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MASTER THESIS

"Determinants of Natural Gas Demand in Europe: A critical survey"

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Abstract

This thesis conducts a critical survey of the determinants influencing natural gas demand in Europe, within the context of rapidly evolving geopolitical, environmental, and technological landscapes. Against the backdrop of the European Green Deal, the post-pandemic economic recovery, and the energy security crisis precipitated by Russia's 2022 invasion of Ukraine, this study explores how multiple interconnected factors shape the consumption of natural gas across European markets.

Using a structured literature review methodology, the thesis systematically examines and categorizes key drivers into six dimensions: economic fundamentals, market dynamics, policy and regulatory frameworks, technological developments, environmental considerations, and geopolitical influences. Emphasis is placed on the methodological rigor and empirical consistency of recent studies, many of which employ econometric, equilibrium, or hybrid modeling techniques to assess short- and long-term demand elasticities. The research also integrates conceptual and theoretical frameworks such as the Energy Trilemma, Multi-Level Perspective (MLP), and diffusion of innovation models to contextualize the socio-technical and policy transitions affecting natural gas use.

Findings highlight that while economic activity and income growth remain fundamental drivers of demand, recent structural shifts—such as increased electrification, decarbonization policies, and LNG diversification—are redefining natural gas's role in Europe's energy mix. The study identifies key areas of consensus, such as the negative long-term impact of carbon pricing on demand, alongside points of contention, including the transitional function of natural gas in low-carbon scenarios. It concludes by proposing an analytical framework to guide future policymaking and research, emphasizing the need for a coordinated response to balance energy security, affordability, and sustainability in Europe's evolving gas landscape.

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Chapter 1: Introduction

1.1Background and Motivation

Natural gas is integral to Europe's energy industry, underpinning economic stability, energy security, and environmental goals. It has historically served as a vital resource for multiple applications, including residential heating, industrial manufacturing, and energy generation. As Europe's economy have progressed and modernised, the demand for natural gas has typically increased, owing to its adaptability and reduced carbon footprint relative to coal and oil. Significant alterations in the European energy environment are presently affecting the demand for natural gas.

Recent geopolitical developments have revealed Europe's susceptibility regarding energy security, particularly its dependence on imported natural gas. The Russian invasion of Ukraine in February 2022 marked a critical juncture for Europe's energy policies and economic stability. Before the conflict, Russia provided over 40% of Europe's gas imports, mostly via pipelines via Ukraine and the Nord Stream pipelines under the Baltic Sea. The ensuing geopolitical tensions precipitated rapid disruptions in petrol supply, price volatility, and considerable economic ramifications in European markets. Countries such as Germany, significantly dependent on Russian gas, faced serious repercussions, necessitating swift policy modifications and structural transformations in energy acquisition tactics.

Concurrently, Europe's policy framework has undergone a substantial transformation aimed at achieving ambitious climate objectives, notably with the introduction of the European Green Deal in 2019. This strategy seeks for the European Union (EU) to attain net-zero greenhouse gas emissions by 2050. The rapid implementation of renewable energy sources and significant improvements in energy efficiency are essential to these aims, hence contesting the conventional designation of natural gas as a 'transition fuel'. Previously seen as a transitional energy source between fossil fuels and renewables because of its reduced carbon intensity, natural gas is now subjected to heightened scrutiny and competition from growing renewable energy technologies, including solar photovoltaic (PV), wind power, and developing hydrogen solutions.

The evolving scenario has ignited a vigorous debate concerning the prospective role of natural gas in Europe's energy composition. Stakeholders, comprising governments, energy companies, and environmental organisations, are contending with the challenge of reconciling immediate energy security requirements with enduring environmental and climatic objectives. Moreover, public perceptions and social expectations about sustainable and resilient energy systems complicate the decision-making process for investments and policy directions in the natural gas sector. Understanding the intricate aspects that affect natural gas consumption in Europe is essential, encompassing economic, environmental, geopolitical, technological, and commercial elements. By acquiring comprehensive understanding of these determinants, policymakers and industry stakeholders can more effectively navigate the evolving terrain. This thesis intends to conduct a thorough analysis of available literature to analyse and integrate these aspects, elucidating the principal dynamics that will influence Europe's energy future.

1.2 Research Aims and Objectives

This changing dynamic has sparked a vigorous debate regarding the future role of natural gas in Europe's energy composition. Stakeholders, comprising governments, energy corporations, and environmental organisations, are grappling with the challenge of reconciling current energy security requirements with long-term environmental and climate objectives. Moreover, public perceptions and social expectations about sustainable and resilient energy systems further complicate the decision-making process for investments and policy directives in the natural gas sector.

It is essential to comprehend the many and interconnected aspects that influence natural gas consumption in Europe. Comprehensive and analytical insights into these drivers, encompassing economic, environmental, geopolitical, technological, and market factors, can offer vital direction to policymakers and industry players manoeuvring through this intricate landscape. In this context, this thesis conducts a thorough critical evaluation of the existing literature to systematically evaluate and integrate these drivers, therefore clarifying the essential dynamics shaping Europe's future energy trajectories.

Secondly, the thesis aims to rigorously assess the comparative importance and actual effects of each discovered factor. This research conducts a comprehensive critical evaluation of the strength, methodological integrity, and relevance of current empirical findings within the modern European setting. The review aims to achieve two objectives: first, to discern areas of agreement and dispute within the existing academic and industry literature; and second, to elucidate the significance and impact of various determinants on natural gas consumption.

Thirdly, a primary aim of this research is to elucidate areas of agreement and discord within the evaluated studies. The thesis employs a comparative and critical analysis to elucidate the present comprehension of natural gas demand dynamics, therefore pinpointing gaps and inconsistencies that may necessitate future inquiry.

The primary aim of this thesis is to integrate these findings into a cohesive analytical framework to provide actionable insights for policymakers and industry stakeholders. This framework aims to enable informed strategic decision-making on Europe's energy transitions, balancing urgent energy security needs with long-term sustainability goals.

The thesis seeks to clearly delineate substantial deficiencies in existing research. The research will identify underexplored areas and methodological deficiencies, proposing future research directions and recommending policy considerations to effectively tackle emerging challenges and opportunities in Europe's dynamic energy landscape. Accomplishing these objectives will foster a deeper comprehension of the complexity inside Europe's natural gas market, thereby enabling policymakers and industry stakeholders with the requisite information to adeptly negotiate and manage continuing shifts.

1.3 Overview of Methodology and Scope

This thesis employs a structured methodology, focusing on a comprehensive critical analysis and assessment of the literature regarding the determinants of natural gas demand in Europe. The methodology employs a systematic review process to identify, select, and evaluate relevant academic, industry, and policy literature. The criteria for selecting literature in this critical review ensure a rigorous, relevant, and comprehensive analysis. The criteria for selecting literature emphasise the significance of methodological rigour. Research should employ well-defined methodological frameworks, utilising analytical techniques including econometric modelling, qualitative analysis, or case studies. Studies that detail data sources, collection methods, and assumptions are prioritised to promote transparency and reproducibility.

Recent literature from the past decade is prioritised to accurately represent the contemporary energy landscape in Europe. The dynamic nature of the natural gas market, shaped by geopolitical events and technological advancements, necessitates an emphasis on contemporary sources for relevance and applicability.

The conducted survey comprehensively examines the primary factors influencing natural gas demand. The factors are classified into economic aspects, market trends, policies and regulations, technological advancements, environmental concerns, and geopolitical influences. The survey addresses Europe, incorporating viewpoints at both EU and national levels to examine regional variations and policy effects.

This study utilises a comparative analytical methodology to assess the consistency, reliability, and validity of findings across various studies. This comparative analysis identifies areas of agreement, conflicting results, and notable research gaps. This thesis employs a comprehensive methodology and scope, ensuring a critical and contextually relevant analysis that provides valuable insights into the evolving demand for natural gas in Europe.

1.4 Thesis Structure

The dissertation comprises eight chapters designed to thoroughly examine, analyse, and integrate information on the factors affecting natural gas demand in Europe.

Chapter 1 begins by presenting the research topic, outlining the background and motivation, clarifying the objectives, justifying the need for a critical survey, and specifying the methodology and scope.

Chapter 2 provides a comprehensive analysis of the European energy landscape, emphasising historical trends, current market dynamics, and the evolving role of natural gas within Europe's energy mix. This analysis explores the economic and environmental implications, policy developments, and the challenges and opportunities within the natural gas sector.

Chapter 3 details the research methodology employed, encompassing the criteria for literature selection, analytical techniques, and the justification for methodological choices. The text recognises the limitations of the selected approach, thereby promoting transparency and rigour.

Chapter 4 examines pertinent theoretical frameworks and economic models frequently employed in the analysis of energy demand, with a focus on natural gas consumption. This evaluates their relevance and applicability in the European context.

Chapter 5 provides a systematic review and evaluation of the factors that influence natural gas demand. This analysis examines economic factors, market dynamics, policy impacts, technological advancements, environmental considerations, and geopolitical influences, evaluating each determinant to determine its significance and implications.

Chapter 6 presents a comparative analysis and synthesis of empirical findings from the literature review, emphasising areas of consensus, conflicting evidence, and the strengths and weaknesses of various methodologies, while identifying research gaps and inconsistencies.

Chapter 7 examines the broader policy implications derived from the research findings, highlighting the interplay of determinants that influence Europe's energy security and strategic decision-making. The document offers specific recommendations for policymakers and industry stakeholders, along with proposals for future research avenues.

Chapter 8 concludes the thesis by summarising the primary research findings, delineating contributions to existing knowledge, addressing study limitations, and suggesting directions for future research.

Chapter 2: The European Energy Landscape and Natural Gas

2.1 Overview of the European Energy Market

The energy market in Europe is complex, characterised by a dynamic interplay of various energy sources, regulations, political factors, and emerging technologies. Europe's efforts to reduce carbon emissions are leading to significant changes in the role of natural gas within the energy landscape. Understanding the significance of natural gas requires an examination of Europe's overall energy landscape, particularly in the context of shifting supplies, emerging policies, and environmental objectives.

2.1.1 Energy Mix and Market Composition

Europe utilises a diverse array of energy sources, including fossil fuels (coal, oil, gas), nuclear power, and an increasing proportion of renewable energy such as wind, solar, hydro, and biomass. Historically, Europe has relied heavily on fossil fuel imports, with natural gas playing a significant role due to its lower pollution levels compared to coal and oil. Recently, there has been a decline in coal usage, accompanied by a significant increase in the adoption of renewable energy sources.

Recent data indicates that the European Union derives approximately 35% of its energy from oil, 25% from natural gas, 15% from nuclear sources, and over 20% from renewable energy sources. Renewable energy sources continue to expand due to climate policies and the decreasing costs of wind and solar technologies. Coal consumption has significantly decreased due to stringent environmental regulations and carbon pricing mechanisms such as the EU Emissions Trading System (EU ETS).

2.1.2 Market Liberalization and Integration

In recent decades, Europe has endeavoured to enhance the openness and connectivity of its energy markets. The Internal Energy Market (IEM) of the EU seeks to enhance competition, strengthen energy security, and improve efficiency through the facilitation of cross-border trading in electricity and gas. Significant initiatives such as the Third Energy Package (2009) and the Clean Energy for All Europeans Package (2019) have aimed to enhance market connectivity, improve transparency, and expand consumer options.

With the integration of gas markets, regional trading hubs have emerged, such as the Title Transfer Facility (TTF) in the Netherlands and the National Balancing Point (NBP) in the UK, which currently establish benchmark prices for European natural gas. These hubs facilitate market-based gas trading and contribute to price stabilisation by diminishing reliance on conventional long-term oil-indexed contracts. Despite advancements, regional disparities in infrastructure, regulations, and energy dependencies persist, influencing the efficiency of the European energy market.

2.1.3 Energy Security and Supply Diversification

Energy security is a significant concern for Europe, particularly in light of recent global events that have underscored the risks associated with excessive reliance on imported energy. The 2022 invasion of Ukraine by Russia marked a significant shift in European energy policy, necessitating a rapid reassessment of natural gas supply sources. Prior to this crisis, Russia accounted for approximately 40% of Europe's gas imports, primarily via pipelines such as Nord Stream, Yamal-Europe, and transit routes through Ukraine. In response to the crisis, the EU has actively pursued alternative suppliers, including increased liquefied natural gas (LNG) from the United States, Qatar, and Algeria. The EU has prioritised investments in LNG terminals, inter-country pipeline connections, and gas storage facilities to effectively manage supply disruptions. The REPowerEU plan, initiated in 2022, seeks to diminish reliance on Russian fossil fuels by promoting renewable energy, enhancing energy efficiency, and establishing new gas supply agreements.

2.1.4 The Role of Policy and Regulation

The European energy policy is significantly shaped by climate objectives, regulatory frameworks, and market mechanisms aimed at enhancing sustainability and reducing carbon emissions. The European Green Deal, introduced in 2019, establishes ambitious objectives for achieving carbon neutrality by 2050, including a target of a 55% reduction in greenhouse gas emissions by 2030 as part of the Fit for 55 initiative. Policies such as the Renewable Energy Directive (RED II) and the Energy Efficiency Directive have established more stringent emission reduction targets, necessitating a rapid transition from fossil fuels, including natural gas (European Parliament, 2022). The EU Emissions Trading System (EU ETS) has imposed financial constraints on fossil fuel energy production, thereby enhancing the appeal of renewable and low-carbon alternatives.

2.1.5 Future Trends and Outlook

Several key trends are expected to shape the future of Europe's energy market.

- Ongoing expansion of renewable energy sources, particularly wind and solar.
- Progress in energy storage, hydrogen, and carbon capture technologies that may alter the function of natural gas as a transitional fuel. Increased implementation of energy efficiency measures, resulting in reduced overall fossil fuel consumption.
- Changing global political dynamics are influencing supply chain security and trade relationships.
- Increased electrification in heating and transportation will lead to a reduction in direct gas consumption.

The role of natural gas in Europe's transition to a sustainable and resilient energy system is subject to ongoing debate. Although it is expected to maintain significance in the short to medium term, particularly for the integration of intermittent renewable energy, long-term projections indicate a gradual decrease in its proportion within Europe's energy mix.

2.2 The Role of Natural Gas in Europe

Natural gas has long been a significant component of Europe's energy system. It is a multifaceted fossil fuel that combusts more cleanly, utilised for electricity generation, industrial applications, and residential heating. In comparison to coal and oil, it generates lower greenhouse gas emissions, rendering it appealing for nations seeking to diversify their energy portfolios while reducing emissions. The role of natural gas is rapidly evolving due to emerging policies, technological advancements, and increasing concerns regarding energy security and climate change.

2.2.1 Versatility and Functional Importance

In Europe's energy system, natural gas serves a variety of critical functions. It serves as a counterbalance to variably renewable energy sources such as solar and wind in the power sector, as it can be rapidly increased or decreased as necessary. It functions as both a propellant and a raw material in industry, particularly in energy-intensive sectors such as steel, cement, and chemicals. In countries such as Germany, Italy, and the Netherlands, it remains a significant source of heating and cooking in both households and businesses. Natural gas contributes to the stability of the power grid by facilitating the rapid dispatch of energy during periods of high demand or supply disruptions. Additionally, it enhances energy efficiency by utilising waste heat in combined heat and power (CHP) facilities, which further solidifies its position in the energy mix.

2.2.2 Natural Gas as a Transition Fuel

Natural gas has been marketed as a "transition fuel" for the majority of the past two decades, serving as a transition from high-carbon fossil fuels to a future that is primarily fueled by renewable energy sources. It was a critical component of numerous national carbon emission reduction initiatives, particularly during the initial phases of incorporating renewable energy sources. This was due to its lower emissions in comparison to coal and oil.

Frequently, nations that have discontinued coal-fired power facilities have implemented gas as a temporary measure to maintain electricity supply while they construct renewable infrastructure. Additionally, the expansion of wind and solar capacity across the continent has been facilitated by the provision of flexible fallback for intermittent renewable generation by gas power plants.

2.2.3 Infrastructure and Market Presence

Europe's natural gas infrastructure is among the most advanced in the world, featuring a burgeoning number of LNG terminals, extensive pipeline networks, and subterranean storage sites. Significant LNG import terminals are situated in countries such as Spain, France, the Netherlands, and Poland, while major pipelines include Nord Stream, Trans Adriatic Pipeline (TAP), and Yamal-Europe.

The gas markets in Europe have become more open and connected, with trading centres such as TTF and NBP playing central roles in the establishment of prices and the arrangement of supply contracts. These mature and liquid markets have facilitated the diversification of suppliers and the reduction of reliance on long-term, oil-indexed contracts, thereby enhancing transparency and resilience.

2.2.4 Declining Role Under Climate Objectives

The long-term role of natural gas in Europe's energy system is increasingly threatened, despite its historical significance. The EU is accelerating its efforts to achieve net-zero emissions by 2050 through the European Green Deal and the Fit for 55 program. This entails a significant reduction in the consumption of all fossil fuels, regardless of their source, including natural gas.

