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Poland's Energy Transition: Nuclear Energy, Security, and Environmental Implications

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AUTHOR'S DECLARATION

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT

This thesis looks at how nuclear power affects environmental and energy stability of a country, looking at Poland's energy scene. Poland must get beyond coal and other non-renewable fuels if it wants to reduce carbon emissions and become energy self-sufficient. The research looks at the advantages and drawbacks of including nuclear power into Poland's Energy Policy until 2040 (EPP2040) in line with the Paris Agreement and European Green Deal. The study explores the relationship between historical energy infrastructure, modern policy ambitions, and global energy transition patterns. It suggests that nuclear power can balance Poland's renewable energy sources and reduce greenhouse gas emissions and can adapt and improve energy security. The study encourages the acquisition of energy transition and policy reform theoretical frameworks for academics, companies, and governments. The study emphasizes evidence-based policymaking and strategic planning in Poland's energy transformation.

Keywords: energy transition, energy security, energy policy, Poland energy dependency, nuclear energy, decarbonization, natural gas, fossil fuel lock-in

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1. INTRODUCTION

1.1 BACKGROUND

The global energy landscape is transforming to tackle climate change and minimize greenhouse gas emissions. Coal, oil, and natural gas are being phased out to make way for cleaner energy. For almost a century, fossil fuels powered industrial expansion. Global agreements like the Paris Agreement strive to avert climate change and move to sustainable energy due to fossil fuel pollution and carbon emissions. This global agreement requires energy decarbonization and it stresses the necessity for 2050 carbon neutrality objectives (Bednarczyk et al. 2022). Thus, nations worldwide are reevaluating their energy policies and strategies to align with goals of sustainability, security, and economic stability, setting ambitious targets of achieving net-zero carbon emissions in the energy sector by 2050.

Nations are increasingly utilizing renewable energy sources like hydroelectric, wind, and solar to meet ambitious targets, diversifying their energy mix, reducing carbon emissions, and increasing renewable resource availability. However, some drawback aspects of the renewable technologies such as the sources being intermittent, making energy supply less reliable, the need for energy storage and a flexible infrastructure to manage supply and demand for fluctuating renewable power sources like wind and solar. Given this, other technologies, specifically nuclear power is being considered crucial to global energy sustainability (Langerak 2023).

Nuclear power facilities provide dependable, large electricity regardless of weather, unlike renewable energy sources. This makes them ideal for baseload power output. Poland and other

energy-secure nations see nuclear power to boost energy autonomy, cut foreign fuel use, and stabilize prices (Janaszek et al. 2023). A worldwide trend reassessing nuclear power's role in energy is seen in Poland. Poland must minimize carbon emissions whilst maintaining energy dependability owing to coal power (Kiciński and Patryk 2021). Different variables affected the nation's strategic nuclear power investment. These include replacing old coal facilities, satisfying environmental standards, and securing energy supply.

This shift minimizes dependency on imported fossil fuels to lessen supply interruptions and energy market uncertainty due to geopolitical concerns. Small modular reactors and upgraded reactors are opening ways to solve nuclear power issues. These innovations try to make nuclear power more accessible to countries seeking energy security and environmental conservation (Kowalska et al. 2022). Nuclear power combined with renewable energy may fulfil future energy needs and lessen environmental effect.

Given global climate change and energy security concerns, Poland is reassessing its energy policies, as are many other nations. Geopolitical tensions are affecting conventional energy supplies, as evidenced by the Russia’s invasion in Ukraine. Thus, energy self-sufficiency and greenhouse gas reduction are driving this transition. Poland urgently needs to switch from coal to renewable energy while maintaining electricity reliability. An important part of this transformation is Poland's Energy Policy until 2040 (EPP2040), which intends to reduce fossil fuel use and increase energy variety (Ministry of Climate and Environment of Poland n.d). The pace and technique of integrating nuclear power into the energy transition are contentious.

To understand Poland's plan, we need to study its energy infrastructure from prior decades. Polish energy strategy is heavily impacted by coal's economic and historical usage (Szpor and Ziółkowska 2018). Environmental, technological, and geopolitical factors are driving Poland's nuclear power change. International commitments and local concerns like cost-effectiveness, public acceptability, and safety must be balanced in the national nuclear power policy. Poland's efforts to diversify its energy sources and reduce its dependency on foreign energy emphasize energy security and reduce supply disruptions.

1.2 RESEARCH IN THE CONTEXT OF POLAND'S ENERGY LANDSCAPE

Figure 1. vividly illustrates Poland's evolving energy landscape. The diagram on the left looks at the energy mix of Poland as of 2022, while the one on the right shows the projected energy mix of Poland by 2040.

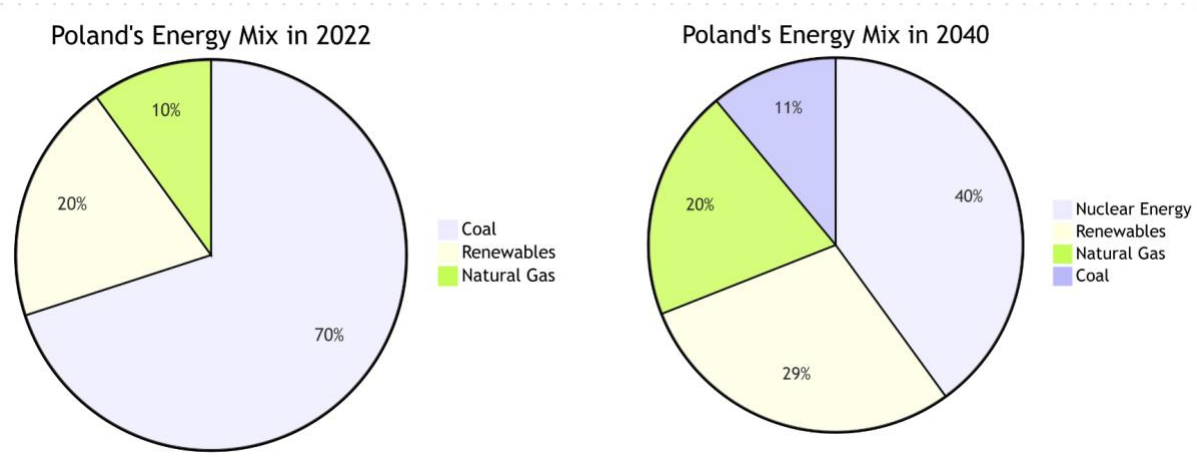

Figure 1. Poland's Energy Mix in 2022 and Projected Poland's Energy Mix in 2040

In 2022, coal dominates the energy mix with a staggering 70%, highlighting Poland's historical reliance on this fossil fuel, which has driven industrial growth but also contributed significantly to environmental challenges. Natural gas and renewables account for 10% and 20% respectively, with nuclear energy absent from the mix. Fast forward to 2040, and the energy landscape

transforms dramatically: coal's share plummets to 11%, while renewables rise to 29%, and nuclear energy emerges as a critical player, expected to provide 40% of the energy mix. This shift signifies Poland's strategic pivot towards cleaner energy sources to meet EU climate goals and reduce its carbon footprint. Our research zeroes in on this pivotal adoption of nuclear energy. We are particularly interested in understanding the multifaceted impacts of this transition—from the policy frameworks that facilitate it, social ramifications, and the technological advancements required. This focus is crucial as nuclear energy not only offers a stable, low-carbon power source but also plays a significant role in enhancing Poland's energy security and economic resilience in an increasingly volatile global energy market.

1.3 RESEARCH AIMS AND OBJECTIVES

Aim:

The primary aim of this research is to understand the interrelationships between the speed of Poland’s energy transition, nuclear energy adoption, and broader energy policies.

Specific Objectives

- Reviewing Poland's Historical Energy Infrastructure: Poland's energy sector's history and infrastructure, particularly its use of coal and other fossil fuels, will be examined for this goal.
- Analyzing Current Energy Policies, Including EPP2040: To understand how Poland's energy policies, particularly the Energy Policy of Poland until 2040 (EPP2040), affect energy transition dynamics and nuclear energy integration, this aim analyses them.

- Identifying the Role of Energy Security in Nuclear Energy Adoption: Poland's energy policy and energy security's impact on nuclear energy uptake are examined in this goal.

1.4 RESEARCH QUESTION

Main Research Question

- How does the desired speed of energy transition in Poland influence the decision to incorporate nuclear energy?

