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GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

Exploring the Effect of Renewable Energy Adoption on Household Electricity Prices in Europe

Autor: Claudia Muñoz Pombo

Director: David Tercero Lucas

Madrid

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

Exploring the Effect of Renewable Energy Adoption on Household Energy Prices in Europe

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Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

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Agradecer a mi tutor David Tercero Lucas por su implicación y ayuda en este trabajo de fin de grado.

EXPLORANDO EL EFECTO DE LA ADOPCIÓN DE ENERGÍAS RENOVABLES EN LOS PRECIOS DE LA ELECTRICIDAD EN LOS HOGARES EUROPEOS

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Director: Tercero Lucas, David.

Entidad Colaboradora: ICAI – Universidad Pontificia Comillas

ABSTRACT

Este Trabajo de Fin de Grado analiza cómo la penetración de energías renovables en el mix de generación eléctrico afecta al precio de la electricidad en los hogares europeos. Utilizando datos panel de 24 países entre 2020 y 2023, se aplican modelos de regresión de efectos fijos con variables logarítmicas y errores agrupados por país. Se incorporan variables de control como los precios del gas natural y de derivados del petróleo, el nivel de competencia en el mercado eléctrico y el poder adquisitivo. Los resultados permiten evaluar el impacto real de las políticas de transición energética sobre el consumidor doméstico

Keywords: Energías renovables, variables, eléctrico.

1. Introducción

En un contexto de creciente compromiso climático, con iniciativas como el Pacto Verde Europeo o los Objetivos de Desarrollo Sostenible (ODS), muchos países han implementado medidas para fomentar el uso doméstico de tecnologías limpias. Sin embargo, persisten grandes diferencias entre países tanto en inversión como en asequibilidad de la energía. Éste estudio investiga cómo la proporción de energías renovables en el mix energético nacional se relaciona con el precio medio de la electricidad para el consumidor doméstico, considerando además factores económicos y estructurales como la liberalización del mercado eléctrico, los precios del gas y las ayudas gubernamentales.

El trabajo tiene un enfoque histórico y analítico. Comienza con una revisión del marco institucional que ha impulsado el desarrollo sostenible, desde el Informe Brundtland (1987) hasta la Agenda 2030, pasando por hitos como la Cumbre de Río o las directrices de la Agencia Internacional de la Energía (IEA).

Se parte de la hipótesis de que un mayor porcentaje de energías renovables en el mix eléctrico nacional reduce el precio medio de la electricidad para los hogares. El análisis considera barreras como los costes de instalación, la intermitencia o la falta de almacenamiento eficiente. Este enfoque permite valorar no solo la viabilidad económica, sino también la equidad en la transición energética.

El estudio contribuye a la literatura actual al ampliar el período de análisis, diferenciar el efecto de cada fuente renovable, incorporar variables de diseño de mercado y explorar interacciones clave. Además, apoya directamente los ODS 7 (energía asequible y no contaminante), 9 (industria e innovación) y 13 (acción por el clima).

2. Definición del proyecto

El proyecto desarrollado en este trabajo parte de una hipótesis inicial definida anteriormente: Un mayor porcentaje de energía renovable en el mix nacional para la producción de electricidad disminuye el precio de la factura del hogar. Con el fin de definir si dicha hipótesis es correcta o no, se plantean tres objetivos principales, que son los siguientes según éste mismo orden:

- Investigar la relación entre la proporción de energía renovable utilizada en Europa y los cambios resultantes en los precios de la electricidad.
- Identificar los factores socioeconómicos que influyen en los precios de la electricidad para los hogares, como los precios de los combustibles fósiles, el precio del gas natural, la demanda eléctrica doméstica, el nivel de liberalización del mercado, el índice HICP o el índice de poder adquisitivo.
- Analizar el impacto y evaluar el efecto de cada tipo de energía renovable en los precios finales de la electricidad, extrayendo conclusiones que permitan fomentar el uso más rentable de las energías renovables en Europa.

Para hacer posible éste análisis se utilizará un panel de regresión lineal de efectos fijos con variables logarítmicas y otras variables como las “time dummies”, utilizadas para controlar los efectos comunes a todos los países a lo largo de los años (crisis energética de 2021-2022), así como los “clustered standard errors” por país para evitar los errores agrupados, ya que, ajustan la incertidumbre de las estimaciones para reflejar que los datos dentro de un mismo país comparten características y tendencias no observables.

3. Descripción del modelo/sistema/herramienta

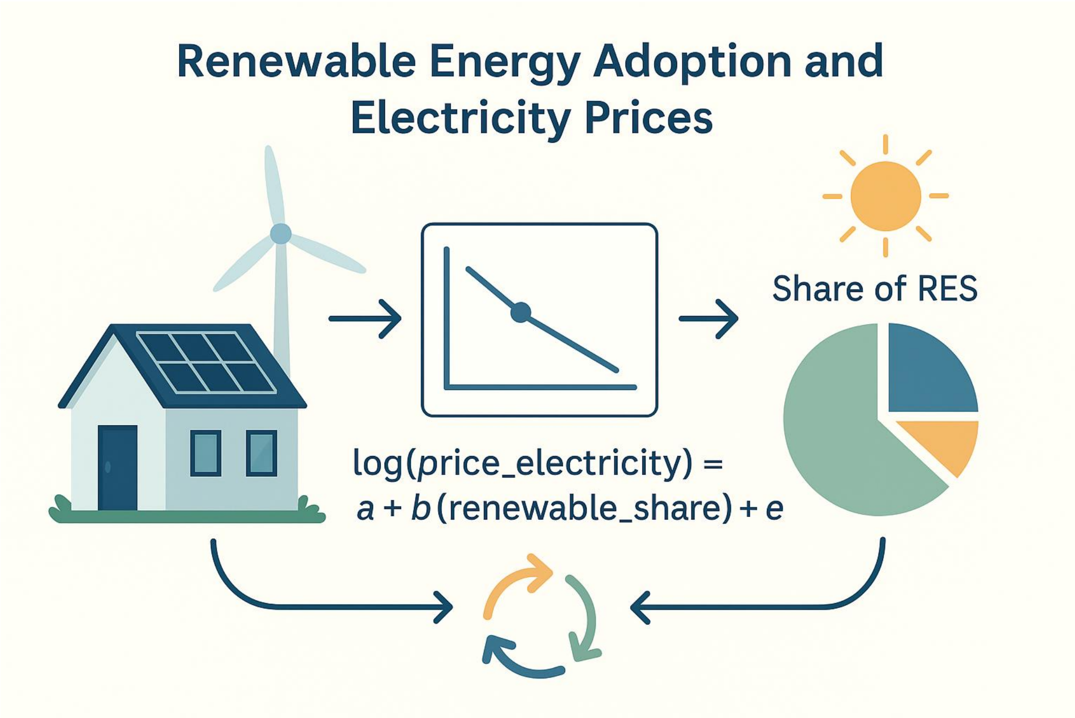
El método de análisis utilizado es el definido anteriormente (regresión lineal) esta metodología permite combinar información tanto temporal (años 2020 a 2023) como transversal (24 países europeos), lo que resulta especialmente útil para estudiar dinámicas económicas y energéticas en contextos comparables entre países.

El modelo de efectos fijos ha sido seleccionado en lugar del modelo de efectos aleatorios tras realizar el test de Hausmann. Este modelo permite controlar la heterogeneidad no observable constante en el tiempo de cada país, como puede ser la cultura energética, el marco normativo o las subvenciones gubernamentales. Al centrarse en las variaciones dentro de cada país a lo largo del tiempo, se minimiza el sesgo causado por características estructurales invariables que podrían confundir la relación entre la adopción de renovables y el precio de la electricidad.

Además, se han incluido variables dummy de año (time dummies) para controlar los efectos temporales comunes a todos los países, como crisis energéticas, fluctuaciones en el mercado internacional o eventos macroeconómicos globales (por ejemplo, el impacto de la pandemia o la guerra en Ucrania). Estas variables permiten capturar shocks o tendencias que afectan simultáneamente a todos los países del panel y evitar que estos se atribuyan erróneamente a otras variables independientes del modelo.

Por otro lado, se han utilizado errores estándar agrupados por país (clustered standard errors by country) con el fin de corregir la posible correlación de los residuos dentro de cada país. En un contexto de datos panel, es habitual que las observaciones de un mismo país estén correlacionadas entre sí, lo que puede llevar a una subestimación de la varianza de los errores y, por tanto, a una sobreestimación de la significación estadística. Agrupar los errores por país permite obtener inferencias más robustas y fiables.

Finalmente, la mayoría de las variables han sido transformadas en logaritmos para interpretar los coeficientes en términos de elasticidades, estabilizar la varianza y facilitar la comparación entre unidades. Únicamente aquellas variables expresadas en porcentaje o proporciones, así como las variables de valores muy pequeños han permanecido en su forma original.


Renewable Energy Adoption and Electricity Prices
Share of RES
log(price_electricity) =
a + b(renewable_share) + e

4. Resultados

El objetivo principal del análisis fue identificar los factores que afectan significativamente al precio final de la electricidad en los hogares europeos. Para mejorar la robustez econométrica y facilitar la interpretación de los resultados, se aplicó una transformación logarítmica a la mayoría de las variables continuas. Esto permitió interpretar los coeficientes como elasticidades y reducir posibles problemas de heterocedasticidad.

Nueve modelos de regresión lineal con efectos fijos fueron estimados usando Python y la librería “linearmodels”, seleccionando diferentes combinaciones de variables para evitar problemas de multicolinealidad. El test VIF (Anexos) confirmó que la multicolinealidad no es un problema relevante en los modelos utilizados.

Variables	Regresión 1	Regresión 2	Regresión 3	Regresión 4	Regresión 5	Regresión 6	Regresión 7	Regresión 8	Regresión 9
log_Gas_Price	0.5665 (0.0000***)	0.5097 (0.0000***)	0.6789 (0.0000***)	0.5124 (0.0000***)	0.4641 (0.0000)	0.4817 (0.0000***)	0.5107 (0.0000***)	0.3999 (0.0000***)	
log_Electricity_Consumption	-0.0209 (0.3068)			0.0053 (0.8680)			(-0.0464) (0.0087***)		
Share_RES	0.0040 (0.0549*)	0.0026 (0.2722)		0.0041 (0.0677*)	0.0024 (0.3049)	0.0028 (0.1270)	0.0005 (0.7914)		
Share_Solar	-0.0009 (0.4143)			-0.0008 (0.5772)			0.0000065 (0.9948)		
log_PPP		-0.0345 (0.3946)							
log_Num_Retailers		0.0163 (0.6663)				0.0375 (0.2255)			
Switching_Rate	0.0063 (0.7057)	0.0063 (0.7057)	(-0.0234) (0.0601*)						
Share_Hydro					(-0.0026) (0.0870*)			-0.0017 (0.1878)	
log_Gov_Subsidies			0.0214 (0.2296)		0.0425 (0.1550)			0.0304 (0.1912)	0.0928 (0.0003***)
Share_Eolic			0.0047 (0.0072***)			0.0046 (0.0033***)			0.0021 (0.2459)
log_HICP				-0.0887 (0.3407)	(-0.1417) (0.0742*)	(-0.1511) (0.0141**)		(-0.1885) (0.0026***)	
Market_Share_Main_Supplier				-0.00001 (0.9943)		-0.0009 (0.6268)			
Taxes							3.6696 (0.0000***)	3.3701 (0.0000***)	4.3067 (0.0000***)
log_Heating_Oil_Price									(-0.3787) (0.0000***)
R2_Within	0,6766	0,7004	0,6356	0,6883	0,6719	0,681	0,7811	0,7876	0,054
Observations	96	96	96	96	96	96	96	96	96
Note: Standard errors are clustered at country level. Statistical significance is represented by pvalue as follows p<0.01***, p<0.05**, p<0.1*									

Los resultados muestran que varias variables son estadísticamente significativas ($p \leq 0.1$) y tienen relaciones consistentes con la variable dependiente (log_Electricity_Price_Incl_Tax). Entre las variables más relevantes se encuentran

- El precio del gas natural tiene un impacto positivo fuerte y constante: un aumento del 1% en el precio del gas se traduce en un incremento de 0,5% en el precio de la electricidad.
- El consumo de electricidad presenta una relación negativa, lo que sugiere que un mayor uso puede reducir ligeramente el precio, por economías de escala o tecnologías eficientes.
- La cuota total de energías renovables (RES) tiene un pequeño impacto positivo (0,4%), con un pvalor de 0,05.
- L**os** impuestos tienen el impacto más fuerte: un aumento de 0,01 €/kWh en impuestos incrementa el precio final de la electricidad en torno al 3–4%.

- Entre las tecnologías renovables, la eólica aumenta el precio (0,46%), la hidráulica lo reduce ligeramente (–0,26%) y la solar no tiene un efecto significativo.
- Las subvenciones públicas muestran una relación positiva con los precios (0,0928%), posiblemente debido a la forma en que se financian los esquemas de apoyo. En cualquier lugar no explican realmente el precio de la electricidad a nivel doméstico (R^2 within=0,054).
- Las variables relacionadas con la liberalización del mercado (número de comercializadoras, tasa de cambio de proveedor, cuota del principal proveedor) no muestran significancia estadística.
- El precio del fuelóleo para calefacción, aunque estadísticamente significativo y con un coeficiente negativo, explica muy poco la variación del precio de la electricidad (R^2 within = 0.054), lo que indica que no tiene poder explicativo real.

5. Conclusiones

Los resultados muestran que el porcentaje total de energías renovables está positivamente relacionado con los precios de la electricidad, lo que sugiere que aumentar la presencia de renovables en el mix energético no implica necesariamente una bajada del precio para los hogares. Esto se debe probablemente a los costes de integración, necesidades de infraestructura y esquemas de apoyo que compensan los beneficios teóricos de costes marginales más bajos.

Al desagregar las renovables por tipo, el efecto varía según la tecnología. La energía eólica mostró una relación positiva y significativa con el precio (aprox. +0,47% por cada 1% adicional), mientras que la hidráulica tuvo un efecto negativo (–0,26%). La solar no presentó un efecto claro. Estos resultados reflejan que no todas las tecnologías renovables afectan igual a los precios, siendo las más antiguas y amortizadas como la hidráulica más estable en términos de coste que las fuentes más intermitentes como la eólica.

Respecto a variables estructurales y de política, los impuestos mostraron ser un factor clave, con coeficientes entre 3,5 y 4, confirmando su fuerte impacto en los precios finales como era de esperar, por ello solo se incluyeron en dos regresiones lineales, ya que es muy explicativa y no permitiría ver el impacto en las regresiones de otras variables de control. Las subvenciones gubernamentales mostraron un coeficiente positivo (0,0928), pero solo fueron significativas en una regresión con muy baja capacidad explicativa (R^2 = 0,054), por lo que este resultado no se considera concluyente. La inclusión del precio del fuelóleo en ese modelo probablemente redujo su ajuste, ya que este combustible tiene un papel indirecto o poco relevante en la generación eléctrica, lo mismo sucede con los subsidios gubernamentales.

En cambio, el gas natural, principal combustible marginal en Europa, mostró un efecto positivo fuerte y consistente sobre el precio de la electricidad (coef.= 0,5, $p < 0,001$), lo que confirma el conocido mecanismo de transmisión entre mercados de combustibles fósiles y precios eléctricos.