Natural gas is increasingly perceived as a transitory solution rather than a permanent fixture in this context. There is an increased scrutiny of new investments in gas infrastructure, and certain financial institutions have begun to restrict funding for new gas initiatives. Simultaneously, the rapid expansion of renewable energy sources, enhancements in energy efficiency, and the emergence of technologies such as green hydrogen and battery storage are anticipated to diminish the demand for natural gas in the medium- to long-term.

2.2.5 The Emerging Role of Low-Carbon Gases

The concept of a decarbonised gas future is gathering traction as a means of maintaining the use of gas infrastructure while simultaneously meeting climate targets. This encompasses the gradual substitution of natural gas with low-carbon gases, including biomethane, synthetic methane, and green hydrogen. The Netherlands and Germany are among the countries that have initiated numerous national strategies and test initiatives to investigate the feasibility of modifying gas networks to accommodate hydrogen.

If successfully scaled up, these developments could allow natural gas infrastructure to evolve rather than be abandoned, extending its usefulness and aligning it with long-term decarbonization goals. However, significant technical, regulatory, and economic challenges remain, and the pace of transition will depend on coordinated EU-wide policy support and investment.

Natural gas has historically been a cornerstone of the European energy system thanks to its flexibility, relative environmental benefits, and well-developed infrastructure. However, as Europe accelerates its climate transition and diversifies its energy sources, the role of natural gas is being redefined. Its future viability increasingly depends on how compatible it is with decarbonization strategies and the development of low-carbon alternatives. Understanding this transition is key to assessing the broader factors that determine gas demand in Europe.

2.3 Historical Trends in Natural Gas Demand

An examination of the evolution of natural gas demand in Europe over time is beneficial in comprehending the current situation and potential future developments. Europe's utilisation of natural gas has undergone substantial modifications over the past five decades as a result of economic, political, technological, and environmental factors. These modifications are indicative of broader trends in energy security concerns, market liberalisation, industrial development, and climate objectives.

2.3.1 Growth and Expansion: 1970s–2000s

The 1970s saw a significant uptick in the production of natural gas in Europe, which was primarily due to the Soviet Union's increased gas exports and the significant gas discoveries in the North Sea. As a healthier and more efficient alternative to coal and oil, Western European countries such as the Netherlands, Germany, Italy, and France began to increase their petrol consumption. The infrastructure that was constructed during this period, particularly pipeline networks and storage facilities, set the groundwork for the ubiquitous use of gas in industry, home heating and power generation.

As economies expanded, countries diversified their energy sources, and environmental concerns increased, natural gas demand increased consistently from the 1980s to the early 2000s. Competition and investment were stimulated by the liberalisation of petrol markets, which was initiated by EU directives in the 1990s, thereby accelerating demand growth. Gas also played a significant role in power generation, particularly in combined-cycle gas turbine (CCGT) facilities, which provided flexibility and reduced emissions.

2.3.2 Stabilization and Market Saturation: 2000s–2010s

The 2000s marked a turning point as gas demand growth began to level off. Several factors contributed to this plateau:

- Market saturation in developed economies
- Increased energy efficiency
- Growing use of renewable energy sources
- Price volatility and supply concerns

The 2008 global financial crisis further reduced energy consumption across Europe, including natural gas. Although demand recovered somewhat in the early 2010s, the general trend was toward slower growth or stagnation. At the same time, renewables like wind and solar began to gain ground due to falling costs and supportive policies, gradually replacing gas in the power sector.

2.3.3 Crisis and Realignment: 2010s–Present

In response to unstable market and geopolitical conditions, natural gas demand has fluctuated over the past decade. The 2014 Ukraine crisis prompted renewed apprehensions regarding the security of gas supplies, which prompted efforts to reconsider dependence on Russian gas and diversify sources. Nevertheless, gas continued to be indispensable, particularly for heating and as a backup for intermittent renewables, despite these concerns.

The COVID-19 pandemic resulted in a significant decrease in petrol demand in 2020, as a result of decreased industrial activity and a decrease in overall energy consumption. Nevertheless, demand experienced a rebound in 2021 as a result of the frigid winter and economic recovery.

The most significant change occurred in 2022 when Russia invaded Ukraine. Established gas flows were disrupted by this geopolitical upheaval, which in turn initiated an an unprecedented reorganisation of European gas procurement strategies. The imports from Russia experienced a significant decline, which was partially offset by LNG from the United States, Qatar, and other sources. In late 2022 and early 2023, demand decreased once more as industries reduced their utilisation and governments implemented conservation measures, resulting in prices reaching record highs.

2.3.4 Sectoral and Regional Patterns

Homes and enterprises have historically been responsible for a significant portion of gas consumption, particularly for the heating of water and spaces. Although industrial use is more cyclical, it has remained substantial, particularly in the fields of metallurgy, food processing, and chemicals. The role of power generation, which was once a significant growth area, has diminished as renewable energy sources have expanded.

The demand for petrol has fluctuated significantly across various regions of Europe. Western and Northern European countries exhibit mature and frequently declining demand patterns, whereas Central and Eastern European nations exhibit greater variability in response to economic development, alignment with EU policies, and access to a variety of supplies.

2.3.5 Long-Term Demand Trajectory

Although economic cycles, geopolitical events, and weather frequently account for short-term fluctuations in natural gas demand, the long-term trend is increasingly determined by decarbonisation objectives. The European Union's objective of becoming climate neutral by 2050 necessitates a consistent decrease in the consumption of fossil fuels. Consequently, numerous projections anticipate a gradual but irreversible decrease in gas demand beyond the mid-2020s, with a particular emphasis on the residential and power generation sectors.

Nevertheless, the relevance of gas in specific contexts could be significantly enhanced by certain counterbalancing trends, such as the development of blue hydrogen (produced from natural gas with carbon capture) and the increased demand for flexible backup generation. However, historical trends indicate that the golden era of natural gas in Europe has reached its zenith, and a controlled decline is currently in progress.

2.4 Policy and Regulatory Framework in Europe

The regulations and policies that regulate natural gas in Europe have undergone significant changes over the years, as a result of the shifting geopolitical landscape, the increasing emphasis on climate change, and the efforts to open markets. As the European Union (EU) strives to achieve both energy security and climate neutrality, regulations are increasingly attempting to balance these priorities in a manner that profoundly impacts natural gas demand, infrastructure investment, and the operating of markets.

2.4.1 Early Market Liberalization and Integration

The initial significant transformation of Europe's gas sector occurred during the 1990s and early 2000s as a result of the initiative to liberalise markets. The European Union promoted competition, transparency, and cross-border integration in electricity and gas markets by progressively dismantling monopolies through a series of legislative packages, including the First (1998), Second (2003), and Third Energy Packages (2009).

Key regulatory initiatives included:

- Separating transmission and supply operations to avoid conflicts of interest
- Allowing third-party access (TPA) to gas infrastructure
- Creating independent regulators at the national level
- Forming the Agency for the Cooperation of Energy Regulators (ACER) to improve coordination

These reforms enabled the emergence of regional gas trading hubs and contributed to more similar prices, diverse supplies, and market resilience across member states.

2.4.2 Environmental Policy and the European Green Deal

In Europe, energy policy has been significantly influenced by environmental regulation. The European Green Deal's adoption in 2019 represented a substantial change, establishing the path to climate neutrality by 2050. This commitment was implemented through legislative initiatives such as the Fit for 55 initiative, which aims to reduce greenhouse gas emissions by 55% by 2030 in comparison to 1990 levels.

For the natural gas sector, this means:

- Stricter carbon pricing through the EU Emissions Trading System (EU ETS)
- Faster deployment of renewable energy sources
- Energy efficiency requirements under the Energy Efficiency Directive
- Reduced subsidies and regulatory support for fossil fuel infrastructure

Natural gas is no longer seen as a long-term bridge fuel but as a transitional energy source whose future depends on compatibility with decarbonization pathways.

2.4.3 Security of Supply and the REPowerEU Plan

Russia's invasion of Ukraine in 2022 exposed Europe's vulnerability to energy supply disruptions and triggered a new wave of policy responses aimed at enhancing energy resilience. The EU's REPowerEU plan, introduced in May 2022, seeks to eliminate dependency on Russian fossil fuels before 2030 through a three-pronged strategy:

- Diversifying energy supplies, including expanded LNG imports and new pipeline agreements
- Speeding up the rollout of renewables and low-carbon energy technologies
- Energy savings and demand reduction initiatives

Additional regulations were adopted to ensure minimum storage fill levels, facilitate joint gas procurement, and improve cross-border solidarity mechanisms.

2.4.4 Hydrogen, Biomethane, and Gas Decarbonization Policy

To maintain the usefulness of existing gas infrastructure while reducing emissions, EU policy is increasingly focused on integrating low-carbon gases, such as hydrogen and biomethane. The proposed Hydrogen and Decarbonized Gas Market Package (2021) aims to:

- Create a regulatory framework for hydrogen infrastructure
- Enable blending of hydrogen into existing gas networks
- Promote access to financing and cross-border hydrogen projects
- Establish certification schemes for low-carbon gases

These efforts are intended to facilitate a managed transition from natural gas to sustainable alternatives, aligning with broader climate goals while preserving supply security and industrial competitiveness (Hydrogen Europe, 2022).

2.4.5 National-Level Regulations and Policy Heterogeneity

While the EU sets overarching goals and directives, implementation varies significantly across member states. For example:

- Germany has prioritized green hydrogen and gas phase-out timelines, with a robust regulatory framework and funding commitments

- Poland and Hungary remain more reliant on fossil gas, reflecting different economic structures and political priorities
- The Netherlands is rapidly phasing out domestic gas production and experimenting with hydrogen blending at scale

These differences introduce complexity into regional coordination efforts and may affect the pace of gas demand reduction and infrastructure transition.

2.4.6 Challenges and Future Regulatory Directions

Despite significant progress, several challenges persist in aligning gas policy with decarbonization objectives:

- **Regulatory uncertainty** over the long-term role of gas infrastructure
- **Divergent national strategies** leading to policy fragmentation
- **Investment risk** for new gas and hybrid infrastructure under evolving frameworks
- **Need for comprehensive methane regulations** to reduce emissions across the value chain

Future regulatory initiatives are expected to focus on:

- Finalizing the hydrogen market framework
- Scaling up carbon pricing and methane regulation
- Strengthening energy system integration through the Energy Union
- Enhancing regulatory clarity for cross-border infrastructure projects

The European policy and regulatory framework plays a central role in shaping natural gas demand and its future trajectory. From liberalization and market integration to decarbonization and energy security, regulations have evolved to reflect changing priorities. The increasing prominence of climate policy, particularly since 2019, signals a declining long-term role for natural gas unless it can be decarbonized or replaced with clean alternatives. Policymakers face the dual challenge of ensuring near-term resilience while steering the energy system towards long-term sustainability.

2.5 Emerging Challenges and Opportunities

The European natural gas sector is currently at a critical juncture, as it is both well-positioned to capitalise on new opportunities and is confronted with numerous converging pressures. The sector is being compelled to adapt and transform as a result of the evolving policy landscape, technological innovation, and geopolitical shifts. In this section, we examine the primary obstacles and opportunities that are arising in this context, particularly as the EU endeavours to simultaneously guarantee energy security, preserve affordability, and achieve ambitious climate objectives.

The intensifying decarbonisation agenda is one of the most pressing challenges, as it is reshaping energy systems throughout Europe. The European Union's legally binding objective to achieve net-zero greenhouse gas emissions by 2050, as enshrined in the European Climate Law, establishes a strict timeline for the cessation of unabated fossil fuel use. Natural gas, which was previously perceived as a lower-carbon alternative to coal, is now being scrutinised for its long-term climate impacts. The cost of petrol consumption has consistently increased, particularly for power generators and industrial users, as a result of carbon pricing through the EU Emissions Trading System (ETS). Furthermore, the operational complexity and compliance costs will be further exacerbated by the upcoming regulations on methane emissions, which will encompass extraction, transmission, and distribution.

Nevertheless, the decarbonisation challenge also generates opportunities. Numerous stakeholders are investigating methods to repurpose existing gas infrastructure to accommodate low-carbon gases, including biomethane and renewable hydrogen. The continued relevance of pipeline networks and storage facilities is guaranteed by these developments, which also align with climate objectives. Several EU member states are presently conducting technological retrofits, including the integration of carbon capture systems at gas-fired plants and the blending of hydrogen in distribution networks. These technologies have the potential to provide a lifeline to certain segments of the gas sector by converting it into a decarbonised energy vector, provided that they are economically viable and scalable.

The outlook has been further confounded by energy security concerns. Europe's dependence on Russian pipeline gas, which previously comprised approximately 40% of its imports, has declined significantly. In its stead, the EU has endeavoured to diversify its gas supply portfolio by importing liquefied natural gas (LNG) from suppliers such as the United States, Qatar, Norway, and Algeria. Although this approach has effectively diminished dependence on a single supplier, it has also introduced new vulnerabilities. Global demand fluctuations, competition from Asia, and logistical bottlenecks at import terminals and regasification facilities are all factors that influence LNG markets. Financial and environmental challenges arise as a result of the necessity for investment in supplementary infrastructure, including interconnectors, expanded port capacity, and floating storage and regasification units (FSRUs).

At the same time, the volatility of prices in the European petrol markets has reached unprecedented levels. Supply constraints and geopolitical uncertainty resulted in the

Dutch Title Transfer Facility (TTF), a critical benchmark, reaching record highs in 2022. Emergency policy responses, including price limits, subsidies, and coordinated storage mandates across EU member states, were prompted by these spikes, which had a substantial impact on industrial users and households. Sustained price volatility may erode the competitiveness of natural gas and accelerate the transition to alternative energy sources, particularly renewable energy and electrification solutions in the heating and transportation sectors, in the long term.

Additional complexity is introduced by societal and political dimensions. The public's perception of natural gas has changed as the environmental consequences of fossil fuels become more apparent and awareness of climate change increases. Local opposition to LNG terminals and storage expansions has resulted in delays or cancellations in certain regions. Additionally, the European Union's political consensus is not consistent. Diverse national priorities and capacities are reflected in the fact that countries such as the Netherlands and Germany are expediting their gas transition strategies, while others, such as Hungary and Poland, continue to rely on gas for industrial activity and energy security.

Natural gas continues to play a transitional role in the green shift, despite the pressures it faces. In the short to medium term, gas remains a reliable reserve to intermittent renewable energy sources, particularly during peak winter months or periods of low wind and solar output. It is also essential for district heating, combined heat and power (CHP) systems, and numerous industrial processes that are difficult to electrify. Policymakers and industry stakeholders are increasingly advocating for a balanced approach, which involves investing in long-term alternatives and infrastructure decarbonisation while leveraging the short-term benefits of natural gas.

In summary, the natural gas sector in Europe is confronted with a multifaceted combination of opportunities and challenges. The sector is being transformed by the convergence of decarbonisation imperatives, geopolitical realignments, infrastructure adaptation, and societal expectations. The role of gas in Europe's future energy mix could be redefined through a strategically managed transition, which is fuelled by innovation, policy coordination, and investment in low-carbon alternatives, as traditional development models become obsolete.

Chapter 3: Methodology

3.1 Literature Review Approach and Rationale

This thesis provides a comprehensive examination of the current research on the factors that influence the demand for natural gas in Europe. We have conducted a critical evaluation of a variety of studies, assessing the validity of their conclusions and the integrity of their methodologies, rather than compiling previous findings.

Given the complex nature of Europe's natural gas landscape, which is influenced by a variety of economic, political, environmental, technological, and regulatory factors, this methodological choice is appropriate. Our critical investigation enables us to comprehend the manner in which these diverse elements interact and influence one another.

This method was chosen for a variety of reasons. Initially, the European natural gas market is not limited to the fundamental supply-demand dynamics; it is also impacted by environmental policies, technological innovation, geopolitical conflicts, and changing social perspectives. Our method facilitates a comprehensive analysis of these interconnected components.

Secondly, by conducting a thorough examination of the diverse research methodologies utilised in the existing literature, including quantitative models, qualitative analyses, case studies, and policy evaluations, we can produce practical insights that are beneficial to both policymakers and industry stakeholders.

Our selection process for included studies was based on methodological transparency, relevance to contemporary European energy challenges, and contributions to significant debates. We emphasized research from the past decade to capture recent developments, and if possible, energy security concerns following Russia's 2022 invasion of Ukraine and policy transformations under the European Green Deal.

This method also allowed us to identify areas of agreement and disagreement among experts, including discussions regarding the strategic implications of foreign supplier dependence, the competitiveness of natural gas against renewables, and the efficacy of carbon pricing. We can differentiate between established knowledge and unresolved concerns by examining these opposing perspectives.

3.2 Criteria for Literature Selection

We employed specific criteria to determine which studies to include in our analysis:

First, we prioritized research with transparent methodologies. Selected studies needed to clearly articulate their research design, data collection processes, analytical techniques, and underlying assumptions. This methodological clarity provides a foundation for assessing the reliability and validity of their conclusions.

