regulatory environment in many transition countries, remains underdeveloped, causing the limitations in the renewable project’s implementation.

This paper talks about Baltic states and Ukraine as well, where basically the same conclusions were made. Baltic States have made a notable stride in RES adoption, especially biomass and wind energy whilst Ukraine has witnessed a rather slower transition towards RES but recent efforts to increase RES consumption have shown a positive correlation with economic growth.

Armeanu et al. (2017) examined the role of RES in promoting sustainable economic development. The authors findings demonstrate that REC, both in general and for specific sources like biomass, hydropower, geothermal energy, wind, and solar energy, positively affects gross domestic product per capita. Among the various types of renewable energy, biomass had the greatest impact, with a 1% rise in solid biofuels production leading to a 0.16% increase in GDP per capita.

This study used fixed-effects panel data regression models to evaluate the effect of renewable energy consumption on economic growth across different EU countries. To confirm the long-term relationship between renewable energy production and economic growth, the researchers employed panel cointegration, fully modified ordinary least squares (hereinafter: FMOLS), and dynamic ordinary least squares (hereinafter: DOLS) methods. The direction of this relationship was explored through Granger causality tests, which found a one-way causal link where economic growth spurred renewable energy production. The research from these three authors is based on established theories such as the feedback, conservation, growth, and neutrality hypotheses, which explore the relationship between energy use and economic growth. Basically, the study supports the conservation hypothesis, which posits that economic growth drives the adoption and production of renewable energy, rather than the other way around. This has implications for EU countries as they work towards meeting renewable energy targets set by Directive 2009/28/EC.

As in the previous literature review, these authors also outlined some of the mail challenges and policy recommendations where they said that structural obstacles as well as high upfront costs can be overcome by increase of investments in renewable energy technologies and implementation of supportive policies to boost the use of renewable sources like solar and wind energy which can support sustainable growth over the long run.

In conclusion, REC has a significant positive effect on sustainable economic growth in the EU-28 countries, with biomass energy making the largest contribution. To ensure long-term sustainability and meet EU targets, governments need to address the structural challenges that hinder the broader adoption of renewable energy technologies.

Apergis & Danuletiu (2014) examined the relationship between REC and economic growth, focusing on data from 80 countries. Using the Canning & Pedroni (2008) long-run causality test, the study finds that there is a significant long-term causal relationship between renewable energy consumption and GDP growth, both globally and regionally. This suggests that renewable energy plays a crucial role in promoting economic growth, while economic growth also encourages further investment in renewable energy. This paper emphasizes the need for government policies to continue supporting the development of the renewable energy sector, highlighting the potential of renewable sources to address concerns over energy security, volatile fossil fuel prices, and environmental sustainability. Some of the key findings of this paper can be seen in strong evidence that renewable energy consumption positively affects economic growth across different regions. Renewable energy, particularly biomass, hydropower, and geothermal, is identified as reliable and important in reducing greenhouse gas emissions. The findings demonstrate a bidirectional relationship between renewable energy and economic growth, suggesting mutual reinforcement between the two. Countries that invest in renewable energy tend to experience long-term economic benefits, while economic growth facilitates increased use of renewable energy technologies. This paper employed panel data analysis, using an error correction model to examine the long-run relationship between renewable energy consumption and economic growth. The authors use data from 1990 to 2012, incorporating variables such as real GDP, renewable energy consumption, in kilowatt-hours, capital stock, and labor force. The Canning & Pedroni framework is particularly useful in this context, as it allows for dynamic error correction within a multivariate panel model, helping to account for country-specific differences.

This study identified several obstacles to the switch to renewable energy, especially in developing nations where the initial outlay for renewable energy infrastructure is substantial. Despite these challenges, the authors recommend consistent investment in renewable energy as a driver of long-term economic growth. They back policies that encourage research and development in renewable technologies, public-private partnerships to facilitate technology transfer, and government incentives to encourage the market adoption of renewable energy solutions.

The study concludes that using renewable energy is crucial for sustainability and long-term economic growth. Countries should keep investing in clean energy technologies, as evidenced by the positive correlation between GDP growth and renewable energy. Through the increased use of renewable energy, the study also emphasizes the significance of international cooperation in tackling the global issues of energy security and climate change.

Žikić et al. (2021) highlight the importance of renewable energy sources in addressing environmental issues while simultaneously promoting economic and social development. The authors emphasize the strategic importance of renewable energy, particularly for areas where it is economically feasible due to its availability. The transition to clean energy offers numerous benefits, such as reducing dependence on fossil fuels, creating jobs, and improving the quality of life in rural communities, they say. Their research indicates that the use of local renewable resources, such as biomass and hydropower, can significantly contribute to reducing energy imports, increasing employment, and boosting the living standards of local populations. In Serbia, biomass is recognized as a vital renewable energy source with enormous growth potential, particularly in the forestry and agricultural industries.

Despite the clear benefits of renewable energy, there are still several challenges to be solved. Among these are the high initial investment costs and the general ignorance regarding the long-term advantages of renewable energy over conventional energy sources. To overcome these challenges, the authors recommend strengthening institutional frameworks, increasing government support for renewable energy initiatives, and raising public awareness of the importance of sustainability. By providing financial incentives like tax breaks and feed-in tariffs, the government can further encourage the use of renewable energy. Public involvement and civil society engagement are essential for the implementation and broader support of renewable energy projects.

The document concludes that renewable energy not only provides environmental benefits but also plays a crucial role in driving economic and social progress. It offers a pathway for sustainable development, particularly in rural and less developed areas. The development of the renewable energy sector is vital for achieving broader societal goals, such as reducing energy dependence, mitigating climate change, and promoting regional economic growth.

Gozgor et al. (2018) talk about how renewable energy is becoming a major force behind economic expansion, especially when it comes to addressing climate change. Since the late 2000s, renewable energy has attracted a lot of attention worldwide because of its potential to lower greenhouse gas emissions and thereby aid in the fight against global warming. The authors note that technological advancements and government initiatives like tax breaks and renewable energy standards have reduced the cost and increased access to renewable energy, which has boosted the economies of many developed and developing nations. According to their research, OECD countries' economic growth is positively impacted by both renewable and non-renewable energy consumption. The study finds that an increase in energy consumption, whether from renewable or non-renewable sources, correlates with higher GDP per capita. Because it lowers carbon emissions and fosters environmental sustainability, renewable energy is especially significant for economic growth. Non-renewable energy, while also contributing to growth, comes with environmental costs that need to be managed.

The study utilizes a growth model that incorporates an Economic Complexity Indicator (hereinafter: ECI) to measure the sophistication of a country’s economic activities. The ECI reflects a nation’s capability to produce and export complex, value-added products. The authors contend that increased economic complexity promotes growth and that more sustainable growth is the outcome of combining economic complexity with the use of renewable energy. The research builds upon the traditional neoclassical Solow-Swan growth model, incorporating energy consumption, both renewable and non-renewable, as key variables influencing economic development.

The authors used panel autoregressive distributed lag and panel quantile regression (hereinafter: PQR) models to analyze data from 29 OECD countries over a period of 23 years (1990–2013). The ARDL model assesses the short- and long-term effects of energy consumption on economic growth, while the PQR model helps understand how the effects of energy consumption differ across countries at various stages of productivity. The findings of the analysis reveal that a 1% increase in non-renewable energy consumption leads to a 1.08% increase in real GDP per labor, while a 1% increase in renewable energy consumption results in a 0.40% increase in real GDP per labor. Moreover, the ECI significantly contributes to growth, with a 1.27% increase in GDP per labor for every 1% increase in the ECI. These results highlight that both energy sources are crucial for growth, though renewable energy offers the additional benefit of environmental sustainability.

Of course, the study suggests that policymakers should continue to promote the use of renewable energy sources while balancing the economic benefits of non-renewable energy. Investments in RES can help ensure sustainable long-term growth, reduce environmental degradation, and contribute to energy security. The paper also recommends that governments focus on enhancing their countries' economic complexity, as doing so can further amplify the positive effects of renewable energy consumption on growth.

