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Exploring Residential and Transportation sectors in Energy Consumption Behaviour in Europe through Data Analysis

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ABSTRACT

This study investigates the evolution of energy consumption across different sectors in the European Union (EU27), focusing on the residential and transportation sectors, from 1971 to 2022. Using official datasets from the International Energy Agency (IEA), Eurostat, and the World Bank, the analysis reveals long-term trends in the use of fossil fuels and renewable energy sources, as well as the relationship between energy consumption and economic performance, as measured by Gross Domestic Product (GDP). The results indicate a partial decoupling of economic growth from energy consumption, particularly after 2000, reflecting improved energy efficiency and structural economic changes. The residential sector shows a significant shift away from coal and oil products toward renewables and waste, while the transport sector remains heavily dependent on oil products, despite policy interventions. The study finds that while EU energy transition policies have had a measurable impact, especially in the residential sector, progress remains uneven across industries. These findings contribute to the broader discourse on sustainable energy transitions and underline the need for continued policy support, technological investment, and behavioural adaptation to achieve EU climate objectives.

Key words: Data analysis, energy consumption, transportation sector, residential sector, EU, policies

1. Introduction

Energy consumption behaviour is a critical component of global efforts to reduce greenhouse gas emissions and transition towards sustainable energy systems (Conradie et al., 2023). Within the

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European context, ambitious targets for energy efficiency and decarbonisation have been established under frameworks such as the European Green Deal, highlighting the necessity of understanding sectoral energy use (Coelho et al., 2024; European Commission, 2022). Behavioural patterns, socio- demographic factors, economic influences, and policy interventions collectively shape how energy is used, particularly in sectors where individuals and households are primary actors (Tiberio et al., 2025).

Among the various sectors, residential and transportation energy consumption stand out due to their significant share of overall energy demand and their strong linkage to individual behaviours (Grozea-Bănică et al., 2025; Schibuola & Tambani, 2025). The residential sector in Europe is responsible for a substantial portion of energy use, driven by factors such as heating, appliance operation, and emerging prosumer behaviours through rooftop photovoltaic systems (Schibuola & Tambani, 2025). Meanwhile, the transportation sector remains heavily reliant on fossil fuels, contributing substantially to CO_2 emissions, despite progressive efforts toward electrification and enhanced public transport infrastructure (Conradie et al., 2023; Gruetzmacher et al., 2022).

This study deliberately narrows its focus on these two sectors —– Residential and Transportation —– to allow for a manageable analysis of sectoral differences in energy consumption behaviour across European countries. This decision aligns with previous literature that emphasises the complexity of sector-specific energy behaviours and the need for tailored interventions (Gruetzmacher et al., 2022; Lopes et al., 2015; Thonipara et al., 2019). Sectors such as industry, commercial and public services are intentionally excluded, given that they often involve corporate or institutional behaviours which differ and waver from household-level or individual energy decisions.

The scientific weight of this project is supported by a body of scientific papers from journals or books to cover the literature part. In the residential sector, socio- demographic factors such as age, household composition, education level, and income significantly influence energy-saving behaviours and decisions (York, 2007). Theories such as the Theory of Planned Behaviour (TPB), the Value-Belief-Norm Theory (VBN), and the Prototype Willingness Model (PWM) provide conceptual frameworks for understanding why individuals adopt —– or fail to adopt —– energy- saving actions (Conradie et al., 2023). In transportation, decisions are similarly complex, shaped by urbanisation levels, fuel costs, availability of sustainable alternatives, and personal norms regarding environmental responsibility (Tiberio et al., 2025).

Recent comparative studies show substantial heterogeneity across Europe in both sectors, emphasising the need for flexible, country-specific policy responses (Thonipara et al., 2019) "One-size-fits-all" approaches are unlikely to succeed; rather, a nuanced understanding of regional, demographic, and socio-economic variations is crucial for designing effective policies

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(Eakins et al., 2025a; Lopes et al., 2015; Thonipara et al., 2019).

Given these considerations, the present study aims to:

- Explore behavioural differences in energy consumption between the residential and transportation sectors across Europe
- Analyse sectoral and different energy sources trends using raw data from Eurostat and IEA and the latest scientific literature

The project is based on data analysis to examine patterns of energy consumption in the residential and transportation sectors across the EU (using data from 27 European countries). The study employs secondary data from Eurostat, IEA, and national statistical agencies, focusing on descriptive and comparative data analysis from 1971/1990 and to 2022. Specifically, it investigates: (1) the trends in fossil vs. renewable energy use, between transportation and residential sectors (2) the influence of policy factors, and (3) how these trends align with EU climate targets (Tzavaras & Stelios, 2022).

2. Literature review

Residential Energy Consumption Patterns and Efficiency

The residential sector in Europe exhibits significant variability in energy consumption patterns, influenced by climatic conditions, building characteristics, and policy frameworks. An exploratory analysis across EU countries identified that factors such as energy prices, income levels, and floor area per dwelling significantly affect energy consumption. Notably, regulatory standards and carbon taxation have been effective in enhancing energy efficiency, with higher carbon taxes leading to more substantial reductions in energy use (Thonipara et al., 2019).

Further, a comparative study of buildings' energy consumption in the EU, US, and China revealed that increased floor area per capita is a primary driver of rising energy use. However, in the EU, improvements in energy efficiency have offset this increase, managing stabilising overall consumption. This underscores the importance of efficiency measures in managing energy demand (González-Torres et al., 2025).

In Southern Europe, simulations of building-plant systems indicate that retrofitting building envelopes and integrating electric heat pumps can substantially reduce non- renewable energy demand. While rooftop photovoltaic systems can cover a significant portion of electricity needs, achieving a positive energy balance consistently requires both building-specific interventions and a higher share of renewable energy in the grid (Schibuola & Tambani, 2025).

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Behavioural Aspects of Residential Energy Use

Behavioural factors play a crucial role in residential energy consumption. Applying theories such as the Theory of Planned Behaviour, Value-Belief-Norm Theory, and the Prototype Willingness Model, a study across 29 European countries found that attitudes, subjective norms, and personal moral norms significantly influence individuals' intentions to reduce heating-related energy use. However, perceived behavioural control did not have a statistically significant association with actual behaviour, highlighting the complexity of translating intention into actual action (Conradie et al., 2023).

An integrative modelling approach further emphasises the need for comprehensive strategies that combine structural improvements, like better insulation, with behavioural interventions to promote energy-saving habits. Such multifaceted approaches are essential for effective energy policy design (Lopes et al., 2015; Thonipara et al., 2019).

Additionally, an analysis of energy-saving behaviours in 27 European countries revealed heterogeneity in "actions taken by individuals". Factors such as age, gender, household composition, and expectations about future energy prices influence the likelihood of engaging in various energy-saving measures. This diversity suggests that flexible, targeted policies are more effective than "one-size-fits-all" approaches (Eakins et al., 2025b).