Sub-questions

- What historical factors have shaped Poland's approach to nuclear energy adoption in the context of its energy transition?
- What are the current policy frameworks and priorities that influence the integration of nuclear energy into Poland's energy mix?
- How do international agreements, trends, and pressures influence Poland's stance on nuclear energy adoption?
- To what extent does nuclear energy align with Poland's commitments and targets for carbon reduction and environmental sustainability?
- What role does energy security play in Poland's strategic decisions regarding the adoption and expansion of nuclear power?

1.5 SIGNIFICANCE OF THE STUDY

This report evaluates Poland's transition from coal to nuclear and renewable energy to improve energy policy. Polish energy policy and the complex interplay of historical, economic, and political

factors are examined in this paper. It highlights the merits and cons of such changes, which may enhance global energy policy negotiations. Policymakers may use the report's energy security and environmental sustainability strategic planning. A steady power supply and carbon emission reduction initiatives may result from the results. This study will educate energy producers and investors about market and regulatory changes that may impact sector operations. This research may assist academics investigate energy transition dynamics and write about sustainable energy. This subject affects national and international policy and strategic planning. The report provides a full Poland case study and a framework for other nations (Mărgineanu and Arkadiusz 2023). Innovation and technology in energy transitions and how to incorporate new technologies into energy systems are also covered (Sainz de Vicuña 2022). This project integrates theoretical concepts with practical applications to provide actionable solutions for sustainable energy policy.

1.6 STRUCTURE OF THE THESIS

This thesis addresses Poland's renewable energy transition in five parts. Chapter 1 presents the study's context, relevance, background, and structure. The first chapter. Switching from fossil fuels to renewable energy sources may increase energy security and sustainability. The second chapter covers energy transition literature, focusing on current findings and theoretical frameworks that motivated the research. This article examines energy policy change studies, concentrating on the main drivers of the transition to more sustainable energy systems and the barriers. Chapter 3 covers methodology, study design, data collection, and analysis. This chapter covers data collection and analysis. Chapter 4 analyses Poland's energy infrastructure and regulations. The chapter covers Poland's coal dependence and renewable energy transition. Polish energy policy was affected by economic, political, and social issues. It evaluates these policies' successes and failures. The thesis

summaries the results and explores their impact on academics, policymakers, and industry stakeholders in Chapter 5. Polish energy revolution governmental policies and long-term strategic planning are also suggested. The chapter also recommends research topics to better understand energy transfer processes.

2. LITERATURE REVIEW

The literature review in this thesis critically examines the existing body of work on nuclear power within the context of Poland's energy transition. It aims to provide a comprehensive analysis of the discussions, empirical studies, and theoretical frameworks that have shaped the current understanding of nuclear energy's role in Poland. This section outlines the extent of previous research, the organization of the scholarly discourse, and the primary themes that emerge from the literature. It evaluates the impact of nuclear energy on policy formulation, energy security, and sustainability. By focusing on the key concerns and debates, this literature review seeks to understand the factors driving the adoption of nuclear power in Poland, analyzing technological adoption models, energy security assessments, and the potential for nuclear energy to reduce reliance on fossil fuels and enhance resilience.

2.1 THEORETICAL FRAMEWORK

Policy changes and energy transitions are one of the main ideas to be understood for this research. Theories and frameworks help reveal the complex and dynamic transition to sustainable energy. The Multi-Level Perspective explains advancements via technology, cultural norms, and institutions (Geels 2011). The aim is to analyze the dynamic interactions between different levels of a system: niches, regimes, and landscapes. The MLP framework consists of three components: the socio-technical landscape, which includes long-term, stable factors like economic conditions, political ideologies, cultural values, and environmental changes; the socio-technical regime, which includes established practices, rules, and norms that stabilize current systems; and the niches, which are protected spaces where radical innovations develop. Transitions occur through interactions between these three levels, with landscape pressures from changes or shocks at the

landscape level creating pressure on existing regimes. Niche innovations gain momentum through experimentation, learning, and support from pioneers and innovators, while regime destabilization creates tensions within the regime, opening windows for new technologies and practices to be integrated or for the regime to transform.

Poland's energy transition is a complex process that requires a multi-level perspective to address the challenges of a coal-dominated regime and the global energy crisis. External pressures, such as EU climate policies and the recent energy crisis, challenge Poland's stability and resistance to alternative energy sources. However, innovations at the niche level, such as nuclear technology advancements and government-supported pilot projects, offer potential pathways for overcoming these barriers. This comprehensive approach ensures that Poland's energy transition covers all aspects of the Multi-Level Perspective framework.

Table 1. Perspectives on Energy Transitions: Systemic Focus, Drivers for Change and Relevance for the Current Thesis

Perspective	Systemic Focus	A Typical Driver for Change	Focus in this Thesis
Landscape	Broad external factors including economic conditions, political ideologies, cultural values, and environmental changes	External pressures such as energy crises and EU climate policies	To what extent landscape pressures like the energy crisis influence Poland's energy strategy and push for diversification
Regime	Established practices, rules, and norms that stabilize current systems, including technological systems and market structures	Stability and resistance to change due to existing infrastructure and economic interests	To what extent Poland's reliance on coal and existing energy policies create resistance to change
Niche	Protected spaces where radical innovations develop and mature, often isolated from mainstream markets	Innovation and development of new technologies through pilot projects and supportive policies	How innovations in nuclear technology and pilot projects can gain momentum and challenge the coal-dominated regime

Source: Information and perspectives adapted from Geels 2011.2.2

2.2 HISTORICAL ENERGY INFRASTRUCTURE IN POLAND

Preston (2013) refers to the way that past decisions and events shape and influence future societal choices and socio-ecological that path dependence refers to the way that past decisions and events shape and influence future societal choices and socio-ecological as a path dependence. It is crucial to consider path dependency when analyzing Poland's energy transition because the country's historical reliance on coal has deeply influenced its current energy infrastructure, policies, and

public perceptions. This is why the next subchapters will look at Poland's historical infrastructure while projecting the future.

2.2.1 POLISH COAL NARRATIVE

Poland's energy infrastructure has a deep-rooted history, heavily influenced by its abundant natural coal resources, geopolitical factors, and economic needs. Coal has been an essential part of Poland's energy mix since the industrial revolution (Szpor and Ziółkowska 2018). Despite a gradual decline, coal usage remains the primary source of power for homes and businesses, accounting for 60.5% of Poland's energy mix as of 2024, which is the lowest share ever recorded (Dusiło, 2024). Poland was Europe's leading coal producer at the end of the 20th century, owing to its extensive coal mining and power plant infrastructure. In Figure 2. we see a comprehenesive overview of Poland's electricity generation by fuel type of the country's energy mix from the year 1990 to 2022. The data shows a significant reliance on coal, which remains the dominant source of electricity.

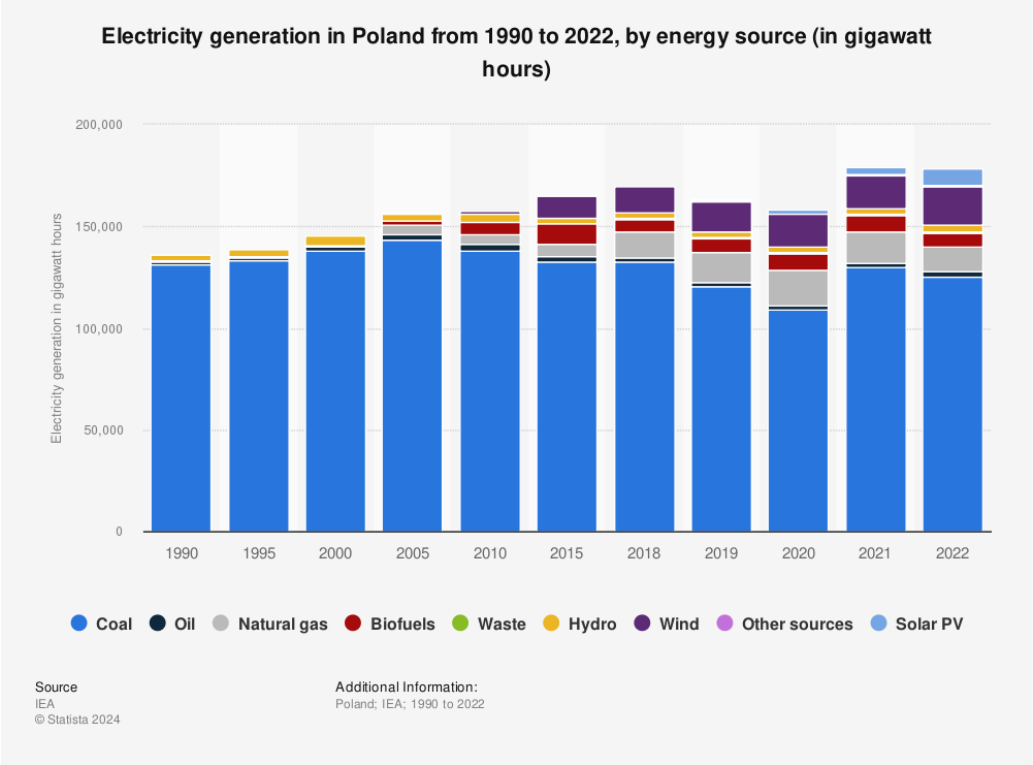

Figure 2.Electricity generation in Poland from 1990 to 2022, by energy source.

