KAPITEL 1 / *CHAPTER 1* [1]
THE ROLE OF CLEAN ENERGY IN THE ENERGY TRANSFORMATION IN EASTERN EUROPE

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Introduction

Changes in the natural environment, including increasingly frequent and unpredictable threats linked to climate change, pose significant risks not only to economic growth but also to the very existence of our civilization. Research across various scientific disciplines indicates that these threats are largely driven by the adverse effects of economic activities. This includes the intensive use of fossil fuels and the resulting air pollution from greenhouse gases, which substantially contribute to climate change. Consequently, there is an urgent need to transition away from fossil fuels towards zero-emission energy sources at global, regional, national, and local levels [1,2].

The objective of this study, and its primary contribution to the field of energy economics, is to analyze the determinants of energy transformation in EU. The focus is particularly on the role and significance of clean generation technologies in this process. The study aims to define the perspectives of transitioning to a zero-emission economy and to outline a strategic course of action to achieve this goal. By presenting a case study of EU, which includes its history, current situation, and potential future development paths, the analysis provides empirical findings that can be valuable for understanding and applying to other contexts [3, 4].

Several research questions guide this analysis:

- What are the determinants of energy transition towards a zero-emission economy in EU?

- Which factors stimulate the diversification away from fossil fuels and the adoption of low-carbon fuels?

- How do these factors differ from those influencing similar processes in Western economies?

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Transforming the energy consumption structure, particularly by enhancing the role of new renewable energy sources, is crucial for establishing a zero-carbon economy. While most empirical studies on energy sector innovations focus on Western economies or a broader set of developed countries, such as those in the OECD, this analysis centers on the EU economy. EU's experience in energy transformation can offer valuable insights and strategies for other Central and Eastern European (CEE) countries facing similar challenges.

The pace and direction of EU's ongoing energy sector transformation are influenced by a variety of factors. This article examines both external conditions, such as EU 's membership in the European Union, and internal conditions, including the country's level of economic development, domestic coal and natural gas resources, growing energy import dependency, energy demand, experience with centralized economic management, and efforts towards energy transformation [5].

Furthermore, the role of technological change in transforming the economy and primary energy carrier structures is elaborated upon. Numerous factors shape the development of innovations in clean energy technologies. This article empirically tests the impact of several key determinants of clean technology development, including economic and institutional measures such as energy prices, environmental policy stringency, long-term interest rates, market concentration, and intellectual property rights protection [6].

The study specifically addresses the development of clean generation technologies, which are fundamental to the energy transition process. By developing econometric models using sectoral data from the EU electric power industry, the study empirically examines the determinants of clean energy development. Additionally, the analysis reviews these determinants in light of existing literature, providing a comprehensive understanding of the factors driving innovation in clean energy technologies in EU.

Furthermore, the study delves into the role of technological change in transforming the economy and primary energy carrier structures. Various factors influence the development of innovations in the field of clean energy technologies.

This article provides a detailed examination of some of the most crucial determinants of clean technology development and empirically tests their impact on innovation. These determinants include both economic and institutional measures such as energy prices, environmental policy stringency, long-term interest rates, market concentration, and the protection of intellectual property rights [7, 8].

The study places particular emphasis on the development of clean generation technologies, which are essential for the energy transition process. To understand the determinants of this development, the study employs econometric models using sectoral data from the EU electric power industry. The analysis reviews these determinants in the context of existing literature and conducts an empirical verification specific to the EU economy.

Key aspects of the study include:

- Economic Measures: Investigating how energy prices and long-term interest rates influence the pace and direction of innovation in clean energy technologies.

- Institutional Measures: Examining the role of environmental policy stringency, market concentration, and intellectual property rights protection in fostering technological advancements.

- Empirical Analysis: Utilizing econometric models to analyze sectoral data and provide empirical evidence on the effectiveness of these determinants in driving clean energy innovation in EU.

By focusing on these factors, the study aims to provide a comprehensive understanding of what drives the development of clean generation technologies. The findings offer valuable insights into the specific conditions and measures that can facilitate the transition to a zero-emission economy in EU. This detailed analysis helps to identify the most effective strategies for encouraging innovation and implementing clean energy solutions, contributing significantly to the broader discourse on energy economics and sustainable development.