Renewable Energy Distribution and Drivers

The adoption of renewable energy sources, particularly wind and photovoltaic (PV) systems, varies across European regions. Spatial econometric analyses indicate that higher GDP per capita positively correlates with renewable energy capacity, while higher population density has the opposite effect. Interestingly, natural resource availability is less influential than socioeconomic and institutional factors. Moreover, spatial spillovers, where regions influence each other's adoption of technologies, play a significant role in the spread of renewables (García-Riazuelo et al., 2025).

A broader trend analysis comparing the EU, US, and China from 1961 to 2011 shows a shift in electricity production structures, with an increasing role for renewables and a decline in oil-based generation. These changes reflect evolving energy policies and economic factors influencing energy mixes (Kaivo-Oja et al., 2016).

Transportation Sector Sustainability and Policy Measures

The transportation sector remains a significant consumer of fossil fuels in Europe. Assessing sustainability performance across 28 European countries using "Benefit-of- the-Doubt" models

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revealed in overall improvements. However, for countries lagging, tailored strategies based on benchmark profiles are necessary to enhance sustainability practices (Gruetzmacher et al., 2022).

Policy interventions, such as imposing taxes on motor vehicle fuels and subsidising renewable electricity generation, have been evaluated for their environmental and economic impacts. Dynamic general equilibrium models for France, Germany, Italy, and Spain suggest that such measures can reduce CO_2 emissions in the transportation sector and promote renewable energy development without adversely affecting economic activity (Bartocci & Pisani, 2013).

Demographic Influences on Energy Consumption

Demographic trends significantly impact energy consumption patterns. An analysis of 14 EU nations from 1960 to 2000 found that population size and age structure directly affect energy use. Projections for 2025 indicate that declining population growth may help limit increases in energy consumption, although economic development and urbanisation continue to drive demand (York, 2007).

Below is presented the summarised table of the literature review articles and papers assessed for the systematic literature review approach.

Table 1: Summary of selected scientific papers discussed in the current chapter

No.	Author(s)	Title	Journal	Year	Main Focus/Contribution
1	Lopes, M., et al.	Towards more effective behavioural energy policy: An integrative modelling approach to residential energy consumption in Europe	Energy Research & Social Science	2015	Integrative behavioral modeling to improve residential energy policies
2	Eakins, J., et al.	Who saves energy and why? Analysing diverse behaviours in 27 European countries	Energy Research & Social Science	2025	Analysis of socio-demographic factors affecting energy-saving behavior
3	González-Torres, M., et al.	Examining the reasons for changes in buildings' energy consumption in the United States, China and the European Union	Energy and Buildings	2025	Decomposition analysis of building energy consumption drivers

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4	Conradie, P., Van Hove, S., et al.	Why do people turn down the heat? Applying behavioural theories to assess reductions in space heating and energy consumption in Europe	Energy Research & Social Science	2023	Application of behavioral theories (TPB, VBN, PWM) to heating energy use
5	Bartocci, A., Pisani, M.	"Green" fuel tax on private transportation services and subsidies to electric energy. A model-based assessment for the main European countries	Energy Economics	2013	Impact assessment of fuel taxes and renewable subsidies in private transport
6	Gruetzmacher, Sarah B., et al.	Sustainability performance assessment of the transport sector in European countries	Revista Facultad de Ingenieria	2022	Evaluation of sustainable performance in transport sector in 28 European countries over four years using Benefit-of-the-Doubt models
7	Kaivo-Oja, J. et al.	Trend analysis of energy and climate policy environment: Comparative electricity production and consumption benchmark analyses of China, Euro area, European Union, and United States	Renewable and Sustainable Energy Reviews	2016	Comparative trend analysis of electricity production and climate policy
8	York, R.	Demographic trends and energy consumption in European Union Nations, 1960–2025	Social Science Research	2007	Impact of demographic changes on EU energy consumption trends
9	Thonipara, A. et al.	Energy efficiency of residential buildings in the European Union – An exploratory analysis of cross-country consumption patterns	Energy Policy	2019	Cross-country differences in residential energy efficiency
10	Schibuola, L.,	Non-renewable energy demand reduction and	Energy and	2024	Achieving Positive Energy Buildings (PEB) in Southern

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	Tambani, C.	positive energy buildings in Southern Europe's urban forms	Buildings		European cities
11	García-Riazuelo, Á., et al.	Spatial distribution and drivers of renewable energies in European regions	Energy Economics	2025	Spatial econometric analysis of renewable energy development drivers

3. Methodology

Research Aim and Approach

This research aims to explore energy consumption behaviour across the residential and transportation sectors in Europe, focusing on literature review and raw data analysis. To achieve this, a primary data analysis approach is employed, synthesising findings from recent peer-reviewed studies that apply empirical methods to European energy consumption data, and a secondary analysis is being followed using data from IEA, ESTAT for comparisons and results

Primary analysis of Systematic Literature Review

The research strategy adopted is a systematic literature review focused specifically on quantitative studies employing data analysis techniques. The literature review was based on 11 systematically selected papers summarised in *Table 1*. A systematic approach ensures objectivity, reproducibility, and comprehensiveness (Agrawal et al., 2024).

Key inclusion criteria for selecting studies were:

- Focus on Europe
- Analysis of either the residential or transportation sectors
- Use of quantitative data analysis methods (e.g., regression, modeling, decomposition analysis)
- Peer-reviewed journal articles published between 2006–2025
- English language

Exclusion criteria included:

- Studies without empirical data analysis

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- Papers focusing on industrial or agricultural sectors
- Non-European case studies
- This strategy ensures that the reviewed literature specifically informs the targeted sectors and analytical approach of this study

The data for this project were collected through structured searches in leading academic databases, particularly ScienceDirect, SpringerLink, and Google Scholar.

The search process included combinations of the following keywords:

- "Residential energy consumption Europe"
- "Transportation energy behavior Europe"
- "Energy consumption data analysis"
- "Energy behavior determinants Europe"
- "Transport sector decarbonization Europe"

Boolean operators (AND, OR) were used to refine searches. After screening titles and abstracts, full texts were reviewed to ensure alignment with inclusion criteria.

The analysis consists of a qualitative synthesis of quantitative results presented in the selected papers. Techniques observed across the studies include:

- Regression Analysis to identify determinants of energy consumption (e.g., demographic factors, economic incentives).
- Decomposition Analysis for sectoral trend breakdown (e.g. Gruetzmacher et al., 2022)
- Structural Equation Modeling linking attitudes and behaviors (e.g., Bartiaux, 2008)
- Benchmarking and Efficiency Analysis using Benefit-of-the-Doubt models (e.g., (Bartocci & Pisani, 2013)
- These diverse methods provide a multi-dimensional understanding of energy behavior patterns, supporting a rich comparative analysis across sectors.