Es interesante que las variables que reflejan la liberalización del mercado eléctrico como el número de proveedores, tasa de cambio de compañía o cuota del principal proveedor, no mostraron significancia estadística, lo que sugiere que dicha liberalización aún no se ha traducido en precios más competitivos para los hogares. Esto podría deberse a una liberalización incompleta, estructuras de mercado heredadas o falta de reacción por parte de los consumidores, como se discute en el Capítulo 2.3.

En cuanto a indicadores macroeconómicos, el PPA (paridad de poder adquisitivo) no presentó relación estadística significativa con los precios, lo que sugiere que el nivel de ingresos de los hogares no influye directamente en el precio de la electricidad, probablemente porque los marcos regulatorios y la estructura del mercado tienen un papel más relevante. Por otro lado, el HICP (índice armonizado de precios de consumo) mostró un coeficiente negativo y significativo en algunas regresiones. Esto puede explicarse por la intervención estatal: los países europeos han protegido el precio de la electricidad frente a la inflación mediante subsidios y topes, como señala Bruegel (2024), que documenta inversiones públicas multimillonarias entre 2021 y 2023 para frenar el impacto de los precios energéticos en los hogares.

Desde el punto de vista metodológico, el análisis confirma la utilidad de dividir el modelo en varias especificaciones para evitar multicolinealidad, como se detalla en el Capítulo 5.4. Los valores de VIF (Apéndice) y los R^2 Within por encima de 0,7 en varias regresiones indican una fuerte capacidad explicativa del modelo.

En resumen, la investigación demuestra que la relación entre energía renovable y precio de la electricidad es compleja y depende de la tecnología. La hidráulica ayuda a reducir precios, mientras que la eólica todavía puede ejercer presión al alza en el corto plazo. Los responsables políticos deben tener en cuenta estas diferencias y acompañar el despliegue renovable con instrumentos regulatorios y fiscales eficientes para proteger a los hogares durante la transición energética.

EXPLORING THE EFFECT OF RENEWABLE ENERGY ADOPTION ON HOUSEHOLD ELECTRICITY PRICES IN EUROPE

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Supervisor: Tercero Lucas, David
Collaborating Entity: ICAI – Universidad Pontificia de Comillas

ABSTRACT

This bachelor's thesis analyzes how the penetration of renewable energy in the electricity mix affects household electricity prices across European countries. Using panel data from 24 countries between 2020 and 2023, fixed-effects regression models are applied with log-transformed variables and clustered standard errors by country. Control variables include gas and heating oil prices, the degree of competition in the electricity market, and purchasing power. The results provide an assessment of the real impact of energy transition policies on household consumers.
Keywords: Renewable energy, variables, electricity

1. Introduction

This thesis examines the impact of renewable energy adoption on household electricity prices in Europe. In the context of increasing climate commitment, through initiatives such as the European Green Deal and the Sustainable Development Goals (SDGs), many countries have implemented policies to promote the domestic use of clean technologies. However, large disparities remain among countries in terms of investment levels and energy affordability. This study investigates how the share of renewable energy in the national energy mix relates to the average electricity price for households, also considering economic and structural factors such as market liberalization, fuel prices, and government subsidies.

The research follows both a historical and analytical approach. It begins with a review of the institutional framework that has driven sustainable development, from the 1987 Brundtland Report to the 2030 Agenda, including milestones like the Rio Earth Summit and the guidelines of the International Energy Agency (IEA).

The working hypothesis is that a higher share of renewable energy in the national electricity mix leads to lower average household electricity prices. The analysis considers barriers such as installation costs, intermittency, and the lack of efficient storage. This approach helps assess not only economic feasibility but also equity in the energy transition.

The study contributes to the current literature by extending the analysis period, differentiating the effect of each renewable source, incorporating market design variables, and exploring key interaction effects. It also directly supports SDGs 7 (Affordable and Clean Energy), 9 (Industry, Innovation and Infrastructure), and 13 (Climate Action).

2. Project Description

This project begins with an initial hypothesis: A higher share of renewable energy in the national electricity mix reduces household electricity bills. To test this hypothesis, three main research objectives are established:

• Investigate the relationship between the proportion of renewable energy used in Europe and the resulting changes in electricity prices.
• Identify the socioeconomic factors that influence household electricity prices, such as fossil fuel prices, natural gas prices, household electricity demand, level of market liberalization, HICP index or Purchasing power index.
• Analyze the impact and evaluate the effect of each type of renewable energy on final electricity prices, drawing conclusions to promote the most cost-effective use of renewables across Europe.

To conduct this analysis, a log-linear fixed-effects panel regression is employed, including time dummies to account for common year-specific effects (such as the 2021–2022 energy crisis), and clustered standard errors by country to correct for within-country correlation of observations. These adjustments improve the robustness and reliability of the statistical results.

3. Model Definition and Methodology

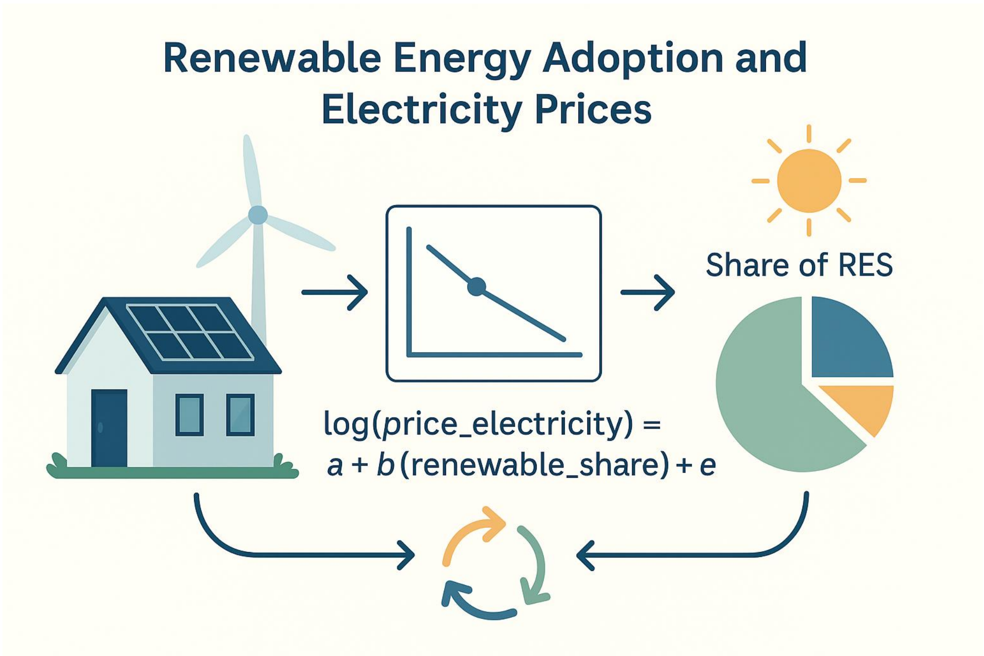
The analyzing model is the one explained before (linear regressions), this method combines both time-series (2020–2023) and cross-sectional (24 countries) data, allowing for an in-depth analysis of economic and energy trends across comparable countries.

The fixed-effects model was selected over the random-effects model after performing the Hausmann test. It helps control unobservable country-specific characteristics that are constant over time, such as regulatory frameworks, energy culture, or institutional incentives. Focusing on within-country variation over time minimizes bias from fixed structural features that might confound the effect of renewable energy adoption on electricity prices.

Time dummies were added to control for shocks and global events affecting all countries (the COVID-19 pandemic, the war in Ukraine), helping isolate the effect of interest.

Moreover, clustered standard errors by country were applied to account for within-country autocorrelation, which can otherwise lead to underestimated standard errors and overestimated statistical significance.

Most variables were log-transformed to allow interpretation of coefficients in terms of elasticities, reduce heteroscedasticity, and improve comparability between variables. Only those expressed as percentages, small variables or ratios were left in their original form.



4. **Results**

The main objective of the analysis was to identify the factors that significantly influence the final electricity price for households in Europe. To improve econometric robustness and facilitate interpretation, most continuous variables were transformed using natural logarithms. This allowed the coefficients to be interpreted as elasticities and helped reduce potential heteroscedasticity issues.

Nine fixed-effects linear regression models were estimated using Python and the linear models library. Different combinations of variables were selected across regressions to avoid multicollinearity. The VIF test (Appendices) confirmed that multicollinearity was not a relevant issue in the models applied.

Variables	Regresión 1	Regresión 2	Regresión 3	Regresión 4	Regresión 5	Regresión 6	Regresión 7	Regresión 8	Regresión 9
log_Gas_Price	0.5665 (0.0000***)	0.5097 (0.0000***)	0.6789 (0.0000***)	0.5124 (0.0000***)	0.4641 (0.0000)	0.4817 (0.0000***)	0.5107 (0.0000***)	0.3999 (0.0000***)	
log_Electricity_Consumption	-0.0209 (0.3068)			0.0053 (0.8680)			(-0.0464) (0.0087***)		
Share_RES	0.0040 (0.0549*)	0.0026 (0.2722)		0.0041 (0.0677*)	0.0024 (0.3049)	0.0028 (0.1270)	0.0005 (0.7914)		
Share_Solar	-0.0009 (0.4143)			-0.0008 (0.5772)			0.0000065 (0.9948)		
log_PPP		-0.0345 (0.3946)							
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Switching_Rate	0.0063 (0.7057)	0.0063 (0.7057)	(-0.0234) (0.0601*)						
Share_Hydro					(-0.0026) (0.0870*)			-0.0017 (0.1878)	
log_Gov_Subsidies			0.0214 (0.2296)		0.0425 (0.1550)			0.0304 (0.1912)	0.0928 (0.0003***)
Share_Eolic			0.0047 (0.0072***)			0.0046 (0.0033***)			0.0021 (0.2459)
log_HICP				-0.0887 (0.3407)	(-0.1417) (0.0742*)	(-0.1511) (0.0141**)		(-0.1885) (0.0026***)	
Market_Share_Main_Supplier				-0.00001 (0.9943)		-0.0009 (0.6268)			
Taxes							3.6696 (0.0000***)	3.3701 (0.0000***)	4.3067 (0.0000***)
log_Heating_Oil_Price									(-0.3787) (0.0000***)
R2_Within	0,6766	0,7004	0,6356	0,6883	0,6719	0,681	0,7811	0,7876	0,054
Observations	96	96	96	96	96	96	96	96	96
Note: Standard errors are clustered at country level. Statistical significance is represented by pvalue as follows p<0.01***, p<0.05**, p<0.1*									

The results show that several control variables are statistically significant ($p \leq 0.1$) and have consistent relationships with the dependent variable (log_Electricity_Price_Incl_Tax). Among the most relevant variables are:

- Natural gas prices show a strong and consistent positive impact: a 1% rise in gas prices leads to 0.5% increase in electricity prices.
- Electricity consumption shows a negative relationship, suggesting that higher usage leads to slightly lower prices, possibly due to scale economies or efficient technologies.
- The overall share of RES has a small but positive impact (0.4%) with a pvalue of 0,05.
- Taxes have the strongest impact: an increase of 0.01 €/kWh in taxes raises electricity prices by around 3–4%.
- Among RES technologies, wind increases prices (0.46%), while hydro slightly reduces them (–0.26%). Solar does not have a significant impact.
- Government subsidies show a positive relationship with prices (0.0928%), possibly due to the way support schemes are financed. Anyhow the R squared value demonstrates that this variable does not explain directly the price of electricity at household level.
- Variables linked to market liberalization (number of retailers, switching rate, market share of main supplier) do not show any statistical significance.
- Heating oil prices, although statistically significant and negative, explain very little of the variation in electricity prices (R^2 within = 0.054), suggesting no real explanatory power.

5. Conclusions

Results show that the overall share of RES is positively related to electricity prices, suggesting that increasing renewable adoption alone does not necessarily lead to cheaper electricity for households. This is likely due to integration costs, infrastructure needs, and support mechanisms, which offset the theoretical benefits of lower marginal costs.

When RES is broken down by technology, the cost effects differ. Wind energy showed a positive and significant association with price (approx. +0.47% per 1% increase), while hydro had a slight negative effect (–0.26%). Solar did not have a strong effect. These results suggest that not all renewables impact prices equally, with older, amortized technologies like hydro offering more cost stability than intermittent sources like wind.

Regarding structural and policy-related variables, taxes proved to be a key driver, with coefficients between 3.5 and 4, confirming their strong influence on final prices. Government subsidies showed a positive coefficient but were only significant in a regression with very low explanatory power ($R^2 = 0.054$), which undermines its reliability. The inclusion of heating oil prices in that model likely contributed to the poor fit, as heating oil is not a main input in electricity generation and has an indirect or irrelevant role in pricing, the same happens with government subsidies.

In contrast, natural gas, a marginal fuel in European electricity generation, showed a consistently strong and positive effect on electricity prices (coeff. 0.5, $p < 0.001$), confirming the expected transmission mechanism between fossil fuel markets and electricity costs.

Interestingly, market liberalization variables such as the number of electricity retailers, switching rate, or main supplier's market share did not show any significant effect, suggesting that liberalization has not effectively translated into more competitive pricing at the household level. This may be due to incomplete implementation, market inertia, or consumer behavior, as discussed in Chapter 2.3.

Regarding macroeconomic indicators, PPP (purchasing power parity) had no significant effect on electricity prices, suggesting that income levels do not directly influence electricity pricing. On the other hand, HICP (inflation) had a surprisingly negative and significant coefficient in some models. This could reflect policy actions taken by European governments to shield households from inflation-driven energy price increases, as supported by Bruegel (2024), who report that EU countries invested billions from 2021 to 2023 to protect consumers.

Methodologically, the segmentation into nine regressions and the use of VIF analysis allowed for robust variable selection and avoidance of multicollinearity. Several models presented high R^2 within values (above 0.7), showing that the selected regressors explain a substantial part of electricity price variation over time.

In conclusion, the study finds that renewable energy has a complex and technology-dependent relationship with electricity prices. Hydro appears to reduce prices, while wind may still exert upward pressure due to integration and support costs. Policymakers should consider these distinctions and complement renewable deployment with strong fiscal and regulatory tools to ensure affordability during the energy transition.

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Capítulo 1. INTRODUCTION

1.1 BACKGROUND AND CONTEXT OF THE TOPIC

In 1987, the Brundtland Report was published by the World Commission on Environment and Development in collaboration with the United Nations. Its main objective was to address the growing global concern about environmental degradation, poverty, and inequality, proposing a development model that balances economic growth with environmental protection and social equity. In this way, the concept of sustainable development was introduced, particularly in Europe, defined in the report as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The report proposes three main strategies to achieve true development: the rational use of energy, the development of clean technologies, and the integration of environmental and economic policies. (World Commission on Environment and Development, 2025).

A few years later, in 1992, the Rio Earth Summit was held, where the United Nations published Agenda 21, proposing a global plan for sustainable development in the 21st century. It recognized the need to reduce dependence on fossil and polluting energy sources and to promote energy efficiency through investment in the research and development of renewable energy sources. (World Comission on Enviroment and Development, 2025)

In 2005, the Renewable Energy Policy Network for the 21st Century (REN21) was published, which essentially compares data on investment in sustainable technologies, policies, and the evolution of the energy mix across different countries. (REN21, 2025)

Later, in 2015, Agenda 2030 was launched with numerous goals to be achieved by the year 2030, including the Sustainable Development Goals (SDGs), which establish energy as a human right and a key pillar of sustainable development. Throughout this project, it will become evident that the adoption of renewable energy for household consumption primarily supports three of the most important goals: affordable and clean energy, sustainable innovation and infrastructure, and climate action. (United Nations, 2025)

More recently, in 2021, the International Energy Agency (IEA) published a detailed roadmap to achieve net-zero emissions by 2050, proposing the phasing out of coal and oil and massive electrification, with the goal that by 2050, 90% of electricity will be generated from renewable sources (International Energy Agency, 2021).