Gozgor et al. (2018) concluded that both renewable and non-renewable energy consumption positively impact economic growth in OECD countries. However, renewable energy stands out for its dual role in promoting growth and supporting environmental sustainability. Policymakers are urged to make investments in infrastructure for renewable energy and innovation while also considering the importance of economic complexity in driving sustained economic development.

In the long term, Piralogea & Cicea (2012) analyzed the relationship between energy consumption and economic growth within the context of Spain, Romania, and the broader European Union from 1990 to 2010, examining both short-term and long-term relationships using various econometric models. In Romania, renewable energy consumption is found to have a positive effect on economic growth, indicating that a transition to renewable energy could also support long-term economic expansion. The research provided insights into the energy-growth nexus, supporting the growth hypothesis, which posits that energy consumption is a key driver of economic growth. The broader EU context shows the importance of both traditional and renewable energy sources in maintaining economic stability. The authors concluded that energy consumption, particularly from petroleum products and renewable sources, plays a vital role in economic growth within the EU, Spain, and Romania, advocating for energy policies that support diversification and renewable energy.

Soava et al. (2018) investigated the link between renewable energy consumption and economic growth within the EU, with a particular emphasis on the EU Directive 2009/28/EC, which aimed to increase the share of renewable energy in final energy consumption. The research evaluated whether increasing the consumption of renewable energy positively impacts the gross domestic product of EU member states and examines trends in renewable energy consumption over time.

The findings imply that the majority of EU nations' economic growth is positively impacted by using renewable energy. Depending on the nation, the study finds both unidirectional and bidirectional Granger causality between GDP and renewable energy consumption. This lends credence to the notion that economic growth is fueled using RES, and in certain situations, economic growth in turn fuels the use of renewable energy. The analysis demonstrates an increasing trend in renewable energy's share of final energy consumption across nearly all EU member states, indicating significant progress toward sustainability goals.

This paper applied several econometric techniques, including the fully modified ordinary least squares and panel data regression models, to assess the relationship between renewable energy consumption and economic growth. The data was collected from Eurostat for the period from 1995 to 2015, covering 28 EU countries. The researchers also conducted Granger causality tests to determine the causal direction between energy consumption and GDP.

Soava et al. (2018) concluded that renewable energy consumption is crucial for both economic growth and the sustainable development of EU countries. The positive relationship between renewable energy and GDP growth justifies the EU's policy initiatives to increase the use of renewables. Further investments in renewable energy and the integration of such policies into national strategies are essential to achieving the EU's long-term sustainability targets.

In the example of Turkey, Dogan & Acicek (2013) explored the causal relationship between economic growth and renewable energy consumption between 1980 and 2013.

The research applied the Granger Causality Test to determine the direction of causality between the two variables. The analysis begins with stationarity tests, followed by the application of cointegration tests to assess the long-term relationship between the variables. The data on Turkey’s GDP and renewable energy consumption (including combustible renewable energy and waste energy) was sourced from the World Bank for the period from 1980 to 2013.

The empirical evidence reveals bidirectional Granger causality between renewable energy consumption and economic growth in Turkey. This means that renewable energy consumption positively affects economic growth, and economic growth also stimulates further renewable energy consumption. These findings support the feedback hypothesis, indicating that renewable energy plays a crucial role in driving Turkey's economic growth, while economic expansion, in turn, promotes the consumption of renewable energy. The study suggests that policies promoting renewable energy ought to be given priority to ensure sustainable economic growth. Limiting renewable energy consumption could negatively impact economic growth, as evidenced by the study's findings. Policymakers are encouraged to focus on increasing the share of renewable energy in the country’s energy mix, as this will not only foster economic development but also help minimize the environmental damage associated with fossil fuel consumption.

The research highlights the vital role of renewable energy in Turkey’s economic development. The bidirectional causality between renewable energy consumption and economic growth suggests that Turkey should continue to promote renewable energy resources as a means of achieving long-term economic and environmental sustainability. The findings align with previous studies that also suggest a positive link between renewable energy consumption and economic growth, reinforcing the importance of renewable energy in modern economies.

Rokicki et al. (2022) examined the growth of renewable energy production in 23 CEE countries between 2011 and 2019. The paper analyzes both the overall renewable energy output and per capita production, focusing on the differences between EU and non-EU nations. Utilizing methods such as index analysis, the Gini coefficient, Lorenz curve, and Grade Data Analysis (hereinafter: GDA), the research reveals significant disparities in renewable energy development. EU countries have experienced more rapid growth, with a shift toward a variety of sources like solar, wind, and bioenergy, while non-EU countries have lagged, relying predominantly on hydropower.

This study made a notable contribution to the literature by providing a comparative analysis of renewable energy trends in the CEE region, underscoring the impact of EU policies in promoting renewable energy adoption. Previous studies have identified the EU's Green Deal and other initiatives as key factors driving renewable energy progress, and this research corroborates that by showing the effects of these policies on energy diversification within member states. Additionally, the use of inequality measures like the Gini coefficient offers a fresh perspective on the uneven distribution of renewable energy production, highlighting the requirement for focused policies to deal with these regional disparities.

Although renewable energy sources are often associated with positive economic effects, certain energy types or specific contexts may have a weaker or even negative impact on growth. In a survey of literature on energy consumption and economic growth from Mutumba et al. (2021), it is said that in transition economies, the shift from fossil to renewable energy sources plays a key role in determination of the path of economic growth. As these transition countries reform their energy sectors post-socialism, they have gradually started embracing RES, all from biomass, wind, hydropower, and solar energy. This move towards cleaner energy is clearly seen as a necessity to achieve sustainable economic growth while adhering to environmental goals, especially for those aligning with the European Union’s energy policies.

While the potential for REC to drive growth is recognized, there are significant challenges that transition economies face. All from infrastructure where the lack of modern infrastructure slows down the integration of RES into national energy mixes. In countries such as Ukraine and Russia there is energy infrastructure built during Soviet era which still predominantly supports fossil fuel consumption. Also, large-scale investments are required to scale-up renewable energy projects and many transition economies struggle with it due to economic instability or lack of capital. When it comes to transition economics, and their movement to renewable energy, it is not only climate-related decision but also an economic one. The shift to RES enables and will enable these economies to be more diversified, as there are examples that show that such as Estonia and its successful integration of biomass and with energy where the reduced reliance on oil share and fostering growth in cleaner, technology driven sectors is clearly visible.

Mutumba et al. (2021), through a meta-analysis of 1,240 studies, reported mixed and insignificant results regarding energy consumption and economic growth in transition economies. This underscores the complexity of the relationship between energy consumption and economic growth, particularly in countries with weaker infrastructure and political instability.

Marinas et al. (2018) studied the link between renewable energy consumption and economic growth in ten Central and Eastern European countries, from 1990 to 2014. The focus of their study was how renewable energy influences economic growth in these transitioning economies. They used the Auto Regressive Distributed Lag method to investigate both long-term and short-term relationships between renewable energy consumption and economic growth. The authors suggest that while renewable energy plays a key role in supporting sustainable economic development in the CEE region, the pace of transition varies significantly. Countries like Hungary and Slovenia are closer to achieving the EU's energy goals.

Marinas et al. (2018) added that the relationship between economic growth and the use of renewable energy is essentially independent for Romania and Bulgaria. For certain CEE countries, this study provides short-term support for the neutrality hypothesis, indicating that there is no meaningful correlation between growth and the use of renewable energy. Furthermore, despite the overall positive long-term relationship between renewable energy use and economic growth, regional variations are persistent. Romania and Bulgaria face more significant challenges due to slower reforms and outdated infrastructure, while Hungary and Slovenia are much better positioned to meet the EU targets.

The overall conclusion of the paper is that while renewable energy consumption positively impacts long-term economic growth in the CEE region, the extent of this impact varies depending on regional and structural factors. Continued support for policy innovation, investment in infrastructure, and regional collaboration will be essential for CEE economies to meet the ambitious goals set out in the Europe 2020 Strategy and the 2030 Agenda for Sustainable Development. The limitation of this paper is its reliance on aggregate data, which may overlook country-specific details that can provide more understanding of the challenges and opportunities for renewable energy adoption.