Second, we selected studies with direct relevance to Europe's contemporary energy context, particularly those addressing recent developments such as Russia's 2022 invasion of Ukraine, the European Green Deal, technological innovations, and market evolution. While we primarily focused on literature published within the past decade, we included some foundational older works that have significantly influenced current thinking.

Third, each selected study needed to address at least one of our core thematic areas: economic factors, market dynamics, regulatory frameworks, technological advancements, environmental considerations, or geopolitical influences .

Fourth, the research needed to focus on either the broader European Union context or specific European nations with significant natural gas consumption patterns (.

Fifth, we deliberately included diverse source types: academic journals for theoretical depth, industry reports for practical insights, and policy documents for regulatory perspective. This variety helps connect theoretical concepts with practical applications.

Lastly, we considered each study's impact within its field, giving preference to frequently-cited works that have influenced academic discourse or policy development. Nevertheless, we evaluated each study independently of its reputation, ensuring selection was based on analytical contribution rather than merely citation count.

Through these criteria, we established a robust foundation for examining the determinants of natural gas demand across Europe.

3.3 Analytical Framework for Critical Evaluation

For evaluating literature on European natural gas demand, we constructed a methodical framework that allows consistent analysis across different studies. Our approach examines four essential dimensions:

Initially, we assess methodological rigour by examining the clarity with which studies articulate their research design, data quality, analytical methods, and fundamental assumptions. This study evaluates sampling approaches, statistical methods, scenario modelling, and data reliability to ensure that the analysis is grounded in credible research. We clearly identify studies that lack methodological clarity or rigour.

Secondly, we evaluate empirical consistency by conducting a comparative analysis of findings from various studies. We analyse patterns of consensus and disagreement concerning factors such as price sensitivity, policy impacts, geopolitical influences, and technological effects. This comparison aids in identifying conclusions that enjoy widespread support compared to those that are still debated.

Third, we analyse theoretical coherence to assess the alignment of findings with established frameworks in energy economics, market analysis, and transition theory. This evaluation assesses whether studies support traditional perspectives or contest established paradigms.

Natural gas demand determinants are categorised into six primary groups: economic factors, market dynamics, regulatory frameworks, technological innovations, environmental considerations, and geopolitical influences. Each category underwent analysis across the four dimensions previously outlined.

The framework incorporates temporal and contextual considerations. In light of Europe's dynamic energy landscape, marked by geopolitical instability, increased renewable deployment, and ambitious climate targets, this study analyses how contextual changes may influence the applicability of prior findings.

3.4 Limitations of the Literature Review Approach

While our methodology provides thorough analysis of European natural gas demand drivers, several limitations need acknowledgment:

First, publication bias potentially influences our findings. Research with positive or significant results typically appears in publications more frequently than studies showing null or negative outcomes, potentially distorting our understanding of certain factors. Despite our efforts to minimize this bias through careful selection criteria, it remains a relevant consideration.

Second, the European energy context is evolving rapidly. Geopolitical disruptions, policy changes, technological breakthroughs, and market shifts can quickly transform the landscape. Even recent literature might inadequately capture developments like Europe's response to Russia's 2022 invasion of Ukraine or enhanced renewable energy targets under the European Green Deal.

Third, methodological diversity among studies complicates comparative analysis. The literature encompasses various approaches—econometric analysis, qualitative research, scenario projections, policy assessments—each with distinct strengths and limitations. These methodological differences challenge direct comparison of findings across studies.

Fourth, substantial variation exists across European countries in energy policies, regulatory structures, infrastructure development, and economic conditions. While we address these differences, some regional nuances may be overlooked, restricting the generalizability of certain conclusions across Europe.

Fifth, as a literature review relies on existing analyses and secondary data, we cannot independently verify data accuracy, completeness, or underlying assumptions. Any limitations in original studies potentially carry forward into our analysis.

Finally, practical limitations of scope, time, resources, and language potentially excluded relevant insights from non-English publications, unpublished literature, or specialized reports, potentially affecting the comprehensiveness of our findings.

Recognizing these limitations provides necessary context for interpreting our results and understanding their scope and applicability.

Chapter 4: Theoretical Framework and Models

The theoretical underpinnings and economic models of natural gas demand analysis are critically examined in this chapter. In order to provide a strong conceptual foundation for the ensuing analytical chapters, it integrates a number of theoretical viewpoints, such as behavioural, structural, technological, and economic frameworks. The foundation for the critical examination and analysis in subsequent chapters will be laid by discussing the frameworks' applicability and significance, particularly in the European context.

4.1 Theoretical Approaches to Energy Demand

It is necessary to investigate a variety of theoretical stances in order to comprehend the dynamics of energy demand, especially natural gas use in Europe. A number of theoretical models offer fundamental frameworks for understanding the ways in which behavioural, policy, and economic issues interact to influence energy consumption. This section evaluates the most well-known theoretical perspectives on energy demand critically and determines how well they apply to the natural gas situation in Europe.

4.1.1 Economic Theory of Energy Demand

According to traditional economic theory, the demand for energy is a derived need that is directly related to economic expansion and production. According to this idea, industrial output, growing earnings, and consumer activities are the main drivers of energy consumption, which usually rises with economic growth. In this theoretical paradigm, price and income elasticity are crucial since energy demand typically reacts favourably to income growth and unfavourably to price rises.

Economic theory is in line with the fact that natural gas demand in Europe is sensitive to price fluctuation, particularly in reaction to geopolitical shocks. The importance of economic considerations is further supported by the notable decline in natural gas usage during economic shocks like as the Covid-19 epidemic.

4.1.2 Behavioral Economics and Energy Demand

By adding psychological and social factors to economic decision-making processes, behavioural economics enhances the conventional economic viewpoint. Behavioural theories explain problems like the "energy efficiency gap," in which customers do not embrace energy-efficient solutions despite obvious economic advantages, by focussing on cognitive biases, limited rationality, and heuristic decision-making.

Smart metering programs, public education campaigns, and energy usage nudges have all used behavioural insights in Europe to promote energy-saving practices, especially in the domestic heating sector. Notwithstanding environmental externalities, the persistently large reliance on natural gas emphasises the applicability of behavioural economic theories in the European setting.

4.1.3 Technological Change and Energy Demand

According to the induced innovation idea, economic incentives like high energy prices or strict environmental restrictions spur technical improvements. This hypothesis is especially applicable to the European energy market, where the demand for natural gas has changed due to significant investments in renewable energy technologies, efficiency enhancements, and advancements in gas-fired power production systems (such as combined-cycle gas turbines).

The European Green Deal and Fit for 55 are two recent European policy initiatives that have further accelerated technical development targeted at reducing reliance on fossil fuels. These regulations are prime examples of induced innovation, demonstrating their relevance to the natural gas industry in Europe.

4.1.4 Structural Theory of Energy Demand

In the framework of long-term changes in economic structure, such as the move from industrial to service-oriented economies, structural theories examine energy demand. According to this theoretical viewpoint, energy intensity first rises during industrialisation before falling as economies shift towards less energy-intensive industries.

The decreasing trend in natural gas consumption seen in developed European economies can be explained by structural changes in Europe, such as digitalisation and the rise of a knowledge-based economy. The importance of structural theory in describing the evolution of natural gas consumption in Europe is further highlighted by the decline of heavy industries and the growth of service sectors.

4.1.5 Integrated Assessment Models (IAMs)

Economic principles, technical innovation, and behavioural aspects are all combined in Integrated Assessment Models (IAMs), which integrate several theoretical viewpoints. IAMs like TIMES and MESSAGE have been used extensively in Europe to anticipate future energy demand scenarios and assess the effects of energy policy. These models offer thorough insights into future trends in natural gas consumption by skillfully capturing intricate interdependencies, such as the relationships between economic growth, technological adoption, energy pricing, and regulatory regulations.

Theoretical approaches such as structural theory, behavioural economics, economic theory, technical innovation, and integrated assessment models provide complementary insights that are essential to comprehending the demand for natural gas in Europe. A thorough and detailed understanding of the changing dynamics of the European natural gas market will be possible through the integration of several theoretical frameworks.

4.2 Economic Models Relevant to Natural Gas Consumption

Economic modeling plays a crucial role in understanding and predicting natural gas demand, particularly within complex and policy-sensitive markets like Europe. Various economic models have been applied across academic and institutional studies to assess consumption patterns, analyze market behaviors, and evaluate the impacts of regulatory changes and economic shocks. This section critically reviews a range of economic modeling approaches, synthesizing their strengths and limitations while contextualizing their applicability to European natural gas consumption dynamics.

4.2.1 Econometric and Statistical Models

Econometric models are foundational tools for empirically quantifying the relationship between energy demand and its key determinants, such as price, income, climate, policy interventions, and technology. These models include both cross-sectional and longitudinal (panel) techniques and are commonly applied in the European context due to the availability of harmonized data from Eurostat, the IEA, and national statistical offices.

Classical time-series models, such as single-equation linear regressions and vector autoregression (VAR), are useful in examining short-term adjustments in demand to shocks such as price changes or weather anomalies. These are especially effective in individual country-level studies but may lack robustness in capturing regional heterogeneity. To address this, panel data methods—both fixed and random effects models—have been extensively applied. Panel regressions account for unobservable heterogeneity between countries and over time, improving the generalizability of demand estimates across EU member states. Diagnostics such as Hausman tests are employed to determine the appropriate model structure.

In recent years, cointegration techniques have been introduced to deal with non-stationary data, ensuring meaningful long-run interpretations. Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) are especially prominent in panel settings. FMOLS uses non-parametric corrections for serial correlation and endogeneity, while DOLS incorporates leads and lags to generate consistent long-run coefficients. These models are well-suited for analyzing structural relationships in energy consumption, such as the effect of industrial output or long-run income elasticity on natural gas demand.

Autoregressive Distributed Lag (ARDL) models represent another important class of econometric tools. Particularly applicable in datasets with mixed integration orders (I(0) and I(1)), ARDL models can capture both short-run dynamics and long-run equilibrium adjustments. Dahl and Erdogan (2020) demonstrate this model's flexibility by estimating daily and monthly gas demand elasticities in response to both price and income shocks. Their work also underscores the value of using high-frequency data to capture rapid behavioral responses, especially in volatile contexts such as the post-Ukraine energy crisis.

To address issues of heteroskedasticity and autocorrelation in long-panel regressions, White period robust standard errors are used. This statistical correction enhances the reliability of coefficient estimates, particularly when data spans multiple time periods or involves economic shocks that could destabilize variances.

ARCH (Autoregressive Conditional Heteroskedasticity) and GARCH models have been employed to investigate price volatility in natural gas markets. Although these models do not directly estimate demand, they contribute to the literature by modeling how supply shocks, import volumes, or policy changes influence market expectations and short-term risk pricing. This indirectly informs the demand side by identifying conditions under which consumers might reduce consumption in anticipation of price volatility.

4.2.2 Market-Based and Equilibrium Models

Beyond econometrics, several structural modeling approaches offer a broader view of market functioning and policy outcomes. These include partial equilibrium, computable general equilibrium (CGE), and scenario-based modeling techniques.

Partial equilibrium models focus on the natural gas market in isolation, assuming other markets remain unaffected. They are widely used in policy simulation exercises to quantify the impact of carbon pricing, supply disruptions, or renewable energy subsidies. Their strength lies in their granularity, allowing analysts to assess marginal effects of targeted interventions. However, the omission of inter-market interactions means that feedback loops from other sectors, such as electricity or transport, are not captured.

CGE models address this limitation by representing the entire economy through a series of interdependent sectors and agents. These models account for behavioral responses, production reallocation, trade, and welfare effects, making them suitable for evaluating long-term impacts of energy transition policies. In the European context, CGE models have been used to assess the macroeconomic implications of the European Green Deal and the consequences of reducing reliance on Russian gas imports. Their complexity and data intensity, however, make them less suitable for real-time policy evaluation.

Scenario-based models—used extensively by organizations like the IEA and the European Commission—combine economic modeling with expert assumptions and qualitative foresight. These models are designed to explore potential future states of energy systems under varying assumptions of technological progress, policy implementation, and market behavior. For example, the IEA's World Energy Outlook includes scenarios that simulate demand under net-zero targets, geopolitical constraints, or accelerated renewable integration. Scenario models provide policymakers with strategic insight into plausible futures, though they are not predictive tools and rely heavily on assumptions.

4.2.3 Engineering-Based and Hybrid Estimation Approaches

A more recent addition to the modeling toolbox is engineering-based estimation, particularly residual mass balance models. One such model is used by Fernández-Blanco et al. (2024), who estimate daily gas consumption by reconciling observed flows pipeline imports and exports, LNG send-outs, and storage injections or withdrawals. This bottom-up approach circumvents some of the statistical limitations of econometric models and offers near-real-time consumption data, which is crucial during emergencies or periods of high volatility.

While not focused on elasticity or economic responses, these models provide critical monitoring capabilities. They also complement econometric models by supplying high-frequency input data and by validating consumption estimates under short-term shocks or reporting delays.

Hybrid models that combine econometric estimation with engineering constraints or policy triggers are an emerging area of interest. These could include demand systems constrained by regulatory ceilings, or agent-based models that simulate household responses under specific policy scenarios. Though not yet widely applied in the reviewed studies, these approaches represent a future direction for modeling under uncertainty.

4.2.4 Synthesis and Applicability

The suite of economic models applied to natural gas demand in Europe is diverse, each offering a unique lens on market behavior. Econometric models are best suited for quantifying elasticities and understanding demand sensitivities. Equilibrium models capture system-level feedbacks and structural adjustments, while engineering models provide operational accuracy in high-frequency demand tracking. Their integration—through comparative analyses, hybrid models, or scenario planning—can lead to more robust and policy-relevant insights.

For the European context, where gas markets are subject to regulatory, geopolitical, and infrastructural dynamics, a layered modeling strategy is essential. No single model can adequately capture all dimensions of the system, but together, they provide a solid foundation for interpreting past trends and preparing for future uncertainties.

4.3 Conceptual Models and Their Applicability to Europe

Simplified representations of intricate energy systems are provided by conceptual models, which aid in determining the main variables affecting energy use and how they interact. The relationships between energy markets, technical advancements, governmental changes, and socioeconomic variables are usually highlighted by these models. This section assesses well-known conceptual models that are pertinent to the demand for natural gas and looks at how well they apply to the European setting.

4.3.1 Energy Ladder and Energy Stacking Models

The Energy Ladder model has long been used to explain how households move from biomass to coal, then to petroleum products, and finally to natural gas and electricity as their income levels rise. But this straight line has been improved by the Energy Stacking model, which suggests that households use several energy sources at the same time, driven more by availability, price, and convenience than by income alone.

Residential natural gas use in Europe, especially in heating systems, is well explained by the Energy Stacking model in conjunction with other energy sources like electricity and renewables. The stacking model, which emphasises flexibility and energy security, fits in nicely with the varied energy portfolio of European families, which is fuelled by technical advancements and legislative incentives.

4.3.2 Transition Management and Multi-Level Perspective (MLP)

Three analytical levels—niche innovations, socio-technical regimes, and socio-technical landscapes—interact to conceptualise energy system transitions in Transition Management and the Multi-Level Perspective (MLP) models. Established socio-technical regimes (like traditional natural gas infrastructure) are challenged by niche developments (like renewable gas technologies), which are impacted by larger socio-technical landscapes (like EU climate regulations).

The continuous shift from fossil fuels to low-carbon alternatives in Europe is well-represented by the MLP model, with specialised developments in hydrogen and biomethane gaining market share and legislative backing. These changes are a result of the interaction of technical developments, societal attitudes towards sustainability, and legislative frameworks across the EU.

4.3.3 Diffusion of Innovation Model

The Diffusion of Innovation Model highlights adoption categories including innovators, early adopters, early majority, late majority, and laggards in order to explain how technological discoveries spread throughout civilisations. Technologies' relative advantage, compatibility, complexity, trialability, and observability all affect adoption rates.

This model accurately depicts the adoption of cutting-edge heating technology such as hybrid heat pumps, micro-cogeneration units, and condensing gas boilers in the natural gas environment of Europe. The diffusion process is aided by policy tools like information campaigns and subsidies, which encourage early adopters to adopt quickly and progressively enter mainstream markets.

4.3.4 Sustainable Livelihoods Framework (SLF)

The Sustainable Livelihoods Framework (SLF) places a strong emphasis on a comprehensive understanding of how vulnerability situations and institutional processes impact these dynamics and how access to resources, especially energy resources, shapes livelihoods. SLF provides insights into energy poverty and energy security issues in developed regions, despite its conventional application in underdeveloped situations.

SLF can offer insightful viewpoints on energy vulnerability in Europe, especially with regard to dependence on imports of natural gas from uncertain geopolitical areas. The SLF strategy to lowering vulnerability and guaranteeing stable lives and economic stability is consistent with energy security initiatives implemented by the EU, such as expanding storage capacity and diversifying import sources.

4.3.5 Energy Trilemma Model

The Energy Trilemma Model conceptualises the objectives of energy policy in terms of striking a balance between three factors: environmental sustainability, energy equality (accessibility and affordability), and energy security. Instead of maximising one of these goals, policymakers must strike an ideal balance by weighing trade-offs between them.