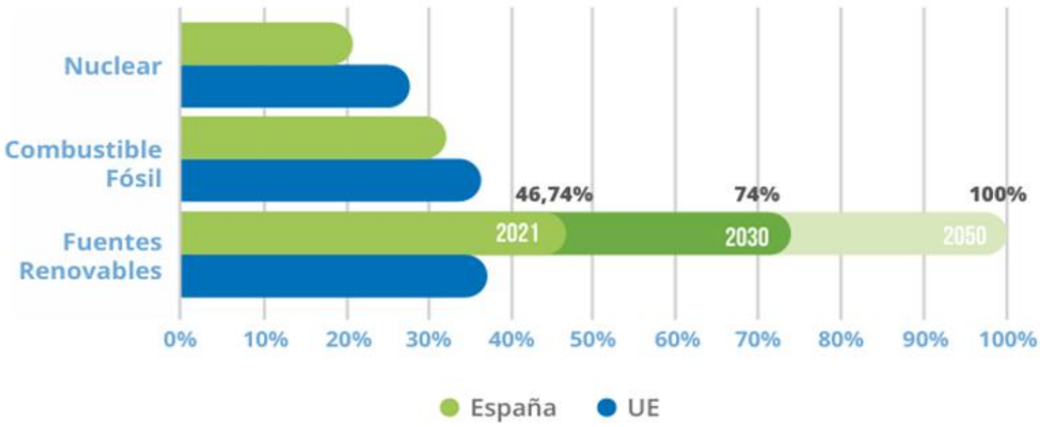

Figure 1: Share (%) of electricity from RES (IEA, 2021)

The most recent information regarding the use of renewable energy in Europe is provided by Eurostat, where we can observe the percentage of energy from renewable sources within the energy mix of each European country, as shown in Figure 2. (Eurostat, 2023)

Countries such as Sweden, Finland, and Denmark are the leading promoters of renewable energy development, with renewable energy accounting for nearly 67% of their energy mix, Sweden at 66.4%, followed by Finland at 50.75% and Denmark at 44.4%. On the other hand, Luxembourg, Belgium, and Malta show minimal levels of renewable energy integration and adoption in their energy mix, with percentages around 12% of the total energy produced.

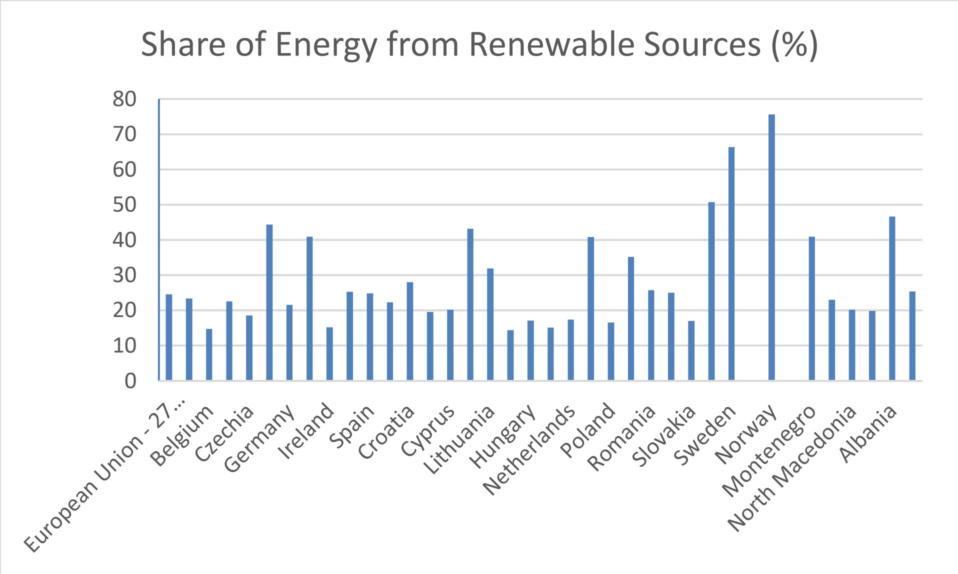

Figure 2: Share of energy from renewable sources (Eurostat, 2023)

The motivation for this project lies in the need to better understand how the transition to renewable energy affects electricity prices for European households. Given the growing commitment to sustainability and changing energy demands, it is essential to assess the economic feasibility of these energy sources and explore mechanisms to reduce their costs.

One of the biggest problems concerning energy sources nowadays is clearly not the fact that there are no ways to produce green energy, but three different complications: the cost of producing this energy, the inability to store this type of energy and the precariousness of this source do to its intermittency and variability (Dai et al., 2023).

1.2 JUSTIFICATION AND RELEVANCE

In recent years, Europe has experienced a growing shift towards renewable energy as part of its broader strategy to achieve climate neutrality and reduce dependence on fossil fuels. This transition is particularly relevant in the domestic sector, where households represent a significant share of total energy consumption.

Encouraged by policy frameworks such as the European Green Deal and national climate targets, many European countries have implemented subsidies and incentives to promote the adoption of renewable technologies to produce electricity at household level. However, despite this progress, there are notable disparities between countries in terms of investment, adoption rates, and energy affordability.

This project aims to explore the relationship between government support schemes and the adoption of renewable energy technologies to produce the electricity consumed in households, as well as analyze the impact of installation costs and storage limitations on the effectiveness and equity of the energy transition across Europe.

As Europe drives the transition toward a more sustainable energy model, it becomes crucial to understand how different types of renewable energy, such as wind, hydro, and solar power, affect electricity prices and assess the feasibility of their implementation.

This research project addresses several gaps identified in the existing literature. First, it extends the analysis period to cover new trends and the cumulative effects of renewable energy policies, specifically from 2020 to 2023. Second, it employs household-level panel data, which allows for socioeconomic differentiation and more granular insights into the impact of renewable energy adoption. Third, it disaggregates renewable energy sources (RES), thereby capturing the heterogeneity in their price effects and carbon emissions impacts. Additionally, the model incorporates variables related to market design, taxation, and behavioral responses. Lastly, it explores interaction effects, such as the relationship between the share of RES in the energy mix and the degree of market liberalization, providing a more comprehensive understanding of the dynamics influencing domestic energy transition across Europe.

It is aligned with several Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy), by exploring strategies to reduce the cost of renewable energy for households. It also supports SDG 9 (Industry, Innovation, and Infrastructure) through the promotion of technological innovation in the energy sector, and SDG 13

(Climate Action), by encouraging the adoption of clean, low-emission energy sources as part of Europe's broader environmental transition.

This final degree project aims to raise awareness among the European population that the only way forward is through the Sustainable Development Goals (SDGs), by protecting the environment and using renewable energy sources.

1.3 RESEARCH QUESTIONS AND HYPOTHESIS

Although the environmental benefits of clean energy are well documented, its economic implications (particularly at the residential level) require further investigation. This research seeks to address that gap by formulating a set of guiding questions and testing a central hypothesis.

The core research question of this study is:

"Does a higher share of renewable energy used for household electricity production lead to a reduction in the final electricity bill paid by consumers?"

This central question emerges from growing debates about the economic viability of renewable energy and the fairness of the energy transition across different European countries. While renewable energy technologies such as solar, wind, and hydropower have become more affordable and widespread, their integration into national energy systems still involves complexities, including intermittency, storage limitations, and varying levels of government support. Moreover, national electricity market structures and levels of liberalization differ significantly across Europe, adding another layer of complexity to the analysis.

From this primary research question, additional sub-questions arise:

- What is the relationship between the share of renewable energy in the national electricity mix and the average household electricity price?

- How do supporting factors such as government subsidies or market liberalization affect the final electricity costs?
- Are certain types of renewable energy (wind, solar, hydro) more effective than others in reducing household electricity costs?
- To what extent do socio-economical factors, such as taxes or macro economical index such as inflation rates (HICP) and purchasing power rates (PPP) influence the final price paid by consumers?

These questions will be examined through a panel data econometric approach, allowing for both temporal and cross-country variation between 2020 and 2023 in 24 European countries.

Based on this framework, the central hypothesis of this research is stated as follows:

H_0: A higher share of renewable energy used for electricity production at the household level reduces the final payment for electricity.

This hypothesis is grounded in the assumption that renewable energy sources, when efficiently integrated and adequately supported by public policy, can lead to lower marginal costs of production, especially when compared to volatile fossil fuel prices. Additionally, greater penetration of renewables is expected to increase energy security, reduce dependency on imports, and lead to more stable electricity markets, conditions that could ultimately benefit the consumer.

This hypothesis will be tested using fixed-effects regression models with log-transformed variables to estimate elasticities and control unobservable heterogeneity across countries. Time dummies and clustered standard errors by country will be included to improve the reliability and robustness of the estimations, particularly in capturing the effects of global shocks such as the COVID-19 pandemic or the 2022 energy crisis.

The outcome of this analysis will help determine whether increased investment in renewable energy is not only environmentally necessary but also economically advantageous for European households.

1.4 OBJECTIVES OF THE PROJECT

To investigate and reach a conclusion on whether the previously stated hypothesis is correct or not, there are fixed research objectives designed to answer the main questions.

The main objective of this study would be assessing whether an increase in the adoption of renewable energy sources (such as solar, wind, and hydropower) impacts household energy prices across European countries. Specifically, the research seeks to:

• Investigate the relationship between the proportion of renewable energy used in Europe and the resulting changes in electricity prices.

• Identify the socioeconomic factors that influence household electricity prices, such as fossil fuel prices, natural gas prices, household electricity demand, level of market liberalization, HICP index or Purchasing power index.

• Analyze the impact and evaluate the effect of each type of renewable energy on final electricity prices, drawing conclusions to promote the most cost-effective use of renewables across Europe.

To perform these goals, linear regressions with fixed effects will be made through a data panel implementing time dummies and clustered standard errors by country. These regressions will be carried out with python, to improve econometric robustness and facilitate interpretation, most continuous variables were transformed using natural logarithms, this allowed the coefficients to be interpreted as elasticities and helped reduce potential heteroscedasticity issues.

The main conclusions after analyzing carefully the results are the following:

The regressions show that some control variables have a statistically significant effect on household electricity prices. Notably:

- Natural gas prices show a strong and consistent positive impact: a 1% rise in gas prices leads to 0.5% increase in electricity prices.
- Electricity consumption shows a negative relationship, suggesting that higher usage leads to slightly lower prices, possibly due to scale economies or efficient technologies.
- The overall share of RES has a small but positive impact (0.4%) with a pvalue of 0,05.
- Taxes have the strongest impact: an increase of 0.01 €/kWh in taxes raises electricity prices by around 3–4%.
- Among RES technologies, wind increases prices (0.46%), while hydro slightly reduces them (–0.26%). Solar does not have a significant impact.
- Government subsidies show a positive relationship with prices (0.0928%), possibly due to the way support schemes are financed. Anyhow the R squared value demonstrates that this variable does not explain directly the price of electricity at household level.
- Variables linked to market liberalization (number of retailers, switching rate, market share of main supplier) do not show any statistical significance.
- Heating oil prices, although statistically significant and negative, explain very little of the variation in electricity prices (R^2 within = 0.054), suggesting no real explanatory power.

1.5 GENERAL METHODOLOGY

To empirically investigate the relationship between renewable energy adoption and household electricity prices in Europe, this study employs a panel data econometric approach. The dataset comprises annual observations from 24 European countries over the period 2020–2023, allowing for both temporal and cross-sectional variation. Panel data techniques are particularly well suited for this type of analysis, as they enable the researcher to control for unobserved heterogeneity across countries, factors such as regulatory culture, long-term policy traditions, or infrastructural characteristics that are not directly measurable but remain constant over time.

The primary analytical tool used is fixed-effects linear regression, chosen over random-effects models after applying the Hausman test, which confirmed the presence of correlation between country-specific effects and the regressors. The fixed-effects model effectively removes time-invariant country-level characteristics, focusing on within-country variations over time. This helps isolate the true impact of the independent variables, such as the share of renewable energy, on the dependent variable, which is the average household electricity price.

To improve model robustness and interpretability, most of the quantitative variables are transformed into their logarithmic form. This transformation helps in several ways.

First, it stabilizes the variance and mitigates obliquity in the data and enables the interpretation of coefficients as elasticities, and second it reduces the impact of extreme values or outliers. Only variables expressed as percentages, small variables or proportions (switching rates, market shares, and RES shares) are kept in their original form.

In addition, the regressions include time dummies for each year in the dataset to capture shocks and trends that affect all countries simultaneously, such as the energy crisis in 2022 or the macroeconomic effects of the COVID-19 pandemic. Dummies help to control time-specific unobserved effects and improve the precision of the estimates.

To further refine statistical accuracy, clustered standard errors by country are used. This adjustment accounts for potential correlation of residuals within countries over time, which is a common issue in panel data and can lead to underestimation of standard errors if not properly addressed.

Before estimating the models, a correlation matrix is constructed to identify potential multicollinearity problems among independent variables. When the correlation between two explanatory variables is significant ($|r| > 0{,}4$), one of them may be excluded from a given regression model to avoid distortions in coefficient estimates and standard errors. This diagnostic step is essential to ensure the internal consistency and interpretability of the models.

Overall, this methodological framework allows for a comprehensive and reliable assessment of the economic implications of renewable energy integration at the household level, using a well-grounded quantitative strategy that combines econometric rigor with policy relevance.

1.6 STRUCTURE OF THE DOCUMENT

The structure of the document follows a structure that guides the reader from the contextualization of the problem to the interpretation of empirical results and their policy implications. It begins with the presentation of the general context and motivation behind the research, emphasizing the relevance of renewable energy adoption in the European domestic electricity market. The research questions and working hypothesis are formulated, and the overall methodology employed throughout the study is introduced. A critical overview of the existing academic and institutional literature related to energy transition, electricity pricing, and renewable energy policy is then provided, to identify existing knowledge gaps and highlight the contribution of this work. The economic, regulatory, and technological context of the European energy market is also explored, including the evolution of sustainable development strategies, international agreements, and the role of institutions such as the European Union and the International Energy Agency (IEA). In addition, the study addresses important structural challenges of the energy transition, such as intermittency, energy storage, and affordability. The empirical approach is described in detail, covering the construction of the panel dataset, the selection of variables, the use of regression models and logarithmic transformations, as well as the application of time dummies and the handling of potential multicollinearity through correlation analysis. The econometric results are then presented and interpreted, incorporating descriptive statistics, correlation matrices, and fixed-effects regressions, with findings discussed in relation to the initial hypotheses and contrasted with previous literature. Finally, the study concludes by summarizing the results and evaluating their relevance to current energy policy debates, while also reflecting on the limitations of the analysis and proposing future lines of research.

Capítulo 2. LITERATURE REVIEW

The literature review serves as a main piece for this research, offering the theoretical and contextual backgrounds that sustain the entire investigation. Through a systematic examination of earlier scholarship and institutional studies on renewable energy, electricity pricing practices, and the evolving architecture of energy markets, this section situates the present research question within a wider intellectual and policy landscape.