In the short run, Piralogea & Cicea (2012) said that the results of their study on how REC influence economic growth, differ between the countries. According to the study, the use of renewable energy in Romania has a positive impact on economic performance, however, the opposite is also true, indicating that renewable energy consumption is not driven by economic growth. Natural gas consumption in Spain contributes significantly to short-term economic growth, highlighting the importance of energy sources in various geographical areas. The study backs up a unidirectional relationship in Romania, where economic growth is influenced by renewable energy use but not the other way around. According to the findings, energy policies ought to be customized for the energy sources that each region uses most successfully to propel economic growth.

Omri (2014) in his paper, surveys the empirical literature on the relationship between total energy consumption, electricity consumption, nuclear consumption, and renewable consumption in relation to economic growth. The review classifies studies according to the four major hypotheses: Growth Hypothesis, Feedback Hypothesis, Conservation Hypothesis and Neutrality Hypothesis.

The paper points out that the mixed results across studies may be due to differences in country characteristics, datasets, variables, and econometric methods used. The diversity in results reflects the unique energy policies, political structures, and economic conditions of the countries involved. Many studies relied on bi-variate models, but some employed more comprehensive multivariate approaches that include additional variables like capital stock and labor force.

Omri (2014) provides a comprehensive review of global studies on the relationship between various types of energy consumption and economic growth, utilizing diverse methodological approaches such as the Granger causality test, cointegration analysis, vector error correction models, and autoregressive distributed lag models. His analysis encompasses four hypotheses: the growth hypothesis, feedback hypothesis, conservation hypothesis, and neutrality hypothesis. Of the studies reviewed, 29% support the growth hypothesis, 27% the feedback hypothesis, 23% the conservation hypothesis, and 21% the neutrality hypothesis. These findings indicate that the impact of energy on growth can vary significantly across countries and energy resources.

The review underscores the complexity of the energy-economic growth nexus and the lack of a consensus on the causal relationship between these two variables. The paper concludes by recommending more sophisticated econometric models and the use of larger datasets to gain a clearer understanding of the dynamics between energy consumption and economic growth. Future studies should aim to explore this relationship in greater depth, incorporating factors like institutional quality, governance, and technological advancements that could influence the energy-growth relationship.

In conclusion, the above-mentioned reviewed papers provide a good understanding of the relationship between REC and economic growth. It emphasizes that while REC has the potential to support sustainable economic growth, the impact varies significantly depending on regional, structural, and policy-specific factors.

Transition economies in CEE illustrate a gradual shift from fossil fuel dependency toward renewable energy sources, driven by policy initiatives, investment in renewable technologies, and the need for energy security. Countries like Estonia and Slovenia have made notable progress, while others like Romania and Bulgaria face significant infrastructural and regulatory challenges. The studies generally align with the conservation and feedback hypotheses, suggesting that economic growth often spurs renewable energy adoption, and in some cases, REC contributes to economic performance.

At the global level, evidence indicates that renewable energy contributes to GDP growth, reduces reliance on imports, and mitigates environmental issues. However, the initial costs, outdated energy infrastructure, and policy gaps pose challenges to a broader transition. The findings also highlight the importance of economic complexity, technological innovation, and international cooperation in maximizing the economic benefits of renewable energy.

Policy recommendations across the studies include increased investment in renewable energy infrastructure, regulatory reforms, public-private partnerships, and enhanced governance to overcome structural barriers. Long-term sustainability requires a tailored approach, considering each country's unique energy mix and economic context. Future research should dive deeper into sector-specific dynamics, address endogeneity concerns, and incorporate variables like institutional quality and governance to develop actionable insights. Furthermore, while the transition to renewable energy is crucial for sustainable development, achieving its full economic potential requires strategic investments, robust policies, and a commitment to innovation and international collaboration.

Certain gaps remain in the literature. While the long-term effects of renewable energy adoption are well-documented, limited research addresses the short-term economic impacts, especially in transition economies where the switch from fossil fuels may initially incur costs. Additionally, much of the current studies consider renewable energy in aggregate, with fewer studies focusing on the distinct effects of specific types of renewable energy, such as wind, solar, and biomass, on economic growth.

Based on the literature review and empirical evidence presented in this section of this master thesis, there is significant support for the connection between the adoption of renewable energy and economic growth in various developing economies, as discussed earlier. However, few studies have delved into the individual contributions of different renewable energy sources to economic development, particularly in regions with diverse energy needs and infrastructural constraints. This presents a gap that we aim to address. Specifically, this master's thesis will examine how specific renewable energy policies and sources contribute to economic growth, particularly in CEE transition economies. Additionally, it will address the unique short-term challenges that may arise during the transition phase in these developing economies.

Table 1: Summary of key literature review findings

Authors	Sample	Time Frame	Dependent variable	Variable of interest	Method of estimation	Result
Mutumba et al.	1,240 studies	1974 - 2021	Economic growth	Energy consumption	Meta-analysis and surveys	Mixed and inconclusive
Shafiei & Salim	OECD countries	1980 - 2011	Economic growth and CO2 emissions	Renewable energy consumption and non-renewable energy consumption	Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model to analyze the determinants of CO_2 emissions.	Non-renewable energy increases CO_2 emissions, while renewable energy reduces them. The study also confirms an Environmental Kuznets Curve (EKC) for urbanization, indicating lower environmental impact at higher urbanization levels.
Marinas et al.	10 EU Member states from CEE	1990 – 2014	Gross Domestic Product (GDP)	Renewable Energy Consumption	Auto regressive and Distributed Lag	Bi-directional causality (mixed results)
Armeanu et al.	28 European Union (EU) countries	2003 - 2014	Gross Domestic Product (GDP) per capita	Renewable energy consumption	Fixed-effects panel data regression model	Positively influences GDP per capita.
Apergis & Danuletiu	80 countries globally	1990 – 2012	Real GDP (economic growth)	Renewable energy consumption	Canning & Pedroni (2008) long-run panel causality test within a panel cointegration framework.	Long-run bidirectional causality between renewable energy consumption and GDP, indicating mutual positive influence.

To be continued

Table 1: Summary of key literature review findings (cont.)

Žikić et al.	The paper examines renewable energy sources in Serbia without a defined empirical sample.	The research covers developments up to 2020 and the historical context of energy sources.	The dependent variable is the economic, environmental, and social impact of renewable energy use.	The primary variable of interest is renewable energy management and its impact on sustainability.	Prior literature and case studies to generalize renewable energy's impact on economic, social, and environmental outcomes.	Renewable energy, especially biomass, offers significant economic, social, and environmental benefits.
Gozgor et al.	29 OECD countries	1990 – 2013	Real GDP per employed person	Renewable energy consumption, non-renewable energy consumption, and economic complexity indicator	The study uses a panel autoregressive distributed lag model and a panel quantile regression	Renewable/non-renewable energy and economic complexity boost economic growth in OECD countries.
Piralogea & Cicada	Spain, Romania, and European Union (EU-27)	1990 – 2010	GDP per capita in constant 2000 US dollars	Energy consumption including renewable energy, petroleum, natural gas, and solid fuels.	The study uses unit root and co-integration tests followed by Granger causality testing	Renewable energy boosts long-run GDP per capita in Romania, but no short-run link in EU-27 per Granger causality test.
Omri	Multiple country-specific studies are surveyed, covering various countries globally.	1978 - 2012	Economic growth (GDP)	Types of energy consumption: total, electricity, nuclear, and renewable energy.	The paper reviews econometric methods like Granger causality, cointegration, VECM, and ARDL models used in various studies.	Findings vary by country and energy type: 29% growth, 27% feedback, 23% conservation, and 21% neutrality hypothesis.
Soava et al.	28 European Union countries	1995 - 2015	Gross Domestic Product at market prices	Renewable Energy Consumption measured as a share of final energy use from renewables.	Panel data analysis using FMOLS regression and Granger causality tests.	The study finds a small but positive impact of renewable energy on economic growth.