Source: International Energy Agency (IEA) 2024.

Historically, Poland's reliance on coal and other fossil fuels (Śliwińska et al. 2022) has been driven by the availability of coal reserves, economic considerations, and the geopolitical need for energy self-sufficiency. This dependency on coal is often described as a Cold War narrative, where coal was seen as a secure and affordable energy source (LaBelle 2020). During the Cold War, Poland's energy strategy was shaped by its coal-dependent membership in the Eastern Bloc. The country's substantial coal resources provided employment, economic stability, and critical energy infrastructure through coal mines, power plants, and related industries (Riepl and Zuzana 2023).

Coal is not just an energy source in Poland; it is a significant part of the national culture and identity. The mining regions, particularly Silesia, are deeply ingrained with coal mining traditions,

and this industry has shaped local communities and their way of life for generations. Coal mining is celebrated in local festivals, cultural events, and folklore, symbolizing resilience and hard work. The legacy of coal is also evident in Poland's socio-political landscape, where coal miners hold substantial influence and the coal sector enjoys strong political backing.

Coal has played a vital role in the country's economy, contributing significantly to its growth and development. Various authors have established a relationship between energy consumption and Gross National Product (GNP), indicating that energy consumption drives economic growth (see Kraft and Kraft, 1978; Akarca and Long, 1979; Yu and Choi, 1985; Stern, 1993, 2000; Cheng, 1995, 1997). However, Gurkul and Lach (2011) argue that closing unprofitable, state-subsidized coal mines in Poland may not significantly harm the national GDP. This suggests that while coal has historically been central to Poland's economy, the future may lie in diversifying its energy sources to ensure economic resilience and environmental sustainability.

Poland's energy policy is now at a crossroads, with increasing pressure to transition towards more sustainable energy sources. This transition is not just about replacing coal but also about transforming the entire energy system to enhance energy security, reduce environmental impact, and align with EU climate policies. The move towards nuclear energy, for example, represents a strategic effort to reduce dependency on coal while meeting the country's energy needs in a sustainable manner. This complex interplay of historical reliance, economic necessity, and future sustainability goals continues to shape Poland's energy narrative, highlighting the cultural significance of coal and the challenges of moving beyond it.

2.2.2 NUCLEAR POWER- AN ALTERNATIVE TO POLAND'S ENERGY MIX

Despite mounting concerns, coal remained the dominant energy source in Poland until the 21st century. The Polish government's efforts towards energy diversification have often been uneven and less effective than hoped (Stevanović 2020). One notable attempt to shift away from coal was the plan to build the Żarnowiec Nuclear Power Plant in the 1980s, marking Poland's first major nuclear energy project. Initiated in 1982, the project aimed to enhance energy security and reduce dependence on coal. However, the project encountered numerous obstacles, including budget constraints, technical issues, and public opposition, which intensified after the 1986 Chernobyl disaster heightened nuclear safety concerns.

The Żarnowiec project was abandoned in 1990 amid the political and economic upheaval following the fall of communism. The new democratic government, prioritizing different goals and facing limited funding, halted construction. Efforts to revive Poland's nuclear energy ambitions resurfaced in the early 2000s, driven by the need to address energy security and reduce carbon emissions. Despite several strategic plans and feasibility studies highlighting the potential benefits of nuclear power for greenhouse gas reduction and energy diversification, progress has been slow. Economic issues such as high upfront costs and construction delays have been significant hurdles (Krupnik 2023). Additionally, political and public support for nuclear power has fluctuated, complicating development efforts. The coal industry's entrenched business and political ties also pose substantial challenges to transitioning to nuclear power (Wen 2023).

Recently, Poland has made significant strides towards realizing its nuclear ambitions. In 2023, Poland signed an agreement with Westinghouse and Bechtel to build its first nuclear power plant,

slated to be operational by 2033. This project, involving the construction of three Westinghouse AP1000 reactors, is a critical step in Poland's strategy to diversify its energy mix and reduce reliance on coal (Westinghouse and Polskie Elektrownie Jądrowe 2023; El País 2023). This development is expected to significantly enhance Poland's energy security and contribute to its climate goals (Euronews 2023).

The persistent reliance on coal has resulted in severe air pollution and greenhouse gas emissions, presenting major health and environmental challenges. Addressing these issues is crucial for Poland's energy future. The government's commitment to nuclear energy, alongside investments in renewable sources, reflects a strategic pivot towards a more sustainable and secure energy system, aligning with EU climate policies and long-term economic and environmental objectives (IAEA 2024).

2.2.3 BENEFITS OF JOINING THE EUROPEAN UNION

Since Poland joined the European Union, the dynamics of its energy policy have undergone significant changes. The EU's stringent climate goals and environmental regulations have placed considerable pressure on Poland to reduce its reliance on coal. The EU Climate Law mandates achieving climate neutrality by 2050, pushing member states to adopt more sustainable energy practices (European Commission n.d.). This regulatory framework is coupled with substantial financial incentives from the EU, aimed at accelerating the transition to renewable energy sources and enhancing energy efficiency (REGlobal 2023). Additionally, Poland is advancing its nuclear energy program, with plans for the first nuclear power plant to become operational in the early 2030s.

Despite these positive developments, Poland faces challenges in aligning its national policies with EU expectations. The lack of a coherent and updated national energy strategy, coupled with political resistance to EU directives under the banner of "sovereignty," has hindered more rapid progress (REGlobal 2023). However, the potential benefits of a successful transition are substantial. The energy transition could stimulate economic growth, create jobs, and enhance energy security. For instance, the development of offshore wind energy alone could generate significant employment and position Poland as a regional leader in clean energy (Ember 2023).

In summary, Poland's post-EU accession energy policy reflects a complex interplay of regulatory pressure, financial support, and the strategic need to diversify its energy mix. The shift towards nuclear energy and increased investment in renewables underscore Poland’s commitment to achieving a sustainable and resilient energy future, despite the ongoing challenges of balancing domestic and international demands.

2.3 CURRENT ENERGY POLICIES IN POLAND

Polish Energy Policy until 2040 (EPP2040) is a comprehensive framework designed to guide Poland's energy transition. This policy aims to balance energy security, economic development, and environmental sustainability while adhering to both local and international requirements, including EU climate objectives and regulations. As Poland moves away from coal-generated power, EPP2040 will play a crucial role in this transition. One of its key goals is to reduce coal consumption for energy generation from 70% to 11% by 2040 (Aruga et al. 2021). To achieve this ambitious target, Poland plans to significantly enhance its solar and wind power capacities, with

offshore wind energy expected to reach 8–11 GW by 2040. Subsidies and incentives for both large-scale and distributed solar power installations are also part of this strategy.

EPP2040 emphasizes the need for a balanced energy mix, incorporating nuclear and renewable energy sources. The policy outlines plans to develop 6 to 9 GW of nuclear electricity by 2040, with the first nuclear unit projected to commence operations by 2033. This reliable, carbon-free power source is expected to improve Poland's energy security and contribute to its climate goals (Mărgineanu and Arkadiusz 2023).

Despite previous attempts to reduce coal consumption, Poland continues to import natural gas. However, the expansion of nuclear power is anticipated to decrease this demand. EPP2040 also prioritizes energy efficiency, aiming to reduce primary energy use by 23% by 2030 compared to 2007 levels. This involves modernizing industrial processes, improving building energy efficiency, and educating the public about energy-saving products and practices, all of which are crucial for reducing costs, enhancing reliability, and lowering emissions (Mărgineanu and Arkadiusz 2023).

EPP2040 and related policies place significant emphasis on enhancing energy security. The strategy includes developing diverse energy sources, minimizing imports, and improving the energy system. For instance, the Baltic Pipe project will facilitate the import of Norwegian gas, and new LNG production infrastructure is being installed. The policy also aims to establish energy reserves and upgrade power infrastructure to better accommodate renewable energy sources. To support this transition, various additional rules and regulations have been implemented, including

the Act on Renewable Energy Sources, which promotes renewable energy development through investment incentives, feed-in tariffs, and auctions (Sainz de Vicuña 2022).