Reviewing the existing literature serves multiple purposes. It identifies the main debates in the field, highlights gaps in the current knowledge, particularly regarding the link between renewable energy adoption and household electricity prices and helps justify the methodological choices made in this project. Furthermore, it offers valuable insights into how different countries have approached the energy transition, and what outcomes have been observed across various regulatory, economic, and technological settings.

At last, this review allows the present study to build upon established findings while addressing underexplored aspects, thereby strengthening its originality and academic relevance. My manuscript specifically contributes to different streams in energy literature. The impact of renewable energy on household prices, the role of market liberalization and policy design.

2.1 IMPACT OF RENEWABLE ENERGY ON HOUSEHOLD ELECTRICITY PRICES

The relationship between the adoption of renewable energy sources (RES) and household electricity prices remains one of the most debated topics in energy economics.

Cech and Janda (2016) employed panel data regression models using data from thirteen European nations between 2010 and 2013. Their study found that a 10% increase in the share of renewable electricity correlates with approximately a 1.92% increase in household electricity prices, primarily due to infrastructure, transmission, and integration costs (Cech

& Janda, 2016), this may be the main reason why in spite of the general high share of renewable energy for total production, the share of renewable energy for final consumption is significantly smaller in some European countries.

After reading and understanding Cech and Janda's document it could be seen that it will be interesting to analyze this relationship between household consumer prices and RES adoption a few years after, in order to analyze whether the high initial investment costs are gradually paid off and allow the European electricity prices to decrease, due to the fact that the costs of obtaining this type of energy, including maintaining and operating costs are very low compared to the maintaining and operating costs of non-renewable sources such as oil, coal or natural gas .

This project seeks not only to understand the relationship between both variables, but also to assess how each type of renewable energy individually affects the final household energy price, and to determine whether, after amortizing the high initial investment costs, the price of renewable energy has indeed decreased.

Cech and Janda (2016), analyzed only four years of data, thus missing post-2015 developments, including the Paris Agreement and the impact of geopolitical shocks like the COVID-19 pandemic (2020) or the war in Ukraine (started in February 2022), this research will enable people to understand and recognize the changes that this geopolitical shocks may cause on renewable energy consumption in Europe.

Other researchers such as Moreno and López (2011) and Würzburg et al. (2013) support the finding that while renewable energy sources (RES) deployment can lower wholesale market prices, household electricity bills may still increase due to additional charges like feed-in tariffs and system fees, then final consumers, families and households may prefer to buy electricity from non-renewable sources as their bill may be reduced.

Therefore, this work aims to truly understand whether there is genuine financial or fiscal support from the government and the EU for households that adopt renewable energy sources for domestic consumption, or whether, on the contrary, the tariffs these families are required to pay do not actually encourage the use of renewable energy.

2.2 ROLE OF MARKET LIBERALIZATION AND POLICY DESIGN

In recent years, the importance of market structure and regulatory design has come to the forefront in studies examining electricity prices.

A recent report titled 'Electricity Prices in Europe' (2023) used dynamic panel modeling (System-GMM) to evaluate how RES integration interacts with market liberalization indicators such as the number of electricity suppliers and market concentration ratios.

Da Silva and Cerqueira (2017) found that past prices, gas prices, electricity consumption, and the share of renewables all had a significant positive impact on electricity prices, while market liberalization had a significant negative effect. Notably, GDP per capita was not a relevant factor. Their findings highlight the importance of considering both technological and policy variables to understand electricity price dynamics.

To approximate the level of electricity market liberalization across European countries, this study relies on a set of structural indicators provided by Eurostat, as no single official liberalization index exists. Three key variables are used to construct a proxy:

First, the number of main electricity suppliers reflects the degree of competition; a higher number suggests a more open and liberalized market. Second, the switching rate of electricity consumers, which indicates the percentage of households that change their electricity provider annually, captures the ease of market access and consumer responsiveness. Finally, the market share of the largest electricity producer serves as a proxy for market concentration, where lower values imply more decentralized and competitive electricity markets.

Combining these indicators offers a practical and quantifiable method to assess market liberalization across countries and to explore its relationship with household electricity prices and renewable energy integration.

Capítulo 3. CONTEXTUAL FRAMEWORK

The energy transition in Europe is not only a technological and environmental challenge, but also a socioeconomic one. While the European Union has made significant progress in expanding renewable energy generation, there remain substantial disparities in how this energy is adopted at the household level. Households are directly affected by fluctuations in electricity prices, the availability of public support schemes, and the uneven costs of installing renewable technologies such as rooftop solar panels. These challenges are further compounded by structural limitations, including insufficient storage infrastructure and the intermittent nature of renewables. Understanding the broader context in which European households interact with clean energy technologies is therefore essential. This framework sets the stage for analyzing the factors that shape renewable energy adoption in the domestic sector, with a particular focus on investment costs, public subsidies, and national differences in energy policy.

3.1 SOCIO-ECONOMIC FRAME

The 2021–2022 energy crisis was one of the most critical episodes in the European energy market in recent decades. During this period, prices for natural gas, oil, and electricity reached historically high levels, affecting households and industry alike, and forcing governments to adopt extraordinary measures to protect consumers (Zettelmeyer, 2022).

Just like energy prices, the prices of tobacco, food, and services also increased due to the abrupt economic rebound following the COVID-19 pandemic. However, the inflation in these categories was much more contained compared to the surge in energy prices (Eurostat, 2025).

The causes of this crisis were multiple and cumulative. First, as mentioned before, the post-COVID-19 economic recovery triggered a sharp surge in global energy demand, while supply remained constrained due to the slowdown in production that had taken place in the previous years (Eurostat, 2025).

Second, unfavorable weather conditions in 2021, including lower than usual wind and solar availability, reduced renewable energy output, increasing dependence on fossil fuels like natural gas (Zettelmeyer, 2022).

In addition, growing competition for liquefied natural gas (LNG) in international markets (especially from Asia) drove up prices. However, the most decisive event was Russia's invasion of Ukraine in February 2022. Since Russia supplied more than 40% of the natural gas (EU Council, 2025) imported by the European Union, the reduction in supply and resulting geopolitical uncertainty caused a severe supply shock.

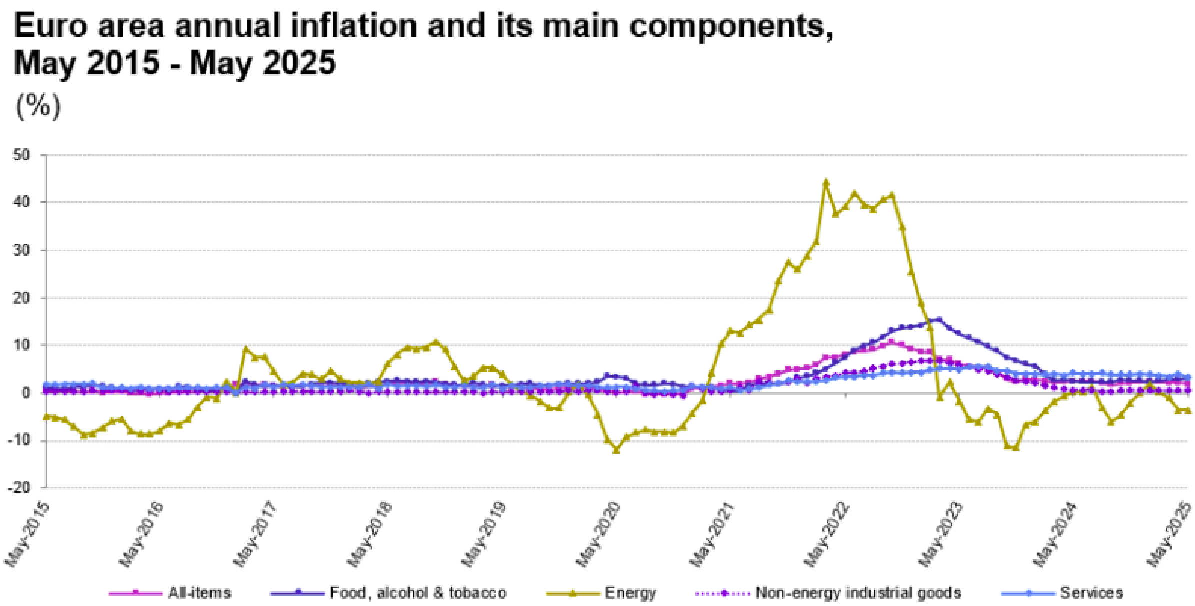

Figura 3: Euro área anual inflation and its main components (Eurostat, 2025)

As a result, household electricity prices skyrocketed, with increases of over 40% on average in Europe (Eurostat, 2025). This exposed the vulnerability of the European energy system due to its reliance on fossil fuels and volatile global markets.

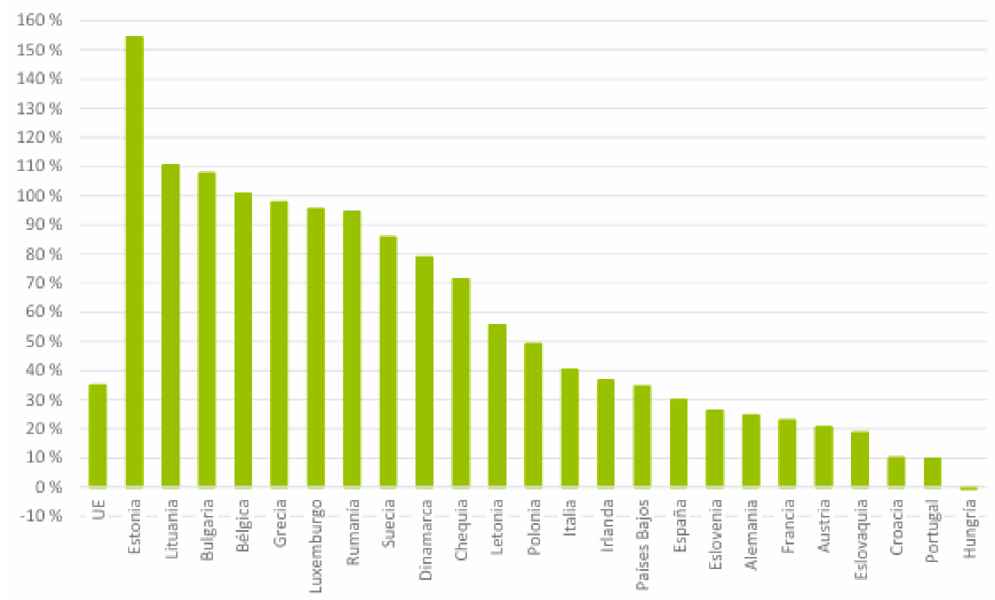

Figura 4: Variation in natural gas average prices for household consumers in 2022 (January- June) compared to 2021 (same period). Source: Tribunal de Cuentas Europeo and Eurostat.

After the energy crisis, starting in 2023, European countries decided to eliminate Russian gas imports by banning new contracts from 2026 and replacing existing ones by 2028. Europe also decided to build floating liquefied natural gas (LNG) terminals in Germany and other locations to substitute the gas previously imported from Russia. According to the European Union Council, the share of Russian pipeline gas in EU imports fell from over 40% in 2021 to around 11% in 2024. When combining pipeline gas and LNG, Russia accounted for less than 19% of the EU's total gas imports in 2024 (The European Union Council, 2025).

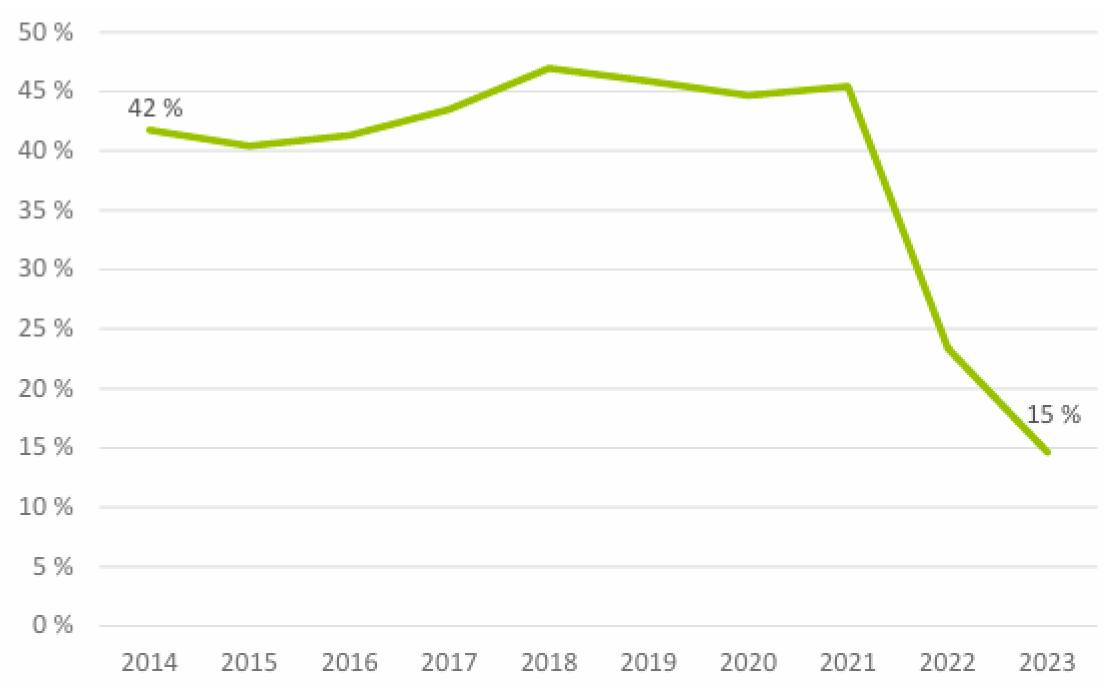

Figura 5: Share of Russian natural gas on the EU imports (2014-2023), Source: Tribunal de cuentas Europeo and Eurostat

RepowerEU, launched in May 2022, was the European Union's direct response to the crisis. Initially aimed at ending the EU's dependency on Russian fossil fuels, the plan has evolved into a broader strategy to accelerate the green energy transition, strengthen energy security, and increase resilience against geopolitical shocks.

The main goals of RepowerEU include phasing out Russian gas imports by 2023, expanding LNG infrastructure and diversifying supply sources, boosting RE adoption and grid modernization, promoting energy solidarity and cross-border cooperation.

RepowerEU supports the EU's 2030 climate goals and marks a historic shift in energy policy, integrating climate action with energy security. It strengthens the EU's geopolitical position while setting a precedent for future climate-resilient strategies in advanced economies.

Through this plan, European Comission has projected a total investment of €210 billion by 2027, allocated across several strategic areas to accelerate a faster and more sustainable energy transition: €113 billion will be directed toward renewables and key hydrogen infrastructure (€86 billion and €27 billion respectively), €56 billion for energy efficiency and heat pumps, €41 billion for adapting industry to reduce the use of fossil fuels, €37 billion to boost biomethane production, €29 billion to reinforce electricity grids, €10 billion to ensure sufficient LNG and pipeline gas supply, and €1.5–2 billion to strengthen oil supply security (European Commission, 2022).