To be continued

Table 1: Summary of key literature review findings (cont.)

Rokicki et al.	23 Central and Eastern European countries	2011–2019	The volume of renewable energy production	Changes in renewable energy production per capita and total renewable energy production	The study used methods like index analysis, the Gini coefficient, Lorenz curve, and Grade Data Analysis	The study finds faster REP growth in the EU, with hydropower dominant in non-EU countries, while the EU diversified into solar, wind, and bioenergy.
Dogan & Acicek	Annual data for Turkey	1980–2013	Economic growth (measured by GDP)	Renewable energy consumption	Granger causality test	The study finds bidirectional Granger causality between renewable energy and economic growth in Turkey.

Source: Own work.

5 EMPIRICAL ANALYSES

5.1 The model and the data

The empirical analysis in this study focuses on eleven Central and Eastern European countries: Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. The analysis is based on the period from the year 2000 to 2021. By examining these countries, the research aims to provide valuable insights into the potential of renewable energy as a driver of economic growth in economies undergoing a transition toward sustainability. We specify the following model to be estimated:

$$RGDPG_{it}=\alpha+\beta_1*REC_{it}+\beta_2*EI_{it}+\beta_3*LF_{it}+\beta 4*GFCF_{it}+\beta_5*FDI_{it}+\beta_6*EXP_{it}+\varepsilon_{it} \quad (1)$$

As per formula (1), the dependent variable, real Gross Domestic Product Growth (hereinafter: RGDPG), $RGDPG_{it}$ stands for changes of real GDP of the country *i* in the period *t*. This model includes several explanatory variables. The first key variable, stands for Renewable Energy Consumption, REC_{it}, which presents Renewable Energy Consumption as a percentage of total final energy consumption for country *i* at time *t*. The model also includes ε_{it}, which denotes the random error term. This component represents unexplained variations in real GDP growth that are not accounted for by the model's explanatory variables. The structure of ε_{it} can vary depending on whether the estimation approach used is ordinary least squares, fixed effects, or panel-corrected standard errors.

In this empirical analysis, as said above, the dependent variable is RGDPG which represents the annual percentage growth in real GDP of a country, which ensures that the measure reflects true economic expansion by excluding price changes over time. The source of the data for this variable is the World Economic Outlook, published by the International Monetary Fund.

The variable of interest in this research is Renewable Energy Consumption. By decreasing dependence on fossil fuels and mitigating the volatility of their prices, renewable energy contributes to economic stability and resilience against energy crises (IEA, 2023). Furthermore, the development of renewable energy sectors stimulates technological development and innovation, increasing productivity and enabling the emergence of new industries (U.S. Department of Energy, 2022; IRENA, 2022). This variable is measured as a percentage of total final energy consumption. The source of the data for this variable is the World Bank Open Data, World Development Indicators.

As said before, the RES sector is a significant source of job creation meaning that it provides employment opportunities in manufacturing, installation, and maintenance. This growth in employment contributes to higher household incomes, thereby stimulating domestic consumption and economic activity (IRENA, 2022). Moreover, RES adoption reduces GGA and pollution, consequently promoting sustainable development and improving public health and quality of life. Transition to renewable energy requires substantial upfront investments, however, the long-term benefits, outweigh these challenges. (IEA, 2023).

While a negative coefficient may suggest high transition costs or implementation inefficiencies, a positive coefficient for renewable energy consumption in econometric models usually indicates its contribution to economic growth (World Bank, n.d.). All things considered, renewable energy provides significant long-term benefits for attaining equitable and sustainable economic growth (IRENA, 2022).

Furthermore, this analysis incorporated several control or independent variables. Control variables include, EI_{it}, which stands for Energy Intensity (hereinafter: EI), which measures the energy intensity level, or the energy used per unit of GDP; LF_{it}, which stands for Labor Force Participation Rate (hereinafter: LF), reflects the proportion of the working-age population actively engaged in the labor market; and $GFCF_{it}$, which stands for Gross Capital Formation (hereinafter: GFCF), or the investment in physical assets as a percentage of GDP. The model also incorporates FDI_{it}, Foreign Direct Investment (hereinafter: FDI), as a percentage of GDP, and EXP_{it}, Exports of Goods and Services (hereinafter: EXP), also as a percentage of GDP.

Energy intensity level of primary energy is a measure of the energy required to generate one unit of GDP and serves as an indicator of energy efficiency within an economy. Energy intensity affects economic growth through resource efficiency, the structure of the economy, and innovation. High energy intensity may support growth during phases of industrialization but increases costs in the long term and can limit competitiveness. Reducing intensity through energy efficiency positively contributes to growth, while high energy prices in energy-intensive countries slow progress. Lower energy intensity indicates more efficient energy use, which can positively influence economic growth by reducing production costs and increasing competitiveness.

This high energy intensity may limit economic growth due to elevated production costs and environmental impacts associated with inefficient energy use. By accounting for energy intensity, the model can better evaluate the role of renewable energy in promoting more efficient, sustainable growth. Lower energy intensity, often linked to increased renewable adoption, may enhance economic competitiveness and sustainability (Mulder & De Groot, 2012), offering valuable insights for these transitioning economies.

In this study, energy intensity is measured as the amount of energy consumed per unit of GDP (e.g., megajoules per dollar of GDP). This metric provides an understanding of how effectively energy is utilized within the economy and serves as a crucial indicator for analyzing resource efficiency and the potential economic benefits of renewable energy adoption. The source of the data for this variable is the World Bank Open Data, World Development Indicators.

The percentage of the working-age population that is actively employed or looking for work is known as the labor force participation rate. Because it represents the availability of human capital, the labor force is a crucial factor in determining economic growth. If backed by the right amount of technology and skill, a larger workforce can increase output and productivity (World Bank, n.d.). High rates of participation are a sign of a healthy labor market, which stimulates demand for both renewable and non-renewable energy sources by promoting growth in production and consumption (OECD, n.d.).

In this study, the labor force participation rate is measured as the percentage of individuals within the total population aged 15-64 who are either employed or actively seeking employment. This metric provides insights into labor market activity and its contribution to economic growth. The source of the data for this variable is the World Bank Open Data, World Development Indicators.

Gross capital formation includes investment in physical assets such as infrastructure, machinery, and buildings. It is a primary driver of economic expansion (World Bank, n.d.). Increased productive capacities, technological advancements, and multiplier effects within the economy are all impacted by higher levels of capital investment, which also boosts production capacity and advances technology (IMF, 2015). Through increased productivity and lower production costs, physical capital investments directly support GDP growth (World Bank, n.d.).

Moreover, GFCF often involves the adoption of new technologies, which enhances productivity and strengthens the competitiveness of the economy (OECD, 2009). In econometric models, gross capital formation is typically included as an independent variable, and its positive coefficient reflects the pivotal role of capital investment in supporting economic growth (IMF, 2015).

In this study, gross capital formation is measured as a percentage of GDP, representing the proportion of total output invested in physical assets. This metric provides insights into the level of investment activity within an economy and its contribution to long-term economic growth. The source of the data for this variable is the World Bank Open Data, World Development Indicators.

Foreign direct investment is a variable associated with technology transfer, job creation, and improvements in managerial practices, all of which can stimulate economic growth (World Bank, n.d.). Through the expansion of capital resources, the transfer of information and technology, the creation of new jobs, the encouragement of exports, and the improvement of the competitiveness of the domestic economy, foreign direct investment has a major impact on economic growth (IMF, 2022). Foreign corporations' investments in infrastructure, production capabilities, and tangible capital have a direct impact on the expansion of the GDP (OECD, 2019).

FDI also facilitates the transfer of advanced technologies and expertise, increasing productivity and efficiency across domestic sectors (IMF, 2022). The multiplier effects of FDI are reflected in heightened demand across related industries. Moreover, foreign companies often use the local economy as a production base for exports, contributing to economic diversification and improving global competitiveness (OECD, 2019). FDI can also have a substantial impact on reducing unemployment through the creation of new jobs and increasing household income, which further stimulates consumption and economic growth (World Bank, n.d.).