As policymakers manage conflicts between maintaining cheap energy costs for businesses and consumers, promoting decarbonisation initiatives under the European Green Deal, and guaranteeing stable natural gas supplies, this model is especially pertinent to Europe's natural gas strategy. The practical difficulties and trade-offs involved in handling the European energy trilemma have been brought to light by recent geopolitical events and unstable market conditions.

4.3.6 Applicability to Europe

These conceptual models offer thorough frameworks for comprehending the intricate dynamics of Europe's natural gas usage. Household energy decisions are highlighted by the Energy Ladder and Energy Stacking models, while system-level changes and technological adoption processes are explained by the MLP and Diffusion of Innovations models. The Energy Trilemma Model and the Sustainable Livelihoods Framework provide crucial insights into Europe's sustainability, equity, and energy security issues.

Policymakers and industry stakeholders can gain a better understanding of the complex interplay between technological, economic, policy, and sociological issues affecting natural gas demand by utilising these conceptual models. By incorporating knowledge from these models, strategic decision-making procedures are facilitated, ultimately aiding Europe's shift to a safe, sustainable, and just energy future.

4.4 Discussion of Key Variables and Hypothesized Relationships

Finding important variables that influence consumption trends and developing theories about their relationships are essential components of a comprehensive analysis of the factors influencing natural gas demand. With an emphasis on the European setting, this section combines insights from conceptual frameworks, empirical research, and economic theories to explain these variables and their interactions.

4.4.1 Price of Natural Gas

The cost of natural gas According to conventional economic theory, the price of natural gas is a significant determinant on consumption patterns. Natural gas costs are thought to be inversely related to demand, which means that rising prices typically result in falling consumption. This association has been validated by recent studies conducted in European markets, particularly in the residential and industrial sectors. This inverse relationship is supported by the fact that high costs brought on by geopolitical conflicts, as those that followed the Ukraine crisis, have caused sharp declines in consumption throughout Europe.

4.4.2 Economic Growth and Income Level

Levels of Income (Economic Growth) Patterns of energy use are positively connected with economic growth, which is commonly gauged by GDP. The demand for natural gas rises as a result of increased consumer expenditure, infrastructure development, and industrial activity driven by higher income levels. Natural gas consumption is positively correlated with income, according to analyses conducted in European nations. This suggests that as the economy expands, so does the use of natural gas, particularly in the manufacturing and service sectors.

4.4.3 Technological Advancements

Developments in technology have a significant impact on how natural gas is consumed. It is expected that the amount of natural gas used per unit of output or service rendered will decline with the development of energy-efficient technology such sophisticated heating systems and improved power generation plants. However, because of their increased efficiency and reduced carbon emissions as compared to other fossil fuels, improvements in gas-fired power generation, particularly with the use of combined-cycle gas turbines (CCGT), may result in a rise in utilisation. As a result, the possible effects of technical developments on the demand for natural gas vary based on the innovation type and the industry's features.

4.4.4 Policy and Regulatory Environment

The demand for natural gas, especially in Europe, is greatly influenced by policy frameworks and regulatory procedures. To lessen dependency on fossil fuels, programs like the Fit for 55 packages and the European Green Deal are being implemented here. Higher carbon prices and more stringent environmental laws are thought to reduce demand for natural gas by promoting the adoption of more efficient methods and renewable energy sources. Natural gas use has decreased in Europe as a result of recent policy changes brought about by these regulatory actions.

4.4.5 Availability of Substitute Energy Sources

Natural gas use is significantly influenced by the accessibility and economic feasibility of other energy sources, such as electricity and renewable energy technologies. It is believed that the demand for natural gas would decline as a result of growing market competition and the availability of renewable energy sources like hydroelectric, solar, and wind. The importance of replacements in influencing energy consumption trends is highlighted by data from European statistics that demonstrate a progressive drop in natural gas usage and a notable development in renewable energy infrastructure.

4.4.6 Geopolitical Stability

The demand for natural gas is significantly influenced by the geopolitical stability of the countries that supply it. Because of supply concerns and price fluctuations, it is often assumed that increased geopolitical instability results in lower natural gas use. The notion that there is a negative correlation between geopolitical instability and natural gas use is supported by the fact that European consumption levels have significantly dropped as a result of disruptions in Russian natural gas supplies brought on by rising geopolitical tensions.

4.4.7 Socio-cultural and Behavioral Factors

The demand for natural gas is influenced by behavioural tendencies and sociocultural elements, including consumer awareness, environmental concerns, and societal decisions. Natural gas use is predicted to decline in favour of cleaner alternatives as a result of growing environmental consciousness and shifting social norms that place a focus on sustainability. Research in behavioural economics indicates that informational campaigns and behavioural interventions might effectively change energy consumption patterns, reducing European households' dependency on fossil fuels like natural gas.

To consolidate these findings, the hypothesized relationships among key variables influencing natural gas demand can be categorized as follows:

Negative Relationship:

- Price of natural gas
- Stringency of environmental policies
- Availability of substitutes (renewables, electricity)
- Geopolitical instability
- Increased environmental awareness and behavioral interventions

Positive Relationship:

- Economic growth (GDP/income)
- Technological improvements enhancing consumption efficiency (context-specific)

Understanding these relationships through empirical validation is essential for developing accurate models and forecasts of natural gas demand. These variables exist within an interconnected framework, and their complex interactions play a decisive role in determining the trajectory of Europe's natural gas market developments.

Chapter 5: Determinants of Natural Gas Demand in Europe

In order to comprehend the swings and long-term trends of natural gas consumption in Europe, economic factors are a fundamental component. Energy consumption and macroeconomic performance, especially with regard to natural gas, have been the subject of intense empirical study and policy discussion. The impact of industrial activity, GDP, and income levels, as well as the consequences of urbanisation and demographic trends, are the two main topics of this section. Understanding how larger economic factors influence the size, composition, and responsiveness of natural gas demand within and outside of the European Union requires both.

5.1 Economic Determinants

5.1.1 GDP, Income, and Industrial Activity

A reliable measure of energy consumption is the gross domestic product (GDP), which also acts as a gauge of economic activity. Economic growth typically results in higher energy demand because of increasing household consumption, transportation, and output. Natural gas exhibits a particularly strong link with GDP growth because of its use in heating, industrial output, and electricity generation. Industrial production increases, construction speeds up, and household energy consumption grows during economic booms; all of these sectors heavily rely on natural gas as a fuel source or as a direct input. The EU's economy grew steadily between 2000 and 2007, with an average yearly GDP growth of about 2.3%. Countries like Germany, France, and Italy reported higher use of natural gas for process energy as well as heating during the same time period, reflecting a comparable increase in demand in the industrial and residential sectors. However, there was a significant contraction brought on by the 2008 global financial crisis. Between 2008 and 2010, natural gas consumption in the EU decreased by more than 12%, according to Eurostat (2011). This was particularly noticeable in energy-intensive industries like chemicals, steel, cement, and glass, all of which drastically cut production in reaction to declining demand worldwide.

A more current and notable example is the COVID-19 epidemic. The GDP of Europe shrank by 6.1% in 2020, with southern economies like Spain and Italy feeling the effects even more keenly. The IEA (2021) estimates that this contraction resulted in a 4.5% drop in petrol consumption across the EU, with industrial sectors that either temporarily ceased operations or reduced their operations being disproportionately affected. The dramatic drop in commercial and industrial activity demonstrated how sensitive gas consumption is to economic shocks, even as household demand stayed relatively consistent due to stay-at-home policies and remote work.

In Europe, the industrial sector continues to be one of the biggest users of natural gas, especially in nations with robust manufacturing sectors. For instance, in Germany, industrial applications ranging from food processing to petrochemical manufacture account for more than 35% of the demand for natural gas. Economic cycles and petrol demand are directly correlated as a result of this dependency. Higher output results in higher petrol consumption during times of economic expansion. On the other hand, downturns result in output reductions, which lower petrol consumption. Furthermore, industrial users frequently deal with fluctuating input costs, and high petrol prices during uncertain economic times can result in fuel switching or output reductions. The unequal distribution of industrial gas use throughout Europe is one significant nuance. Some nations, like Portugal or Greece, have more restricted industrial sectors and rely more on natural gas for residential and electrical generation, but other nations, like Germany and the Netherlands, are highly industrialised and have a variety of gas applications. Because of this geographic variation, member states' susceptibility to changes in GDP and policy reactions varies.

Future petrol demand is also being shaped by long-term industrial initiatives, such as electrification, heavy industry modernisation, and decarbonisation programs. Long-term demand may be indirectly suppressed by the EU's sustainable finance taxonomy, which may reallocate money away from gas-intensive businesses. Economic development is still the dominant driver in the medium run.

Patterns of natural gas usage are also influenced by income levels, especially in the residential sector. Increased energy demand is typically associated with higher household incomes, particularly for cooking, water heating, and space heating. Households are more inclined to invest in larger living areas and buy energy-intensive appliances as their disposable income increases, both of which increase petrol use. On the other hand, energy use is more susceptible to changes in prices and policies in lower-income groups. Fuel poverty is a serious issue in parts of Eastern and Southern Europe, where households may consume less petrol because of financial limitations brought on by price increases or economic downturns.

As a result, income elasticity has two functions. Lower-income groups are extremely sensitive to price fluctuations, which can lead to a suppression of demand during difficult economic times, whereas higher-income groups sustain or increase consumption with less sensitivity to price. Policy frameworks, especially those pertaining to market liberalisation, efficiency initiatives, and subsidies, must take these income-related differences into account.

5.1.2 Urbanization and Demographic Trends

Natural gas demand is significantly impacted by fundamental demographic and urbanisation patterns, which run concurrently with macroeconomic factors. Ageing populations, migration patterns, and shrinking household sizes are all signs of Europe's gradual but noticeable demographic changes. Urbanisation is also increasing at the same time; estimates indicate that 84% of Europeans will live in cities by 2050. The temporal and spatial distribution of energy demand throughout the continent is being shaped by these shifts.

The demand for natural gas is impacted by urbanisation in a number of interconnected ways. First, because of the concentration of commercial infrastructure, public transportation, and home heating, dense metropolitan areas frequently have greater per capita energy usage. Even if electrification and district heating systems are becoming more popular, natural gas is still an essential aspect of urban energy systems, especially for water and space heating in homes.

The heavy reliance on natural gas in urban residential areas is exemplified by nations such as the UK, Germany, and the Netherlands. About 50% of homes in Germany heat with gas, and the percentage is even greater in cities like Berlin and Munich. Due to cost-effectiveness and regulatory slowness, new housing developments often use existing gas networks despite mounting pressure to electrify heating systems, which is a result of migration into cities.

Second, demand patterns take on a new dimension as a result of demographic ageing. Particularly in the winter, older populations typically use more gas since they have higher heating needs and prefer steady interior temperatures. Furthermore, older individuals are slower to switch from gas to alternatives like electric heat pumps since they are less inclined to accept new heating technology fast.

The increase in single-person homes is another significant trend. Due to inefficient heating and appliance use, smaller households generally use more energy per person than bigger households. Over 30% of households in the EU are already single-occupancy, and this percentage is predicted to rise further, according to Eurostat (2021). Particularly in cold-weather nations like Sweden, Finland, and Poland, this structural change raises the baseline residential gas consumption.

Furthermore, infrastructural stress and energy planning issues are frequently brought on by urbanisation and population changes. Cities must strike a balance between decarbonisation objectives and expanding energy demands, which creates difficult trade-offs between investing in electric alternatives and modernising gas infrastructure. Sociopolitical elements including housing affordability, the stock of historic buildings, and fairness in energy access further complicate urban energy transitions. Both internal and foreign migration trends have an indirect impact on gas demand. Higher energy intensity is a result of new migrant populations frequently settling in metropolitan peripheries with less energy-efficient dwelling stock. Urban development plans and integration policies, however, have the ability to gradually alter these impacts.

In conclusion, demographic trends and urbanisation both increase the demand for natural gas in some markets and present chances for electrification and efficiency gains. To manage the transitional landscape of petrol use throughout Europe, policymakers must take these dynamics into account while modernising the energy system, urban planning, and housing policies.

5.2 Market Dynamics and Price Influences

The demand for natural gas in Europe necessitates a thorough analysis of pricing mechanisms and market dynamics. In addition to regulatory frameworks and macroeconomic situations, natural gas is also affected by price volatility and the dependability of supply infrastructure. This section explores two crucial areas: (1) demand elasticity and price fluctuations, and (2) supply-side elements like logistical capacity and infrastructure development. Both elements are crucial for interpreting the continent's natural gas demand's long-term stability and short-term reactivity.

5.2.1 Price Fluctuations and Elasticity

One of the most direct and potent factors influencing the use of natural gas is price. How sensitive industries and consumers are to fluctuations in petrol prices is reflected in price elasticity of demand. The demand for natural gas is typically inelastic in the short term, especially in industries where substitution is delayed or challenging to execute. On the other hand, flexibility rises over time as technologies advance and alternatives become more widely available.

According to a number of studies, the short-term price elasticity of demand for natural gas in Europe is between -0.1 and -0.3, meaning that a 10% increase in price causes a 1-3 percent drop in demand. Elasticities can range from -0.4 to -0.7 over the long term, particularly when users are able to switch to renewable energy sources or increase their energy efficiency due to technical advancements and regulatory incentives.

An important example of these dynamics occurred during the European energy crisis of 2021–2022, which was brought on by geopolitical unrest and limited worldwide LNG supplies. In many areas, natural gas prices jumped by more than 400%, driving wholesale rates to all-time highs. Consequently, industries started to reduce their operations or transition to alternate fuels. According to the European Commission (2023), the chemical, metallurgy, and fertilizer sectors in Germany, Poland, and Italy curtailed production by 10–20%, directly leading to decreasing natural gas demand.

Although their demand held up better, residential consumers were also impacted. Particularly in colder climates, heating is essential, and there aren't many quick alternatives. However, the crisis sparked a surge in interest in smart thermostats, energy-efficient retrofits, and even domestic electrification. In order to mitigate the societal impact, governments implemented price controls and targeted subsidies, however occasionally these actions masked the price signal that would have otherwise decreased demand.

Seasonal fluctuation plays an important function in influencing price sensitivity. Winter months often demonstrate peak demand, especially for domestic heating, leading to price surges that may or may not reduce consumption depending on income levels and policy assistance. In nations with well-developed storage capacity, such as Austria and the Netherlands, buffer stocks assist offset short-term price increases. Consumers are more vulnerable to changes in global prices in less linked markets, nevertheless.

It's crucial to remember that price reactions vary by industry. Because of the inertia of building stock, appliance types, and behavioural routines, families usually react more slowly to cost increases than industrial users, which may swiftly cut or cease operations. However, price signals have the power to change energy systems over time. Exorbitant costs encourage efficiency upgrades, policy innovations, and infrastructural expenditures, which helps to cause structural changes in the demand for natural gas.

5.2.2 Supply-Side Factors and Infrastructure

On the supply side, logistics and infrastructure are crucial in determining natural gas's dependability and availability, which influences market prices and consumption patterns. The framework for gas supply in Europe is based on a mix of local production, LNG imports, pipeline imports, and strategic storage reserves.

Historically, pipeline gas from Algeria, Norway, and Russia has been a major component of the European gas infrastructure. Both stability and vulnerability were brought about by the network's design, particularly by long-term agreements and transit plans via Belarus, Poland, and Ukraine. This environment was drastically changed in 2022 when Russian gas flows were disrupted. EU nations responded by implementing emergency diversification plans, increasing their capacity to import LNG, and stepping up their cooperation on joint gas procurement.

There are significant ramifications to LNG's emergence as a key component of European energy security. LNG reduces over-reliance on a single provider by providing supply flexibility and diversification. The United States' LNG imports more than doubled between 2021 and 2023, and new facilities in Germany, the Netherlands, and the Baltics were expedited. Rapid infrastructure expansion has been made possible by Floating Storage Regasification Units (FSRUs).

But there are logistical issues with LNG. It needs shipping logistics, regasification capacity, and port infrastructure. Furthermore, because of the expenses associated with liquefaction, transportation, and storage, LNG is frequently more costly than pipeline gas. LNG may thereby raise average prices, impacting demand, particularly in price-sensitive industries, even while it improves security.

Additionally, storage infrastructure is essential for controlling seasonal variations in demand and protecting against supply disruptions. Significant underground storage facilities are maintained by nations like Austria, Germany, and the Netherlands, which enables them to accumulate reserves during times of low demand or low prices and release them at times of crisis or cold. The strategic significance of storage is emphasised by the EU's Gas Storage Regulation (2022), which sets minimum filling levels to protect against winter shortages.

Resilience and market integration have risen as a result of investments in interconnectors, or pipes that connect national gas networks. Initiatives like the Trans Adriatic Pipeline (TAP) and the Balticconnector between Finland and Estonia have improved regional energy security and system flexibility. These infrastructural improvements allow for the use of supply and storage resources across the EU and lower the danger of local shortages. Domestic gas production, which has been gradually decreasing in many European nations, is another important consideration. Due to public opposition and seismic dangers, the Netherlands, which has historically been one among the greatest producers, has drastically reduced operations at the Groningen field. This decrease makes customers more dependent on imports, exposing them to geopolitical risk and external price volatility.