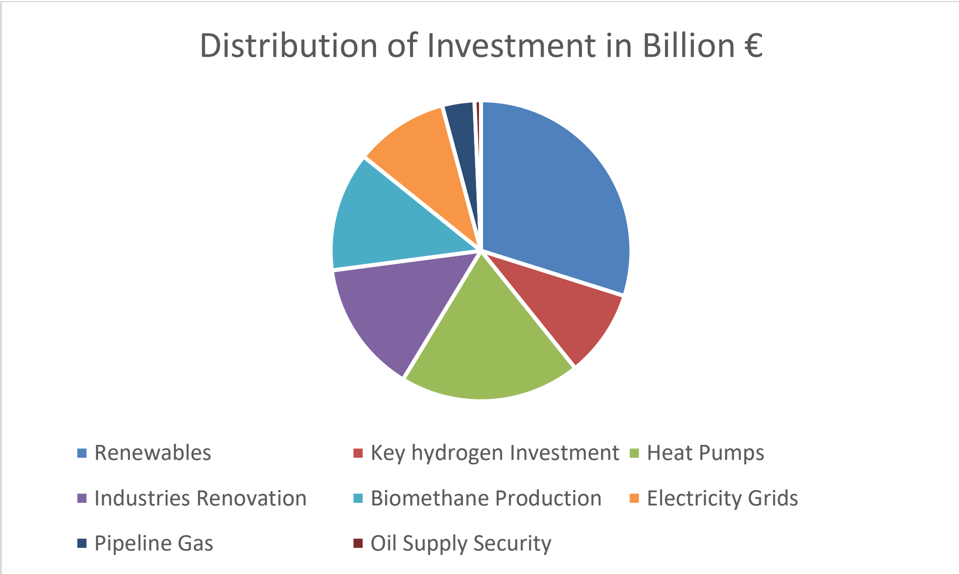

Figure 6: Distribution of Investment in Billion € (Author´s elaboration) based on European Comission, 2022

3.2 TECHNOLOGICAL FRAME AND CURRENT CHALLENGES

This section is essential to understanding the structural and technological barriers that still limit the full integration of renewable energy at the household level in Europe. While progress has been made, challenges such as limited storage infrastructure, high upfront installation costs, and uneven government support continue to slow the transition.

By exploring these issues, that are supported by data from ENTSO-E (Red Europea de Operadores de Sistemas de Transmisión de Electricidad), Eurostat, and other sources, this section helps contextualize the economic models developed later in the thesis. It connects technical and social realities to electricity prices and renewable adoption rates, ensuring a more accurate and grounded analysis. Ultimately, addressing these challenges is key to building a fair, efficient, and sustainable energy future across the EU.

Despite the significant progress made in the deployment of renewable energy across Europe, several critical challenges still hinder its full integration at the household level. One of the most pressing issues is the limited storage capacity available to absorb excess renewable energy production, particularly during periods of low demand.

The 2022 TYNDP report by ENTSO-E highlights the economic and environmental consequences of this gap, showing that insufficient infrastructure leads to substantial energy curtailment and lost decarbonization opportunities. At the same time, the financial burden of adopting renewable technologies, especially the high upfront investment required for systems like photovoltaic panels, remains a major barrier for many households, that is an issue compounded by the uneven distribution of subsidies and support schemes across European countries. Territorial disparities and social resistance to local installations, the NIMBY effect (Not In My BackYard) refers to public support for renewable energy in principle, but local resistance to having infrastructure, this also contributes to an unequal energy transition. This section explores these multifaceted barriers in greater depth and evaluates their implications for achieving a fair, cost-effective, and efficient decarbonization of the domestic energy sector across the European Union.

The first, and one of the main challenges that Europe has nowadays, is that it still lacks large-scale storage systems such as batteries that can store excess renewable energy for times of low production (Reuters, 2025).

According to the TYNDP 2022 report by ENTSO-E, addressing system infrastructure needs across Europe could generate savings of approximately 9 billion euros per year from 2025 to 2040. These savings stem from a more efficient use of the pan-European generation mix, which would directly reduce electricity costs for consumers (ENTSO-E, 2022).

A major benefit of reinforcing transmission and storage infrastructure is the reduction in curtailment of renewable energy (energy that is generated but cannot be used due to insufficient grid or storage capacity).

Without investment, Europe is expected to lose up to 78 TWh of renewable energy per year by 2040. With coordinated infrastructure development, this curtailment could be reduced by 42 TWh annually, allowing for better integration of clean energy into the system (ENTSO-E, 2022).

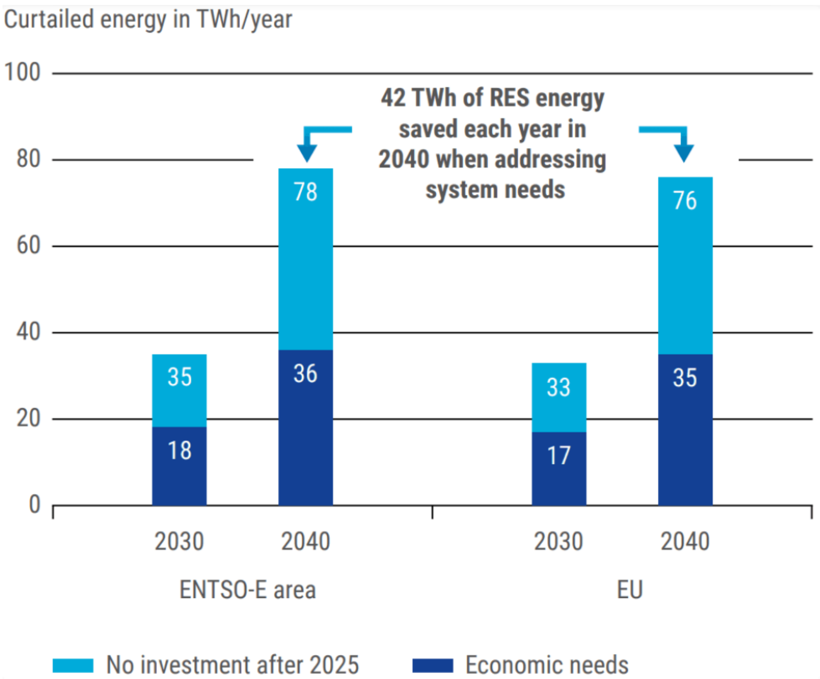

Figure 7: Curtailed Energy in (TWh/year) (ENTSO-E, 2022)

Moreover, improved infrastructure would reduce CO_2 emissions by 31 million tonnes per year by 2040, primarily by replacing fossil-based thermal generation. It would also enhance energy security: the volume of energy not served (energy demand that cannot be met) is expected to drop from 1,604 GWh to just 5 GWh across the EU by 2040, significantly improving supply resilience. Overall, these investments not only support the EU Green Deal objectives but also deliver a strong economic return (ENTSO-E, 2022).

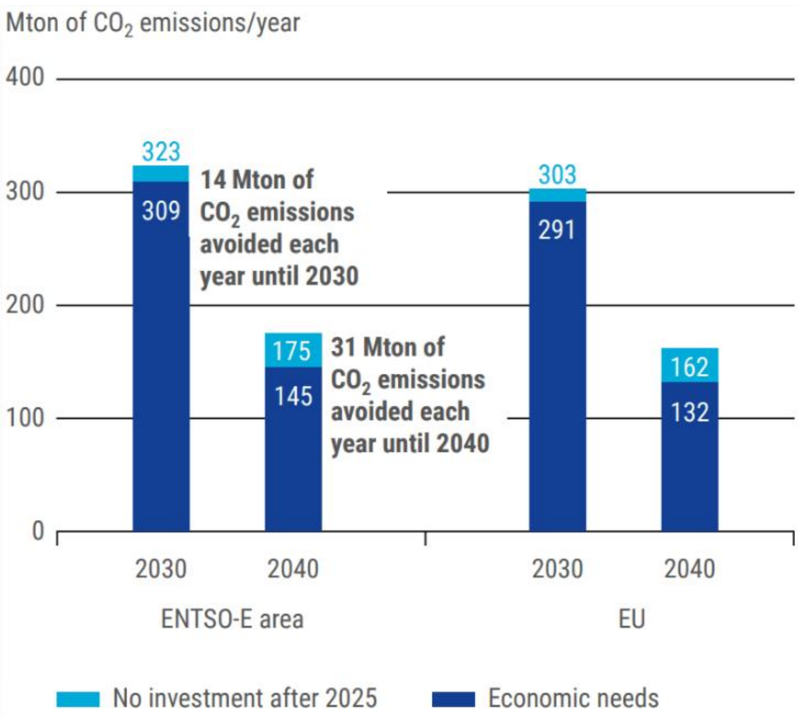

Figure 8: Mton of C02 emissions/year (ENTSO-E, 2022)

Other main barrier to the widespread adoption of renewable energy technologies in European households is the combination of high upfront costs and uneven subsidy schemes (EcoExperts, 2024).

Installing systems such as rooftop solar panels or home batteries often requires significant initial investment, which many households cannot afford without financial support. Although these technologies become economically viable in the long term through energy savings, their accessibility largely depends on national or regional incentives (EcoExperts, 2024).

In Europe, subsidies and tax relief measures vary greatly between countries, creating clear inequalities in adoption rates. While countries like Germany, Belgium, or Italy have implemented robust and stable support frameworks, such as feed-in tariffs or net metering, other countries like Spain or Greece have seen slower growth due to more limited or unstable incentive programs. This uneven landscape hinders the equitable transition to renewable energy and highlights the need for coordinated policy efforts to reduce regional disparities and accelerate household-level decarbonization across the EU (Climate Action Network Europe, 2024).

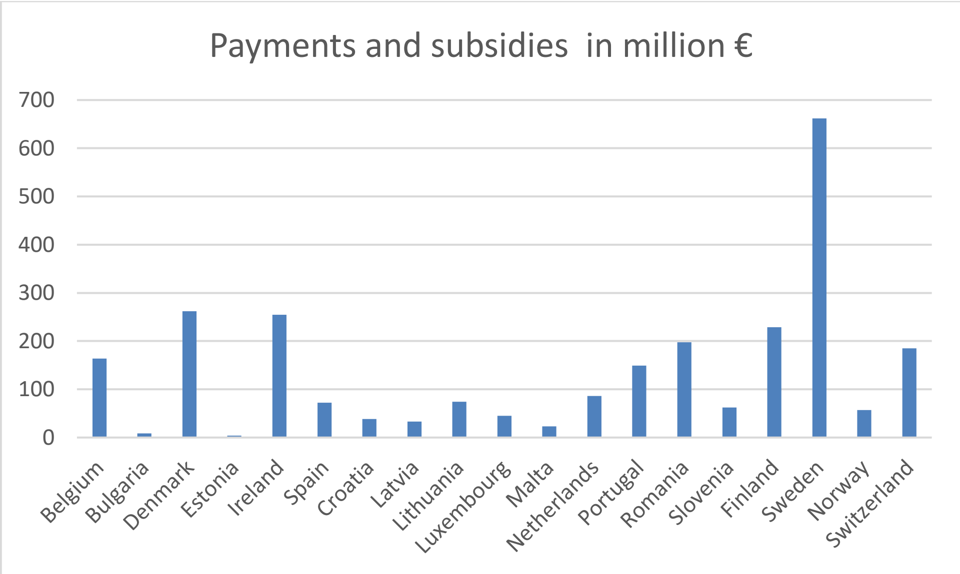

Figure 9: Payments from governments in million € (Eurostat, 2024c)

This project will examine the relationship between state subsidies and financial support provided to various European countries and the electricity final price at household level.

The other important challenge is territorial inequality, as rural areas with greater renewable potential do not always align with the regions of highest energy demand.

The article "Costs of Regional Equity and Autarky in a Renewable European Power System" (Neumann, 2020) analyzes how the pursuit of territorial equity and autarky affects the cost and structure of a 100% renewable electricity system in Europe. It evaluates the cost impact and the composition of the power system when investment is distributed more fairly among countries and regions of the continent, rather than focusing only on economic efficiency. The study compares three system designs: the most cost-optimal, a regionally equitable model (which limits differences in installed capacity between regions), and a fully autarkic model (with closed electricity borders, where each country is self-sufficient).

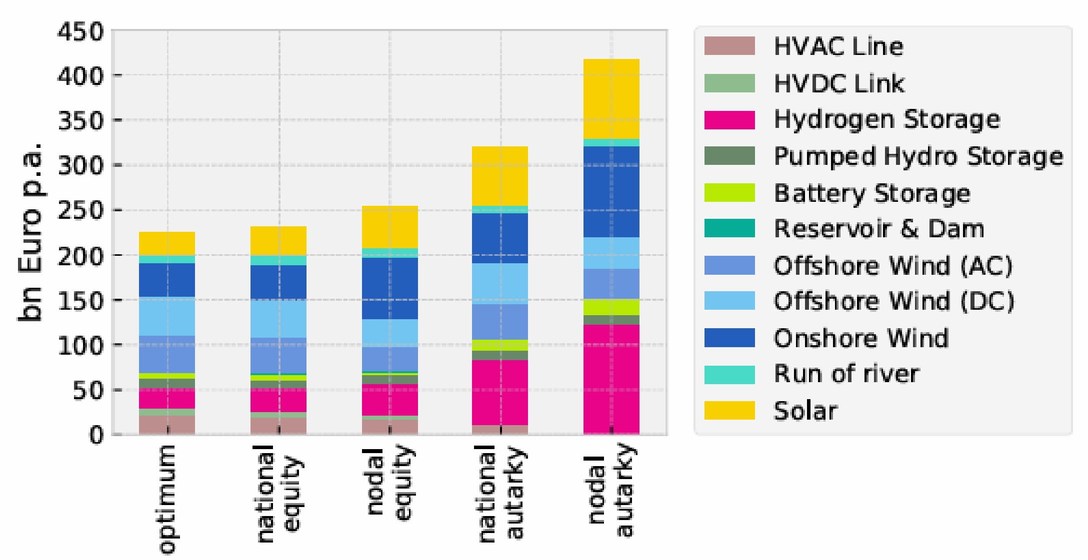

Figure 10: Total system cost impact of autarky on national and nodal levels compared to optimal solution and maximal equity constraints. (Neumann, 2020)

A cost-optimal solution leads to a highly uneven distribution of renewable energy capacity across Europe: certain countries, such as Denmark or the Netherlands, concentrate a large share of installations, while others contribute relatively little. Enforcing a more uniform distribution at the national level increases total system costs by only around 4% above the minimum (Neumann, 2020), while still maintaining high efficiency. In contrast, fully autarkic solutions (where no electricity is exchanged between countries) are significantly more expensive (18% more expensive), highlighting the value of regional cross-border electricity trade in a renewable European power system.

Nowadays, European governments may seek a more equative distribution of energy installations among different regions in Europe, assuming the cost will rise a little bit, but it can be acceptable. It is important to consider that all regions accept the installation of renewable technologies (such as wind turbines), it is important to note that in some rural areas, where installation would be highly efficient, projects are not being implemented because residents oppose their development (NIMBY effect).

Overcoming this resistance could also improve the equitable distribution of renewable installations, as they would be more evenly spread across the territory. Anyhow, total autarky in Europe is a totally utopic model, because the costs are not manageable. European countries should work together towards a future with 100% clean energy.

Explaining these technological barriers is crucial to fully understanding the dynamics of renewable energy adoption at the household level across Europe. The storage problem and curtailment of excess renewable energy during low demand periods reduce the efficiency and economic viability of clean energy systems, ultimately limiting the supply of renewable electricity available for household consumption.