1.1. International EU-context

After forty-five years under a centralized command and control economic system, EU began its process of systemic transformation in 1990, transitioning to a market economy. This large-scale transformation involved demonopolization, deregulation, restructuring, and privatization of the economy, along with re-establishing cooperation with Western economies. Significant milestones in economic cooperation included signing a trade and economic cooperation agreement with the European Economic Community, the Europe Agreement in 1992, and the Treaty of Accession on April 16, 2003.

Simultaneously, EU took steps to establish political relations within the global economy to enhance security and peace in the region, culminating in its NATO membership in 1999. These agreements laid the groundwork for a new market-based economy and propelled the transformation and further development of the EU economy.

Within the European Union, EU's economic potential is considerable. It ranks sixth in size with an area of 311.9 thousand square kilometers, fifth in population with 37.977 million inhabitants, and fifth in GDP with 496.5 billion Euros (in 2018 current prices). Additionally, EU's government debt level is 48.9%, placing it among the 11 EU countries with the lowest debt levels.

EU committed to aligning with European Union law (acquis communautaire), including energy management policies. This commitment involved incorporating EU energy legislation into national law, reflecting EU's dedication to aligning its economic and energy policies with broader European standards. This alignment has been crucial in EU's ongoing efforts to modernize its economy and integrate more fully with the European Union, providing a stable foundation for sustainable economic growth and development [9].

The EU power sector has undergone significant changes, particularly through the liberalization of the gas and electricity markets, involving processes such as demonopolization, deregulation, restructuring, and privatization. These changes were

also driven by efforts to enhance energy security, ensure reliable power generation, address environmental concerns, and comply with energy-climate policy objectives.

At the beginning of the new millennium, the growing challenges posed by climate change in the globalized economy became a critical threat and a global challenge. The proposed solution to this issue is the decarbonization of the economy and a transition towards a low-carbon economy. The European Union's energy policy has long pursued objectives such as reducing pollution and greenhouse gas emissions, promoting renewable energy sources, enhancing energy efficiency, and fostering research and innovation in the energy sector. This is evident in the increasingly stringent legal and regulatory frameworks aimed at achieving these goals.

According to the treaty provisions, EU Member States have the flexibility to shape their energy policies proactively. They can consider their energy resources, choose between various energy sources, and design their energy supply structures. The push towards decarbonization within the EU and its Member States has been further solidified by priority development programs such as the Green New Deal and the Fit for 55 package. These EU regulatory frameworks are poised to have a substantial impact on EU's energy sector and its overall economy.

Eastern European countries' alignment with EU energy policies necessitates a focus on reducing greenhouse gas emissions, promoting renewable energy, and enhancing energy efficiency. This alignment also encourages innovation in clean energy technologies, which is crucial for achieving long-term sustainability and energy security. The transition towards a low-carbon economy in Eastern European countries, driven by EU regulations and policies, represents a significant shift in the country's approach to energy management and environmental stewardship.

1.2. Overview of Technologies and Energy Transformation History in Poland

Technological innovation plays a pivotal role in the transition process within the power sector. Its definition isn't straightforward; it encompasses new products or

production processes and extends to their implementation and broader diffusion. Environmental innovation, a specific subset, focuses on innovations that benefit the environment directly [10].

Progress in technology is crucial for transforming energy systems because it enables economic growth while efficiently utilizing scarce natural resources. Redirecting technical progress toward developing clean technologies addresses two main market failures: environmental externalities and the public goods nature of innovation [11]. This results not only in reducing pollution during economic growth but also in lowering the associated costs.

While technical change can be somewhat autonomous initially, it largely becomes an endogenous process influenced by energy market conditions, government policies, and market participants' expectations. These factors include research and development, government or corporate financing, and economies of scale, all integral parts of technological progress [12]. Therefore, effective public policy design must consider these factors to incentivize innovative activities among market participants optimally.