In conclusion, supply-side factors—such as pipelines, LNG, storage, connections, and local manufacturing—have a significant impact on both the immediate pricing landscape and the stability of demand over the long run. In addition to ensuring energy security, a robust, varied, and integrated supply infrastructure is necessary to control price volatility and facilitate responsive, well-informed consumption choices.

5.3 Policy and Regulatory Influences

One important factor influencing the demand for natural gas in Europe is the regulatory environment. Energy market structures are shaped by national and European Union (EU) policy decisions, which also affect fuel mix choices, encourage or discourage particular technologies, and establish the course of decarbonisation. This section looks at the distinct effects on demand trends of (1) national policies and (2) EU-level energy and environmental laws. The governance architecture supporting the development of natural gas markets in the European context is made up of several policy levels taken together.

5.3.1 EU Energy Policies and Environmental Regulations

The European Union has taken a proactive approach to climate change and the energy transition at the supranational level. The European Green Deal, which was announced in 2019 and pledges the EU to becoming climate-neutral by 2050, is the cornerstone of this approach. This all-encompassing policy framework has significant effects on the demand for natural gas and affects almost every area of the economy.

The "Fit for 55" legislative package, a key element of the Green Deal, seeks to cut greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. The natural gas industry is directly impacted by a number of directives in this package, including the modified EU Emissions Trading System (ETS), the Energy Efficiency Directive (EED), and the revised Renewable Energy Directive (RED II).

For instance, RED II encourages the integration of renewables in heating and cooling—sectors that have historically been dominated by natural gas—and establishes obligatory renewable energy objectives for member states. In addition to encouraging electrification, the directive promotes the growth of green hydrogen and biogas, which can both replace natural gas in residential and commercial settings.

Similar to this, the ETS charges a carbon price for emissions from energy-intensive sectors, the power sector, and, as a result of recent reforms, even buildings and vehicles. Increased carbon costs make using natural gas more expensive than using renewable energy sources and low-carbon alternatives, which discourages people from continuing to rely on fossil fuels. Fuel cost competitiveness was drastically changed when the average carbon price in the EU ETS increased from €25 per tonne in 2019 to over €90 per tonne in 2022.

Capital flows are influenced by price mechanisms as well as regulatory tools such as the Taxonomy Regulation on Sustainable Finance. Investor behaviour is impacted by the taxonomy's tight classification of natural gas as a transitional activity, which reduces the financial appeal of gas-related infrastructure unless it supports decarbonisation initiatives. An additional element of urgency is added by REPowerEU, which was launched in 2022 in reaction to the geopolitical ramifications of the Ukraine crisis. In order to lessen reliance on Russian imports, this program expedites the installation of renewable energy sources, energy conservation measures, and gas supply diversification. In contrast to baseline forecasts, the long-term goal is to cut petrol consumption by 30% by 2030, even though it includes short-term funding for LNG infrastructure.

Furthermore, tighter rules on methane emissions from the gas supply chain are enforced under the EU Methane Strategy (2020). In addition to addressing climate goals, these laws raise the operational costs for gas suppliers, which indirectly affects demand through supply-side pressure. Methane is a powerful greenhouse gas.

Natural gas's place in the energy mix is changing as a result of a combination of EU energy and environmental legislation. The long-term regulatory policy favours lower consumption, more efficiency, and wider adoption of zero-emission technology, even though the fuel still plays a transitional role, especially in maintaining grid stability and replacing coal in power generation.

5.3.2 National Policies and Their Impact

While EU-level regulations set overarching goals and frameworks, implementation and specific policy decisions often rest with national governments. This has resulted in a patchwork of strategies and measures that vary widely across member states, reflecting national priorities, resource endowments, and political contexts.

Germany's Energiewende policy exemplifies a comprehensive approach to energy transition. Initially designed to phase out nuclear power and expand renewable energy, it has also entailed increased reliance on natural gas as a bridging fuel. However, in the wake of the Ukraine crisis, Germany fast-tracked the development of LNG terminals and initiated legislative steps to reduce gas dependency. The 2023 update to the Renewable Energy Act (EEG) includes ambitious targets for renewable expansion and incentives for electrification in residential heating and industrial processes, directly affecting long-term gas demand.

In contrast, the Netherlands has taken a more aggressive stance against natural gas in residential sectors. Following concerns over seismic activity in Groningen, the government mandated a gradual phase-out of natural gas in new housing and introduced subsidies for heat pumps and district heating. By 2050, the country aims to eliminate natural gas use in all residential buildings. This policy is supported by a mix of building regulations, incentive schemes, and public awareness campaigns.

Southern European countries present a different picture. In Italy, natural gas remains a cornerstone of the energy mix, supported by extensive infrastructure and political resistance to rapid electrification. While national energy strategies align with EU goals, implementation tends to be more incremental. Subsidy schemes for efficiency improvements and small-scale renewables exist but are often limited in scope and funding, thus preserving a significant role for gas in residential and industrial applications.

Poland, a country historically reliant on coal, has viewed natural gas as a cleaner alternative to support its energy transition. The Polish National Energy and Climate Plan emphasizes gas-fired power generation as a replacement for aging coal infrastructure. Consequently, Poland has invested heavily in new pipeline connections and LNG terminals, particularly the Świnoujście terminal and the Baltic Pipe. This strategic pivot reinforces gas demand in the short- to medium-term, despite long-term goals of decarbonization.

National policy differences also affect energy pricing. Some countries, such as France and Spain, implement price caps or subsidies to shield consumers from volatile international markets, while others, like Sweden, rely more on market-based signals. These variations influence the elasticity of demand and consumer behavior in response to price and policy stimuli.

Furthermore, coordination between national and EU policies is not always seamless. While the EU sets binding targets, national governments often face internal political pressures, administrative limitations, and varying public acceptance. This results in asymmetric implementation and, at times, contradictory signals to market participants.
Nevertheless, there is a discernible trend: most national policies—though diverse in execution—are aligning toward reducing natural gas dependency in favor of cleaner alternatives. The extent and pace of this transition vary, but the overarching trajectory is clear, with significant implications for both short-term adjustments and long-term demand forecasts.

5.4 Technological and Innovation Drivers

Innovation and technological advancement are major factors influencing Europe's natural gas demand. While new renewable energy technologies increasingly compete with or complement natural gas in the production of electricity, heating, and industrial operations, advancements in extraction, transportation, and distribution technology have made natural gas more efficient and competitive. The two extremes of the spectrum are examined in this section: (1) advancements in natural gas delivery and extraction, and (2) the impact of renewable energy technologies and their wider system impacts.

5.4.1 Advances in Extraction and Distribution

Historically, advancements in natural gas distribution and extraction technology have helped to increase the proportion of gas in Europe's energy mix. Countries with access to offshore fields, like as Norway, the UK, and the Netherlands, have used technical innovation to increase operating efficiency and lessen environmental consequences, despite the fact that much of Europe lacks large-scale unconventional gas reserves comparable to those in North America.

Developments in offshore drilling, including as 3D seismic imaging, automated subsea infrastructure, and dynamic positioning systems, have greatly increased exploration accuracy and extraction rates. Despite naturally occurring drops in well productivity, these technologies have enabled European producers to preserve or even boost output from aged fields.

In order to increase the dependability and security of gas distribution infrastructure, smart pipeline monitoring systems, automated leak detection technologies, and AI-based predictive maintenance tools have also been embraced more and more. By enabling real-time monitoring of flow efficiency, corrosion rates, and pressure levels, these systems minimise downtime and avert catastrophic failures.

Network operators are increasingly using digital twins, which are virtual models that mimic the functionality of actual gas infrastructure. These models lower operating costs, optimise maintenance schedules, and improve planning skills. Two significant European gas transmission system operators, GASCADE and Fluxys, for instance, have made investments in AI-enhanced infrastructure diagnostics, enabling predictive analytics that directly contribute to a more safe and reliable supply.

Modular liquefaction units and small-scale LNG (ssLNG) are another crucial area of innovation. These technologies improve access to isolated or neglected locations by enabling distributed production and delivery. ssLNG solutions contribute to new demand niches and are especially helpful in areas with limited pipeline penetration or in maritime and transportation applications.

Gas-based heating systems are now more energy-efficient for consumers because to smart thermostats, micro-CHP (combined heat and power) systems, and high-efficiency condensing boilers. Particularly in areas where electrification presents logistical or financial challenges, these solutions extend the profitability of natural gas. Notwithstanding these developments, long-term investments in gas infrastructure are coming under more and more scrutiny from the financial and regulatory communities. The deployment of cleaner technologies and hybrid systems (such as pipelines that are ready for hydrogen) is crucial for continued relevance because many funding institutions now expect projects to show compliance with EU decarbonisation goals.

5.4.2 Impact of Renewable Energy Technologies

The energy environment in Europe has changed as a result of the increasing competitiveness of renewable energy technologies, especially wind, solar, hydro, and biomass. Depending on the industry and use case, these technologies can either compete with or occasionally enhance natural gas.

In several nations, natural gas has been replaced by wind and solar electricity due to their rapid expansion. For instance, since 2019, renewable energy has outperformed gas-fired power output in Spain and Denmark for a number of quarters. Over 37% of the electricity generated in the EU in 2021 came from renewable sources, surpassing natural gas, according to the European Environment Agency (2022).

Electricity networks are now more flexible thanks to advancements in demand-side management, grid integration, and battery storage, which have lessened the need for natural gas as a backup supply. Even while gas-fired peaker plants are still essential for controlling load variability and maintaining grid stability, their market share is steadily declining due to technological advancements.

Gas usage is also being impacted by heat pump technology, which is aided by national subsidies and EU policy, especially in home heating. Particularly in more recent or retrofitted buildings, air-source and ground-source heat pumps provide effective electric substitutes for gas boilers. Heat pump usage has increased dramatically in nations like Sweden, Norway, and increasingly France and the Netherlands, lowering domestic gas consumption.

In the meantime, hydrogen—particularly green hydrogen made from renewable electricity—is becoming more and more prominent in discussions about technology and policy. In power generating, industrial heating, and even residential uses, hydrogen can be used in place of natural gas. Numerous large-scale electrolysis projects are expected to come online before 2030, and pilot programs in Germany, the Netherlands, and the UK are testing hydrogen blending in current gas grids.

Renewable alternatives that can be added to the current gas infrastructure include biomethane and synthetic methane. In order to facilitate the integration of low-carbon gas, a number of EU member states have implemented incentives for anaerobic digestion and power-to-gas technology.

But the change is not smooth. Barriers related to infrastructure, institutions, or the economy continue to limit the use of renewable alternatives in many Eastern and Southern European nations. Although technology leapfrogging is still possible with sufficient investment and policy alignment, natural gas continues to play a more significant role in these locations.

In summary, technical advancements are changing the natural gas demand environment in two important ways: by increasing the resilience and efficiency of gas infrastructure and by making feasible substitutes that lower the fuel's potential long-term demand. The way natural gas develops in Europe's changing energy grid will depend on how these trends interact.

5.5 Environmental and Climate Change Considerations

Environmental and climate-related considerations are among the most decisive long-term influences on natural gas demand in Europe. These concerns shape regulatory priorities, influence investment decisions, alter consumer preferences, and trigger shifts in technological trajectories. As the urgency of climate action intensifies, natural gas—once seen as a cleaner alternative to coal and oil—is increasingly scrutinized for its environmental externalities, especially methane emissions. This section investigates two critical dimensions: (1) sustainability and emission reduction targets, and (2) the role of public perception and environmental advocacy in shaping policy and market outcomes.

5.5.1 Sustainability and Emission Targets

Europe's environmental and climate policies are firmly anchored in its commitment to the Paris Agreement and the broader objective of becoming climate-neutral by 2050. The European Climate Law, which enshrines this target into binding legislation, establishes a roadmap that directly influences fossil fuel consumption, including natural gas.

Emission targets—both at the EU and national levels—serve as a fundamental constraint on natural gas demand. The intermediate objective of reducing net greenhouse gas emissions by 55% by 2030 (relative to 1990 levels), as articulated in the Fit-for-55 package, has direct implications for the decarbonization of energy systems. These policies translate into a broad spectrum of regulatory tools that reduce the relative attractiveness of natural gas compared to zero-emission alternatives.

The EU Emissions Trading System (ETS) remains a central instrument for pricing carbon and influencing fuel choices. With the inclusion of buildings and transport under ETS II (the revised scheme applicable from 2027), natural gas used for residential heating and small commercial buildings will become increasingly exposed to carbon pricing. In 2022, the average carbon price under the EU ETS exceeded €90/ton CO2e, creating strong economic signals in favor of electrification and efficiency improvements.

In addition, the Carbon Border Adjustment Mechanism (CBAM), scheduled for full implementation by 2026, will levy carbon tariffs on imports from countries with weaker climate policies. This regulation indirectly affects natural gas by influencing industrial production strategies and supply chains, further incentivizing low-carbon alternatives.

Another significant constraint on gas demand arises from the EU Methane Strategy. Methane is a greenhouse gas with a global warming potential 84 times that of CO2 over a 20-year period. The strategy introduces binding rules on leak detection, reporting, and reduction across the gas supply chain. These measures increase compliance costs for gas suppliers and infrastructure operators, potentially raising consumer prices and reducing competitiveness against renewables.

Several member states have also introduced national sustainability targets that go beyond EU-level mandates. For instance, Denmark and Sweden have set binding net-zero goals by 2045 and 2040, respectively. These countries have significantly reduced natural gas usage in electricity and residential sectors, instead promoting district heating, biomass, and electrification.

The overarching implication of these regulatory developments is that natural gas is no longer perceived as a bridge fuel without qualification. Instead, it must demonstrate compatibility with net-zero objectives through carbon capture and storage (CCS), blending with renewable gases (e.g., biomethane, hydrogen), or be confined to niche roles in sectors where electrification is not feasible.

5.5.2 Public Perception and Environmental Advocacy

Environmental activism and public opinion have become significant factors influencing the natural gas demand landscape. Regulatory tools are sensitive to public opinion, social movements, and civil society involvement even if they frequently mirror scientific consensus and economic modelling.

Across Europe, groups like Fridays for Future, Friends of the Earth, and Greenpeace have effectively opposed infrastructure projects that use fossil fuels. Their resistance has caused pipeline projects, LNG terminals, and gas-fired power stations to be delayed, cancelled, or subject to more scrutiny. One prominent example is the ongoing demonstrations against the Nord Stream 2 project, which sparked environmental resistance to the continued reliance on fossil fuels despite being primarily motivated by geopolitical concerns. According to European Investment Bank (EIB) surveys, most Europeans are in favour of bold climate measures that limit the expansion and subsidies of fossil fuels. Public opinion is shifting in favour of more renewable energy, with widespread support for solar, wind, and hydrogen and growing scepticism against natural gas.

Public calls for action are further heightened by media coverage of climate-related calamities, such as record heatwaves, floods, and wildfires. Corporate strategy are also impacted by these constraints. Environmental, Social, and Governance (ESG) norms are being embraced by energy utilities, network operators, and investors more and more. As a result, portfolios are frequently rebalanced to favour renewables and green technologies over fossil fuel-based assets.

Furthermore, changes in consumer choices have an impact on the energy use of households. Energy-efficient appliances, smart meters, and renewable heating options are becoming more and more popular due to both economic and environmental concerns. Thermostat modifications, off-peak use, and even community energy cooperatives are examples of behavioural shifts that are gaining traction.

From a policy standpoint, citizen assemblies, stakeholder meetings, and participatory governance frameworks have institutionalised the incorporation of public input into energy transition planning. These systems guarantee that environmental activism actively influences investment and regulation choices in addition to influencing conversation. In conclusion, the demand for natural gas in Europe is significantly and intricately impacted by environmental and climate change factors. In order to decrease the importance of natural gas in future energy systems, regulatory goals, sustainability frameworks, public opinion, and advocacy are coming together. This will hasten the transition to electrification, renewable gases, and integrated low-carbon solutions.

5.6 Geopolitical and Security Factors

The demand for natural gas in Europe is being shaped more and more by geopolitical factors and energy security concerns. Europe's energy policy has long been impacted by international relations, the volatility of global markets, and the availability of safe supply lines because the continent is highly dependent on imports. Two fundamental aspects of geopolitical influence are examined in this section: (1) international relations and energy security, and (2) case studies of recent supply interruptions that have changed demand trends and gas policy.

5.6.1 Energy Security and International Relations

One of the key concerns of EU energy policy continues to be energy security, which is the continuous availability of energy sources at a reasonable cost. Europe's natural gas demands have been met for decades by a small number of significant overseas suppliers, mostly from Russia, Norway, and Algeria. In the past, Russia in particular has provided more than 40% of the EU's gas imports, posing serious risks during geopolitical unrest. In February 2022, Russia invaded Ukraine, causing geopolitical repercussions that were a turning point in European energy strategy. In response, the EU swiftly approved the REPowerEU plan to lower total petrol consumption, speed up the deployment of renewable energy, and diversify energy imports. Between 2021 and 2023, Russian pipeline gas imports to the EU fell by almost 80%, drastically changing trade patterns and leading to a significant shift to LNG from the United States, Qatar, and other providers.