At the same time, high upfront installation costs and the uneven distribution of subsidies can create clear disparities in access as we could see through Eurostat studies, as the main renewable energy consumers countries in Europe are either the ones with cheaper installation costs or the ones with higher government subsidies (Eurostat, 2025).

Territorial inequalities further worsen this issue, as households in regions with low renewable deployment, either due to poor infrastructure or social resistance, may be left out of the energy transition. By exploring these structural and economic obstacles, this research gains a more comprehensive view of the factors that influence the final price and accessibility of renewable electricity for households, helping to explain not only the average cost differences across countries but also the uneven pace of adoption. Therefore, incorporating these barriers is essential to assess the real potential and limitations of achieving a fair and cost-effective renewable transition at the domestic level.

3.3 CURRENT HOUSEHOLD SITUATION

As it could be seen in the previous sections, Europe is consistently working to achieve the energy transition and independence, but this European transition toward renewable energy is deeply shaped by the technological maturity, availability, and efficiency of various energy sources. This section outlines the main renewable energy technologies currently deployed in households and electricity generation, with a focus on wind, solar, hydro, and bio-based systems. It also integrates updated data from Eurostat (2024b, 2024d, 2024f) and the European Environment Agency (2024) to assess the distribution of energy consumption across households, distinguishing between electricity from renewables, direct renewable use (biomass or solar thermal), and fossil-based sources. These insights provide a technical foundation for understanding how different renewable technologies contribute to domestic energy supply and how their adoption may influence household electricity prices across Europe.

In recent years, the adoption of renewable energy has grown exponentially in Europe, driven by international commitments and the need to reduce greenhouse gas emissions. The main technological solutions related to renewable energy generation include:

- Wind energy: Installation of both onshore and offshore wind farms.
- Solar energy: Photovoltaic panels for distributed generation and large-scale solar plants.
- Hydropower: Utilization of reservoirs and watercourses.
- Biomass and geothermal energy: Complementary technologies for electricity generation.

Although these technologies contribute to sustainability, the variability of their production and the costs associated with infrastructure and storage can significantly influence final electricity prices, this challenge will be later discussed.

To accurately assess the current situation in households specifically, we used data from Eurostat (2024b, 2024d, 2024f) and the European Environment Agency (2024) to analyze three distinct aspects.

First, the distribution of household energy consumption by end use, that is, the purpose for which the energy is used, the main consumption sources that a household includes are the following:

- Electricity: all generated electricity, regardless of the original energy source.
- Natural Gas: Fossil Fuel used directly in households (heating, cooking…)
- Renewable energy consumed directly: biomass, pellets, sollar thermal… (does not include the renewable share of electricity)
- Petroleum Products: diesel, kerosene, butane…
- Derived Heat (district heating): Heat supplied to buildings through urban networks. Its origin may be fossil-based or renewable

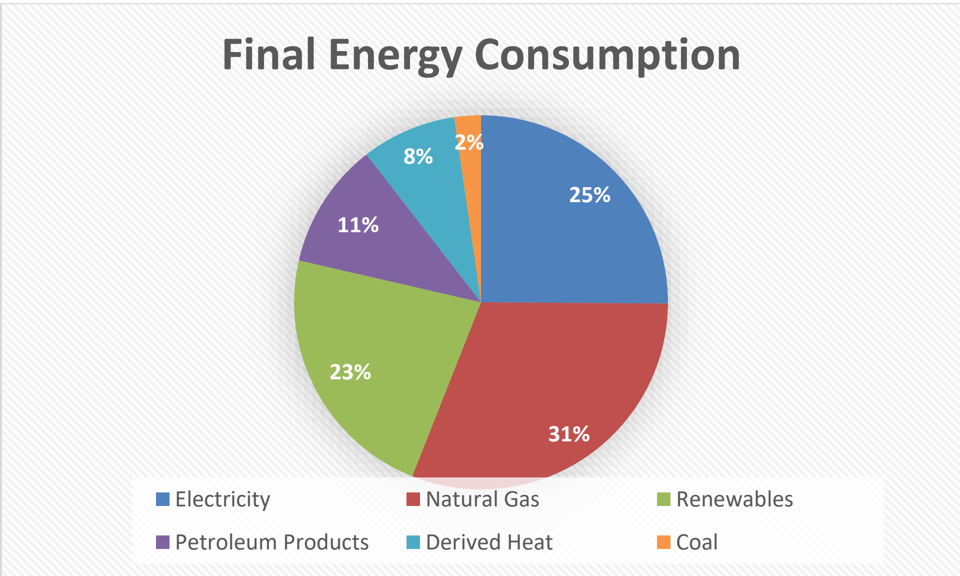

Figure 11: Final Energy Consumption (Author´s elaboration) through Eurostat (2024b), European Environment Agency (2024).

Second, we examined the share of each major renewable source used in electricity generation, including the three main renewable energy sources (wind, solar and hydro), taking into account that the share of the total electricity consumed by households that comes from RES is 34,3%, from that 34,3%, 15,4% is eolic, 11,2% is hydropower and 7,7% is solar.

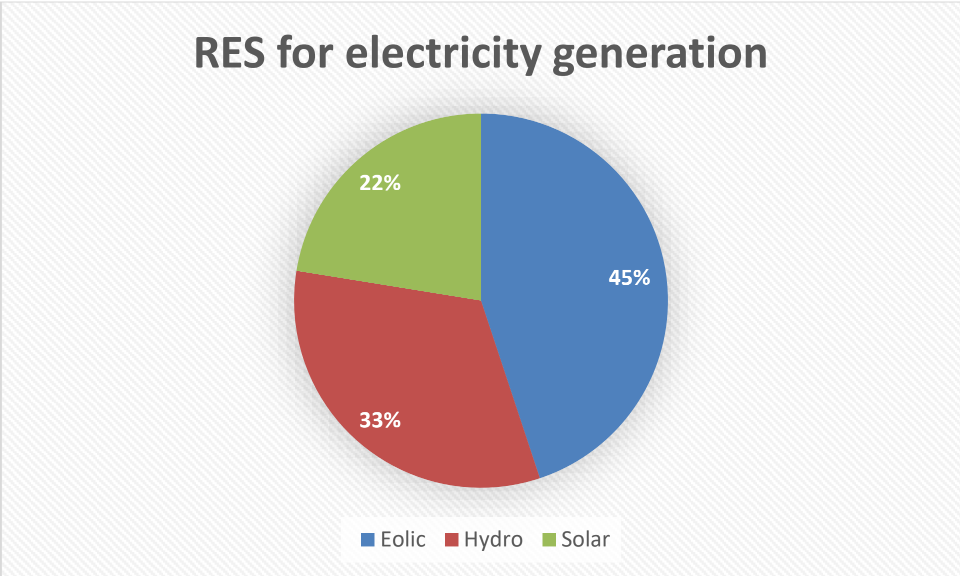

Figure 12: RES for electricity generation (Author´s elaboration) through Eurostat (2024f), European Enviroment Agency (2024)

Finally, we considered the total use of renewable energy, including both the renewable energy used to generate electricity and the one which is consumed directly (such as biomass, pellets, solar thermal, etc.)

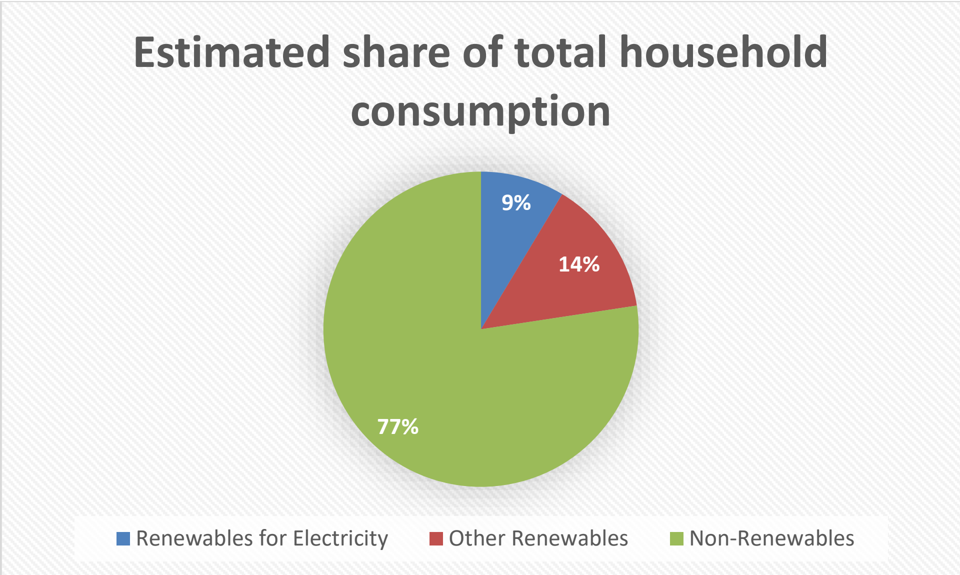

Figure 13: Estimated share of total household consumption (Author´s elaboration) through Eurostat (2024d), European Enviroment Agency (2024)

Estimation based on 2022 data reported by Eurostat and confirmed in 2023–2024 by the European Environment Agency, stands that the 22,6% of the energy consumed at European homes comes from RES.

Capítulo 4. METHODOLOGY

This Final Degree Project is framed within a quantitative and correlational research approach, with the main objective of analyzing the relationship between the adoption of renewable energy and household electricity prices in Europe. This analysis requires an empirical approach that allows for the observation and quantification of the effects of variations in the share of renewable energy sources on the average domestic electricity price.

4.1 METHODOLOGIC DESIGN

The methodological design is based on a panel data analysis, which combines time series with cross-sectional data. This type of design is particularly useful for studying economic phenomena at the country's level, as it allows for controlling both the specific characteristics of each nation and the temporal evolution of the variables. Additionally, it facilitates the identification of common patterns and divergences between countries over time.

The study adopts a longitudinal approach using annual data from a representative sample of European countries for the period 2020 to 2023, enabling the analysis to capture the effects of the sustained growth in renewable energy adoption. Moreover, it follows an explanatory design, as the goal is not only to describe the relationship between variables but also to explain the reasons behind certain variations in electricity prices.

The approach is also comparative, since countries with different energy structures, economic conditions, and climatic characteristics are analyzed. This enriches the study by allowing for the evaluation of the differential impact of renewable sources depending on national contexts. These include factors such as the availability of natural resources, the structure of the electricity market, or the degree of government intervention.

The methodological process consists of several stages.

First, a panel dataset is constructed in Excel, where both control variables and the dependent variable are presented. The dataset includes values for the following 23 countries (Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Lithuania, Luxembourg, Hungary, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden) over four years (2020, 2021, 2022, and 2023). This table is included in the annexes.

Once the dataset is ready, the Hausman test is performed as a key tool to select the most appropriate econometric model for the panel data analysis. This test determines whether it is more suitable to use a fixed effects model or a random effects model, depending on whether there is correlation between country-specific unobservable effects and the explanatory variables included in the model.

The fixed effects model assumes that these unobserved characteristics (such as institutional structure, climate conditions, or national energy policies) are correlated with the independent variables. In contrast, the random effects model assumes that these country differences are random and uncorrelated with the regressors.

The Hausman test compares both models and assesses whether the differences in the estimated coefficients are statistically significant. If the result of the test indicates a significant difference ($p < 0.05$), the null hypothesis is rejected, and it is concluded that the random effects model is inconsistent, meaning the fixed effects model should be used. Conversely, if the p-value is greater than 0.05, both estimators are considered valid, and the random effects model may be preferred due to its greater efficiency.

In this study, the test is applied to ensure the statistical validity of the chosen model, thereby confirming that the conclusions about the relationship between renewable energy adoption and electricity prices accurately reflect the reality of each country while properly controlling structural characteristics.

Subsequently, the methodological process continues with the application of fixed effects linear regressions.

This approach allows for estimating the specific impact that an increase in the share of renewable energy in a country's energy mix has on the average electricity price.

Furthermore, by including various control variables (such as natural gas prices, purchasing power, inflation, or electricity consumption), the model seeks to isolate the true effect of renewable energy from other factors influencing electricity prices. This also enables controlling for structural and time-invariant characteristics of each country (e.g., energy regulation or climate).

In addition, year-specific dummy variables are included to capture common trends across all countries during particular periods (such as economic crises or regulatory changes), and clustered standard errors at the country level are used to correct for potential internal correlations within the data.

This methodology provides a rigorous and robust framework to assess whether the transition toward more sustainable energy sources is contributing to lowering electricity costs for European consumers.

These regressions also allow for identifying the main factors explaining price differences between countries and overtime. Variables such as natural gas prices, GDP per capita, electricity consumption, inflation, and the level of competition in the energy market are included as controls so that the analysis more precisely reflects the specific impact of renewable energy.

Through this approach, the study aims not only to verify whether a statistically significant relationship exists, but also to measure the magnitude and direction of this relationship. For example, it can determine whether a 1% increase in the share of renewable energy leads to a decrease (or increase) in the final electricity price, and to what extent.

Therefore, the use of linear regression models becomes a tool to extract empirically grounded conclusions, assess the economic viability of the energy transition, and provide evidence-based policy recommendations on how clean energy promotion strategies may affect final consumers.

4.2 DATA SOURCE AND VARIABLES

To carry out the proposed analysis, secondary data sources from reliable international organizations and widely used public databases in economic and energy studies will be employed. These sources include:

• Eurostat: Provides detailed information on electricity prices, tax burdens, inflation, and macroeconomic data.

• International Energy Agency (IEA): Offers energy statistics and fossil fuel price data.

• IRENA (International Renewable Energy Agency): Provides data on the penetration of renewable energy.

These sources allow for the construction of a robust dataset that includes both dependent and independent variables, as well as control factors to adjust the econometric model.

The study variables are classified as follows:

	Variable Type	Source	Units	Description
Share of renewable energy	Main Independent	Eurostat/IRENA	€/kWh	Share of renewable energy in final electricity production
Heating oil price	Control	European Comission	€/1000l	Price of heating oil used used to heat homes, especially in northeastern Europe
Natural gas price	Control	Eurostat	€/kWh	Price of natural gas used to power boilers and radiators, among others
PPP	Control	Eurostat	€ per capita	Purchasing capacity of a country's citizens, adjusting for price level differences between countries. It's an indicator of living standards
HICP	Control	Eurostat	Index (base 100)	Evolution of the overall price level of consumer goods and services in a country. It helps control for the effects of inflation in the analysis of electricity prices
Electricity Price (including taxes)	Dependent	Eurostat	€/kWh	Average price households pay per kWh of electricity, including all taxes and levies. It reflects the actual final cost for residential consumers
Electricity Price (excluding taxes)	Control	Eurostat	€/kWh	Average price per kWh paid by households excluding taxes and levies. It allows for the analysis of the base cost of electricity before fiscal intervention.
Electricity Consumed at the household level	Control	Eurostat	GWh	Total amount of electricity consumed by households in a country. It is a key indicator of residential electricity demand
Market Share of the main electricity provider	Control	Eurostat	%	Represents the percentage of the electricity market controlled by the leading supplier in a country. A high value indicates lower competition and greater market concentration.
Number of electricity providers	Control	Eurostat	Units	Indicates how many companies offer electricity supply services in a country. It is used as a proxy for the level of liberalization and competition in the electricity market
Electricity switching rates	Control	Eurostat	%	Percentage of consumers who switch electricity providers within a given period. A high rate suggests a dynamic market with greater competition and consumer choice.