The Energy Efficiency and Electromobility and Alternative Fuels Acts are designed to enhance the use of electric vehicles and charging stations. The Act on Energy Efficiency sets targets and constraints for energy efficiency improvements. The National Energy Conservation Plan (NECP) 2021–2030 provides further strategies and targets to meet EU energy and climate goals, emphasizing the importance of research, innovation, and digitization in transforming the energy sector. EPP2040 also addresses the economic and social implications of the energy shift. The coal transition strategy includes measures to support workers and communities affected by coal mine closures, such as retraining programs, economic diversification efforts, and financial assistance. This approach aims to ensure a fair and sensible transition that offers new opportunities for coal-dependent communities (Strugała-Wilczek et al. 2022).

2.4 SPEED OF ENERGY TRANSITION

Since the late 1970s, energy technology researchers have focused on understanding the process of technological substitution in energy supply. Over the past 50 years, researchers have identified patterns in historical shifts in energy supply, noting that large-scale technological changes historically took decades to materialize (e.g., Smil 2016). However, addressing climate change necessitates a much faster transformation of modern energy systems compared to these historical precedents (e.g., Vinichenko, Cherp, and Jewell 2021). Consequently, the duration of low-carbon energy transitions and the potential for their acceleration are critical questions for both scientists

and policymakers. In the subchapter we look at the technology as a driver of the speed of energy transition as well as the geopolitical component as a driving factor.

2.4.1 TECHNOLOGY AS A DRIVING FACTOR

Whether a nation uses conventional or renewable technologies determines its renewable energy adoption rate. Recently, solar photovoltaic (PV) systems, wind turbines, and alternative battery storage technologies have improved in efficiency and cost. Technical advances have led to widespread usage of this technology in power grids, reducing carbon emissions in many countries. However, technological innovation in the energy sector is not solely confined to renewables; advancements in fossil fuel technologies or any other that can potentially improve a country's national innovation capacity can also enhance a country's 'innovativeness' (LaBelle 2016).

Scholars argue (see, e.g. Smil 2010; Fouquet and Pearson 2012; Grübler and Wilson 2013) that significant shifts in energy systems typically take decades due to economic factors, technological innovations, and infrastructure. Large scale technologies require more time to enter the market due to the cost and complexity of experimentation (Bento 2013). Estimating the transition of nuclear power to a new energy source is challenging (Kiciński and Patryk 2021). Nuclear power's minimal carbon emissions and continuous electrical output make it an appealing energy source. Nuclear power facility regulations are overly strict, causing high costs and delays. Renewable technology may be adopted quicker, but these limits may slow the energy shift. Nuclear power's effects on various countries may be seen in their case studies. Kamyk et al. (2021) report that French policymakers considered nuclear power to overcome oil shortages in the 1970s.

The adoption of nuclear energy in Poland is becoming increasingly feasible and attractive due to advancements in nuclear technology, particularly with the development of Small Modular Reactors (SMRs). SMRs offer significant advantages over traditional large-scale nuclear power plants, including enhanced safety features, reduced construction times, and lower initial capital investment. These reactors are designed to be more adaptable and scalable, allowing for incremental capacity additions that can match the pace of demand growth and technological innovation (Direkli et al. 2023).

One of the key benefits of SMRs is their enhanced safety profile. They incorporate advanced passive safety systems that can operate without human intervention or external power sources, significantly reducing the risk of accidents (European Comission n.d). This safety feature is particularly appealing in the post-Fukushima era, where public and political acceptance of nuclear energy heavily depends on perceived safety.

In addition to safety, SMRs are designed for rapid and cost-effective deployment. Unlike traditional reactors, which can take over a decade to construct, SMRs can be built in modular factory settings and then transported to the site for assembly (European Comission n.d) . This modular construction approach not only shortens construction timelines but also reduces costs by standardizing components and processes. As a result, the financial barriers to nuclear energy adoption are lower, making it a more viable option for countries like Poland that are seeking to diversify their energy mix and enhance energy security (IAEA 2022).

2.4 ENERGY SECURITY AND INDEPENDENCE

Energy security, in general is defined by the four As: availability, accessibility, affordability and acceptability (Cherp and Jewell 2014). LaBelle delves deeper in the energy security debates

explaining how in 2021, Russia deliberately reduced gas supplies to Europe, using energy as a weapon to gain leverage over EU Member States; that what was once considered secure and affordable became unacceptable (2024). Societal aspirations and economic growth depend on energy security. In Poland's changing energy environment, infrastructure accessibility, energy source diversity, energy cost, energy supply dependability, and energy system resilience must be considered. Energy security is becoming more important as Poland moves from coal to cleaner energy sources, according to (Tobór-Osadnik et al. 2023). Poland's energy security strategy aims to reduce dependency on Russian natural gas supply to enhance national sovereignty and reduce geopolitical risk (Doś et al., 2023). This plan change supports energy self-sufficiency and resilience. Poland, a coal-dependent nation, prioritizes energy independence. The Paris Agreement's global environmental requirements make this particularly applicable (Tobór-Osadnik et al., 2023). Polish officials are contemplating nuclear power to boost energy independence and fulfil environmental criteria. Unlike fossil fuels, nuclear power generates no CO2.

Poland's search for renewable energy relies on this attribute (Proskurina et al. 2023). Polish officials are considering nuclear power to reduce their dependency on the volatile global energy market and strengthen their electrical infrastructure. According to Proskurina et al. (2023), Poland must emphasize nuclear infrastructure and technology advances to ensure energy security and that adding nuclear power to Poland's energy mix might boost economic growth, job creation, and technology. Nuclear power might help Poland fulfil its 2050 carbon neutrality targets and contribute to global climate goals by replacing coal-fired electricity (Tobór-Osadnik et al. 2023). Nuclear power has many advantages but also major drawbacks. According to Śliwińska et al. (2022), open and inclusive approaches are necessary to address important issues such as safety,

processing radioactive waste, regulatory compliance, and public acceptability are crucial. Śliwińska et al. (2022) emphasize the need of excellent communication and stakeholder participation for successful nuclear energy projects in Poland, ensuring public support and successful execution.

2.5 ENVIRONMENTAL SUSTAINABILITY AND CARBON REDUCTION

Poland faces a significant challenge in reducing its carbon emissions after decades of reliance on coal for electricity generation. This reliance has hindered the country's environmental sustainability. However, Poland's energy strategy and commitment to international agreements, such as the Paris Agreement, demonstrate its dedication to cutting carbon emissions and transitioning to a low-carbon economy (Wen 2023).

Historically, coal has been a reliable but environmentally detrimental energy source due to its greenhouse gas emissions. To address climate change and meet international requirements, Poland has committed to decrease carbon emissions and move towards cleaner energy. Nuclear power is central to this transition, offering a solution to reduce carbon emissions significantly and achieve environmental sustainability. Unlike coal-fired power plants, nuclear reactors do not emit greenhouse gases, making them more environmentally friendly base-load energy producers. Poland's reliance on nuclear power aims to minimize carbon emissions in the energy sector while ensuring a dependable electricity supply (Krupnik 2023).

Nuclear power is a key component of Poland's energy program to reduce fossil fuel use and diversify its energy portfolio. By incorporating nuclear energy, Poland seeks to enhance grid

stability and resilience while also leveraging renewable energy sources like solar and wind. This strategic approach not only benefits the environment but also stimulates the economy by fostering innovation and creating jobs in the renewable energy sector.

However, the widespread adoption of nuclear energy in Poland requires thorough analysis and the overcoming of several obstacles (Śliwińska et al. 2022). Key challenges include safety concerns, radioactive waste management, and environmental impacts, which continue to shape public opinion on nuclear power. Addressing these issues necessitates clear, honest information, robust regulatory frameworks, and active stakeholder engagement to garner support for nuclear energy programs.

Despite these challenges, advancements in nuclear technology have led to significant improvements in waste management, safety regulations, and reactor design. Modern nuclear reactors offer enhanced safety and efficiency, reducing environmental and operational risks. These technological improvements contribute to the long-term environmental benefits of nuclear power, making it a viable solution for Poland's energy transition (Sainz de Vicuña 2022).

2.6 SUMMARY OF THE LITERATURE REVIEW

In conclusion, the literature review highlights the complex interplay between historical reliance on coal, economic necessities, and future sustainability goals in shaping Poland's energy transition. The Multi-Level Perspective framework, emphasizing the dynamic interactions between different systemic levels, provides a valuable lens to understand the challenges and opportunities in this transition. Historical analysis reveals how Poland's energy infrastructure and policies have been

deeply influenced by its abundant coal resources and geopolitical factors, underscoring the importance of path dependency in current decision-making processes.