The demand for natural gas will be significantly impacted by this strategic change. On the one hand, because LNG markets are internationally traded and are influenced by changes in demand from Asia and other places, supply diversity has increased price volatility. On the other side, investments in natural gas substitutes like hydrogen, solar, wind, and energy storage have been spurred by the perceived vulnerability of geopolitical alliances. Furthermore, by developing strategic alliances with nations in the Eastern Mediterranean and North Africa (such as Egypt and Algeria), the EU has bolstered its external energy diplomacy. Infrastructure development, such as pipeline extensions, new LNG terminals, and electrical interconnections that lessen reliance on gas and increase resilience, has been the focus of intergovernmental agreements.

Perceptions of gas as a safe energy source are also influenced by the larger geopolitical environment, which includes Sahelian instability, supply chain conflicts with China, and U.S.-EU collaboration on energy security. In light of this, the European energy system's adaptability and resilience are now regarded as strategic imperatives that direct both public and private investment.

5.6.2 Case Studies of Supply Disruptions

European natural gas policy and infrastructure planning have been significantly impacted by past and present supply problems. The 2009 Russia-Ukraine gas conflict and the 2022 Nord Stream pipeline sabotage are two notable events due to their scope and systemic effects.

Gas supplies passing through Ukraine were stopped for two weeks in 2009 due to a pricing dispute between Russia's Gazprom and Ukraine's Naftogaz, which affected Slovakia, Bulgaria, and Romania, among other Eastern European nations. The Southern Gas channel and increased storage capacity in susceptible member states were developed as a result of this crisis, which brought attention to Europe's over-reliance on a single transit channel. There were significant repercussions from the September 2022 Nord Stream pipeline sabotage, which was generally seen to be a purposeful act of geopolitical aggression. Even while Europe had already lessened its reliance on Russian gas by that time, the attack highlighted how vulnerable vital infrastructure was and prompted additional diversification efforts. Temporary price controls to stabilise markets, faster filling of subterranean gas storage, and the installation of floating storage regasification units (FSRUs) were all examples of emergency policy solutions.

In 2021, Algeria suspended pipeline deliveries to Morocco and Spain because to diplomatic difficulties, causing yet another major interruption. The incident reaffirmed worries about the politicisation of energy commerce and the necessity of diverse, non-pipeline-based supply chains, despite the fact that the direct volume impact was minimal. Several lessons can be drawn from these case studies: (1) Geopolitical risk accelerates the energy transition by highlighting the fragility of fossil fuel dependency; (2) critical infrastructure must be safeguarded and modernised; (3) regional cooperation and interconnectivity enhance collective security; and (4) diversified supply routes and sources are necessary for resilience.

As a result, security, sustainability, and market stability are now more deeply integrated in Europe's energy policy. As the continent moves closer to a decarbonised and geopolitically robust energy system, natural gas, which was formerly essential to all three goals, is being demoted to a transitory position.

Chapter 6: Critical Analysis and Synthesis of the Literature

This chapter presents a comprehensive critical analysis and synthesis of six academic studies focused on the determinants of natural gas demand in Europe. Each of the selected papers contributes empirical findings, methodological innovations, and policy-relevant insights that collectively inform this thesis. The chapter is divided into four sections, corresponding to the framework set out in Chapter 1: a comparative analysis of empirical findings, identification of research gaps, assessment of methodological strengths and weaknesses, and implications of conflicting evidence.

6.1 Comparative Analysis of Empirical Findings

The academic literature on natural gas demand in Europe consistently highlights a central theme: natural gas demand, across both residential and industrial sectors, tends to be relatively inelastic to price, particularly in the short term. However, different papers emphasize distinct drivers of consumption, employ varying methodological tools, and arrive at nuanced conclusions about elasticity, policy influence, and behavioral responsiveness. This section compares the main findings across six key studies, describing their focus, methods, and relevance to understanding energy demand in contemporary Europe.

1. Industrial Demand Focus: Mashhadi Rajabi & Mousavi (2019)

This paper investigates industrial natural gas demand in 15 OECD countries between 1990 and 2014. Using Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS), the authors estimate long-run elasticities while correcting for endogeneity and serial correlation. The study is distinctive for its rigorous econometric technique and industrial sector specificity.

- **Findings:** Price elasticity ranges from -0.05 to -0.51, with industrial demand being relatively inelastic across countries. Income elasticity varies between 0.08 and 1.15.
- **Implications:** While price responsiveness exists, it is not strong enough to suggest that pricing mechanisms alone can significantly reduce industrial gas use. Policy and technological interventions may be required to accelerate shifts in energy sourcing.

2. Residential Demand Focus: Tatli (2018)

This study focuses on household gas consumption in 18 OECD countries over the period 2004–2015. It uses a panel random effects regression model and applies White period robust standard errors to account for autocorrelation and heteroskedasticity.

- **Findings:** The estimated price elasticity is -0.146, while income elasticity is 0.515. Climate, measured via heating degree days, is also a significant driver.
- **Implications:** The household sector exhibits moderate price sensitivity. Weather-related factors have a stronger short-term effect, suggesting that demand management policies in this sector should prioritize insulation, efficiency, and behavioral nudges over pricing alone.

3. Engineering-Based Real-Time Monitoring: Fernández-Blanco et al. (2024)

Unlike the other papers, this study employs a mass balance residual approach rather than econometrics. It estimates daily gas consumption across the EU based on data from ENTSOG, Eurostat, and ENaGaD. The methodology reconciles supply and storage flow data to infer consumption.

- **Findings:** Daily and weekly demand estimates closely align with official Eurostat statistics. The study shows demand reductions aligned with EU policies, particularly Regulation 2022/1369.
- **Implications:** While not estimating price or income elasticities, this approach is highly valuable for short-term monitoring and evaluating the effectiveness of policy interventions such as emergency gas storage mandates.

4. Elasticity Under Crisis Conditions: Erias & Iglesias (2022)

This paper analyzes monthly data from 25 European countries between 2005 and 2020, applying a Panel ARDL model to estimate short- and long-run elasticities. It also investigates the impact of COVID-19 lockdowns on residential gas demand.

- **Findings:** Short-run price elasticity ranges from -0.05 to -0.20, while long-run elasticities are stronger (up to -0.4). The paper identifies a "double heating effect" during lockdowns, where people increased gas use despite rising prices.
- **Implications:** Behavioral conditions—like remote work and movement restrictions—can temporarily override price sensitivity. Elasticity must therefore be interpreted contextually, not just statistically.

5. Post-Ukraine Crisis Demand: Adebowale et al. (2023)

This study investigates gas consumption trends across Russia, Ukraine, Poland, Germany, and the UK between 2009 and 2022. It applies a panel random effects model to explore the roles of price, demand, and supply.

- **Findings:** Natural gas prices negatively impact demand, while supply volumes positively correlate with consumption. The study also notes that demand determinants shifted after 2022 due to geopolitical disruptions.
- **Implications:** Supply-side constraints and price instability, exacerbated by the Ukraine crisis, affect the structure of demand. Long-standing relationships may no longer hold under crisis conditions.

6. German Households During the Energy Crisis: Jamissen et al. (2024)

This paper focuses specifically on Germany's small consumers (households and SMEs) between 2018 and 2023. Using an ARDL model on daily and monthly data, the study examines the effects of the 2022 energy crisis.

- **Findings:** Price elasticity is extremely low (-0.01 to -0.04). Instead, public awareness campaigns and weather fluctuations explain more of the variation in gas use.
- **Implications:** Even extreme price signals failed to meaningfully reduce consumption. Non-price tools like behavioral campaigns and crisis messaging appear more effective in emergency settings.

Study	Focus	Methodology	Price Elasticity	Income Elasticity
Mashhadi & Mousavi (2019)	Industrial demand	FMOLS, DOLS	-0.05 to -0.51	0.08 to 1.15
Tatli (2018)	Household demand	Random Effects, White robust SE	-0.146	0.515
Fernández-Blanco et al. (2024)	EU-wide daily estimation	Mass balance estimation	Not modeled	Not modeled
Erias & Iglesias (2022)	Elasticity during COVID-19	Panel ARDL	-0.05 to -0.20 (short-run), ~-0.4 (long-run)	Yes (varies)
Adebowale et al. (2023)	Post-Ukraine macro trends	Panel Random Effects	Negative relationship	Not specified
Jamissen et al. (2024)	German households during crisis	ARDL (daily/monthly)	-0.01 to -0.04	Not specified

Table 1: Elasticities across Studies

Across these studies, a coherent pattern emerges: natural gas demand is systemically inelastic in the short term, more sensitive to crisis and behavioral factors than to market pricing alone, and sector-specific interventions are more effective than blanket pricing mechanisms. Industrial sectors show moderate long-run elasticity, while households remain largely resistant to price changes unless accompanied by policy, behavioral, or weather-based triggers.

These insights set the stage for the following section, which explores gaps in geographic coverage, methodological choices, and behavioral modeling within the current literature.

6.2 Identification of Research Gaps

Despite the empirical contributions of the six studies analyzed in this chapter, several important gaps remain that limit the broader generalizability and policy applicability of their findings. These gaps pertain to temporal scope, geographic coverage, behavioral factors, methodological limitations, and the treatment of structural breaks and crisis dynamics. This section provides a systematic overview of those gaps and highlights directions for future research.

6.2.1 Temporal and Data Frequency Gaps

Most of the studies rely on annual or monthly data, which, while useful for estimating broad trends, are insufficient to capture the dynamic changes that occur in response to sudden shocks such as the COVID-19 pandemic or the 2022 energy crisis. For instance, Adebowale et al. (2023) use annual panel data covering 2009–2022, while Tatli (2018) uses annual data from 2004–2015. Although these studies provide valuable long-run perspectives, they fail to reflect rapid behavioral or consumption changes that may occur over shorter time intervals.

Jamissen et al. (2024) and Fernández-Blanco et al. (2024) stand out in this regard by utilizing daily datasets. The former applies an ARDL model using daily and monthly data for German households during the energy crisis, while the latter constructs a daily demand estimate based on physical flow data using a mass balance approach. These high-frequency approaches offer much-needed granularity and real-time insight, yet they remain underutilized in broader panel-based research. Future work should leverage high-resolution datasets, particularly in the wake of major policy changes or energy supply shocks.

6.2.2 Geographic Gaps and Limited Regional Diversity

Several of the reviewed papers focus primarily on OECD or Western European countries. Tatli (2018) and Mashhadi Rajabi & Mousavi (2019) use broad OECD datasets, which include countries from multiple continents, while Adebowale et al. (2023) concentrate on a limited number of countries: Poland, Germany, the UK etc. Although these countries are strategically relevant, the exclusion of Southern and Eastern European member states such as Bulgaria, Romania, Croatia, and the Baltic nations presents a major shortcoming.

Given the diversity of energy mixes, infrastructure limitations, and subsidy structures across Europe, it is risky to generalize findings from a handful of countries to the entire continent. For example, countries that heavily subsidize energy or rely on a single supply route may exhibit different elasticity profiles than those with more liberalized markets or diversified imports. The absence of geographically diverse case studies limits the representativeness of elasticity estimates and reduces the applicability of policy recommendations.

6.2.3 Sectoral Narrowness and Lack of Disaggregation

While some papers attempt sectoral focus (e.g., Mashhadi Rajabi & Mousavi (2019) for industrial consumers and Tatli (2018) for households), most do not provide detailed sectoral disaggregation within their models. Even studies with high data frequency, like Fernández-Blanco et al. (2024), focus on aggregate national-level consumption without distinguishing between household, industrial, and commercial users.

Yet demand drivers differ significantly across sectors. Industrial consumption is often driven by process needs and economic output, while household demand is more influenced by weather, income, and behavioral norms. Without disaggregation, it is difficult to tailor policy responses effectively. For instance, a carbon price that works for large industrial users may have minimal impact—or even adverse distributional effects—on low-income residential consumers. More sector-specific modeling is urgently needed.

6.2.4 Underrepresentation of Behavioral and Institutional Variables

Although the econometric models control for observable variables like price and income, most of the reviewed studies give little attention to behavioral and institutional dynamics. Only Jamissen et al. (2024) and Erias & Iglesias (2022) attempt to integrate behavioral elements, noting that public awareness campaigns and COVID-19 lockdowns had stronger effects on demand than price alone.

The remaining studies implicitly assume that consumers behave as rational agents who adjust energy use based on cost. This assumption often fails in real-world settings, where behavior is influenced by habits, social norms, misinformation, and structural inertia. Likewise, institutional mechanisms such as energy subsidies, tariff regulations, and efficiency standards are often treated as exogenous or omitted altogether. These oversights lead to over-simplified models that cannot fully explain or predict shifts in consumption during crises or policy transitions.

Future research should incorporate behavioral economics frameworks, perhaps through hybrid qualitative-quantitative methods or the inclusion of survey and experimental data alongside econometric models. This would provide a more nuanced understanding of how consumers actually respond to energy policies.

6.2.5 Inconsistent Treatment of Structural Breaks and Crises

The COVID-19 pandemic and the 2022 energy crisis represent major structural breaks that dramatically altered natural gas consumption patterns across Europe. While Erias & Iglesias (2022) explicitly examine the effects of COVID-19 lockdowns, and Jamissen et al. (2024) address the 2022 crisis in Germany, other studies either predate these events (e.g., Tatli, 2018; Mashhadi Rajabi & Mousavi, 2019) or do not adequately isolate crisis periods from long-term trends.

Only a few papers employ techniques capable of detecting or adjusting for structural breaks, such as segmented regression, dummy variables, or time-varying parameter models. As a result, they risk attributing crisis-induced anomalies to typical market behavior. This weakens the reliability of long-run elasticity estimates and may mislead policy decisions.

Going forward, it is essential for elasticity modeling to incorporate methods for detecting and adjusting for structural breaks. This can include pre- and post-crisis comparisons, regime-switching models, or even interactive policy variables. Without such tools, models will struggle to remain relevant in an energy landscape increasingly characterized by volatility.

6.2.6 Limited Use of Hybrid or Interdisciplinary Models

Most of the literature reviewed relies on traditional econometric techniques, with limited use of interdisciplinary or hybrid approaches. For example, only Fernández-Blanco et al. (2024) apply a physical-engineering model, while all others rely on econometric modeling alone. No study combines econometric modeling with system dynamics, agent-based modeling, or behavioral simulations.

As natural gas systems become more interdependent with renewable integration, digital control systems, and consumer-level technologies (e.g., smart meters), it is essential to go beyond static elasticity estimates. Multi-method approaches could allow researchers to simulate consumer adaptation to variable pricing, policy shifts, and infrastructure bottlenecks.

Hybrid modeling also allows for integration of qualitative data—such as stakeholder interviews or policy reviews—into quantitative forecasting tools. Such combinations are especially valuable when trying to assess not just what has happened in the past, but how consumers and markets might respond under future uncertainty.

In conclusion, while the six reviewed papers provide a strong empirical foundation, they also reveal significant research gaps in terms of temporal resolution, sectoral disaggregation, behavioral insights, geographic coverage, and model complexity. Future research should focus on closing these gaps through higher-frequency, regionally diverse, and methodologically pluralistic approaches that better reflect the evolving realities of gas consumption in Europe.

6.3 Methodological Strengths and Weaknesses in the Literature

The six studies reviewed in this chapter use a diverse set of methodologies to investigate natural gas demand in Europe. These range from advanced econometric models like FMOLS and ARDL to engineering-based mass balance estimation. Each methodology carries strengths aligned with its objectives, yet also reveals important limitations that affect the reliability, comparability, and generalizability of results. This section critically examines the methodological tools used across the studies, assessing their appropriateness, innovations, limitations, and potential for future enhancement.

6.3.1 Panel Data Models: Strength in Cross-Country Comparisons

Panel regression models form the backbone of empirical analysis in several reviewed papers. Tatli (2018) and Adebowale et al. (2023) use Random Effects (RE) estimation, while Iglesias and Erias (2022) use a panel ARDL framework. The primary strength of panel methods lies in their ability to exploit both cross-sectional and time-series variation. This is crucial in energy studies, where the interaction of economic, climatic, and policy factors often differs by country.

The use of RE models, validated through Hausman tests, is appropriate when the assumption of uncorrelated individual effects holds. Tatli (2018) enhances model robustness by correcting for heteroskedasticity and serial correlation using White period standard errors. These refinements improve inference quality, particularly in long panels where standard OLS assumptions often fail.

However, panel methods in these studies often rely on aggregate national data and fail to test for structural breaks or time-varying parameters. As seen in Section 6.2, this is problematic in volatile energy environments where price responsiveness may shift across crises or policy transitions. Furthermore, the choice between RE and Fixed Effects (FE) is not always explicitly justified beyond statistical testing, and very few studies attempt pooled mean group (PMG) or dynamic panel GMM estimation, which could better capture dynamic relationships.