Government Subsidies	Control	Eurostat	Million €	Government financial support aimed at promoting environmental protection and the use of renewable energy sources. It reflects public commitment to a sustainable energy transition.
Taxes	Control	Eurostat	€/kWh	Represents the difference between electricity prices with and without taxes, expressed in euros per kilowatt-hour. This measure reflects the tax burden borne by residential consumers in each country and allows for analysis of the fiscal impact on the final electricity price
Share of eolic energy for electricity consumption	Control	Eurostat	%	Share of eolic energy used for electricity generation. It allows readers to understand the importance of this type of RES in each country and each period
Share of Hydraulic energy for electricity consumption	Control	Eurostat	%	Share of Hydraulic energy used for electricity generation. It allows readers to understand the importance of this type of RES in each country and each period
Share of solar energy for electricity consumption	Control	Eurostat	%	Share of solar energy used for electricity generation. It allows readers to understand the importance of this type of RES in each country and each period

Table 1: Variables (Author´s elaboration)

4.3 ANALYSIS TECHNIQUES

The analysis proposed in this work relies on statistical tools, specifically regression models applied to panel data. This approach makes it possible to leverage both the temporal dimension (the evolution of each country over time) and the cross-sectional dimension (comparisons between countries) to identify significant relationships between variables.

The project will be conducted using statistical tools such as Python. This includes running the Hausman test, as well as implementing fixed effects panel regression models. Excel will be used for exploratory tasks or initial data visualization, such as building the panel dataset. Ultimately, the methodological approach aims to ensure econometric rigor and statistical validity in the results obtained.

We are going to use a panel data regression analysis, specifically a fixed effects model, as mentioned before, to analyse the relationship between renewable energy adoption and household energy prices in European countries over a period.

Regression Model Specification:

The general regression equation can be structured as:

Electricity price = β0 + β1 * Renewable energy share

+ β2 * PPP per capita it

+ β3 * Natural gas price it

+ β4 * Heating oil price it

+ β5 * Inflation rate (HICP) it

+ β8 * Subsidies to support RES it

+ β9 * Electricity consumption (GWh) it

+ β10 * Taxes it

+ β11 * Share of Solar energy in total RE consumption

+ β12 * Share of Eolic energy in total RE consumption

+ β13 * Share of Hydraulic energy in total RE consumption

+ error term

Where:

- i represents the country: Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Lithuania, Luxembourg, Hungary, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland and Sweden.
- t represents the year: 2020, 2021, 2022 and 2023.

The fixed effects model allows us to control for time-invariant characteristics of each country (such as geography or the structure of the electricity market), while the random effects model assumes that differences between countries are random and uncorrelated with the explanatory variables. The choice between both models will be determined by the Hausman test.

In addition, the following classical linear model assumptions will be tested:

- Homoscedasticity and absence of autocorrelation
- Normality of residuals
- No multicollinearity between independent variables

If issues are detected, robust standard errors or variable transformations will be applied.

4.4 UNIVERSE AND SAMPLE. METHODOLOGICAL LIMITATIONS

The universe of the study is composed of countries from the European Union and the European Economic Area, as they share certain regulatory frameworks and common policies regarding energy and sustainability. These countries are ideal for analysis due to their strong commitment to the energy transition, the high quality of their public statistics, and the availability of homogeneous data.

The sample will consist of 24 European countries that have complete and comparable information for the study period, which is expected to range approximately from 2020 to 2023. The final selection of countries will depend on the consistency and continuity of data available from the various sources.

Among the most relevant methodological limitations, we can highlight:

1. Data availability and consistency: Not all countries publish information with the same frequency or structure. This may affect the sample size or require interpolations or estimations.
2. Endogeneity: It is possible that electricity prices also influence investment decisions in renewable energy, which could bias the model's results if not properly addressed.
3. Institutional differences: While European countries share many common regulations, there are still significant differences in national regulatory frameworks, subsidies, and fiscal policies.
4. Lagged and technological effects: The impact of some investments or innovations may appear with a time lag, which can make direct measurement difficult.

Despite these limitations, the methodological design is intended to maximize both the internal and external validity of the study, combining statistical rigor with an appropriate contextual interpretation of the results.

Capítulo 5. ANALYSIS AND INTERPRETATION OF RESULTS

This section presents the outcomes of the empirical analysis carried out. The goal is to examine how the adoption of renewable energy affects household electricity prices across European countries between 2020 and 2023. The results obtained from the fixed-effects models are interpreted considering the theoretical framework and previous literature.

First, descriptive statistics and correlation matrices are discussed to provide a preliminary understanding of the distribution and relationships between the variables. Following this, the results of the nine linear regression models are presented, including the coefficients, standard errors, and significance levels, with time dummies and clustered standard errors by country.

The interpretation focuses on how changes in each independent variable, particularly the share of renewable energy and the share of renewable enery types independently are associated with variations in electricity prices. The robustness of the results is also considered by comparing models with and without outlier adjustments. This section aims to evaluate whether the initial hypothesis is supported by the data and to identify key patterns and implications for the energy transition in Europe.

5.1 DESCRIPTIVE ANALYSIS AND STUDY VARIABLES

	Mean	Std. Deviation	Min	Q 25%	Q 50%	Q 75%	Max
Heating Oil Price	1097,16	337,99	468,1	846	1086,4	1300,9	1978,5
Electricity Consumption (GWh)	58459,7	78771,41	1868,1	15248,033	29726,518	49870,25	339552,35
Share of RES	36,53788	18,1514	9,489	22,77625	35,8685	46,6477	87,764
Electricity Price w/o taxes	0,1744	0,0818	0,079	0,116925	0,1488999	0,207	0,459
Electricity Price with taxes	0,2237	0,08419	0,0982	0,163675	0,2143	0,26245	0,5871
HICP	116,97322	12,3956	101,17	107,6675	114,12	122,9	160,59
Gas Price	0,091413	0,047119	0,0295	0,0552	0,07895	0,118575	0,2751
PPP	21446,875	4680,8895	12500	17775	20750	24900	35400
Num_Retailers	173,26	307,3383	7	26,75	50	171	1439
Market Share Main Supplier	38,2578	19,80404	9,15	22,68725	30	53,4	78,99
Switching Rate	5,5028	3,7267	0,95	2,94	4	6,1625	17
Gov Subsidies	3586,93864	5850,3045	79,51	560	1273,375	3782,5	28700
Taxes	0,063905	0,045203	0,0004	0,03482	0,0523	0,078224	0,223
Share of Solar	26,9951182	25,329536	0,17402052	7,81102429	20,2522073	34,9847589	99,9893203
Share of Hydro	34,8023976	30,8168388	0	6,78413852	29,0383389	61,1476861	94,8098216
Share of eolic	38,2024843	26,3244834	0,01067975	18,1757998	34,0497441	59,7128124	93,1674526

Table 2: Descriptive Analysis (Author´s elaboration)

The descriptive statistics obtained provide an initial detailed view of the behavior of the variables considered in the analysis. This step is essential to understand the logic of the data and assess their coherence with the energy and economic reality of European countries between 2020 and 2023.

- Heating Oil Price: The average price of heating oil is approximately €1097 per 1000 liters, with high dispersion (±€338) and values ranging from €468 to €1978. This wide variability reflects both international fluctuations in energy markets and fiscal differences across countries.

- Electricity Consumption (GWh): The average electricity consumption is high (58460 GWh), but with a very large standard deviation, indicating notable heterogeneity among countries. The minimum value is 1868 GWh, while the maximum exceeds 339000 GWh, which is consistent with differences in population, industrialization level, and climate.

- Share of RES: The percentage of renewable energy in the mix used to generate electricity has an average of 36,5%, with a wide range (from 9,5% to 87,8%), reflecting the varying degrees of progress in the energy transition across countries. The high dispersion highlights its relevance for comparative analysis.

- Electricity Prices (w/o and with taxes): Electricity prices excluding taxes average €0,174/kWh, while prices including taxes are €0,224/kWh. This gap is consistent with the fiscal burden observed in the European energy sector. Both show moderate variability, reflecting regulatory and market structure differences.

- HICP (Harmonized Index of Consumer Prices): The average is 116,97, with a range between 101,17 and 160,59, reflecting accumulated inflation during the period. This indicator is key to controlling general price evolution.

- Gas Price: The average natural gas price is €0,091/kWh, with a maximum value of €0,275/kWh, illustrating the price shocks in the gas market during recent years, particularly following the invasion of Ukraine.

- PPP (Purchasing Power Parity): The average purchasing power per country is €21447, with large differences between the minimum and maximum values, evidencing economic inequality among the studied European countries.

- Number of Retailers: The average number of electricity providers is 173, but with a high standard deviation (±307), which reveals significant variation between countries with highly liberalized markets and those with more concentration. The maximum value (1439) confirms this.

- Market Share of Main Supplier: The average is 38,26%, with values ranging from 9,15% to nearly 79%, indicating that some countries have a dominant operator, while others have a more competitive environment. This is a key variable for analyzing electricity market liberalization.

- Switching Rate: The average switching rate between electricity providers is 5.5%, which suggests a moderate level of competition in terms of consumer behavior. Lower switching rates may indicate more rigid or less transparent markets.

- Government Subsidies: The average amount of government subsidies is €3,59 billion, with very high dispersion (€5,85 billion), which is coherent with the fiscal capacity and renewable energy strategies of each country.

- Taxes over electricity: It is calculated as the difference between the electricity prices with and without taxes, to analyze the tax burden in the electricity sector.

- Share of Solar Energy: Around 27% of the renewable energy used to produce electricity consumed in households comes from solar energy

- Share of Eolic Energy: Around 38% of the renewable energy used to produce electricity consumed in households comes from eolic energy

- Share of Hydraulic Energy: Around 35% of the renewable energy used to produce electricity consumed in households comes from hydraulic energy

	Mean	Std. Deviation	Min	Q 25%	Q 50%	Q 75%	Max	IQR	LI	LS	OUTLIER I	OUTLIER S	Max. Final
Heating Oil Price	1097,16	337,99	468,1	846	1086,4	1300,9	1978,5	454,9	163,65	1983,25	0	0	1978,5
Electricity Consumption (GWh)	58459,7	78771,41	1868,1	15248,033	29726,518	49870,25	339552,35	34622,217	-36685,2925	101803,576	0	1	101803,576
Share of RES	36,53788	18,1514	9,489	22,77625	35,8685	46,6477	87,764	23,87145	-13,030925	82,454875	0	1	82,454875
Electricity Price w/o taxes	0,1744	0,0818	0,079	0,116925	0,1488999	0,207	0,459	0,090075	-0,0181875	0,3421125	0	1	0,3421125
Electricity Price with taxes	0,2237	0,08419	0,0982	0,163675	0,2143	0,26245	0,5871	0,098775	0,0155125	0,4106125	0	1	0,4106125
HICP	116,97322	12,3956	101,17	107,6675	114,12	122,9	160,59	15,2325	84,81875	145,74875	0	1	145,74875
Gas Price	0,091413	0,047119	0,0295	0,0552	0,07895	0,118575	0,2751	0,063375	-0,0398625	0,2136375	0	1	0,2136375
PPP	21446,875	4680,8895	12500	17775	20750	24900	35400	7125	7087,5	35587,5	0	0	35400
Num_Retailers	173,26	307,3383	7	26,75	50	171	1439	144,25	-189,625	387,375	0	1	387,375
Market Share Main Supplier	38,2578	19,80404	9,15	22,68725	30	53,4	78,99	30,71275	-23,381875	99,469125	0	0	78,99
Switching Rate	5,5028	3,7267	0,95	2,94	4	6,1625	17	3,2225	-1,89375	10,99625	0	1	10,99625
Gov Subsidies	3586,93864	5850,3045	79,51	560	1273,375	3782,5	28700	3222,5	-4273,75	8616,25	0	1	8616,25

Table 3: Descriptive Analysis (Author´s elaboration)*

As can be observed, there are several upper outliers in the values of the mentioned variables, although there are no lower outliers. Therefore, it was decided to apply a "winsorization" and replace the maximum values with the upper limit to avoid distortions in the linear regression, so that the final descriptive statistics are those shown in the table. The next step is to modify the panel data, so that when the value of a variable exceeds the upper limit, it is replaced by that limit. We will then have two data panels: one with the initial data without modifications and another with adjusted maximum values. Initially, the linear regressions will use the original data, and only if the results are distorted by extreme values, will the second panel be used.

The descriptive analysis confirms that the dataset exhibits variability consistent with structural, geographic, and regulatory differences across European countries. This diversity fully justifies the use of techniques such as fixed effects regression models, which control for time-invariant country-specific factors, and the inclusion of control variables to isolate the impact of renewable energy adoption on household electricity prices.

5.2 HAUSMANN TEST

To determine the most appropriate panel data model for this analysis, a Hausman specification test was made to compare the fixed effects and random effects estimators. The Hausman test evaluates whether the unobserved individual effects (in this case, country-specific characteristics) are correlated with the explanatory variables included in the model.

The results of the test showed a Chi-squared statistic of 77.46 with a p-value of 1.19e-14, which is far below the conventional significance level of 0,05. This extremely low p-value leads to the rejection of the null hypothesis, which states that the individual effects are uncorrelated with the regressors. As a result, the assumption underlying the random effects model is violated.

Therefore, we conclude that the fixed effects model is the most suitable approach for this analysis. This implies that there are time-invariant characteristics specific to each country, such as regulatory frameworks, market structures, or geographic and institutional factors, that are likely correlated with explanatory variables such as the share of renewable energy, government subsidies, or household income levels.

By using a fixed effects model, the analysis can effectively control for these country-specific unobserved heterogeneities, ensuring that the estimated relationship between renewable energy adoption and household electricity prices is not biased by omitted variable issues. This strengthens the internal validity of the study and allows for more accurate inference regarding the impact of renewable energy penetration on energy affordability across Europe.

5.3 CORRELATION MATRIX

The correlation matrix displays the degree of linear association between the variables included in the analysis. Correlation values range from -1 to 1, where:

- A value close to **1** indicates a strong positive correlation, meaning that as one variable increases, the other also tends to increase.
- A value close to -1 indicates a strong negative correlation, meaning that as one variable increases, the other tends to decrease.
- A value close to 0 suggests no linear relationship between the variables.

This analysis is fundamental in the context of this project, as it allows for the exploration of potential structural relationships between variables and helps identify multicollinearity issues that could affect regression models.