Several limitations should be acknowledged:

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- Selection Bias: Although systematic, the selection process may inadvertently favour more recent or accessible studies.
- Scope Restriction: By focusing only on residential and transportation sectors, insights on cross-sectoral interactions are not addressed.
- Nonetheless, the advantages of breadth, comparability, and empirical rigour outweigh these limitations for this project.

Given that this study exclusively uses publicly available secondary data and published literature, no direct ethical risks to participants exist (Snyder, 2019). Proper citation and referencing practices are rigorously followed to ensure intellectual honesty and prevent plagiarism.

It should also be noted that the methodological use of data analysis is not confined to the field of energy research. For example, entrepreneurship studies have explored how startups can employ Big Data and Artificial Intelligence to support decision-making under resource limitations and dynamic market conditions (Davalas, 2020). Although conceptually distant, such work further illustrates the broad applicability of data-driven approaches across distinct domains

Secondary Data analysis

For the secondary analysis, data, i.e. total energy consumption, production, energy sources consumption, residential, transport energy etc. from IEA and ESTAT were found and processed.

Key inclusion criteria for selecting data were:

- European Union countries
- Energy for residential and transportation sectors
- Energy sources that will be compared i.e. renewables and coal
- Period of data, which years will be selected
- Availability of the data for further analysis
- Format of data, i.e. xlsx files, txt etc.

The search process in ESTAT and IEA databases is the same as in the literature review part, using basically the same keywords, i.e. European Union, energy consumption, transportation, residential sector, renewables etc.

Several limitations should be acknowledged:

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- The availability of the data found in ESTAT was from 1990-2022 and not from 1971-2022 as all the other raw data for energy consumption found in IEA database
- The data includes 27 countries of the European Union: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden
- A wide range of data analysis -raw data from total final energy consumption in EU27 and not in a specific country- might end up in generalised results and interpretation

4. Data Analysis and Results

Introduction to Data Analysis

In this chapter, the raw datasets obtained from internationally recognised sources such as the International Energy Agency (IEA, 2024), Eurostat (Eurostat, 2025), and the World Bank (DataBank, 2025). The goal of this section is to objectively display historical trends in total energy consumption, sector-specific consumption (residential and transportation sectors), and other relevant indicators such as Gross Domestic Product (GDP), without yet interpreting the data.

Regarding the data of the products found in IEA databases (different energy sources), they have the following characteristics:

- Coal, peat and oil shale: Coal includes all coal, both primary (including hard coal and lignite) and derived fuels (including patent fuel, coke oven coke, gas coke, BKB, gas works gas, coke oven gas, blast furnace gas and other recovered gases). Peat (including peat products) and oil shale are also included in this figure where applicable.
- Oil products: Oil products comprise refinery gas, ethane, LPG, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin waxes, petroleum coke and other oil products.
- Renewables and waste: Renewables and waste comprises hydro, geothermal, solar, wind and tide/wave/ocean energy and the use of these energy forms for electricity and heat generation, as well as solid biofuels, liquid biofuels, biogases, industrial

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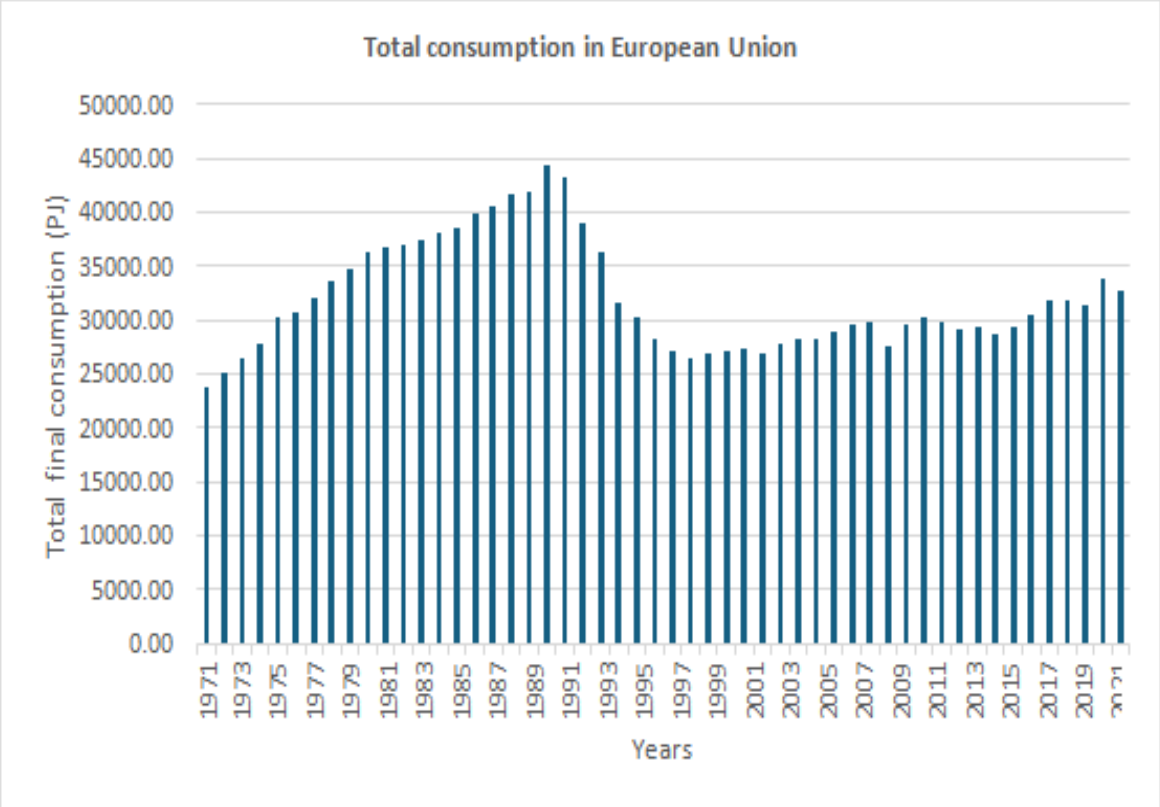
waste and municipal waste.

It is important to emphasise that this work uses official raw data directly available for analysis, ensuring scientific robustness. Our mixed approach offers a real-world, cognitive perspective, complementing the results of previous bibliographic studies presented in Chapter 2.

Total Energy Consumption & trends in energy sources in the European Union (EU27)

To begin the analysis, the total final energy consumption in Peta Joules in the European Union (EU27) from 1971 to 2022, based on data from the IEA (2024), was examined.