In this study, foreign direct investment is measured as the percentage of inward FDI stock relative to GDP. This metric captures the role of foreign investments in boosting economic resources and fostering growth through capital inflows and technology transfer. The source of the data for this variable is the World Bank Open Data, World Development Indicators.

Exports of goods and services, can be a key component of economic growth by providing access to broader markets, increasing production, creating new jobs, and bringing in foreign currency inflows that stabilize domestic currencies and strengthen foreign reserves (World Bank, n.d.). Participation in international markets allows domestic firms to achieve economies of scale, reducing unit costs and enhancing competitiveness (OECD, 2020). Additionally, international trade facilitates the transfer of knowledge and technology from developed economies, boosting productivity and fostering innovation in domestic sectors (IMF, 2021).

Export diversification contributes to the resilience of an economy against external shocks and reduces reliance on domestic consumption, while global market competition motivates local businesses to improve their products and processes (OECD, 2020). These advantages position exports as a vital driver of sustainable economic growth, which is why it is included in the model as a critical variable for understanding the factors contributing to real GDP growth (IMF, 2021).

In this study, exports of goods and services are measured as the percentage of GDP, reflecting the scale of an economy's engagement in international trade relative to its total output. This metric highlights the role of exports in fostering economic growth through market access, foreign exchange earnings, and competitiveness. The source of the data for this variable is the World Bank Open Data, World Development Indicators.

This research utilizes panel data, which involves observations of multiple variables across time for the same set of countries. Panel data integrates cross-sectional data, capturing the differences between these countries, and time series data, tracking changes within each country over time. This combined approach enhances the analysis by allowing the examination of both variations across countries and trends within countries over the selected time frame (Wooldridge, 2010). The use of panel data offers several advantages, including a larger number of observations, which improves the reliability and accuracy of the model's estimates. Additionally, it allows for the control of unobserved country-specific factors that remain constant over time, leading to more precise results. By applying panel data, this research can effectively assess the factors influencing renewable energy consumption and provide more comprehensive insights into how these variables evolve across different economic and policy contexts (Baltagi, 2008).

In the Table 2, presented below, we can find summary of all variables, their full names, their abbreviations used in the formula, the source of the data and the expected result, positive or negative.

Table 2: Variables

Variable	**Abbreviation**	**Source**	**Expected sign**
Real Gross Domestic Product growth	RGDPG	WEO	(+/-)
Renewable energy consumption (% of total final energy consumption)	REC	WDI	(+)
Energy intensity level of primary energy	EI	WDI	(-)
Labor force participation rate, total (% of total population ages 15-64)	LF	WDI	(+)
Gross capital formation (% of GDP)	GFCF	WDI	(+)

Table continues

Table 2: Variables (cont.)

Foreign direct investment, inwards stock (% of GDP)	FDI	WDI	(+)
Exports of goods and services (% of GDP)	EXP	WDI	(+)

Source: Own work.

By analyzing these variables, this model seeks to explain the rather complex relationships between them, in these eleven transition economies, as said above. The goal is to assess the extent to which economic growth, energy efficiency, labor market dynamics, domestic and foreign investment, and trade openness drive the shift toward RES.

5.2 Method of estimation

The research was conducted using quantitative analytical techniques, with descriptive analysis preceding inferential statistics. The descriptive analysis provided an overview of the collected data, with a particular focus on identifying trends related to economic growth rates, renewable energy consumption, foreign direct investment, etc., of the analyzed countries. Tables 3 and 4 present the descriptive statistics for the variables used in the analysis and the correlation matrix, respectively.

Table 3: Descriptive statistics

Variable	**Observations**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
RGDPG	242	3.2364	4.1312	-14.7	13
REC	242	19.3269	9.5552	3.7	47.2
EI	242	4.7133	1.3437	2.37	9.08
LF	242	56.7469	3.6154	48.811	64.41
GFCF	242	24.7420	4.7757	12.657	41.5597
FDI	242	5.6806	10.5185	-40.0864	106.4988
EXP	242	58.4372	18.4523	21.5889	95.8359

Source: Own work.

As for the variable Renewable Energy Consumption, which represents the share of renewable energy in total energy consumption, expressed as percentage, the descriptive statistics indicate that the average share of renewable energy across the observed countries and time period is approximately 19.33%, with a standard deviation of 9.56%, as indicated in table above. This reflects significant variation in the adoption of renewable energy sources across the countries in Central and Eastern Europe.

Over the period 2000–2021, the minimum observed share of renewable energy was 3.7%, while the maximum reached 47.2%, demonstrating a wide disparity in the commitment and capacity of these economies to transition toward RES. The data also suggests that, for much of the observed period, renewable energy remained a relatively small fraction of total energy consumption in many countries, reflecting the ongoing dominance of conventional energy systems that rely on fossil fuels.

The trend analysis shows that the adoption of renewable energy increased gradually in the latter half of the observed period, coinciding with the implementation of European Union directives and policies such as the Renewable Energy Directive and the European Green Deal. Despite this progress, the high variability across countries underscores the uneven pace of transition within the region, influenced by factors such as economic conditions, political priorities, and infrastructural limitations.

The modest average share of renewable energy consumption during this period may help explain its limited impact on economic growth, as identified in the econometric analysis. For renewable energy to contribute more significantly to economic performance, a greater focus on investment in infrastructure, technology, and policy alignment will be necessary.

Table 4: Correlation matrix

	RGDPG	REC	EI	LF	GFCF	FDI	EXP
RGDPG	1.0000						
REC	-0.0941	1.0000					
EI	0.1851	-0.5412	1.0000				
LF	0.0061	0.2092	0.0638	1.0000			
GFCF	0.3768	-0.0843	0.2655	0.1799	1.0000		
FDI	0.0266	-0.1256	0.0801	-0.0846	0.2164	1.0000	
EXP	-0.0532	-0.0587	-0.0712	0.3816	-0.0431	0.0903	1.0000

Source: Own work.

The correlation matrix shows several important relationships that are in line with economic theory, including the negative correlation between energy intensity and renewable energy consumption and the positive relationship between capital investment and economic growth. However, most other correlations display low intensity, implying that variables largely operate independently or through indirect mechanisms. These results highlight the need for additional regression analysis to determine causal relationships and find other factors affecting the study's findings.

For the analysis, both fixed and random effects models were employed, each with distinct assumptions and applications. The fixed effects model assumes that individual effects are constant for each observation unit and are part of the model, with the additional assumption of equal variance and slopes within groups (Wooldridge, 2016). It posits that unobserved individual characteristics may influence the predictors or dependent variables, requiring these effects to be controlled. This approach effectively eliminates the impact of time-invariant characteristics from the predictor variables, enabling the estimation of their net effects.

Conversely, the random effects model assumes that individual effects are independent and uncorrelated with the regressors, focusing on the decomposition of variance components within and between groups (Greene, 2018). A critical difference between these two models lies in the treatment of time-invariant variables. In the fixed effects model, these variables are absorbed into the intercept, whereas in the random effects model, they are included in the error component.

The best model for the analysis was identified using the Hausman test. The results of this test showed that the fixed effects model was more appropriate than the random effects model, with a statistically significant difference between the two (Hausman, 1978). The random effects model was found to be inconsistent with the results, which indicated a correlation between independent variables and individual effects.

Further analysis employed a fixed effects regression model with year-specific controls, isolating the influence of temporal characteristics such as economic cycles, political changes, and global shocks. This approach improved the statistical stability of the model and allowed for a more accurate assessment of the remaining variables. A joint significance test of year dummy variables demonstrated that the years, as a group, significantly affect the dependent variable. The fixed effects model results are summarized in Table 5.