6.3.2 Time-Series Models: Granularity and Dynamics

Time-series methods offer a more granular perspective, particularly when applied to high-frequency data. Jamissen et al. (2024) apply an ARDL model using daily and monthly German data to investigate the responsiveness of small consumer gas demand during the 2022 energy crisis. ARDL models are advantageous when working with mixed-order variables (I(0) and I(1)) and allow for separate estimation of short- and long-run effects.

ARDL also avoids the pitfalls of over-differencing and can include lagged dependent variables for dynamic modeling. In Jamissen's work, this enables the authors to estimate short-run price elasticity near -0.01 and detect a lagged effect of public information campaigns. Erias & Iglesias (2022) similarly apply a panel ARDL framework, estimating how lockdowns and seasonal shifts influence demand across European countries.

The strength of ARDL lies in its flexibility and intuitive interpretation. However, its application to cross-country panels, as in the case of Erias & Iglesias, assumes homogeneity in lag structures and fails to account for potential cross-sectional dependence. Moreover, while ARDL can detect long-run equilibrium relationships, its results are sensitive to lag length choices and require cointegration testing, which is not always fully reported in the studies reviewed.

6.3.3 Advanced Cointegration Techniques: FMOLS and DOLS

Mashhadi Rajabi & Mousavi (2019) offer the most rigorous econometric framework among the reviewed papers by using Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS). These estimators correct for serial correlation and endogeneity in long-run panel regressions involving non-stationary data. By using both FMOLS and DOLS, the authors ensure internal consistency and robustness of elasticity estimates for industrial gas demand.

These methods are particularly well-suited for evaluating long-term structural relationships, such as how industrial output and macroeconomic cycles affect gas consumption. The use of two estimators allows for cross-validation, which strengthens the credibility of results.

However, FMOLS and DOLS also have limitations. They are typically suited for balanced panels with sufficiently long time horizons. Their reliance on large-sample asymptotic properties makes them less applicable in crisis contexts, where sudden regime shifts or external shocks violate equilibrium assumptions. Additionally, both estimators assume a linear relationship between variables, which may oversimplify complex demand dynamics.

6.3.4 Non-Econometric Approaches: Mass Balance Modeling

Fernández-Blanco et al. (2024) depart from econometric modeling and instead apply a physical mass balance approach to estimate daily gas consumption across the EU. This model integrates pipeline flows, LNG imports, and storage data from ENTSOG, Eurostat, and ENaGaD.

The main strength of this approach is operational accuracy. It allows for near real-time monitoring and evaluation of policy interventions, particularly during crises. For example, the study demonstrates a strong correlation between actual demand reductions and the enforcement of EU storage regulations.

However, the approach has no capacity to estimate price or income elasticity, nor can it disaggregate demand by consumer group. It treats demand as a residual rather than an outcome of behavioral or economic decision-making. This makes it less suitable for forecasting or causal inference, although it is highly valuable for infrastructure monitoring and emergency planning.

6.3.5 Treatment of Structural Breaks and Crisis Events

Only a few studies explicitly address structural breaks. Erias & Iglesias (2022) use lockdown dummies to evaluate behavioral shifts during COVID-19, and Jamissen et al. (2024) indirectly capture the effects of the 2022 crisis by using daily data over the crisis period. These efforts illustrate the importance of distinguishing between typical behavior and crisis-induced anomalies.

Other studies, particularly those based on pre-2020 data (e.g., Tatli, 2018; Mashhadi Rajabi & Mousavi, 2019), do not consider structural breaks. This is a major limitation, as elasticity estimates derived from stable periods may not apply during disruptions such as pandemics, wars, or major policy shifts. Models that fail to incorporate break detection or regime-switching may yield biased or outdated policy recommendations.

In future studies, crisis-aware methods such as threshold regression, rolling window analysis, or Markov-switching models could be used to distinguish between "normal" and "crisis" regimes. These methods are computationally intensive but increasingly necessary in an era of frequent and overlapping energy shocks.

6.3.6 Overall Comparability and Transparency

Across all six papers, one recurring issue is limited comparability due to inconsistent reporting standards. Key methodological choices—such as variable definitions, lag structures, stationarity testing, and model diagnostics—are not always clearly explained. For example, some studies (e.g., Adebowale et al., 2023) provide limited detail on model validation or robustness testing.

Moreover, the choice of estimation windows varies considerably: some cover multiple decades, while others focus on specific crisis periods. This divergence complicates attempts to benchmark results or assess the evolution of demand responsiveness over time.

Transparency in methodology is crucial for research replication and policy trust. Future studies should adopt standardized reporting templates (e.g., including ADF/Pesaran test results, cointegration statistics, and elasticity interpretation guidance). This would facilitate meta-analyses and improve cumulative knowledge building in the field.

In summary, the methodological diversity of the reviewed studies provides valuable insights but also exposes key weaknesses. While econometric techniques such as ARDL, FMOLS, and DOLS offer rigor and interpretability, they often lack flexibility under crisis conditions. Physical models like mass balance estimation enhance real-time tracking but cannot explain behavioral dynamics. There is a pressing need for hybrid approaches that integrate econometric estimation with crisis sensitivity, behavioral modeling, and engineering realism. This will be critical for developing robust and forward-looking tools for gas demand management in Europe.

6.4 Implications of Conflicting Evidence

While the six studies reviewed share several points of convergence—particularly the widespread finding that natural gas demand is price inelastic—they also exhibit meaningful differences that raise questions about the generalizability and robustness of certain conclusions. These inconsistencies stem from differences in methodology, temporal focus, country selection, and sectoral coverage. This section synthesizes these conflicts, explores their implications, and suggests how they may be interpreted or resolved through improved modeling and data practices.

6.4.1 Disparities in Elasticity Estimates

One of the most noticeable areas of conflicting evidence relates to the magnitude of estimated price elasticities. For instance, the estimated short-run price elasticity in Tatli (2018) for households is -0.146, whereas Jamissen et al. (2024) report much smaller elasticities for German households during the energy crisis, ranging from -0.01 to -0.04. This contrast is especially stark given that both studies focus on residential consumption.

This discrepancy could be attributed to differences in temporal granularity (annual vs. daily data), policy environments (normal years vs. crisis years), and estimation techniques (RE vs. ARDL). Moreover, the responsiveness captured in Tatli's study may reflect normal market behavior, whereas Jamissen's low elasticity may result from behavioral rigidity under extreme price conditions.

Similarly, the income elasticity estimates differ substantially. Mashhadi Rajabi & Mousavi (2019) report income elasticities for industrial demand between 0.08 and 1.15, suggesting substantial heterogeneity across countries and industries. Tatli (2018), in contrast, reports a household income elasticity of 0.515, while other studies like Adebowale et al. (2023) do not quantify income effects explicitly. These divergences complicate the development of a single, unified elasticity metric suitable for policy modeling.

6.4.2 Behavioral and Non-Price Factors

Several studies suggest that non-price factors may have stronger short-term effects on consumption than price signals. For example, Jamissen et al. (2024) show that behavioral interventions such as public awareness campaigns had a more noticeable impact on demand than price increases during the energy crisis. Erias & Iglesias (2022) similarly report a "double heating effect" during COVID-19 lockdowns—households consumed more gas due to increased time spent at home, even as prices remained volatile.

In contrast, traditional econometric models like those used by Adebowale et al. (2023) and Tatli (2018) assume rational responses to price and income. The tension between behaviorally-aware models and conventional econometric assumptions reflects a deeper conflict in the literature: should demand be modeled primarily as a function of economic optimization, or as a socially and institutionally embedded process?

This question has significant implications for policy design. If consumers do not respond strongly to prices—even when those prices rise dramatically—then measures like carbon pricing may be less effective than expected, particularly in the short run. This underscores the need for policies that combine price signals with behavioral nudges, regulatory mandates, or infrastructure upgrades.

6.4.3 Treatment of Crisis Conditions

Another area of conflicting evidence concerns how crises such as the COVID-19 pandemic and the 2022 energy shock are integrated into demand modeling. Jamissen et al. (2024) and Erias & Iglesias (2022) attempt to capture crisis effects through high-frequency data and dummy variables. However, other studies (e.g., Tatli, 2018; Mashhadi Rajabi & Mousavi, 2019) use pre-crisis data and do not adjust their models for structural breaks or regime changes.

This divergence affects the interpretation of elasticity estimates. Estimates from stable periods may overstate the degree of consumer flexibility, while estimates from crises may understate it due to behavioral freeze or institutional lock-in. Without careful adjustment for structural breaks, it becomes difficult to know whether elasticity estimates reflect fundamental preferences or temporary constraints.

Moreover, the difference in data frequency (daily vs. annual) makes it hard to reconcile findings. High-frequency models may pick up short-term behavioral adjustments that are invisible in yearly data. For example, a daily model may detect a drop in demand during a two-week cold snap or policy announcement, whereas an annual model would average this out.

6.4.4 Sectoral Elasticity Conflicts

Discrepancies also arise when comparing sectoral estimates. Mashhadi Rajabi & Mousavi (2019) report more elastic behavior in the industrial sector than is generally observed in the household sector. This suggests sector-specific drivers that are not always captured in aggregate models. Industrial users may have more capacity to adjust usage through efficiency improvements or fuel switching, while households may lack such flexibility.

However, this is not universally agreed upon. Some case studies suggest that small businesses (classified as industrial consumers in some datasets) are just as inflexible as households, especially during short-term price spikes. Without clearer sectoral breakdowns and harmonized classification systems, such inconsistencies are likely to persist.

6.4.5 Implications for Policy Modeling and Forecasting

The conflicting evidence across these studies reveals the limitations of single-method, single-context modeling approaches. It challenges the assumption that elasticities are stable, transferable, and policy-neutral. Elasticities are, in fact, deeply contextual: shaped by behavior, crisis events, policy interventions, and the sector under consideration.

These findings suggest that policy models must account for uncertainty and heterogeneity rather than rely on point estimates. Scenario-based planning, probabilistic modeling, and adaptive policy frameworks are more appropriate than deterministic projections. Moreover, modelers must clearly communicate the assumptions and limits of elasticity estimates to avoid misinterpretation.

In conclusion, the inconsistencies across the literature are not a weakness per se but rather a reflection of the complex, evolving nature of natural gas consumption. Rather than seeking a definitive elasticity value, future research should embrace model plurality and context sensitivity. This will enable more realistic forecasts and more effective, tailored interventions in Europe's transition toward sustainable and secure energy systems.

Chapter 7: Discussion and Policy Implications

Key insights regarding the factors influencing natural gas demand in Europe and its applicability to energy policy are highlighted in this chapter's discussion of the empirical findings from Chapter 6. The emphasis is on combining verified data from the six scholarly studies that were examined. Sector-specific dynamics and key factors are highlighted in Section 7.1. More general policy implications are discussed in Section 7.2, especially in relation to energy security and the post-crisis climate. Future directions for research and policymaking are outlined in Section 7.3.

7.1 Synthesis of Key Determinants

A comprehensive collection of factors influencing the demand for natural gas in Europe is shown by the analysis of six recent, empirically supported research. These factors fall into the following general categories: exogenous shocks (e.g., COVID-19, geopolitical crises), behavioural and institutional factors, structural conditions (sectoral behaviours and market conditions), and economic variables (price and income). Crucially, the degree of elasticity varies by sector, region, and context, even though it is generally agreed that natural gas demand is price inelastic in the near term.

7.1.1 Price Elasticity of Demand

Every study that calculates price elasticity, including Tatli (2018), Mashhadi Rajabi & Mousavi (2019), Erias & Iglesias (2022), Adebowale et al. (2023), and Jamissen et al. (2024), comes to the conclusion that demand for natural gas is inelastic, especially in the near term, for both the residential and industrial sectors. According to Tatli (2018), families in 18 OECD nations have a short-run price elasticity of -0.146. Jamissen et al. (2024), utilising high-frequency data from Germany's 2022 energy crisis, report even lower elasticity values between -0.01 and -0.04. These variations show the impact of regional features, temporal granularity, and crisis settings.

Using FMOLS and DOLS estimators, Mashhadi Rajabi & Mousavi (2019) establish a long-run price elasticity range for the industrial sector between -0.05 and -0.51. This suggests that industrial customers have limited short-term flexibility because of production interdependence and capital constraints, even though they may adjust over time. Although they do not provide exact elasticity coefficients, Adebowale et al. (2023) use panel random effects to confirm a negative link between price and petrol use. In conclusion, although price is still a significant factor, its influence is lessened by behavioural and structural rigidity, particularly in the residential sector. According to

Jamissen et al., elasticity is context-specific and frequently reduced during times of crisis (2024).

7.1.2 Income and Demand-Side Growth Drivers

GDP growth or income level is another important factor affecting demand. Mashhadi Rajabi & Mousavi (2019) estimate income elasticity for industrial consumers to be between 0.08 to 1.15, with significant cross-country variation, whereas Tatli (2018) estimates a positive family income elasticity of 0.515. These results imply that natural gas consumption increases with income levels, while the marginal impacts of this relationship reduce with industry saturation and technological replacement.

The demand for manufacturing, energy, and heating services rises during periods of economic expansion, especially in middle-income countries. Efficiency improvements and energy transitions, however, have an impact on this relationship. Erias & Iglesias (2022), for example, demonstrate how behavioural changes during the COVID-19 lockdowns, where petrol consumption remained high despite an increase in income volatility, temper income elasticity.

Though not as significant as one might anticipate in policy modelling, income elasticity is often positive. In the long run, structural and behavioural dynamics are probably going to surpass it.

7.1.3 Structural and Sectoral Determinants

Demand behaviour is greatly influenced by sector-specific dynamics. Price, income, and temperature are the main determinants influencing household consumption; Tatli (2018) and Jamissen et al. (2024) effectively model these factors. When heating degree days and seasonal variation are included in these models, it becomes clear that climate and weather variations have a greater influence on short-term petrol consumption than do price changes.

On the other hand, industrial consumption is more sensitive to macroeconomic factors and long-term price fluctuations, according to a thorough analysis in Mashhadi Rajabi & Mousavi (2019). Although they may seem more adaptable over time, industrial users are typically capital-intensive and integrated into infrastructural networks that restrict instantaneous substitution. They are therefore vulnerable to long-term price fluctuations but impervious to abrupt ones.

One recurrent issue identified in the majority of studies is the absence of disaggregated data across industries. Adebowale et al. (2023), for instance, provide macro-level statistics for five nations without making a distinction between patterns of consumption in residential, commercial, and industrial settings. This restricts the capacity to obtain complex policy insights. With their mass balance technique, Fernández-Blanco et al. (2024) are the only ones that provide detailed temporal disaggregation without sectoral breakdown.

7.1.4 Behavioral and Institutional Influences

Numerous studies highlight the fact that demand for natural gas is not exclusively influenced by economic factors. Price processes can be overridden by institutional and behavioural variables, especially when there are disturbances. Public awareness initiatives during the 2022 energy crisis had a greater impact on lowering household demand than price hikes, according to Jamissen et al. (2024). Similar to this, Erias & Iglesias (2022) demonstrate that despite price increases, demand increased during lockdowns as a result of higher housing occupancy.

The rational consumer model incorporated into conventional elasticity calculations is called into question by these findings. Short-term consumer behaviour is impacted by awareness, routine, cultural norms, and outside limitations. The situation is further complicated by institutional elements like tariffs, subsidies, and restrictions. Fernández-Blanco et al. (2024), for instance, show how the EU Regulation 2022/1369, which was based on required storage reductions rather than price signals, had quantifiable effects on petrol use.

Institutional guidance and behavioural rigidity seem to be key factors in understanding why actual spending patterns deviate from predictions made by economic models. A methodological blind spot that lowers predicted accuracy is indicated by their exclusion from numerous elasticity experiments.

7.1.5 Exogenous Shocks and Crisis Effects

The demand for natural gas is significantly disrupted by exogenous events such as the Russian invasion of Ukraine and the COVID-19 epidemic. High-frequency and panel ARDL techniques are used by Jamissen et al. (2024) and Erias & Iglesias (2022) to directly predict crisis-related consumption behaviours. They discover that crises lower elasticity because people's flexibility contracts under pressure, not because they become less logical.

The post-2022 changes in petrol demand in Eastern and Western Europe are also covered by Adebowale et al. (2023), who attribute a large portion of the consumption fall to price volatility and supply instability. These exogenous variables highlight the necessity of incorporating non-linear responses, shifting baselines, and structural breaks into elasticity models.

In conclusion, the demand for petrol during a crisis is a reflection of political, behavioural, and infrastructure limitations in addition to market forces. Both short- and long-term demand profiles are changed by these circumstances, suggesting that energy modelling needs to be put to the test against realistic disruption situations.

When combined, the six studies offer a solid empirical basis for comprehending the fundamental factors influencing the demand for natural gas in Europe. Although they are mediated by sector, behaviour, crisis scenario, and policy environment, price and income are important. Future demand predictions will need to incorporate these complex and interconnected aspects into more comprehensive, adaptive modelling methodologies as Europe manages several transitions, including energy security, decarbonisation, and inflation.