Figure 1: Total consumption (PJ) in the European Union from 1971 to 2022 using data from IEA



Energy consumption trends in the European Union have evolved over the past five decades due to economic shifts, technological advancements, and policy interventions. The analysis of total final energy consumption reveals a steady increase from 1971, peaking around 1990, followed by a decline in the 1990s. This reduction corresponds with improved energy efficiency and

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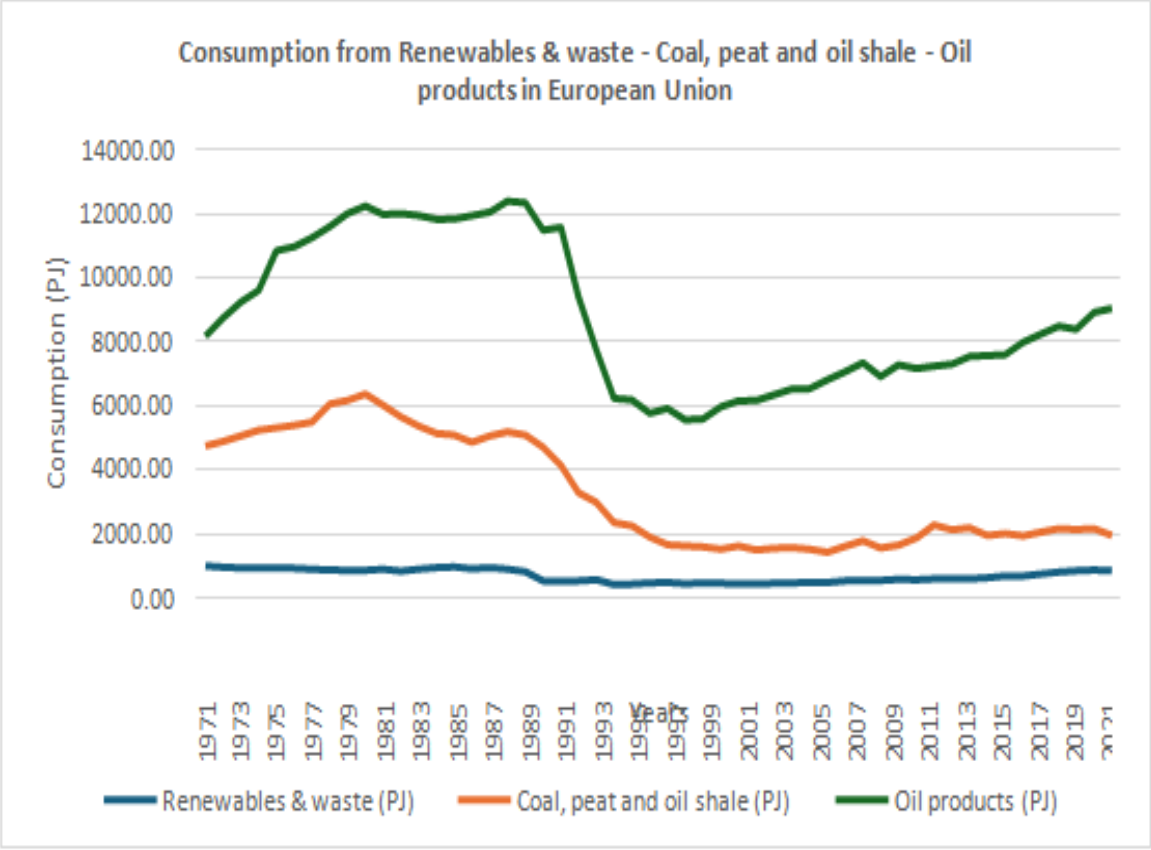
economic restructuring, particularly in post-industrial economies (IEA, 2023).

Policy-driven energy efficiency measures, such as the EU Directive on Energy Efficiency (2012/27/EU), may have contributed to stabilising consumption post-2000 by setting targets for reducing energy demand across sectors (European Commission, 2021). Additionally, fluctuations in energy consumption align with global economic crises, including the 2008 financial crisis, which led to a temporary contraction in industrial activity and energy demand (DataBank, 2025).

The stabilisation observed after 2000 where a balance between technological improvements—such as advancements in insulation and industrial efficiency— occurred and continued energy demand, particularly in transportation and residential sectors (IEA, 2023). However, continued reliance on fossil fuels remains a challenge, necessitating further policy intervention to achieve EU climate targets (European Commission, 2022).

Figure 2: Consumption from Renewables, coal, and oil products in European Union using data from IEA



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An analysis of energy consumption trends in the European Union reveals significant shifts in reliance on different energy sources over the past five decades. The graph indicates that oil products have historically dominated the EU's energy mix, peaking around 1980 at approximately 13,000 PJ before experiencing a decline in the 1990s. This reduction aligns with improved energy efficiency measures and diversification of the energy portfolio, influenced by global oil market fluctuations and policy interventions such as the EU Renewable Energy Directive (2009/28/EC) (Environment Agency, 2001).

Coal, peat, and oil shale consumption peaked in 1980, at approximately 6,500 PJ. Its subsequent decline reflects the EU's transition away from high-emission fuels, driven by regulatory efforts such as the Large Combustion Plant Directive (2001/80/EC), which set emission limits on industrial facilities (Environment Agency, 2001). By 2021, coal consumption had fallen to approximately 2,000 PJ, showcasing the effectiveness of decarbonisation strategies and the growing preference for cleaner energy alternatives (*World Energy Outlook 2023 – Analysis - IEA*, 2023).

Despite efforts to increase the share of renewables and waste in energy consumption, their growth has remained relatively modest. Renewable energy sources fluctuated between 0 and 1,000 PJ across the years, illustrating the challenges of widespread adoption, including infrastructure limitations and policy discrepancies across EU member states (Eurostat, 2022). This slow uptake underscores the necessity for continued investment and policy refinement to accelerate the transition toward sustainable energy sources.

These findings emphasise the interplay between market forces, policy frameworks, and technological advancements in shaping the EU's energy landscape. While progress toward reducing reliance on fossil fuels is evident, further integration of renewable energy remains essential to achieving long-term climate goals.

Correlation between Total Energy Consumption and GDP in European Union (EU27) during 1990–2023

An additional analysis was performed, comparing the trends in Gross Domestic Product- GDP (in USD) with energy consumption measured in Peta Joules. Both datasets were sourced from ESTAT and IEA data bases.