The review also identifies the strategic pivot towards nuclear energy as a critical component of Poland's efforts to diversify its energy mix and meet EU climate goals. Despite the significant hurdles, including high upfront costs and public opposition, advancements in nuclear technology, such as Small Modular Reactors, offer promising solutions. The integration of nuclear power with renewable energy sources is seen as a viable path towards achieving a stable, low-carbon energy future for Poland. This comprehensive analysis provides a solid foundation for understanding the multifaceted impacts of nuclear energy on Poland's energy security, environmental sustainability, and economic resilience.

3. METHODS

3.1 RESEARCH DESIGN

The research uses a qualitative interpretivist approach to understand the complex social, political, economic, and ecological factors influencing Poland's decision to adopt nuclear power. This approach examines meanings, perceptions, social constructions, and energy policy choices. The acoption of nuclear energy is impacted by different stakeholders, policy narratives, and institutional contexts (Doś et al., 2023). Interviews were conducted with Polish professionals to gather insights on nuclear energy implementation issues. These findings help analyze the sociopolitical factors influencing policy and public opinion. These are all well aligning with the interpretivist paradigm that emphasizes societal and individual interpretations of energy policy (Tobór-Osadnik et al., 2023).

Energy policies are shaped by sociocultural factors rather than being purely technological. They are influenced by politics, history, and society. This research employs interpretivist analysis to examine the symbols and rhetoric surrounding Polish nuclear energy. This approach reveals the intentions of officials and the sociopolitical factors affecting policy decisions. A review of Poland's energy strategy until 2040, known as EPP2040, is integral to this method. This involves analyzing public pronouncements, legislative texts, and policy documents (Proskurina et al., 2023). The analysis determines the policy's objectives, implementation methods, and alignment with national and international goals.

The effectiveness, consistency, and practicality of current policies are assessed to promote nuclear power as a safe and environmentally friendly alternative to fossil fuels. The energy policy analysis examines both the intended and unintended social, economic, and environmental impacts (Śliwińska et al. 2022). The study identifies gaps, contradictions, and bottlenecks in the development of Polish nuclear power plants by reviewing key standards.

3.2 INTERVIEWS

The interview method was employed to gather qualitative data, capturing in-depth insights and personal perspectives on Poland's nuclear energy transition. A semi-structured interview guide was developed, covering topics such as energy policy, nuclear energy adoption, environmental concerns, and socio-economic impacts. Interviews were conducted through Zoom each lasting approximately 30 to 40 minutes. Participants were informed about the study's purpose, assured of confidentiality, and provided consent for recording. All interviews were audio-recorded, transcribed verbatim, and cross-checked for accuracy before analysis. The transcripts were imported into qualitative data analysis software for systematic coding. An initial set of codes was developed based on the interview guide, with additional codes emerging during the iterative review of the transcripts. The coded data were grouped into themes representing key topics and patterns in the participants' responses. Thematic analysis was used to interpret the data, identifying common themes and divergent viewpoints, aiming to uncover the underlying motivations, values, and decision-making processes influencing Poland's nuclear energy policies. Triangulation was employed to enhance the validity and reliability of the findings by cross-referencing interview data with information from document analysis and participant observation. Ethical considerations included obtaining informed consent, ensuring confidentiality, and secure data storage. This

interview method provided rich qualitative insights into the complex factors influencing Poland's nuclear energy transition, contributing significantly to understanding the social, political, and economic dimensions of energy policy in Poland.

3.3 SECONDARY RESEARCH

Polish energy policy, particularly regarding nuclear power and energy transition projects, is analyzed using secondary data sources and data analysis methods. Secondary sources provide a comprehensive assessment of Poland's energy policy, including its historical context, international obligations, and parallels with other energy transitions. These sources include journal articles, policy papers, reports from national and international organizations, trade journals, energy and environmental research websites, and other credible sources. Peer-reviewed scholarly papers explore the social, economic, technical, and environmental impacts of nuclear energy. Policies from government ministries, regulatory bodies, and international organizations play a crucial role in shaping energy policy and strategy.

Assessing Poland's energy transition and carbon reduction commitments involves examining them against the Paris Agreement, EU directives, and the Energy Policy until 2040 (Swora 2023). Reports from organizations like the International Energy Agency (IEA), European Commission, World Bank, and national energy bodies analyze trends in the energy industry and provide policy recommendations. Empirical data, case studies, and comparative evaluations of energy policies in different countries help readers understand the best practices and challenges associated with transitioning to alternative energy sources.

For research purposes, secondary data analysis involves combining data, identifying patterns, and drawing conclusions using both quantitative and qualitative methodologies. The study identifies patterns, debates, and information gaps in the field to generate research questions and hypotheses. It also highlights emerging trends through a thorough review of the literature. Content analysis is used to interpret policy documents, reports, and academic studies, aiding in understanding and advancing Poland's energy policy and strategic objectives (Krawczyńska et al. 2024).

The method begins with a detailed literature review, comparing policy goals, technologies, and socioeconomic impacts. Content analysis categorizes text to identify patterns and compare perspectives, enhancing the development of Poland's energy policy. This approach contrasts Poland's energy policy with those of other nations facing similar energy transition challenges and opportunities. Case studies and international benchmarks are used to evaluate policies, technological choices, regulatory frameworks, and socio-economic outcomes in diverse contexts (Drożdż et al. 2021). A detailed analysis of multiple approaches helps Poland understand the implications of nuclear energy and make informed energy policy decisions.

3.4 DATA ANALYSIS TECHNIQUES

This thesis examines Polish energy policy, with a particular focus on nuclear power and energy transition. The data analysis methods employed include qualitative theme analysis and policy analysis frameworks.

3.4.1 QUALITATIVE THEME ANALYSIS

Thematic analysis is a reliable method for identifying, analyzing, and interpreting themes within qualitative data. This technique allows researchers to uncover underlying meanings and patterns

within Poland's comprehensive energy policy. The initial step in qualitative analysis involves mastering various methodologies, such as open-ended surveys, focus groups, and interviews. This process includes multiple reviews of transcripts to thoroughly understand the content.

First, the data is systematically coded by selecting and categorizing relevant segments. These codes help assess the viability of nuclear energy, the efficacy of policies, stakeholder views, and socioeconomic impacts. By grouping codes based on similarities and connections, researchers can identify themes (Ciołek, Maciej et al. 2022). These themes reveal trends and provide insights that inform Poland's energy strategy. The study continuously reviews and refines these themes to maintain coherence and relevance. Understanding the linkages between themes and subthemes is crucial for comprehending Polish energy policy.

3.4.2 POLICY ANALYSIS

Policy analysis is used to examine Poland's nuclear energy and energy transition policies, regulations, and strategies. This comprehensive approach combines qualitative and quantitative data to evaluate the effectiveness of policies, highlight their advantages and disadvantages, and suggest practical and successful policy adjustments. Policy analysis must consider the environmental, social, and political factors influencing energy policymaking (Wiśniewska et al., 2021). It is essential to account for internal factors, international obligations (such as the Paris Agreement), and historical events in Poland's energy strategy.

Explaining Poland's energy policy to reduce carbon emissions, improve energy security, and deploy renewable energy is crucial. Evaluating Poland's Energy Policy until 2040 helps understand policymakers' objectives and strategies (Plich et al. 2020). Polish energy strategies should be

assessed concerning their available resources. Legislation, financial incentives, technical assistance, and public-private partnerships can support nuclear energy and energy transition goals. Understanding the roles, concerns, and impacts of stakeholders is vital when developing and implementing energy policy. Stakeholders may include government bodies, private organizations, educational institutions, energy companies, environmental groups, and local communities (Zoll 2022). Analyzing stakeholder dynamics can provide insights into policy endorsement, cooperation, and implementation challenges.

Impact studies on socioeconomic conditions, environmental sustainability, and energy security are necessary to evaluate energy policy. These assessments measure policy implementation progress and goal achievement. The study offers evidence-based energy policy recommendations to enhance Poland's efficiency, consistency, and sustainability. Policy, regulatory, investment, and capacity-building measures can promote nuclear power and facilitate the energy transition. Systematic policy analysis supports informed decision-making, improves policy effectiveness, and enhances the understanding of Polish and international energy policy trends. Ethical considerations in data analysis ensure honesty, transparency, and stakeholder involvement throughout the policy analysis process (Żak-Skwierczyńska 2022).