Table 5: Fixed Effect Regression Results

Variable	**Coefficient (Standard error)**
REC	0.0012 (0.0798)
EI	0.6824* (0.3702)
LF	-0.0986 (0.0898)
GFCF	0.4034*** (0.0580)
FDI	-0.0181 (0.0157)
EXP	0.1698*** (0.0370)
R-squared	0.7622
Wald chi2 Prob > F	0.000
No. of observations	242

Note: *, **, *** denote significance levels at 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses.

Source: Own work.

The fixed effects regression results indicate that most variables do not have a statistically significant impact on the dependent variable. Renewable energy consumption and labor force participation rate exhibit statistically insignificant effects. Energy intensity shows a positive impact that is marginally significant, suggesting the potential for a moderate effect that warrants further examination. On the other hand, gross fixed capital formation and exports are statistically significant, with positive coefficients (0.4034 and 0.1698, respectively), highlighting their strong contributions to the dependent variable. Foreign direct investment demonstrates a negative but statistically insignificant effect.

To ensure the robustness of the results, diagnostic tests were conducted, including the modified Wald test for groupwise heteroskedasticity, the Wooldridge test for first-order autocorrelation in panel data, and the Breusch-Pagan LM test for residual independence. The Wald test confirmed the presence of heteroskedasticity across groups, while the Wooldridge test identified first-order autocorrelation. The Breusch-Pagan LM test detected significant correlations between residuals of different panel units. For detailed results, please see Appendix 1.

To address these analytical challenges, the Panel-Corrected Standard Errors approach, as developed by Beck & Katz (1995), was applied. This method corrects for heteroskedasticity, autocorrelation, and cross-sectional dependence while accounting for country-specific and time-specific effects. Following the recommendations of Beck & Katz (1995), the estimations were conducted using a time-series cross-sectional Prais-Winsten regression model with panel-corrected standard errors. This approach enhances the precision and reliability of the analysis. By employing a comprehensive methodology and addressing specific panel data challenges, this analysis ensures robust results and accurately assesses the impacts of key variables.

5.3 Results

The results in the Table 6 presents regression results using Time-series cross-sectional Prais–Winsten regression model with panel-corrected standard errors.

Table 6: Time-series cross-sectional Prais–Winsten regression model with panel-corrected standard errors (PCSEs).

Independent variable	Coefficient (Standard error) (PCSE)
REC	-0.0186 (0.0954)
EI	0.7714* (0.3914)
LF	-0.0127 (0.1034)
GFCF	0.3984*** (0.0740)
FDI	-0.0175* (0.0093)
EXP	0.1568*** (0.0392)
R-squared	0.7942
Wald chi2 Prob > F	0.000
No. of observations	242
R-squared	0.7942

Note: *, **, *** denote significance levels at 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses.

Source: Own work.

The results of the Prais–Winsten regression model with panel-corrected standard errors reveal varying effects of the independent variables on the dependent variable. The coefficient for REC is negative but statistically insignificant, indicating that REC does not have a significant impact on the dependent variable. The positive and significant coefficient of energy intensity (at the 10% level) suggests a potential link between increased energy use and economic performance, possibly reflecting the energy-dependency of key economic sectors. The labor force participation rate shows a negative and statistically insignificant effect.

Conversely, gross fixed capital formation exhibits positive and statistically significant effect at the 1% level, affirming its critical role in driving economic growth. Foreign direct investment shows a negative and marginally significant effect, which may point to challenges related to the effective utilization of foreign capital. This result could be explained by the fact that a large share of FDI is directed toward the service sector, which often has a less direct impact on productivity and export-driven growth. Exports show a positive and statistically significant impact at the 1% level, highlighting their crucial role in driving economic growth. Overall, the model demonstrates high explanatory power ($R^2 = 0.7942$), with its overall significance confirmed by the Wald chi-squared test.

6 CONCLUSION

This master's thesis examined the relationship between renewable energy consumption and economic growth in Central and Eastern European countries from 2000 to 2021. The empirical analysis employed the Time-series cross-sectional Prais–Winsten regression model with panel-corrected standard errors to achieve this.

The central finding of this research highlights that renewable energy consumption does not show a significant and positive impact on economic growth, as evidenced by the results of the econometric analysis. This finding is consistent with the neutrality hypothesis, which states that energy consumption, whether derived from renewable or non-renewable sources, may not serve as a critical determinant of economic growth, particularly over shorter time horizons. This suggests that while energy is undoubtedly a vital component of economic activity, its contribution to growth may be less direct or immediate, emphasizing the need to consider broader structural and policy factors when evaluating the economic impact of energy transitions. The obtained results can be interpreted in light of several factors specific to the energy sector and the unique characteristics of the economies in this region. Firstly, the share of renewable energy in total energy consumption remained relatively low for most of the analyzed period. Traditional energy sectors, heavily reliant on fossil fuels such as coal, oil, and natural gas, continued to dominate, while renewable sources like solar, wind, and hydropower were still in the developmental stage. This reliance on fossil fuels stems from the region's long-standing dependence on these traditional energy resources, which have been crucial for energy stability, employment, and revenue generation.

Secondly, the transition toward renewable energy could have been faster and faced numerous obstacles. Many countries in the region began their shift to renewables only in the latter half of the observed period, supported by incentives from the European Union, such as the Renewable Energy Directive and the European Green Deal. However, adopting and implementing these policies required significant time and investment, delaying the potential impact of renewable energy on economic growth.

Thirdly, the high initial costs of developing RES posed a significant challenge. Infrastructure construction, such as wind turbines, solar panels, and hydropower plants, demanded substantial capital investments, with returns often realized only in the long term. In the early stages, these high costs were not sufficiently offset by economic benefits, temporarily neutralizing their impact on economic growth.

Additionally, infrastructural, and technical limitations further slowed the progress of the RES sector. Energy systems in many CEE countries were outdated and unable to support the flexible utilization of renewable energy. Modernizing energy grids, investing in energy storage technologies, and enhancing technical capacities are necessary steps many countries in the region have only recently begun to address.

Political and regulatory frameworks also significantly limited renewable energy's potential. Inadequate implementation of laws and policies, unclear strategic goals, and insufficient institutional support further constrained the sector's development.

Finally, the long-term nature of renewable energy's impact should also be considered. Its contributions to economic activity are often realized over extended periods, whereas short-term effects are less pronounced. During the 2000–2021 period, many countries were in the early stages of their transition, meaning that the economic effects of renewable energy were not yet fully measurable.

The lack of a significant impact of renewable energy consumption on economic growth during the observed period reflects the complex challenges faced by the sector. These challenges include low initial adoption rates, excessive reliance on fossil fuels, infrastructural and regulatory barriers, and the need for long-term investments. As renewable energy adoption increases, technical and regulatory support improves, and energy systems modernize, it is expected that the contribution of renewables to economic growth will become more pronounced in the coming decades.

Additionally, the analysis showed a strong positive correlation between economic growth and energy intensity. This relationship aligns with the structural characteristics of Central and Eastern European economies, where energy-intensive industries, such as manufacturing and heavy industry, play a pivotal role in sustaining GDP growth. The positive coefficient for energy intensity suggests that energy-intensive sectors contribute to short-term economic expansion, although this reliance poses challenges for long-term sustainability. While these industries drive immediate economic outputs, their high energy consumption per unit of GDP indicates inefficiencies that could be mitigated through enhanced energy efficiency measures.

The results underscore the need for a strategic approach to managing energy intensity to ensure sustainable economic growth. Transitioning to more efficient energy consumption practices could enable economic growth without increasing total energy usage. Modernizing industrial sectors through investments in energy-efficient technologies is critical for reducing reliance on high energy consumption while maintaining economic output. Diversifying the economy by developing less energy-intensive sectors, such as services and technology, can further reduce dependence on energy-intensive activities while preserving economic benefits. While energy-intensive sectors remain significant for regional growth, long-term technological innovation and energy efficiency investments are essential for sustainable and competitive growth.

Gross capital formation emerged as a significant positive factor influencing GDP growth, with results indicating a highly significant coefficient. This emphasizes the role of investments in infrastructure, machinery, and technology in enhancing productivity and driving economic growth. The strong association highlights the importance of capital accumulation as a key driver of economic performance and long-term development.