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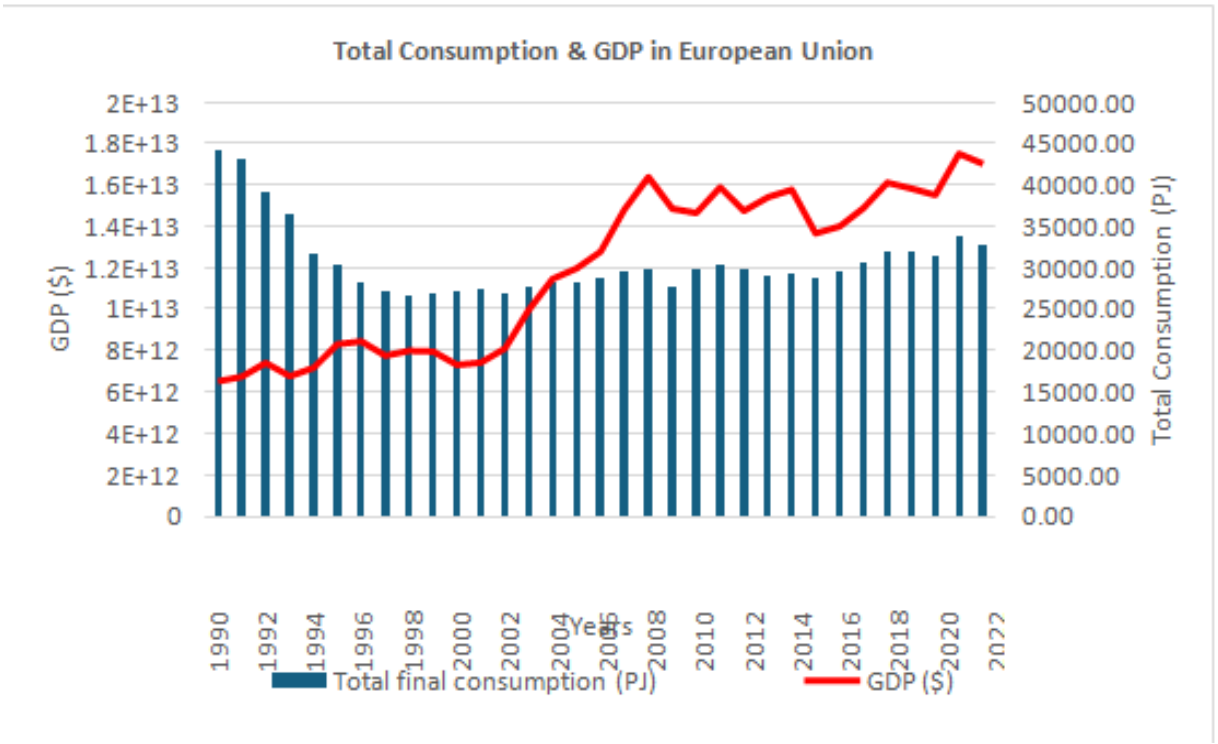
Figure 3: Total Consumption and GDP in the European Union using data from IEA and ESTAT



The relationship between energy consumption and economic growth -using GDP- is crucial to understanding long-term trends in the European Union's energy demand.

The graph illustrates the correlation between total final energy consumption (measured in PJ) and GDP (measured in dollars) from 1990 to 2022. It highlights a pattern where GDP has consistently risen, whereas total energy consumption has remained relatively stable over the decades.

During the 1990 to 2000 period, both GDP and energy consumption showed a gradual increase, reflecting economic expansion across EU member states (IEA, 2023). However, as technological advancements and efficiency measures took effect, energy consumption began decoupling from economic growth, particularly after 2004. This phenomenon suggests that the EU's energy efficiency policies and innovations have enabled economic growth to continue without a proportional increase in energy demand (European Commission, 2021).

Notably, temporary dips in GDP align with global economic crises, such as the 2008 to 2010 financial downturn, which led to a contraction in industrial activity and energy demand (World Bank, 2010). Despite these fluctuations, energy consumption has remained relatively steady, further reinforcing the effectiveness of regulatory frameworks in mitigating excessive energy use

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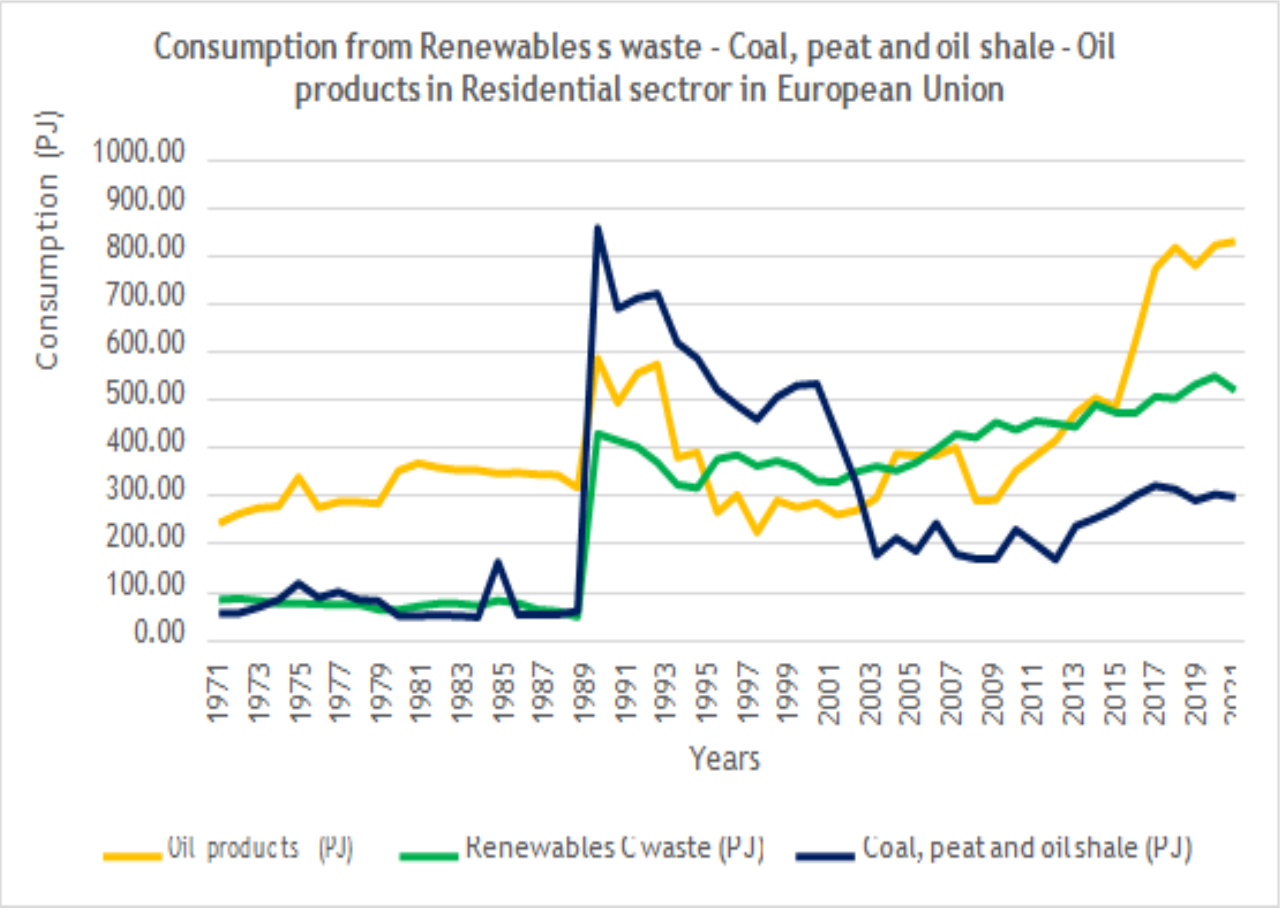
while sustaining economic productivity.