4. RESULTS

The study's primary findings on energy policy and nuclear energy in Poland are summarized below, providing a foundation for the discussion on energy transition and policy linkage. The research highlights Poland's ongoing energy transformation and the key challenges faced within the sector. Historically, Poland's energy mix has heavily relied on coal and other fossil fuels. However, the transition to greener electricity sources remains challenging (Mysak et al. 2024). The study further reveals the complexities of balancing environmental protection, economic profitability, and energy security.

The discussion section analyzes these findings, exploring their significance and implications from various perspectives. It starts with a detailed examination of how Poland's energy infrastructure and regulatory frameworks have influenced energy transition efforts. The Polish energy strategy for 2020–2040 (EPP2040) emerges as a pivotal policy shaping the current energy transition landscape (Wyrwa et al. 2022). The analysis compares Poland's energy transformation against international commitments like the Paris Agreement and the European Green Deal, as well as regional and global developments. This comparative approach aims to evaluate the alignment of Poland's energy policies with sustainability objectives and identify potential areas for improvement.

Additionally, the study focuses on the role of nuclear power in enhancing energy security, reducing carbon emissions, and its economic impact within Poland's energy mix. It critically assesses the benefits and drawbacks of incorporating nuclear energy. The thesis concludes with policy and strategic recommendations derived from the comprehensive investigation, aiming to support Poland's sustainable energy transition..

4.1 HISTORICAL INFLUENCES ON NUCLEAR ENERGY ADOPTION

Poland's nuclear energy views are complicated, as the interview results show. According to interviews with the experts, the Polish government's nuclear power policy is impacted by several energy industry factors. Interviews indicate that Poland's energy infrastructure and legislation are rooted in coal and other fossil fuels. For decades, coal has been the country's main energy source due to its huge coal deposits and long-standing economic benefits of mining and electricity generation (Kamyk et al. 2021). Given all these constraints, nuclear power and other alternative energy sources have made little progress despite environmental concerns and global energy consumption trends. The interviewees also noted geopolitical issues, such as energy security concerns due to the rising use of imported fossil fuels. The justification for coal usage were “low cost, high security and social support” (LaBelle 2020, 92). These were all questioned after the Russia used energy as a weapon. After recent geopolitical events disrupted energy supply networks, it is advised to be cautious when contemplating nuclear power to diversify the energy mix, improve energy security, and minimize imports (Kowalska et al. 2022).

Recent studies of Poland's energy infrastructure demonstrate that the government has long financed coal-fired power units and connected firms. Energy and economic resilience policy and public perception have been affected by this infrastructure. Even though nuclear power may cut carbon emissions and supply base-load electricity, coal's continued usage in energy production has hampered the shift. Kiciński and Patryk (2021) also highlight the importance of economic concerns, public opposition, and regulatory issues in past nuclear energy projects' triumphs and

failures. Due to historical disputes, politicians must balance economic growth, environmental protection, and energy self-sufficiency.

4.2 CURRENT POLICY PRIORITIES FOR NUCLEAR ENERGY

After reviewing Poland's nuclear energy policy goals, several interesting results emerged. The findings explain EPP2040's long-term goals and how they connect with the nation's nuclear energy strategy. Energy policy Plan 2040 (EPP2040) is crucial to Poland's nuclear power use (Janaszek et al. 2023). Diversifying the energy mix, reducing greenhouse gas emissions, and improving energy security are the main goals of the strategy. These findings suggest that nuclear power is essential for phasing out coal whilst providing a stable and sustainable energy supply. Additionally, the policy analysis emphasizes the government's commitment to nuclear power as a reliable base-load electricity source. Energy security concerns due to Poland's previous coal use and the need to reach EU energy transition targets drove this plan (Langerak 2023). However, the interviews show that there is concern regarding how how ambitious the strategy questioning whether it will be able to operate as per the said deadline, not putting into question whether this is the right move or not.

The complete EPP2040 framework facilitates nuclear energy deployment. It includes legislative reforms, infrastructure construction, and financial incentives. To increase grid stability and meet rising energy demand, Poland must invest heavily in nuclear generating stations to reach carbon neutrality by 2050 (Bednarczyk et al. 2022). The policy framework incorporates public support, environmental concerns, and technical readiness whilst developing nuclear power stations.

4.3 INTERNATIONAL PRESSURES AND GLOBAL TRENDS

Understanding how international agreements and global trends have affected Poland's energy policy is essential to understanding its energy transition plans and nuclear power strategy. International agreements like the Paris Agreement and the European Green Deal affect Poland's energy strategy. These treaties required Poland to switch from coal to cleaner electricity. These accords have lofty greenhouse gas emission and renewable energy objectives. The accords aimed to reduce atmospheric hydrogen and carbon dioxide. Poland must adapt its energy strategy to comply with these agreements, which mandate rigorous climate change mitigation (Hafner et al. 2020). To meet global expectations and obligations, this will be done. The energy shift worldwide favors nuclear power due to its dependability and minimal carbon emissions.

Countries like China, Finland, and France have successfully integrated nuclear power. These countries demonstrate that nuclear power may support energy security and climate development. Polish energy planners should note these achievements as they suggest nuclear power is a viable and beneficial choice. Reason: worldwide transition towards sustainable energy systems. Comparing energy transitions in various countries helps us understand nuclear power's merits and downsides. Various EU states have used various tactics regarding their national energy transitions (Ciołek, Maciej et al. 2022). Germany and Sweden are switching from nuclear to renewable energy. However, Russia and the US continue to expand their nuclear capabilities, highlighting the relevance of nuclear power in carbon mitigation and energy security. Poland is adopting foreign methods to handle nuclear power's social, scientific, and regulatory issues (Plich et al. 2020). To

completely understand nuclear power's pros and downsides in Poland's energy transition, one must understand its regulatory frameworks, public views, and economic effects.

4.4 ALIGNMENT WITH CARBON REDUCTION TARGETS

It is important to consider nuclear energy's environmental effect, conflicts, and synergies whilst assessing its position in Poland's energy strategy. Poland must move away from coal usage to cut carbon emissions. Poland produces most of its energy from coal. Although nuclear power may be more environmentally friendly. Nuclear power may reduce Poland's emissions and carbon impact (Żak-Skwierczyńska 2022). The Paris Agreement and European Green Deal set global climate targets. Nuclear power also provides reliable nighttime energy, which helps compensate for wind and solar's less predictable output. Poland can speed up its decarbonization by using this synergy. Poland can increase sustainable energy production and power infrastructure stability with this partnership (Konopelko et al. 2023). Nuclear power stations' electricity producing capabilities help Poland combat climate change and increase energy security.

The interviews show that for Poland the main driving factors for change are the energy security and the air pollution caused because of coal burning. However, of course nuclear energy has its environmental advantages compared to fossil fuel sources. The interviews also make it clear that public perception regarding nuclear safety has changed during the recent years. The economic viability of nuclear power facilities must be carefully considered together with their construction and legal compliance costs (Zoll 2022). To optimize Poland's energy transition, nuclear and renewable energy technologies may be integrated. Mixing nuclear and renewable energy may

make hybrid power systems more resilient to energy price swings and supply outages. Energy efficiency, sustainability, and environmental effect may be enhanced by legislative frameworks and strategic planning that support nuclear-renewable energy collaboration (Malec 2022).

4.5 ENERGY SECURITY AND NUCLEAR POWER

Polish energy security is a major issue as it weighs nuclear and renewable energy options. Nuclear power must be strategically used to improve energy security, diversify Poland's energy mix, and reduce its dependency on imported fossil fuels (Pluta et al. 2023). Nuclear power provides reliable energy, unlike wind and solar, which are weather-dependent (Pluta et al. 2023). Nuclear power offers continuous electricity generation during peak hours or when weather circumstances prevent renewable energy supply. Customer and business satisfaction depend on it. Improved energy security in Poland creates a more stable and robust system that can endure power outages. Chernobyl and Fukushima have raised concerns about nuclear power's safety (Gierszewski et al., 2021). Although the nuclear industry has established tight safety regulations and technical improvements, nuclear power's potential risks need strict safety measures, extensive emergency preparation, and efficient public-private collaborations to reduce them.

The interviews assessing the move of introducing nuclear as a means of energy security do not show a concern of the fact that Poland will still rely on imports for its nuclear fuel. This is a crucial point since Poland must examine its nuclear fuel imports. This emphasizes the significance of stable supply networks and worldwide links for contemporary energy independence and security. Poland can meet its energy demands and reduce its dependence on fossil resources by importing nuclear fuel, despite its aspirations to increase nuclear power generation. Wind and solar energy

are abundant and environmentally friendly, but weather may impact their predictability. This creates challenges in maintaining system stability and meeting energy needs (Krawczyńska et al. 2024).