Similarly, exports were found to impact GDP growth substantially positively. This underscores the role of trade in fostering economic resilience and generating income by providing access to larger markets. The positive relationship between exports and growth suggests that integrating renewable energy into production processes could enhance the competitiveness of Central and Eastern European countries in global markets, particularly as sustainability becomes an increasingly important factor.

Labor force participation and foreign direct investment did not significantly affect GDP growth. Several key factors can explain this. The lack of significance for the labor force participation rate suggests that merely increasing the workforce size is insufficient to stimulate economic growth without simultaneous improvements in productivity and structural adjustments within the economy. This may reflect inefficiencies in labor market integration and challenges aligning workforce expansion with high-productivity sectors.

Moreover, labor force participation alone does not guarantee GDP growth, as its effect largely depends on workforce productivity. In Central and Eastern European countries, there is often a mismatch between workforce skills and labor market demands, coupled with the migration of skilled workers to more developed countries. These factors diminish the potential contribution of labor force participation to overall economic growth. Although labor force participation rates may be high, their impact on GDP remains limited without adequate technological support, innovation, or investments in education and workforce training.

The analysis also revealed that FDI, while marginally significant with a negative coefficient, may have mixed impacts depending on its focus and the sectors it targets. This implies that the effectiveness of FDI depends on whether it supports innovation and sustainable energy development or remains tied to traditional, less productive sectors. The findings indicate that the type of FDI is critical in determining its contribution to economic growth.

According to the results, foreign direct investment appears to have a limited and marginally significant impact on economic growth in the region. This may be due to the fact that much of the FDI is directed toward low value-added sectors, such as basic manufacturing and domestic services like retail and banking, which offer limited productivity or innovation spillovers. Additionally, weak technology transfer, the dominance of efficiency-seeking investment, and institutional challenges—such as corruption and inefficient governance—

further constrain FDI’s growth-enhancing potential. These factors suggest the need for policies that attract higher-quality, innovation-oriented FDI and strengthen institutional capacity to support its effective utilization.

Furthermore, the analysis highlights the ongoing challenges Central and Eastern European countries face in reducing reliance on fossil fuels and transitioning to renewable energy sources. Despite efforts to expand renewable energy capacity in recent years, many countries in the region remain heavily dependent on coal, natural gas, and other fossil fuels. This reliance limits the broader macroeconomic impact of renewables. The slow pace of renewable energy integration can be attributed to outdated energy infrastructure, political and regulatory challenges, and the significant investments required to modernize the energy grid and systems.

The research's findings emphasize the necessity of a thorough approach to developing the renewable energy sector to enhance its contribution to the overall energy system and economic growth. Increasing capital investments in renewable energy through direct government funding, subsidies, and tax incentives for private investors is crucial for building wind, solar, and hydropower infrastructure. The gradual transition from fossil fuels requires clearly defined policies that enable a phased shift away from traditional sources while maintaining energy stability.

Modernizing energy infrastructure, including digitizing grids, introducing innovative systems, and implementing energy storage technologies, is essential for the flexible and efficient integration of renewable energy sources. Furthermore, improving the regulatory framework with long-term strategies, streamlined permitting processes, and mechanisms for incorporating renewables into energy systems should align with European Union goals, such as those outlined in the European Green Deal.

Innovation in the sector can be further stimulated by fostering research and development of new technologies, supported by collaborations with universities and the encouragement of start-ups. Developing human capital is also critical for the transition, requiring educational programs and training initiatives to prepare the workforce to meet the demands of the renewable energy sector.

Regional cooperation among CEE countries can facilitate information exchange, resource optimization, and collaborative project execution. Additionally, establishing systems to monitor and evaluate the long-term impacts of renewable energy investments will ensure the effectiveness of policies, allow for necessary adjustments, and identify areas for further improvement.

In summary, policies ought to give priority to increasing the share of RES through strategic investments, modernizing infrastructure, and implementing supportive regulations while fostering innovation and collaboration. These efforts can help Central and Eastern European countries achieve sustainable economic growth and effectively incorporate renewables into their energy systems. Investments in energy-efficient technologies are crucial for reducing energy intensity without hindering economic productivity. Enhanced energy efficiency lowers production costs and contributes to more sustainable and balanced growth.

While renewable energy did not demonstrate significant effects on economic growth, ongoing investment, and policy support remain essential for achieving long-term benefits. Incentivizing renewable energy projects and upgrading outdated energy systems are critical to enhancing the sector's contribution to economic performance.

Modernizing and upgrading infrastructure can improve energy efficiency and reduce overall energy intensity. Advancements in technology will further facilitate a smoother transition to renewables, creating economic and environmental advantages. A gradual and balanced approach to renewable energy integration, underpinned by investments in reliable and adaptable energy systems, is key to maintaining economic stability while ensuring energy security during the transition.

The limitations of this research lie in its problem of addressing the endogeneity between REC and economic growth. There is a possibility of bidirectional causality, where economic growth may drive increased REC while energy consumption simultaneously stimulates growth. This could lead to potential biases in the results. Additionally, the study does not account for sectoral energy consumption, specifically how different economic sectors utilize renewable energy. A detailed analysis could offer deeper insights into which sectors contribute most significantly to economic growth, thereby enhancing understanding of the interrelationship between renewable energy and economic development.

Recommendations for future research highlight several key aspects that could improve the understanding of the relationship between renewable energy consumption and economic growth. First, it is essential to address the endogeneity between these variables. Advanced econometric techniques, such as instrumental variables or methods like Granger causality tests, could help identify the direction of causality and ensure more accurate estimates of the effects. Second, future studies should analyze sectoral energy consumption to determine which economic sectors significantly impact growth through renewable energy use. This approach could inform the development of sector-specific policies and strategies for transitioning to sustainable energy sources. Moreover, future research should examine how political frameworks and energy market structures influence the effectiveness of renewable energy strategies, as this could provide valuable insights for designing more efficient energy transition plans.

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APPENDICES

Appendix 1: Fixed Effect Regression Results

xtreg GDPpcGROWTH REN EI LF GFCF FDI EXP i.YEAR, fe

```
Fixed-effects (within) regression            Number of obs      =      242
Group variable: ID                         Number of groups   =       11

R-sq:  within  = 0.7622                    Obs per group: min =       22
       between = 0.0089                                   avg =      22.0
       overall = 0.3898                                   max =       22
                                          F(27,204)          =    24.22
corr(u_i, Xb)  = -0.6655                    Prob > F           =   0.0000
------------------------------------------------------------------------------
 GDPpcGROWTH |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         REN |   .0011666   .0798083     0.01   0.988    -.1561884    .1585216
          EI |   .6824295   .3702086     1.84   0.067    -.0474964    1.412355
          LF |   -.098607   .0898015    -1.10   0.273    -.2756651    .0784511
        GFCF |   .4034185   .0579618     6.96   0.000     .2891374    .5176996
         FDI |   -.018119   .0157165    -1.15   0.250    -.0491066    .0128686
         EXP |   .1698107    .037016     4.59   0.000     .0968278    .2427936
             |
        YEAR |
       2001  |  -.7573466   .9251673    -0.82   0.414    -2.581463     1.06677
       2002  |   .2372964   .9300499     0.26   0.799    -1.596447    2.071039
       2003  |   .4529539   .9352944     0.48   0.629    -1.391129    2.297037
       2004  |   .2728439   .9671304     0.28   0.778    -1.634009    2.179697
       2005  |  -.0520821   1.013188    -0.05   0.959    -2.049746    1.945581
       2006  |  -.3433556   1.100317    -0.31   0.755    -2.512808    1.826097
       2007  |   -1.04919   1.166584    -0.90   0.370    -3.349298    1.250918
       2008  |  -5.054931   1.160223    -4.36   0.000    -7.342498   -2.767365
```