This correlation between GDP and energy consumption underscores the role of energy efficiency policies, technological developments, and structural economic shifts in shaping the EU's energy landscape. The data suggests that while GDP growth continues, a shift toward more efficient and sustainable energy practices has helped limit the rise in overall consumption.

Energy Consumption using different energy sources in the Residential Sector

In this section, the focus is placed on the residential sector's final energy consumption, using data derived from IEA.

Figure 4: Consumption from Renewables, coal, and oil products in the Residential sector in the European Union using data from IEA



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The residential sector in the European Union has experienced significant shifts in energy consumption patterns over the past five decades. The graph highlights the consumption trends of three major energy sources: oil products, renewables & waste, and coal, peat, and oil shale from 1971 to 2021.

Key Observations:

- Oil Products: Historically, oil products dominated residential energy consumption, peaking sharply around 1990 at approximately 600 PJ. However, this trend reversed in 1991, with a decline that persisted into the early 2000s. The resurgence of oil consumption in the residential sector post-2000 may be linked to fluctuations in energy prices and the continued reliance on oil-based heating systems in certain regions (IEA, 2023).

- Coal, Peat, and Oil Shale: Consumption of these fossil fuels peaked around 1990 but declined significantly thereafter until at least 2015. This shift aligns with the EU's decarbonisation policies, including the Large Combustion Plant Directive (2001/80/EC), which imposed stricter emission limits on residential heating systems (European Environment Agency, 2001).

- Renewables & Waste: Unlike fossil fuels, renewables have shown a gradual increase over time, reflecting the EU's commitment to sustainable energy. The Renewable.

Energy Directive (2009/28/EC) played a crucial role in promoting cleaner energy sources, leading to a steady rise in renewables & waste consumption in residential heating (European Commission, 2009).

Interpretation:

The decline in coal and oil consumption, coupled with the slow but steady rise of renewables, underscores the impact of policy interventions, technological advancements, and consumer preferences in shaping residential energy trends. While fossil fuel reliance remains a challenge, the increasing adoption of renewables suggests a gradual transition toward sustainability.

Energy Consumption using different sources in the Transportation sector

The transportation sector in the European Union has historically been dominated by oil products, which have remained the primary energy source for decades. The graph illustrates the consumption trends of oil products, renewables & waste, and coal, peat, and oil shale from 1971 to 2021.

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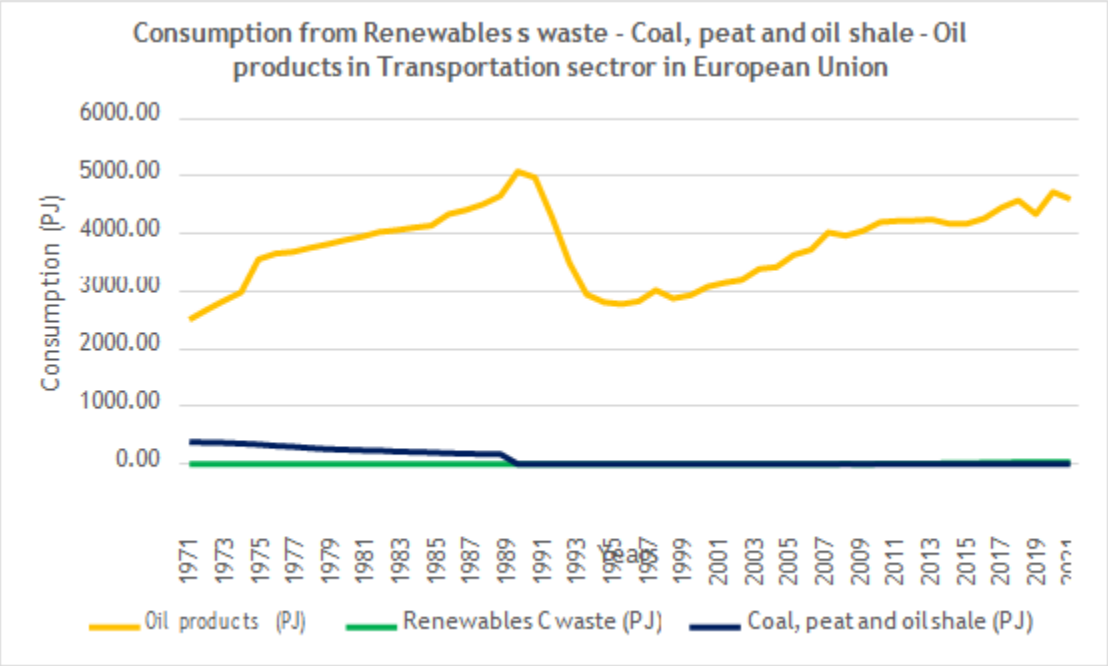
Figure 5: Consumption from Renewables, coal, and oil products in the Transportation sector in the European Union using data from IEA



Key Observations:

- Oil Products: The consumption of oil products peaked around 1990, reaching approximately 5,000 PJ, before experiencing a decline in 1991. This drop aligns with early efforts to improve fuel efficiency and reduce emissions, particularly through policies such as the EU Fuel Quality Directive (98/70/EC), which set stricter standards for fuel composition (European Commission, 1998). However, oil consumption rebounded in the 2000s, reflecting continued reliance on petroleum-based fuels in road and air transport (IEA, 2023).

- Coal, Peat, and Oil Shale: The use of these energy sources in transportation has steadily declined since the 1980s, nearing complete phase-out by 2000s. This trend is largely driven by the shift toward cleaner fuels and the EU's decarbonisation policies, which discourage coal-based energy in transportation sector (Eurostat, 2022).