Installing backup power sources or energy storage technology to reduce fluctuations makes renewable energy integration harder and more expensive. Nuclear power plants may be extended to satisfy a major portion of Poland's energy demands since they typically generate enormous amounts of electricity. This capability strengthens Poland's energy security by diversifying and strengthening its energy portfolio. Nuclear power may be integrated with renewable energy sources via smart grids or hybrid energy systems to improve energy management and resilience to external interruptions (Swora 2023). Poland's energy security strategy may improve reliability by integrating nuclear and renewable energy.

4.6 ECONOMIC AND STRATEGIC IMPLICATIONS

Many essential factors must be considered when considering the geopolitical and economic effects of Polish nuclear power ambitions. Significant initial investment is necessary. Building nuclear power plants is expensive. Prerequisites include infrastructure development, licence acquisition, and strict safety requirements (Kiciński and Patryk, 2021). Nuclear generating plants must pay these costs for safety and reliability. Despite greater beginning costs, nuclear power plants offer lower running costs than fossil fuel plants. Because nuclear power plants are more efficient than fossil fuel ones. Because nuclear fuel is more cost-effective than fossil fuels, long-term electricity

prices remain steady. For energy-intensive companies, energy cost certainty helps them reduce operational costs and boost economic competitiveness.

However, numerous factors affect Polish nuclear power facilities' financial sustainability. Skilled workers and engineers throughout construction and operation, enough money, and government support and incentives to enable project execution are important (Janaszek et al. 2023). Interviews brought to light the discussion of how strategically this is not just about investing and incorporating a cleaner technology, it is also about the process of shutting down this long-lived coal industry and infrastructure that exists in the bones of the Polish community and economy. Interviews also indicate that Polish nuclear energy projects' futures are questionable. Due to financial risks and regulatory issues, stakeholders doubt these projects will proceed.

Nuclear power is included in Poland's Energy Policy until 2040 (EPP2040) to increase energy independence and reduce fossil fuel imports. According to Ciołek et al. (2022), nuclear power offers reliable electricity, unlike wind and solar. For Poland's energy security, the energy system must be reliable to maintain stability and resilience in the event of resource supply disruptions. Poland's long-term environmental goals and global greenhouse gas reduction goals support nuclear power. According to Hafner et al. (2020), effective communication, strict safety protocols, and stakeholder engagement throughout the project's lifespan are essential to building public trust and addressing scientific concerns about nuclear energy.

4.7 POLICY RECOMMENDATIONS

The extensive project study provided several important policy suggestions. These suggestions aid Polish stakeholders and policymakers in nuclear resource deployment. The study found that nuclear power plants struggle with complex and unexpected regulations. Politicians must simplify regulations to reassure developers and investors. Safety, environmental impact evaluations, and nuclear energy project licencing regulations are developed throughout this phase. Polish nuclear infrastructure development rules must be transparent and streamlined to speed up and attract investment. Policymakers should research and subsidise nuclear energy projects to mitigate hazards and increase practicality due to their large upfront costs. Tax breaks, loans, and reimbursements may be provided for early capital investments (Bednarczyk et al., 2022). By investigating novel finance models like PPPs, public and private sectors may better match financial incentives and share risks. Research and development must be sponsored to improve nuclear safety and efficiency.

Universities, companies, and NGOs should receive government funding for joint R&D. Promote innovative waste management, nuclear fuel cycle management, and reactor development. Poland may pioneer safe, sustainable nuclear energy by fostering research and development (Konopelko et al. 2023). Concerns regarding radioactive waste management and public safety may prevent nuclear power adoption. We must communicate properly and include the public to build trust and dispel myths. Nuclear energy safety, environmental advantages, and energy security should be government education priorities. Local communities and stakeholders must be informed and included during projects. This enables open contact and addresses their issues. For energy

sustainability and security, nuclear energy growth must complement Poland's energy policy objectives.

The Polish Energy Policy until 2040 (EPP2040) requires updating for nuclear energy issues. This involves setting nuclear energy capacity goals, integrating renewable energy into the power grid, and promoting low-carbon technology collaboration. Given the worldwide scope of nuclear energy policy and technology, governments must prioritize cross-border collaboration. Sharing technical knowledge, regulatory experiences, and best practices with nuclear suppliers, international bodies, and neighboring governments is essential (Wiśniewska and J. 2021). Poland can strengthen nuclear energy project execution, safety, and non-proliferation compliance by joining international forums. A credible monitoring and assessment approach is required to evaluate nuclear energy plans and programs throughout time. Policymakers should track financial, energy, and environmental objectives via KPIs. To fit nuclear energy projects to public preferences, market circumstances, and technical improvements, adaptive policymaking requires frequent reviews and assessments.

4.8 SUMMARY OF KEY FINDINGS

Nuclear energy deployment in Poland was extensively studied. Here's a brief overview of the biggest findings and their implications. Nuclear power reduces Poland's dependence on coal and boosts energy self-sufficiency, according to the findings. Nuclear power is reliable and consistent, reducing use of foreign energy and supply chain hazards. This kind ensures a consistent and uniform energy supply, particularly during peak demand or resource delivery outages. Nuclear power's potential to help Poland's environmental sustainability goals is notable. Nuclear power

generation's minimal greenhouse gas emissions may help meet global carbon reduction targets like the Paris Agreement. This study shows that Poland can meet its energy goals using nuclear power, a low-carbon alternative that can complement intermittent renewable sources and contribute to a cleaner, more sustainable energy future. These findings illuminate Poland's nuclear power transition's pros and cons. Nuclear generating plants need large upfront investments. However, they also provide long-term economic benefits including stable energy prices and specialized industry employment.

Nuclear power also boosts Poland's strategic autonomy by minimizing its need on foreign energy sources and guaranteeing a steady, cost-effective energy supply throughout the mission. The findings suggest that a legislative framework and reduced regulatory structure are necessary for a Polish nuclear energy adoption strategy to succeed. Polish nuclear energy development is guided by EPP2040, the energy policy until 2040. It specifies capacity-building objectives. Streamlining regulatory obligations, gaining public support, and integrating nuclear energy into energy policy objectives are ongoing challenges. Studies have demonstrated that public opinion and stakeholder participation considerably affect nuclear energy acceptability. To address safety risks, resolve misconceptions, and build confidence amongst local communities and stakeholders, the report recommends clear communication, education, and involvement.

Communication with stakeholders and participatory decision-making are needed to get public acceptance and agreement on nuclear energy projects. International collaboration and scientific advances are crucial to Polish nuclear energy usage, according to the research. Knowledge transfer, safety improvements, and nuclear energy best practices may be achieved by working with

regulatory organizations, foreign partners, and nuclear suppliers. Research and development also advance technological improvements, improves reactor performance, and resolves nuclear waste and decommissioning issues. This study then advises Polish lawmakers and other stakeholders on several important issues. A few ways to address the issue are simplifying regulations, funding relevant causes, engaging the public, integrating nuclear power into comprehensive energy policies, promoting international collaboration, and implementing rigorous assessment systems to track progress. These guidelines must be followed to maximize nuclear power's benefits and minimize its hazards.

5. DISCUSSION

The discussion section of this thesis explores the multifaceted dynamics of Poland's energy transition, focusing on the significant role of nuclear energy in this process.

5.1 HISTORICAL RELIENCE ON COAL

Poland's historical reliance on coal and other fossil fuels has been a defining characteristic of its energy sector. This dependence has not only fueled industrial growth but also contributed significantly to environmental and energy security challenges. The transition to greener electricity sources remains a complex endeavor, fraught with economic, environmental, and geopolitical hurdles (Mysak et al. 2024).

5.2 ENERGY POLICY UNTIL 2040 (EPP2040)

The Energy Policy of Poland until 2040 (EPP2040) is pivotal in shaping the country's future energy landscape. This policy aims to drastically reduce coal consumption, increase renewable energy use, and integrate nuclear power to ensure a stable and sustainable energy supply (Wyrwa et al., 2022). The policy outlines ambitious targets, such as reducing coal's share in the energy mix to 11% by 2040 and enhancing the capacities of solar and wind power. Nuclear energy is projected to play a crucial role, providing a reliable base-load power source that complements intermittent renewables.

5.3 ECONOMIC AND GEOPOLITICAL INFLUENCES

From a historical perspective, Poland's energy infrastructure and regulatory frameworks have been heavily influenced by its coal-dominated past. The interviews conducted during this research reveal that economic benefits, geopolitical considerations, and social factors have all contributed to the sustained reliance on coal. However, recent geopolitical events, such as the Russia-Ukraine conflict, have underscored the vulnerabilities of relying on imported fossil fuels, prompting a reconsideration of energy strategies (Kowalska et al. 2022).