2009	-11.03586	1.106369	-9.97	0.000	-13.21724	-8.85447
2010	-4.054789	1.145107	-3.54	0.000	-6.312552	-1.797027
2011	-3.230048	1.252365	-2.58	0.011	-5.699287	-.7608095
2012	-5.147751	1.324516	-3.89	0.000	-7.759247	-2.536255
2013	-5.319237	1.371148	-3.88	0.000	-8.022677	-2.615797
2014	-3.558823	1.406348	-2.53	0.012	-6.331665	-.7859811
2015	-2.805179	1.416356	-1.98	0.049	-5.597751	-.0126056
2016	-2.857324	1.424467	-2.01	0.046	-5.66589	-.0487572
2017	-1.621008	1.459745	-1.11	0.268	-4.499129	1.257113
2018	-2.417712	1.485963	-1.63	0.105	-5.347527	.5121041
2019	-2.361437	1.523358	-1.55	0.123	-5.364983	.6421089
2020	-8.568541	1.514186	-5.66	0.000	-11.554	-5.583079
2021	.2967118	1.583598	0.19	0.852	-2.825606	3.41903
_cons	-11.52806	6.332302	-1.82	0.070	-24.01321	.9570917

-------------+--

sigma_u | 3.5628281

sigma_e | 2.1628856

rho | .73070901 (fraction of variance due to u_i)

F test that all u_i=0: F(10, 204) = 6.05 Prob > F = 0.0000

. testparm i.YEAR

(1) 2001.YEAR = 0

(2) 2002.YEAR = 0

(3) 2003.YEAR = 0

(4) 2004.YEAR = 0

(5) 2005.YEAR = 0

(6) 2006.YEAR = 0

(7) 2007.YEAR = 0

(8) 2008.YEAR = 0

(9) 2009.YEAR = 0

(10) 2010.YEAR = 0

(11) 2011.YEAR = 0

(12) 2012.YEAR = 0

(13) 2013.YEAR = 0

(14) 2014.YEAR = 0

(15) 2015.YEAR = 0

(16) 2016.YEAR = 0

(17) 2017.YEAR = 0

(18) 2018.YEAR = 0

(19) 2019.YEAR = 0

(20) 2020.YEAR = 0

(21) 2021.YEAR = 0

F(21,   204) =   15.35

Prob > F =   0.0000

. xttest2

Correlation matrix of residuals:

	__e1	__e2	__e3	__e4	__e5	__e6	__e7	__e8	__e9	__e10	__e11
__e1	1.0000										
__e2	0.1812	1.0000									
__e3	-0.0690	-0.2789	1.0000								
__e4	-0.1112	-0.0898	-0.2937	1.0000							
__e5	0.3043	0.0469	0.0655	-0.1926	1.0000						
__e6	-0.2352	-0.1143	-0.6299	0.4513	-0.2674	1.0000					
__e7	-0.1318	-0.4202	-0.4772	0.4303	-0.1141	0.5285	1.0000				
__e8	-0.0291	-0.0915	0.6508	-0.5399	-0.0057	-0.6895	-0.6460	1.0000			
__e9	-0.2187	-0.2063	0.0021	-0.3537	-0.0248	0.0579	-0.1577	0.0021	1.0000		
__e10	-0.0777	-0.1981	0.5064	-0.4898	-0.2811	-0.4959	-0.1843	0.6025	-0.2746	1.0000	

__e11 -0.0217   0.5137   0.0534 -0.1592   0.2652 -0.5256 -0.4095   0.2103 -0.2529 0.1191   1.0000

Breusch-Pagan LM test of independence: chi2(55) =   134.798, Pr = 0.0000

Based on 22 complete observations over panel units

Appendix 2: Results of the time-series cross-sectional Prais–Winsten regression model with panel-corrected standard errors

xtpcse GDPpcGROWTH REN EI LF GFCF FDI EXP i.ID i.YEAR, correlation(psar1) rhotype(tscorr)

Prais-Winsten regression, correlated panels corrected standard errors (PCSEs)

Group variable: ID Number of obs = 242

Time variable: YEAR Number of groups = 11

Panels: correlated (balanced) Obs per group: min = 22

Autocorrelation: panel-specific AR(1) avg = 22

max = 22

Estimated covariances = 66 R-squared = 0.7942

Estimated autocorrelations = 11 Wald chi2(37) = 10736.64

Estimated coefficients = 38 Prob > chi2 = 0.0000

GDPpcGROWTH	Coef.	Panel-corrected Std. Err.	z	P>|z|	[95% Conf. Interval]	
REN	-.0185682	.095449	-0.19	0.846	-.2056449	.1685084
EI	.7714487	.3913901	1.97	0.049	.0043382	1.538559
LF	-.0127007	.1033915	-0.12	0.902	-.2153443	.1899429
GFCF	.3983723	.07401	5.38	0.000	.2533153	.5434293
FDI	-.0175394	.0092825	-1.89	0.059	-.0357327	.0006539
EXP	.1567786	.0391804	4.00	0.000	.0799865	.2335707
ID						
2	3.237182	1.750412	1.85	0.064	-.1935617	6.667926
3	-4.447064	1.230646	-3.61	0.000	-6.859086	-2.035041
4	-4.229738	1.665093	-2.54	0.011	-7.493261	-.9662154

5	-3.525634	1.337548	-2.64	0.008	-6.14718	-.9040877
6	1.229667	2.552645	0.48	0.630	-3.773426	6.23276
7	1.690653	1.404882	1.20	0.229	-1.062865	4.444171
8	3.944398	1.328028	2.97	0.003	1.34151	6.547285
9	4.868912	1.605401	3.03	0.002	1.722385	8.01544
10	-4.627996	1.670744	-2.77	0.006	-7.902595	-1.353398
11	-2.119186	1.185615	-1.79	0.074	-4.442949	.2045762
YEAR						
2001	-.7812013	.2246462	-3.48	0.001	-1.2215	-.3409029
2002	.2548131	.2913006	0.87	0.382	-.3161255	.8257517
2003	.5523237	.3417672	1.62	0.106	-.1175278	1.222175
2004	.1690854	.4794219	0.35	0.724	-.7705642	1.108735
2005	.0280383	.6059461	0.05	0.963	-1.159594	1.215671
2006	-.2328554	.8139613	-0.29	0.775	-1.82819	1.362479
2007	-.7848872	.9361233	-0.84	0.402	-2.619655	1.049881
2008	-5.16579	.8888746	-5.81	0.000	-6.907952	-3.423628
2009	-10.97957	.7366054	-14.91	0.000	-12.42329	-9.535846
2010	-3.940752	.8193705	-4.81	0.000	-5.546689	-2.334815
2011	-3.201936	1.019252	-3.14	0.002	-5.199634	-1.204238
2012	-4.646721	1.125558	-4.13	0.000	-6.852773	-2.440669
2013	-4.880465	1.181949	-4.13	0.000	-7.197043	-2.563888
2014	-3.099725	1.241502	-2.50	0.013	-5.533025	-.6664248
2015	-2.206492	1.260733	-1.75	0.080	-4.677483	.2644988
2016	-2.370789	1.268031	-1.87	0.062	-4.856083	.1145058
2017	-1.144134	1.330809	-0.86	0.390	-3.752471	1.464204
2018	-1.870853	1.370211	-1.37	0.172	-4.556418	.8147121
2019	-2.080464	1.434562	-1.45	0.147	-4.892154	.7312258

```
    2020  |  -7.916985   1.436907    -5.51   0.000    -10.73327   -5.100698
    2021  |   .6440409   1.514377     0.43   0.671    -2.324083    3.612165
          |
   _cons |  -15.45434   6.459338    -2.39   0.017    -28.11441   -2.794268
------------------------------------------------------------------------------
    rhos =  .3852225 -.2355669  .3662236  .3409264  .1917556 ...  .5402896
------------------------------------------------------------------------------
```

Appendix 3: Tests for Autocorrelation and Heteroskedasticity

Modified Wald test for groupwise heteroskedasticity

in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (11) = 163.34

Prob>chi2 = 0.0000

. xtserial GDPpcGROWTH REN EI LF GFCF FDI EXP

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

F(1, 10) = 10.247

Prob > F = 0.0095