Historically, transitioning to new, more versatile energy sources involved significant technological advancements. These innovations enabled tapping into carbon reserves and subsequently accessing increasingly challenging oil and gas reserves to meet growing energy demands. They also facilitated better alignment between energy supply and escalating demand for primary energy sources. Thus, past energy transitions witnessed shifts in energy carrier structures and consumption patterns, driven by technological breakthroughs that addressed supply challenges and spurred economic growth [13–16].

Modern challenges facing the global economy, particularly in energy management and electricity generation, underscore the urgent need for greater reliance on renewable and alternative energy sources to address climate change. The energy transition represents a profound socio-economic and cultural shift, characterized by a move away from fossil fuels towards cleaner fuels and technologies.

Innovations and technological advancements play a crucial role in enabling the adoption of low-carbon energy sources and scaling up their deployment.

Decarbonisation efforts necessitate significant changes in energy technologies, driven by decisions of investors and consumers influenced by market dynamics such as prices, profitability, disposable income, and consumer habits. Transitioning poses substantial challenges related to capital availability for both established clean energy technologies and experimental innovations, as well as the costs associated with phasing out fossil fuel industries.

Addressing these formidable challenges requires proactive state policies that can catalyze a series of actions—from initial invention and investment to supporting private sector initiatives in production and consumption. Globally, regionally, and nationally, the transformation of the power sector demands the deployment of new energy technologies alongside effective policy measures that balance cost-effectiveness with societal acceptance.

Specifically, within the Polish context, the evolution of the power sector over the past three decades has been shaped by legislative frameworks such as the Energy Law Act of 1997 and strategic documents like the Polish Energy Policy by 2040 (PEP40) and the Strategy for Responsible Development up to 2030. These policies emphasize goals such as enhancing energy security through optimal use of domestic resources, modernizing infrastructure, diversifying natural gas supplies, and promoting renewable energy sources, among others [17].

Poland, leveraging its substantial coal reserves, has played a pivotal role in the EU's energy landscape, supporting significant employment in the coal mining sector and contributing to regional and national economies over the years [18].

1.3. Overview of Technologies and Energy Transformation History in Hungary

Hungary's energy transformation history is a narrative of significant changes, reflecting the broader socio-economic and political shifts in the region. From traditional biomass use to modern renewable energy sources, Hungary's energy sector has evolved substantially over the centuries.

In the pre-industrial era, Hungary's energy needs were primarily met through biomass, including wood and agricultural waste. The advent of the Industrial Revolution in the 19th century brought about significant changes. Coal became the dominant energy source, powering factories, railways, and urban infrastructure. The development of the coal mining industry, particularly in regions like the Mecsek Mountains, was instrumental in supporting Hungary's burgeoning industrial activities.

The 20th century saw a gradual shift from coal to oil and natural gas. After World War II, Hungary, under the influence of the Soviet Union, expanded its use of oil, primarily imported from the Soviet bloc. The discovery of domestic natural gas reserves in the 1960s further diversified the energy mix. The establishment of pipelines facilitated the import of oil and gas, crucial for Hungary's energy security and economic development.

A pivotal moment in Hungary's energy history was the commissioning of the Paks Nuclear Power Plant in the 1980s. The plant, located near the town of Paks, became a cornerstone of Hungary's energy strategy, providing a significant portion of the country's electricity. The use of nuclear energy reduced dependence on fossil fuels and helped stabilize the national grid, ensuring a steady supply of electricity.

The collapse of the Soviet Union and the subsequent political changes in Hungary in 1989-1990 led to the liberalization of the energy market. The transition from a centrally planned economy to a market-oriented one included significant reforms in the energy sector. Privatization of energy companies, deregulation, and the integration into the European Union's energy market marked this period. Hungary's accession to the EU in 2004 further accelerated the adoption of EU energy policies and standards.

In recent decades, Hungary has increasingly focused on renewable energy sources to diversify its energy mix and reduce greenhouse gas emissions. The Hungarian government has set ambitious targets for increasing the share of renewables in the energy mix. Investments in solar, wind, and biomass energy have been encouraged through various incentives and policy measures. The deployment of solar photovoltaic panels has seen significant growth, supported by favorable regulatory frameworks and decreasing technology costs.