5.4 NUCLEAR POWER AS A KEY SOLUTION

Nuclear power emerges as a key solution in this context, offering a means to enhance energy security, reduce carbon emissions, and support economic growth. The adoption of nuclear energy is not without challenges, including high upfront costs, regulatory complexities, and public perception issues. Nevertheless, advancements in nuclear technology, particularly the development of Small Modular Reactors (SMRs), have made nuclear energy more accessible and safer (Direkli et al. 2023).

5.5 INTERNATIONAL COMMITMENTS AND COMPARISONS

International agreements and global trends also exert significant pressure on Poland's energy policies. Commitments to the Paris Agreement and the European Green Deal necessitate a rapid transition from coal to cleaner energy sources. The study compares Poland's energy transition efforts with those of other countries, highlighting successful nuclear integration cases like China, Finland, and France. These comparisons provide valuable insights into best practices and potential pitfalls (Hafner et al. 2020).

5.6 BACK TO THE RESEARCH QUESTION

The primary research question—how the desired speed of energy transition in Poland influences the decision to incorporate nuclear energy—is answered by the findings. The urgency of reducing carbon emissions and enhancing energy security has driven Poland to adopt nuclear power as a crucial component of its energy strategy. Technological advancements and international commitments have further accelerated this transition, demonstrating that a rapid and balanced approach to integrating nuclear energy with renewables is necessary for achieving Poland's energy and environmental goals.

The discussion highlights the complex interplay of historical, economic, environmental, and geopolitical factors in Poland's energy transition. The findings suggest that nuclear power can significantly reduce Poland's dependence on coal, enhance energy security, and contribute to environmental sustainability. However, successful implementation requires a supportive legislative framework, public acceptance, and international cooperation.

6. CONCLUSION

6.1 SUMMARY OF RESEARCH

This study assessed nuclear power's merits, cons, and options in light of Poland's changing energy situation. The research investigated Poland's energy strategy to see whether nuclear power can increase energy security, environmental protection, and economic development. Poland's energy policy sought global influences. Polish Energy Policy till 2040 was another target to evaluate. The inquiry exposed Poland's intricate nuclear energy use. Understanding how nuclear power helped Poland switch from coal and other fossil fuels to a more diverse energy mix was the first step to energy security. This understanding precedes Poland's energy security boost. Poland needs nuclear electricity for environmental sustainability. Low-carbon nuclear power helps Poland satisfy international climate agreements including the Paris Agreement's carbon reduction commitments. Polish nuclear power facilities have good and negative economic consequences, study revealed. The ability to choose energy buying methods, steady power cost, and specialization are further advantages.

Despite hefty startup costs, long-term benefits exist. The report advocated a supportive legislative framework, a favorable regulatory environment, and stakeholder-involved methods to launch nuclear energy projects. Public opinion and stakeholder participation impact nuclear power integration speed, study shows. To solve safety issues and gain societal acceptability, honest communication, education, and collaborative decision-making were recommended. This was the only method to fulfil these aims. International cooperation and nuclear energy technology have

improved decommissioning, waste management, and safety. The social, policy, and strategic impacts of nuclear energy in Poland are examined in this study. Goals, obstacles, and conclusions of the research are listed below. Nuclear energy's diversified role in Poland's energy transition is addressed here. To maximize nuclear energy's advantages and mitigate its drawbacks, well-rounded policy efforts, strong regulatory institutions, and stakeholder participation are needed.

6.2 CONTRIBUTIONS TO KNOWLEDGE

To comprehend nuclear power in Poland, this study investigates its intricacies and implications. Empirical data and theoretical frameworks illustrate energy transition challenges in a coal-dependent economy, increasing our understanding. This improves energy policy and change theory. The article shows how politics, economics, technology, and history impact nuclear energy policy. The study addresses gaps in our understanding of nuclear power's capabilities to promote sustainable development in Central Europe, reduce greenhouse gas emissions, and boost energy security. This research examines nuclear power's social acceptability, environmental implications, and economic feasibility using primary and secondary sources. Poland's energy policy includes these viewpoints. By studying complicated energy policy challenges utilizing policy analysis frameworks and qualitative-interpretivist approaches, the research advances methodology.

This rigorous method may enhance academic debate of empirical energy policy, environmental governance, and sustainable development research. Polish policymakers, industry stakeholders, and strategic planners may alter the energy sector using the study's practical results. Nuclear power's vital position in Poland's energy mix as a dependable, low-carbon alternative to coal and other fossil fuels is highlighted here. Results show nuclear power can help sustainable

development. They advocate for integrated energy solutions that balance economic, environmental, and national security. The report suggests nuclear energy-friendly measures. Openness and honesty are necessary for popular support. Investment in advanced nuclear technology, security regulatory frameworks, and international cooperation to use discoveries and best practices are also crucial. Successful nuclear energy facilities need extensive long-term planning and infrastructure investment. Economic development, skilled employment, and energy resilience may result from these initiatives. Poland can improve its image and satisfy energy demands responsibly by adopting the Paris Agreement.

6.3 LIMITATIONS OF THE STUDY

The study's heavy use of qualitative-interpretivist policy analysis frameworks is problematic. They provide valuable insights into stakeholder viewpoints and policy processes, but they may not be able to quantify quantitative indicators or attain statistical generalizability. But approaches are subjective. This limits the study's conclusions to its geographic or geopolitical context. This might happen without validation or comparisons. Secondary data sources like scholarly publications and policy papers are abundant and may be biased. Even with triangulated data from several sources, flaws or quality issues may compromise analysis and findings. Further difficulties include results generalizability and sample selection. This research polled Polish energy authorities and nuclear energy stakeholders using purposive sampling. This technique permitted thorough investigation into certain public opinion and personal experiences. However, public opinion on nuclear energy and research results' importance to all stakeholders must be addressed.

The research only investigated Poland's energy environment and policy framework; therefore, its conclusions may not apply to other nations or regions going through comparable energy transitions. This research may not apply to other countries owing to political, economic, and sociological considerations affecting nuclear energy viability and acceptance Issues with data dependability and availability hinder studies. We endeavored to acquire reliable and up-to-date information from reputable sources, but data accessibility or reporting limitations may have caused research errors. This restriction may leave policy and strategic notions incomplete. Time and scope constraints may have impeded a complete assessment of Poland's nuclear energy deployment. Energy policy and nuclear technologies need ongoing study and supervision. Time-sensitive studies may not precisely anticipate Poland's energy transition trajectory.

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6.4 RECOMMENDATIONS FOR FUTURE RESEARCH

Research should compare energy transitions amongst nations, especially those with different nuclear power use. Legal frameworks, public opinion, scientific breakthroughs, and economic considerations determine nuclear energy acceptability. Various social and political case studies may assist scholars comprehend these concerns. Comparative studies would improve worldwide nuclear energy policy. Longitudinal studies are needed to assess energy policies like Poland's Energy Policy until 2040 (EPP2040). Over time, these studies would evaluate policy implementation, effects, and sustainability and energy security objectives. Longitudinal assessments may aid sustainable energy transitions via policy reforms. These assessments highlight how government policy, technology, and socioeconomics interact. Researchers should examine nuclear power's merits and downsides from public, company, and government

viewpoints. Understanding the causes of nuclear energy adoption may aid targeted communication, policy outreach, and public engagement.

Participatory decision-making research and stakeholder engagement may make energy policy more transparent and inclusive. Future nuclear development should stress speed and safety. Investigate new nuclear reactor designs, safety standards, and regulations. Safety and feasibility study is needed to understand how advanced nuclear technologies like SMRs and generation IV reactors may diversify energy sources, decrease carbon emissions, and increase energy security. Research on nuclear waste management technology and environmental impact assessments must be done concurrently to meet nuclear energy growth sustainability challenges. Nuclear energy projects must undertake financial risk and cost-benefit evaluations regardless of legal or economic conditions.

Analysing long-term expenditures, renewable energy competitiveness, and government subsidies and incentives may enhance energy industry investment and resource allocation. Public-private partnerships and international cooperation may reduce the financial risks of large-scale nuclear energy infrastructure projects. Future research should provide new institutional structures and policy reforms to encourage nuclear energy for sustainable development. Studying regulatory frameworks, policy tools, and governance structures that allow integrated energy planning, grid modernization, and resilience-building may help construct a low-carbon, resilient energy system. Studying regional, national, and global policy coordination strategies may unite sectors and ensure policy consistency. This stage produces energy independence, environmental preservation, and economic prosperity.

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