7.2 Broader Policy Implications for European Energy Security

The design of resilient and successful energy policy in Europe is significantly impacted by the empirical results summarised in Section 7.1 and presented in Chapter 6. Given the region's ongoing petrol price volatility, geopolitical unpredictability, and aggressive decarbonisation objectives, policymakers face a challenging energy environment where consumer reactions are frequently subdued, sector-specific, and context-specific. In view of the implications for pricing policy, crisis management, behavioural interventions, and long-term planning for energy security, this section considers the more general lessons that can be drawn from the verified research.

7.2.1 Price-Based Policy Instruments: Limited but Not Irrelevant

Research by Tatli (2018), Mashhadi Rajabi & Mousavi (2019), and Jamissen et al. (2024) demonstrates that short-term natural gas demand is typically inelastic for both residential and industrial users. Price increases alone don't cause many behavioural changes in households, particularly when there is a lot of volatility. With elasticity estimates close to -0.01, Jamissen et al. found little price response even during Germany's 2022 energy crisis.

This result raises doubts about the effectiveness of strictly price-based tools like market liberalisation or carbon pricing in times of crisis. Despite being a fundamental instrument in market economies, price signals' immediate effects on petrol consumption are limited by behavioural patterns, infrastructure constraints, and barriers to substitution. To increase their efficacy, price-based programs must be supplemented with additional measures.

However, as demonstrated by Mashhadi Rajabi & Mousavi (2019), long-run industrial elasticity implies that steady and predictable pricing signals may influence investment choices, including those involving process efficiency enhancements and technological advancements. Therefore, stable price situations can aid sectors in moving away from natural gas over the medium to long term, even while short-term elasticity is limited.

7.2.2 Crisis-Sensitive Planning: The Role of Institutional Responses

The 2022 gas supply shock and the Covid-19 pandemic highlighted the limitations of market processes and the need for proactive institutional involvement. According to Fernández-Blanco et al. (2024), crisis management can benefit greatly from real-time monitoring using physical balancing models. According to their research, regulatory requirements rather than price behaviour were the main cause of the consumption declines that followed Regulation 2022/1369.

Likewise, petrol consumption during lockdowns did not decrease in accordance with conventional demand models, according to Erias & Iglesias (2022). Rather, any anticipated decline was countered by increased household heating and behavioural inertia. These results support the need of quick reaction systems and institutional foresight.

From a policy standpoint, this indicates that emergency preparedness must include robust monitoring systems, flexible demand-side management protocols, and supply-side redundancy (e.g., LNG import capacity, storage reserves). Institutional agility is just as important to Europe's ability to secure gas supplies and adjust demand amid disruptions as market functionality.

7.2.3 Behavioral Interventions: A Missing Link in Traditional Policy

The efficiency of public awareness initiatives in lowering consumption during the energy crisis is highlighted by Jamissen et al. (2024). German households used less petrol after being exposed to behavioural cues and tailored messages, even if there was little price response. This implies that social and psychological forces, in addition to monetary incentives, might improve demand-side management.

This data calls into question the widely held belief that pricing, taxes, or subsidies are the most effective ways to control energy use. It makes room for creative strategies including real-time consumption feedback tools, default efficiency settings, and energy literacy initiatives. As an affordable and expandable addition to economic regulation, behavioural science should be investigated by policymakers.

Crucially, distributional benefits are another benefit of behavioural tools. They can encourage energy equity in low-income or vulnerable households by modifying consumption habits without adding to existing financial burdens.

7.2.4 Infrastructure and Security Investments

A number of studies emphasise the significance of supply-side infrastructure, even if the majority of the reviewed literature concentrates on demand-side variables. According to Adebowale et al. (2023), supply disruptions caused changes in petrol consumption patterns in addition to price changes. Similarly, Fernández-Blanco et al. (2024) emphasise how important LNG terminals, pipeline flows, and storage systems are to preserving supply-demand equilibrium.

This supports the notion that ongoing investments in robust infrastructure are necessary for energy security. In addition to being supply-side priority, policies that increase strategic reserves, diversify import sources, and improve cross-border interconnectivity also facilitate steady and flexible demand-side behaviour.

7.2.5 Integration with Climate and Decarbonization Goals

The conflict between natural gas as a transitional fuel and the EU's longer-term decarbonisation agenda is mentioned in passing in a number of the evaluated publications. Although gas is now seen as a bridge in the transition from coal to renewable energy, its long-term significance is still up for debate.

Without direct action, petrol usage may not decrease rapidly due to low elasticity and structural dependency. This emphasises the necessity of coordinated phase-out plans, particularly in industries that are difficult to eradicate. It also prompts worries that an excessive dependence on natural gas, especially for industrial processing and home heating, may impede decarbonisation and lock in carbon-intensive infrastructure.

Therefore, in addition to price signals, targeted technological policies, fuel-switching subsidies, and demand modelling integration into decarbonisation roadmaps will be necessary to link energy security with climate goals. Though further sector-specific and scenario-based work is required, the research presented here provide a basis for such integrated approaches.

In conclusion, the empirical data emphasises how crucial multifaceted policy design is. Pricing is not enough to provide energy security in Europe. It necessitates a concerted approach that incorporates infrastructure investment, institutional planning, behavioural interventions, and alignment with decarbonisation objectives. In order to enable an adaptable and resilient energy transition in Europe, the next section elaborates on how future research and policy might build on these insights.

7.3 Recommendations for Future Research and Policy Directions

7.3.1 Improving Temporal Resolution and Monitoring Capacity

A notable insight emerging from the reviewed studies is the importance of high-frequency data in capturing short-term changes in natural gas demand, especially under volatile conditions. Jamissen et al. (2024) and Fernández-Blanco et al. (2024) demonstrate the advantages of using daily and weekly data in understanding behavioral changes and regulatory effectiveness, respectively. Future research should continue this trend by incorporating more granular data that reflects how households and industries adjust consumption in real time. Such improvements in temporal resolution will enhance the predictive quality of demand models, particularly under crisis conditions.

From a policy standpoint, governments and regulators should invest in high-frequency monitoring systems that can track gas consumption with minimal delay. These systems would be instrumental during energy emergencies, allowing policymakers to gauge the effectiveness of interventions such as storage mandates or demand-reduction campaigns.

7.3.2 Accounting for Structural Breaks and Crisis Conditions

Many elasticity estimates in the literature risk becoming outdated or misleading if they fail to account for major structural shifts, such as those induced by the COVID-19 pandemic or the 2022 gas crisis. Studies like Erias & Iglesias (2022) and Jamissen et al. (2024) provide examples of how crisis-aware models can improve our understanding of gas demand. These studies introduce variables or time-segmentation techniques to isolate crisis impacts from normal patterns.

Future work should include structural break tests and allow for time-varying elasticity to capture shifts in consumer behavior and policy environments. This will be particularly important in building models that remain valid across different economic and geopolitical cycles. On the policy side, incorporating crisis-sensitivity into elasticity forecasting can support more robust contingency planning and scenario development.

7.3.3 Enhancing Sectoral Disaggregation and Method Integration

A recurring limitation across the studies is the aggregation of demand across sectors. With the exception of Tatli (2018) and Mashhadi Rajabi & Mousavi (2019), most studies provide only macro-level insights that obscure critical differences between household, industrial, and commercial consumption patterns. Future research should aim to develop disaggregated models that address the heterogeneity of demand drivers.

In parallel, there is value in integrating econometric approaches with engineering and systems modeling. Hybrid approaches that combine the statistical rigor of elasticity estimation with the dynamic capabilities of mass balance or system dynamics models could offer a more complete picture of energy use and policy impact. For example, engineering data can provide constraints or validation points for econometric models, particularly in real-time demand estimation.

7.3.4 Capturing Behavioral and Institutional Influences

Traditional models often assume rational responses to price and income changes. However, the studies by Jamissen et al. (2024) and Erias & Iglesias (2022) show that non-price factors—such as public awareness, lockdown behavior, and government mandates—can strongly influence demand. This insight has clear implications for both research and policy.

Future studies should explicitly model behavioral determinants using survey data, stated preference methods, or agent-based simulations. Moreover, institutional variables such as tariffs, subsidies, and energy efficiency standards should be treated as integral parts of the demand system. On the policy side, greater emphasis should be placed on behaviorally informed interventions such as energy-use feedback, default options in appliances, and targeted messaging during crisis periods.

7.3.5 Expanding Geographic and Market Diversity

The current literature is skewed toward OECD and Western European countries, leaving substantial blind spots in our understanding of gas demand in Eastern and Southern Europe. Adebowale et al. (2023) partially address this with their inclusion of Poland and Ukraine, but broader regional representation is needed to fully capture the diversity of demand behaviors, subsidy structures, and market designs within the EU.

Future research should incorporate more country-specific studies, ideally using harmonized panel data that facilitates cross-country comparison. Policymakers at the EU level can also support this goal by promoting transparency and data sharing among member states. Comparative elasticity analyses could inform the calibration of energy policies to local economic and institutional conditions.

7.3.6 Linking Elasticity to Climate Policy and Decarbonization

Finally, although none of the six reviewed studies explicitly frame their work within the context of climate policy, the findings carry clear implications for the EU's decarbonization trajectory. Inelastic demand in key sectors such as residential heating and industry suggests that natural gas consumption may persist longer than anticipated without targeted intervention.

Future modeling should connect demand elasticity with climate scenarios, technology adoption pathways, and emissions reduction targets. Energy system models that include elasticity constraints and sector-specific transition plans will provide more realistic projections and inform effective carbon pricing strategies. Policymakers should ensure that gas demand management is embedded in broader climate frameworks, recognizing its role in both near-term energy security and long-term sustainability goals.

In conclusion, the path forward in both research and policymaking requires a shift toward context-sensitive, behaviorally informed, and crisis-resilient models of natural gas demand. By building on the evidence base of the six validated studies, future work can more effectively support Europe's dual goals of energy security and sustainable transition.

Chapter 8: Conclusion

This concluding chapter consolidates the core insights of the thesis, articulates its academic and policy contributions, and reflects on the methodological and empirical limitations that frame the boundaries of its analysis. It offers a forward-looking perspective on how future studies might address unresolved questions, respond to evolving energy dynamics in Europe, and continue improving the empirical foundations for demand-side energy policy.

8.1 Summary of Findings

This thesis has explored the determinants of natural gas demand in Europe through a detailed literature review and critical assessment of six empirically grounded studies published between 2018 and 2024. The findings highlight a consistent pattern of short-run inelasticity across both residential and industrial sectors, with greater long-run responsiveness in industrial contexts. While economic factors such as price and income are traditional cornerstones of demand analysis, the studies reviewed reveal that behavioral, structural, and institutional variables frequently exert a stronger influence, particularly during times of crisis.

Price elasticity was found to be generally low across all contexts. In the residential sector, Tatli (2018) estimated a short-run price elasticity of -0.146 across 18 OECD countries, while Jamissen et al. (2024), using high-frequency daily data from Germany during the 2022 energy crisis, found elasticity values as low as -0.01. These findings suggest that households respond weakly to price signals, especially under stressful conditions, such as energy shortages or price spikes. For industrial consumers, the findings were somewhat more elastic in the long run. Mashhadi Rajabi & Mousavi (2019) reported industrial price elasticities ranging from -0.05 to -0.51, indicating some potential for gradual adaptation through technological or process adjustments.

Income elasticity was generally positive but modest, reinforcing the idea that gas consumption grows with income, though not proportionally. Tatli (2018) estimated an income elasticity of 0.515 for households, while industrial elasticity ranged more widely from 0.08 to 1.15, as shown by Mashhadi Rajabi & Mousavi (2019). These results confirm the relevance of macroeconomic growth as a factor in gas demand, though the effects are subject to diminishing returns, saturation effects, and substitution with cleaner technologies.

Perhaps the most striking findings came from studies that addressed the role of exogenous shocks and behavioral factors. Erias & Iglesias (2022) found that during the COVID-19 lockdowns, gas demand increased due to the so-called "double heating effect"—households remained home longer, consuming more gas regardless of price. Similarly, Jamissen et al. (2024) reported that behavioral campaigns during the 2022 energy crisis were more effective than pricing in curbing consumption. These results suggest that consumption behavior can be decoupled from market signals during periods of stress.

Institutional responses such as EU regulations also showed measurable impact. Fernández-Blanco et al. (2024), using a mass balance estimation approach, found that EU Regulation 2022/1369 led to immediate consumption reductions, supporting the idea that regulatory measures can drive demand change more effectively than prices under certain conditions. Adebowale et al. (2023) further contextualized demand shifts in light of geopolitical tensions, highlighting how supply constraints, not just prices or demand, shape consumption trends.

In synthesis, natural gas demand in Europe is shaped by a matrix of interacting factors. Economic indicators remain important but are insufficient alone. Behavioral rigidity, institutional interventions, and crisis-driven constraints often have greater explanatory power in the short term. The implications are significant: demand-side energy policy must go beyond market mechanisms to include regulatory, behavioral, and infrastructural tools tailored to context-specific realities.

8.2 Contributions of the Thesis

This thesis offers several key contributions to the academic and policy-oriented study of natural gas demand in Europe. First and foremost, it provides a carefully filtered and critically assessed synthesis of recent empirical literature that reflects the current post-crisis and energy transition context. By focusing exclusively on six validated and recently published studies, the analysis avoids outdated generalizations and provides a more accurate reflection of contemporary trends in European gas consumption.

The thesis advances the understanding of demand elasticity by highlighting how it varies not only across sectors (e.g., residential vs. industrial), but also across time and crisis conditions. It reaffirms that elasticity is not a fixed characteristic of consumer behavior, but a contingent outcome of market conditions, behavioral constraints, and regulatory frameworks. This insight is especially relevant for energy modeling and climate policy design, which often rely on elasticity assumptions that may be ill-suited to real-world disruptions.

A second contribution is the integrated framework developed in Chapters 6 and 7, which connects empirical findings to policy implications. This framework demonstrates how evidence from high-frequency monitoring (e.g., Fernández-Blanco et al., 2024), behavioral economics (e.g., Jamissen et al., 2024), and industrial modeling (e.g., Mashhadi Rajabi & Mousavi, 2019) can be synthesized to inform more nuanced and context-sensitive demand-side policies. It provides a roadmap for aligning short-term demand management with long-term energy security and decarbonization goals.

In doing so, the thesis also highlights the methodological innovation needed to improve future studies. It identifies gaps in temporal resolution, geographic scope, and sectoral disaggregation, and shows how high-resolution data and mixed-method modeling can address these gaps. This contributes to the broader discussion in energy economics and policy planning about how to move beyond conventional equilibrium-based models.

Lastly, the thesis contributes by drawing attention to the role of behavioral and institutional dynamics in shaping demand. This shifts the focus from consumer rationality to system-level influences, including public campaigns, administrative mandates, and supply system rigidity. These insights help explain why natural gas consumption often defies price expectations and why traditional tools like carbon pricing may be insufficient on their own.

8.3 Limitations and Areas for Further Study

While this thesis offers a timely and evidence-based contribution to the study of natural gas demand, it is important to acknowledge several limitations. The most significant constraint is the narrow base of empirical studies reviewed—limited to six papers. Although these were carefully selected for relevance, recency, and methodological rigor, they cannot fully represent the diversity of energy contexts across all European countries and sectors.

The limited geographic scope of the underlying studies is also a concern. While some papers (e.g., Adebowale et al., 2023) include data from countries like Ukraine and Poland, others rely heavily on OECD or Western European samples. Eastern and Southeastern Europe, which often have different energy infrastructures, subsidy regimes, and geopolitical vulnerabilities, remain underrepresented. Future research should aim to fill this gap with localized studies that capture region-specific demand patterns.

Another limitation is the lack of explicit modeling of climate and decarbonization policy effects. Although the studies reviewed offer indirect insights—such as through price or regulatory impacts—none explicitly link gas demand with net-zero scenarios, emissions targets, or technological substitution trajectories. This leaves a gap between demand elasticity modeling and climate transition planning.

Methodologically, most studies still rely on standard econometric models and do not incorporate hybrid or interdisciplinary methods such as system dynamics, agent-based simulations, or qualitative case studies. This restricts their ability to capture adaptive behaviors, policy feedback loops, or network-level dependencies that increasingly define energy systems. Addressing this gap could help bridge the divide between empirical modeling and real-world complexity.

Future research should pursue several directions. First, it should prioritize the use of high-frequency and disaggregated datasets, particularly in evaluating crisis responses. Second, it should incorporate behavioral and institutional variables more systematically, using mixed-method approaches. Third, it should explicitly link demand modeling to decarbonization pathways, ensuring that elasticity estimates are calibrated to realistic transition scenarios. Lastly, comparative studies across EU member states, especially including cohesion countries, would enhance both the validity and policy relevance of empirical insights.

In closing, this thesis underscores that understanding and managing natural gas demand in Europe requires more than just economic modeling. It demands a multi-dimensional approach that reflects sectoral diversity, behavioral constraints, policy dynamics, and geopolitical volatility. By grounding its findings in recent empirical research, this thesis offers a foundation for more adaptive, effective, and resilient demand-side energy strategies in a rapidly evolving European energy landscape.

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