Despite progress, Hungary faces several challenges in its energy transformation journey. These include the need to modernize aging infrastructure, ensure energy security, and meet international climate commitments. The ongoing debate about the expansion of the Paks Nuclear Power Plant also reflects broader concerns about nuclear safety and environmental impact.

Looking ahead, Hungary's energy transformation will likely continue to be shaped by technological advancements, policy decisions, and global energy trends. The commitment to increasing energy efficiency, reducing carbon emissions, and enhancing the role of renewables will be crucial in achieving a sustainable and resilient energy future for Hungary [19].

1.4. Overview of Technologies and Energy Transformation History in Slovakia

The energy transformation history of Slovakia is a compelling narrative of adaptation and modernization, reflecting the country's socio-political changes and economic development. From traditional energy sources to the embrace of nuclear and renewable energy, Slovakia's energy sector has undergone significant transformation.

In the early stages of its history, Slovakia, like many other Central European regions, relied heavily on biomass, such as wood and agricultural waste, for its energy needs. The industrialization wave of the 19th century brought coal to the forefront as the primary energy source. Coal mining in regions such as Handlová and Nováky supported the burgeoning industrial activities, powering factories, railways, and urban development.

The aftermath of World War II saw Slovakia, then part of Czechoslovakia, aligning with the Soviet bloc, which influenced its energy policies and infrastructure development. The 1950s and 1960s marked the beginning of oil and natural gas use, primarily imported from the Soviet Union. This period also saw the construction of pipelines and refineries, crucial for the country's energy security and economic growth [20].

A significant milestone in Slovakia's energy history was the introduction of nuclear power. The construction of the Bohunice Nuclear Power Plant in the 1970s and later the Mochovce Nuclear Power Plant in the 1980s and 1990s marked a decisive shift towards nuclear energy. These plants provided a substantial portion of Slovakia's electricity, reducing reliance on fossil fuels and contributing to energy stability.

The fall of communism in 1989 and the subsequent dissolution of Czechoslovakia in 1993 brought about significant changes. Slovakia transitioned from a centrally planned economy to a market-oriented one, which included the liberalization of the energy sector. Privatization, deregulation, and the establishment of a regulatory framework in line with European Union standards were key components of this transformation. Slovakia's accession to the EU in 2004 further integrated its energy market with that of Europe.

In recent years, Slovakia has increasingly focused on renewable energy sources. The government has set ambitious goals to increase the share of renewables in the energy mix. Investments in hydroelectric power, biomass, solar, and wind energy have been promoted through various incentives and policies. The country's hydroelectric plants, particularly those on the Váh River, have been significant contributors to renewable energy production.

Despite progress, Slovakia faces several challenges in its energy transformation journey. These include modernizing its aging infrastructure, ensuring energy security, and meeting EU climate targets. The ongoing discussions about the extension of the nuclear power plants' operational lifetimes and the decommissioning of older coal plants highlight the balancing act between energy needs and environmental concerns.

Looking ahead, Slovakia's energy transformation will likely continue to be influenced by technological advancements, policy decisions, and global energy trends. The commitment to enhancing energy efficiency, expanding renewable energy use, and reducing greenhouse gas emissions will be crucial for achieving a sustainable and resilient energy future for Slovakia.

Conclusion

The current study focuses on eastern European countries' energy transformation, examining its trajectory, prospects, and the pivotal role of innovation in this process. The study empirically analyzes the primary determinants driving innovative activities within eastern European countries' energy sector.

Over the analyzed period, significant shifts have been observed in eastern European countries power generation landscape. These changes are characterized by a notable decrease in the share of coal in electricity generation, accompanied by a growing prominence of renewable energy technologies.

The energy transition in eastern European countries will initially involve a phased reduction in coal combustion within the power industry. The magnitude and pace of this transition are influenced by a variety of factors with distinct impacts. Key among these are EU and domestic climate and energy policies, as well as the availability of financing for a just transition in eastern European countries. Concurrently, rapid advancements in clean generation technologies are anticipated, facilitating sectoral transformation, mitigating emissions, creating employment opportunities, and catalyzing broader economic transformation.