- Renewables & Waste: Despite policy efforts to promote renewable energy, its adoption in transportation has remained relatively low. The Renewable Energy Directive (2009/28/EC) aimed to increase the share of renewables in transport, yet the data suggests slow progress, with renewables & waste consumption hovering around

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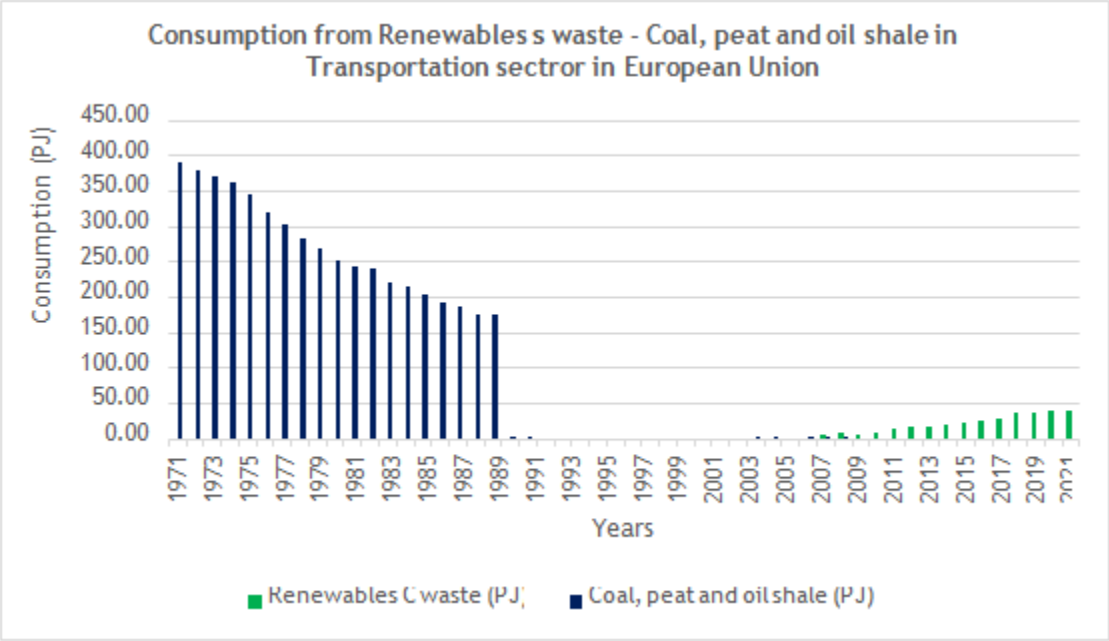
– 40 PJ in 2021 (European Commission, 2009). This highlights the challenges of infrastructure adaptation and market readiness for alternative fuels.

Interpretation:

The dominance of oil products in transportation underscores the sector's dependence on fossil fuels, despite regulatory efforts to encourage cleaner alternatives. While coal and peat have been largely phased out, the slow uptake of renewables suggests that further investment and policy refinement are necessary to accelerate the transition toward sustainable energy sources.

A comparison of renewables & waste with coal in transportation is presented below in the graph.

Figure 6: Consumption from Renewables & coal in the Transportation sector in the European Union using data from IEA



The reverse evolution of renewables and coal consumption in the EU transportation sector presents a striking contrast in energy transition patterns. The graph illustrates a steady decline in coal, peat, and oil shale use alongside a gradual increase in renewables & waste, reflecting the broader decarbonisation efforts and policy-driven shifts toward cleaner energy sources.

Key Observations:

– Coal, Peat, and Oil Shale: Historically, coal played a minor role in transportation, peaking around 1980 at approximately 400 PJ before undergoing a steep decline. By

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2000, coal consumption in the sector had nearly disappeared, reflecting legislative measures such as the EU Emissions Standards for Vehicles and the Large Combustion Plant Directive (2001/80/EC) (European Commission, 2009).

- Renewables & Waste: In contrast, the consumption of renewables has shown a gradual upward trend, particularly after 2005, coinciding with the implementation of the Renewable Energy Directive (2009/28/EC)(European Commission, 2009). The rising trajectory suggests the growing adoption of biofuels and other sustainable alternatives, although progress remains slow relative to total energy consumption.

Interpretation:

The opposing trends of coal phase-out and renewable uptake highlight the impact of policy interventions in shaping the EU's transportation energy mix. While coal has been almost eliminated from the sector, renewable energy still represents a relatively small fraction of total consumption. This indicates that while regulatory frameworks have succeeded in reducing reliance on carbon-intensive fuels, further investments and incentives are required to accelerate the adoption of renewable alternatives.

Summarising data analysis findings

Chapter 4 presents a comprehensive analysis of energy consumption patterns across different sectors in the European Union. Key findings include:

- Total Energy Consumption Trends: Energy consumption peaked in the late 1980s but stabilised post-2000 due to efficiency measures and economic shifts.
- Correlation Between Energy Consumption and GDP: While GDP has steadily increased, energy consumption has remained relatively stable, suggesting improved efficiency and policy interventions.
- Residential Sector Energy Use: A decline in coal and oil consumption contrasts with the gradual rise of renewables, reflecting policy-driven shifts toward cleaner energy.
- Transportation Sector Energy Use: Oil remains dominant, but coal has nearly disappeared, while renewables show slow but steady growth.
- Inverse Relationship Between Coal and Renewables: The phase-out of coal in transportation coincides with the gradual adoption of renewables, highlighting the impact of EU decarbonisation policies.

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These trends underscore the EU's ongoing transition toward sustainable energy while balancing economic growth and environmental concerns. Further correlations, such as energy consumption vs. CO_2 emissions or household income, could provide deeper insights into the effectiveness of energy policies and socioeconomic influences on consumption.

5. Interpretation and Discussion

Overview and Purpose

This chapter synthesises the quantitative findings from Chapter 4 with the theoretical and policy frameworks discussed in Chapter 2. Literature review. The objective is to interpret the energy consumption trends observed in the EU27 over the past decades and assess the extent to which they reflect progress toward sustainability, energy efficiency, and decarbonization goals as outlined in EU directives and literature review.

Decoupling Economic Growth from Energy Demand

The data in Chapter 4 demonstrates a notable decoupling between Gross Domestic Product (GDP) and total energy consumption in the EU27 from the early 2000s onwards. While GDP has shown a steady growth, energy consumption has plateaued or even declined. This trend illustrates the success of energy efficiency measures and structural economic changes, such as a shift from manufacturing to service-based economies.

These outcomes are aligned with EU-level policy frameworks, particularly the Energy Efficiency Directive (2012/27/EU), which has promoted more efficient energy use across sectors. As shown in the data, even during periods of economic growth (e.g., post-2010), total final energy consumption remained stable, supporting the view that efficiency and innovation can enable sustainable economic expansion without proportional increases in energy demand (European Commission, 2021).

Sectoral Dynamics: Residential and Transport

Residential Sector: Policy-Led Shift Toward Cleaner Sources

Data from Chapter 4. Data Analysis and Resultshighlight a significant decline in the use of coal and oil products in the residential sector, particularly since the 1990s. This shift corresponds to introducing emissions regulations (such as the Large Combustion Plant Directive, 2001/80/EC) and the Renewable Energy Directive (2009/28/EC), which incentivised cleaner heating solutions and building retrofits.

At the same time, the use of renewable energy, though still modest, has grown steadily in the

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residential sector. This evolution mirrors policy goals aiming to promote sustainable energy, and reflects the impact of EU-wide initiatives such as the Energy Performance of Buildings Directive (2010/31/EU). However, the relatively slow rise in renewable usage compared to the sharp decline in fossil fuels indicates ongoing challenges, including infrastructure readiness, socioeconomic disparities and political reasons in renewable technology adoption.

Transport Sector: Continued Fossil Fuel Dependence

In contrast, Chapter 4 indicates that oil products continue to dominate the EU transportation sector, with limited penetration by renewable sources such as biofuels. Despite a complete phase-out of coal in transport and moderate policy efforts (e.g., Renewable Energy Directive's transport targets), renewable consumption remains minimal, hovering around 40 PJ as of 2021.

These patterns reflect and underline what has been presented in Chapter 2 regarding the transport sector's inertia due to high infrastructure costs, limited availability of charging networks, and slow vehicle turnover. Despite policy support, a structural transformation in this sector remains underdeveloped.

Drivers of Transition: Policy, Technology, and Markets

The comparative analysis of sectoral energy consumption trends in Chapter 4 highlights a confluence of factors that shape the EU's energy transition:

- The decline in oil and coal consumption in residential settings after the 1980s parallels major legislative shifts and growing public support for clean energy
- The stabilisation of energy use alongside rising GDP from the 2000s suggests a maturation of both policy tools and technological innovations
- The modest yet visible increase in renewable energy across sectors, especially residential, underscores the cumulative effect of incentives like feed-in tariffs, green certificates, and EU funding mechanisms.

These insights affirm what the literature has emphasized, that effective transitions occur when technological capability aligns with regulatory ambition and market viability (European Commission, 2021; IEA, 2023)

Beyond the field of energy policy, recent entrepreneurship research has examined the role of Artificial Intelligence in startup valuation processes, emphasizing strengths, weaknesses, opportunities, and threats in adopting AI-based assessment tools (Davalas, Charalabidis, & Fenekoy, 2022). While conceptually distant, such approaches once more demonstrate how AI-

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driven frameworks can be applied across diverse sectors to enhance decision-making

Limitations and Considerations

Despite positive trends, there are several critical limitations to consider:

- Time lag in policy outcomes: Some key strategies, such as the European Green Deal (2019), may not yet be fully reflected in the available data
- Uneven sectoral progress: While the residential sector shows marked improvements, the transportation sector remains largely fossil fuel-dependent
- Aggregate-level analysis: EU27-level data may obscure national or regional disparities, which could be affected by policy relevance and effectiveness across member states.

These limitations suggest that future research should include more granular analyses, possibly by member state or income group, to capture the differentiated nature of energy transitions.

Conclusion: Transition in Motion

The findings from Chapter 4 confirm that the EU is making gradual but tangible progress toward a more sustainable energy system. The decoupling in energy consumption from GDP suggests that economic growth no longer necessitates increased energy use, a foundational principle for sustainable development. In the residential sector, the decline of coal and oil, alongside a rise in renewable use, affirms the effectiveness of targeted EU directives and technological shifts.

Conversely, the transportation sector presents a more complex challenge. While coal has been eliminated, oil retains dominance, and renewables have made only limited progress. This disparity illustrates that progress is sector-specific and that a one-size- fits-all policy approach may not be sufficient. More relevant and accurate research would be on country-specific areas where more relevant regulations, socioeconomic characteristics, and geopolitical aspects occur (Sgantzos, et al, 20242).

Overall, the data support the conclusion that while the EU's energy transition is real and measurable, it is uneven. Ongoing policy refinement, technological innovation, and social adaptation will be essential to accelerate and harmonise this transition across all sectors of the economy.

6. Conclusion and Policy Implications

Summary of Key Findings

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This study analysed the evolution and trends of energy consumption across various sectors in the European Union (EU27), focusing on the period from 1971 to 2022. Drawing from official datasets (IEA, Eurostat, DataBank), the analysis revealed several critical trends that should be noted below:

- Decoupling of Economic Growth and Energy Consumption: As evidenced by Chapter 4, GDP growth has continued steadily while total final energy consumption stabilised post-2000. This decoupling suggests that EU-level energy efficiency measures and structural economic changes have successfully mitigated energy demand despite ongoing economic expansion.
- Residential Sector Transition: Fossil fuel use, particularly coal and oil, has markedly declined in the residential sector. This shift corresponds with an increase in renewable and waste-based energy sources, illustrating the influence of the Renewable Energy Directive (2009/28/EC) and efficiency-related investments.
- Stagnation in Transport Sector: In contrast to the residential sector, the transport sector continues to depend heavily on oil products. While coal has been nearly eliminated, the transition to renewables has progressed slowly, signalling implementation and infrastructural barriers.
- Policy and Market Interplay: Trends in energy use reflect interactions among regulatory instruments, technological advancement, and market forces. For instance, the stabilization of energy consumption post-2005 coincides with major EU directives and maturing clean energy technologies.

Implications for EU Energy Policy

The findings offer clear guidance for shaping future energy and climate strategies:

- Accelerated Policy Measures for Transport: The persistent dominance of oil in the transport sector calls for intensified regulatory action. This could include expanded investment in electric vehicle infrastructure, stricter CO_2 emissions targets, and behavioural incentives for modal shifts to public and non-motorized transport.
- Equity-Focused Energy Transition: The uneven pace of renewable energy adoption in the residential sector suggests a need for socioeconomically sensitive approaches. Policy frameworks should prioritise inclusivity, offering targeted financial support to vulnerable households and by addressing infrastructural disparities.
- Integrated, Long-Term Planning: While recent initiatives like the European Green Deal

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have set ambitious goals, sustained and coherent implementation across all Member States is essential. Monitoring tools and feedback mechanisms should be institutionalised to ensure progress and accountability.

- Recognition of National Diversity: EU-wide targets must be reconciled with national differences in energy systems, economic capacities, and demographic factors. This calls for policy flexibility and region-specific roadmaps that support Member States in achieving decarbonisation at different starting points each time.

Limitations and Directions for Future Research

Although this study provides an overview in trends and behaviour in energy sector, several limitations must be noted:

- Aggregate Data Bias: The use of EU27-level data may mask important national or regional variations, thus limiting the specificity of insights
- Temporal Gaps: The effects of the most recent policies (e.g., the European Green Deal or Fit for 55 Package) are not yet observable in the data due to lagging time in implementation and impact
- Exclusion of Qualitative Factors: Social, behavioral, and institutional dimensions— such as consumer behavior, political will, or public perception—were not examined in depth in this project

Future research should address these gaps by:

- Incorporating disaggregated, country-level data
- Studying social dynamics and behavioral determinants of energy consumption
- Evaluating the real-time policy impacts of post-2019 strategies

Final Remarks

The European Union's transition toward a sustainable energy system is evident but remains uneven. Economic growth has been decoupled from energy consumption, and the residential sector shows strong signs of decarbonization. However, persistent reliance on fossil fuels in transportation, coupled with socioeconomic disparities in access to clean energy, underscores the need for continued and differentiated policy action.

Achieving climate neutrality will require not only technological innovation and regulatory

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enforcement but also a commitment to equitable and inclusive transformation—ensuring all sectors and regions to grow together toward a more resilient energy future.

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