Heatmap of Correlation Matrix

	log_Price_heating_oil	log_electricity_consumed	log_HICP	log_Natural_gas_price	log_Purchasing_Power_Parities	log_Number_of_electricity_retailer	log_Subsuidies_to_household	Electricity_switching_rate	Market_Share_main_retailer	Taxes	Share_of_RES	Share_of_Solar	Share_of_Hydraulic	Share_of_Eolic
log_Price_heating_oil	1.00	0.17	0.40	0.51	0.24	0.10	0.27	0.19	-0.12	0.12	0.10	-0.06	0.04	0.02
log_electricity_consumed	0.17	1.00	-0.15	0.29	0.17	0.80	0.79	0.19	-0.11	0.20	0.17	0.09	0.00	-0.09
log_HICP	0.40	-0.15	1.00	0.16	0.15	-0.02	0.05	-0.26	0.09	-0.17	0.03	0.32	-0.07	-0.22
log_Natural_gas_price	0.51	0.29	0.16	1.00	0.57	0.23	0.38	0.52	-0.36	0.29	0.08	0.04	-0.05	0.01
log_Purchasing_Power_Parities	0.24	0.17	0.15	0.57	1.00	0.22	0.42	0.41	-0.39	0.34	0.00	0.01	0.07	-0.10
log_Number_of_electricity_retailer	0.10	0.80	-0.02	0.23	0.22	1.00	0.65	-0.03	-0.25	0.22	0.16	0.23	-0.02	-0.20
log_Subsuidies_to_household	0.27	0.79	0.05	0.38	0.42	0.65	1.00	0.34	-0.10	0.22	0.20	0.11	-0.03	-0.07
Electricity_switching_rate	0.19	0.19	-0.26	0.52	0.41	-0.03	0.34	1.00	-0.22	0.21	-0.14	-0.39	0.14	0.21
Market_Share_main_retailer	-0.12	-0.11	0.09	-0.36	-0.39	-0.25	-0.10	-0.22	1.00	-0.21	-0.22	-0.29	0.07	0.20
Taxes	0.12	0.20	-0.17	0.29	0.34	0.22	0.22	0.21	-0.21	1.00	0.37	-0.06	-0.27	0.36
Share_of_RES	0.10	0.17	0.03	0.08	0.00	0.16	0.20	-0.14	-0.22	0.37	1.00	0.20	-0.23	0.08
Share_of_Solar	-0.06	0.09	0.32	0.04	0.01	0.23	0.11	-0.39	-0.29	-0.06	0.20	1.00	-0.57	-0.29
Share_of_Hydraulic	0.04	0.00	-0.07	-0.05	0.07	-0.02	-0.03	0.14	0.07	-0.27	-0.23	-0.57	1.00	-0.62
Share_of_Eolic	0.02	-0.09	-0.22	0.01	-0.10	-0.20	-0.07	0.21	0.20	0.36	0.08	-0.29	-0.62	1.00

Table 4: Heatmap of the Correlation Matrix

This tool, as previously mentioned, is one of the most important for measuring the relationship between the different independent variables: the correlation matrix. As shown in the heatmap, it illustrates when the correlation values between independent variables are low, moderate, or high. For the analysis, we will use the following criteria:

- If r < |0.4|, the value is standard, and both variables can coexist.
- If |0.7| > r > |0.4|, the value is high, and there may be collinearity issues.
- If r > 0.7, the value is very high, and there are strong collinearity problems.

When the value for r > 0,4 or r < -0,4, we should eliminate one of both correlated variables to avoid multicollinearity problems. Due to this fact, more than one linear regression will be used.

The correlation matrix and the corresponding heat map offer key insights into the relationships among the main variables included in the analysis. These tools are crucial for identifying multicollinearity risks and guiding the construction of linear regression models by determining which variables can be included simultaneously without distorting the results.

Among the most significant correlations is the strong positive relationship between the number of electricity retailers and electricity consumption (r = 0.79), as well as with government subsidies to households (r = 0.65). These results suggest that countries with more open electricity markets and greater financial support for households tend to consume more electricity—potentially due to increased access or affordability.

Government subsidies also correlate positively with electricity consumption (r = 0.79) and with purchasing power parities (r = 0.42), suggesting that countries with higher household purchasing capacity tend to allocate more public resources toward renewable energy support. Additionally, electricity switching rate is positively associated with both subsidies (r = 0.34) and purchasing power (r = 0.40), possibly reflecting that in wealthier or more liberalized systems, consumers are more active in changing electricity providers.

In terms of energy source composition, there are strong negative correlations between the share of solar and the share of hydraulic energy (r = -0.58), and between hydraulic and wind energy (r = -0.62). This likely reflects the structural or geographic exclusivity of certain renewable resources in different regions—for instance, areas rich in hydropower may not simultaneously develop large wind or solar infrastructures. Additionally, solar share is negatively correlated with the electricity switching rate (r = -0.39) and with market concentration (r = -0.29), suggesting that solar energy adoption may be more widespread in liberalized and competitive markets.

On the contrary, the share of RES shows only mild correlations with other variables, such as taxes (r = 0.37) and subsidies (r = 0.20), indicating that while policy support may encourage the growth of renewables, its effect is more diffuse when considering all renewable sources together.

In summary, the correlation matrix provides important validation of the theoretical and empirical structure of this study. It confirms the relevance of including specific control variables such as gas price, purchasing power, inflation, and government subsidies, while also supporting the methodological choice to use fixed effects models to control for country-specific structural characteristics. Furthermore, it reveals that the share of renewable energy, as the main variable of interest, behaves independently from other economic drivers, which is ideal from an econometric standpoint. Overall, the matrix not only reinforces the credibility of the dataset but also guides the model specification used to explore the relationship between renewable energy adoption and household electricity prices in Europe.

5.4 LINEAR REGRESSIONS

To improve the interpretability and econometric strength of the panel data regression models, most variables in the dataset have been transformed using natural logarithms. This is a common practice in empirical economics and econometrics for several reasons. First, it helps linearize relationships that may be nonlinear in levels, allowing for better model fit. Second, coefficients in a log-log model can be interpreted as elasticities, making it easier to understand the relative effect of one variable on another. Third, log transformation reduces heteroscedasticity and normalizes data distributions, enhancing the reliability of statistical inference.

The variables transformed into logarithmic form include:

- Heating oil price (€/1000l)
- Electricity consumption (GWh)
- HICP (index)
- Natural gas price (€/kWh)
- Purchasing Power Parity per capita
- Number of electricity retailers
- Government subsidies (million €)

In contrast, percentage variables such as the share of renewable energy, market share of the main electricity provider, switching rates, share of eolic, share of hydro and share of solar energy and tax values (in €/kWh) have been kept in their original scale, as they are already ratios or small magnitudes that do not benefit from logarithmic transformation.

The electricity prices with and without taxes are not going to be used for the linear regressions due to its high relationship with the dependent variable. Both variables were only used to calculate the taxes over the electricity price.

These transformations facilitate the interpretation and comparability of results across countries and years and contribute to more stable and consistent fixed-effects regression estimates.

As explained before; to avoid multicollinearity problems, several regressions will be made to solve these problems. Particularly, nine regressions will be developed as shown in the following table, where green means that the variable is active in the linear regression and red means it is not active in the regression.

	Heating Oil Price	Gas Price	Electricity Consumption	Share of RES	PPP	HICP	Gov. Subsidies	Market Share of Main Su	Num Retailers	Switching Rate	Taxes	Share of Solar	Share of Hydr	Share of Eolic
Regresion 1	0	1	1	1	0	0	0	0	0	0	0	1	0	1
Regresion 2	0	1	0	1	1	0	0	0	1	1	0	0	1	1
Regresion 3	0	1	0	0	0	0	1	0	0	1	0	0	0	1
Regresion 4	0	1	1	1	0	1	0	1	0	0	0	1	0	0
Regresion 5	0	1	0	1	0	1	1	1	0	0	0	0	1	0
Regresion 6	0	1	0	1	0	1	0	1	1	0	0	0	0	1
Regresion 7	0	1	1	1	0	0	0	0	0	0	1	1	0	0
Regresion 8	0	1	0	0	0	1	1	0	0	0	1	0	1	0
Regresion 9	1	0	0	0	0	0	1	0	0	0	1	0	0	1

Tabla 5: Linear Regression (Author´s elaboration)

In order to confirm that multicollinearity problems don´t exist and that the regressions have been well selected, the VIF test is going to be used and runned in python (Appendices). As it can be seen there are not important multicollinearity problems, to analyze the results the following criteria has been used:

- If VIF index is below 5 (VIF<5) multicollinearity problems do not exist
- If VIF index is between 5 and 7 multicollinearity problems may exist and they may be important enough to affect the results
- If VIF index is higher than 7 serious multicollinearity problems exist and the results of final regressions are affected

As most of this index are around 1 or 2, it is assumed that there are not important or severe multicollinearity problems, then the regressions will carry solid results.

To improve the robustness of the regressions and control for unobserved shocks that may have affected all countries simultaneously, time dummies for the years 2021 and 2022 were included in the model. These years correspond to highly disruptive periods due to the COVID-19 economic recovery and the energy crisis triggered by the Russian invasion of Ukraine. By including time fixed effects, the model isolates these common shocks from the variation of interest across countries, ensuring that the coefficients of the explanatory variables are not biased by external, time-specific events that affected the whole European electricity market.

In addition, clustered standard errors by country were used to account for the potential correlation of errors within each country over time. Since the dataset is structured as a panel with repeated observations for each country, standard errors may be underestimated if this correlation is ignored. Clustering by country ensures that the inference is more reliable and has robust to autocorrelation at the national level.

The fixed effects linear regressions are carried out through python as well, with the library "linear models" and through the command "panelOLS" specifically used for data frames and this type of linear regression (Appendices).

The results obtained are the following:

Variables	Regresión 1	Regresión 2	Regresión 3	Regresión 4	Regresión 5	Regresión 6	Regresión 7	Regresión 8	Regresión 9
log_Gas_Price	0.5665 (0.0000***)	0.5097 (0.0000***)	0.6789 (0.0000***)	0.5124 (0.0000***)	0.4641 (0.0000)	0.4817 (0.0000***)	0.5107 (0.0000***)	0.3999 (0.0000***)	
log_Electricity_Consumption	-0.0209 (0.3068)			0.0053 (0.8680)			(-0.0464) (0.0087***)		
Share_RES	0.0040 (0.0549*)	0.0026 (0.2722)		0.0041 (0.0677*)	0.0024 (0.3049)	0.0028 (0.1270)	0.0005 (0.7914)		
Share_Solar	-0.0009 (0.4143)			-0.0008 (0.5772)			0.0000065 (0.9948)		
log_PPP		-0.0345 (0.3946)							
log_Num_Retailers		0.0163 (0.6663)				0.0375 (0.2255)			
Switching_Rate	0.0063 (0.7057)	0.0063 (0.7057)	(-0.0234) (0.0601*)						
Share_Hydro					(-0.0026) (0.0870*)			-0.0017 (0.1878)	
log_Gov_Subsidies			0.0214 (0.2296)		0.0425 (0.1550)			0.0304 (0.1912)	0.0928 (0.0003***)
Share_Eolic			0.0047 (0.0072***)			0.0046 (0.0033***)			0.0021 (0.2459)
log_HICP				-0.0887 (0.3407)	(-0.1417) (0.0742*)	(-0.1511) (0.0141**)		(-0.1885) (0.0026***)	
Market_Share_Main_Supplier				-0.00001 (0.9943)		-0.0009 (0.6268)			
Taxes							3.6696 (0.0000***)	3.3701 (0.0000***)	4.3067 (0.0000***)
log_Heating_Oil_Price									(-0.3787) (0.0000***)
R2_Within	0,6766	0,7004	0,6356	0,6883	0,6719	0,681	0,7811	0,7876	0,054
Observations	96	96	96	96	96	96	96	96	96
Note: Standard errors are clustered at country level. Statistical significance is represented by pvalue as follows p<0.01***, p<0.05**, p<0.1*									

Table 6: Results (Author´s elaboration) (Appendices)

As it can be seen different control variables have been consider significant in the definition of the dependent variable (log_electricity_price_including_taxes), with pvalues<=1.

- Log_Gas_Price (Natural Gas): with a coefficient of 0.5 and a pvalue of 0, if the price of natural gas increases 1%, then the final price of electricity also increases by 0,5%.
- Log_Electricity_Consumption: with a coefficient of -0.0464 and a pvalue of 0.008, represents an inverse relationship with the electricity price, if the total consumption of electricity increases by 1% then the final price of it will decrease in 0.0464%.
- Share_RES: with a coefficient of 0,004, and a pvalue of 0,0549, if the share of renewable energy used for household electricity generation increases by 1%, the price of the electricity increases in 0,4%.
- Log_PPP (Purchasing Power Parities) do not show any significant relation with the electricity prices.

- Log_HICP (Harmonised Index of Consumer Prices): with a coefficient of -0,1885 and a pvalue of 0,0026, if the inflation increases by 1%, then the electricity price decreases by 0,18%.
- Log_Heating_Oil_Price: with a coefficient of -0.3787 and a pvalue of 0.000, represents an inverse relationship with the electricity price, if the heating oil price increases by 1%, then the electricity price reduces its value in 0.3787%, anyhow the value of R squared within existing in this last regression, determines that the electricity price is not explained (does not depend on this control variable).
- Log_Gov_Subsudies: with a coefficient of 0.0928 and a pvalue of 0.0003, represents a direct relationship with the electricity price, if the government decides to increase the value of the subsidies by 1% to promote the use of RES, then the electricity price increases its value in 0.0928 %, anyhow the value of R squared within existing in this last regression, determines that the electricity price is not explained (does not depend directly on this control variable). Even though there is not a direct relation between both variables, on the next chapter it will be seen that indirect effects of government help will indeed affect final electricity prices.
- Taxes: with a coefficient of between 3,5 and 4 and a pvalue of 0.000, as expected there is a very strong relation between the final price and the taxes, if the taxes increase in 0.01 €/kWh then the final electricity price increases by around 3%.
- Share of Eolic energy in total share of renewable energy: with a coefficient of 0.0046 and a pvalue of 0.0033, if the share of eolic energy increases in 1%, then the final price of electricity increases by 0.46%.
- Share of Hidraulic energy in total share of renewable energy: with a coefficient of -0.0026 and a pvalue of 0.087, if the share of hydraulic energy increases by 1%, then the final price of electricity decreases by 0.26%.
- Share of Solar energy in total share does not have a direct relationship with the final price of the electricity.
- The control variables studied to measure the impact of market liberalization (number of retailers, switching rate and market share of the main supplier) on the electricity prices at household level, do not show any statistical significance, so there is no result

that demonstrates the relationship between the degree of market liberalization and the price of electricity.

The price of natural gas emerges as one of the key drivers, confirming its central role in marginal electricity pricing systems. This aligns with the theory that fossil fuel volatility directly affects electricity markets. In contrast, heating oil, despite being statistically significant, does not truly explain electricity prices and it is likely that captures indirect effects or sectoral substitutions.

Renewables, as a whole, do not lead to lower electricity prices. In fact, the share of RES shows a slight upward pressure on prices, and when disaggregated, wind increases prices, while hydro slightly reduces them, and solar has no clear effect. These results underline that not all renewables are equal in their economic impact, with intermittency and support scheme costs playing a role.

Taxes are by far the most powerful explanatory variable, confirming their central role in final price formation. Government subsidies, although intended to support RES adoption, do not directly explain the final price of electricity consumed at household level.

Interestingly, market liberalization does not seem to affect prices in a meaningful way. This suggests that formal liberalization alone is not enough, structural barriers and lack of consumer engagement may limit its impact.

In conclusion, the analysis shows that decarbonization through RES requires different policies. Simply increasing renewables is not enough to ensure lower prices. Policymakers must consider the cost structure of each technology and accompany the transition with smart tax, subsidy, and market design strategies to shield households from unintended price shocks.

CHAPTER 6. CONCLUSIONS AND FUTURE WORK

To successfully complete this work, it is necessary to re-establish and recall the initial objectives. As we saw in the previous section, these objectives led to the creation of a set of fixed-effects linear regressions to achieve the objectives and answer the research questions.

The established objectives are as follows:

• Investigate the relationship between the proportion of renewable energy used in Europe and the resulting changes in electricity prices. Linked to this objective the main research question arises: "What is the relationship between the share of renewable energy in the national electricity mix and the average household electricity price?"

• Identify the socioeconomic factors that influence household electricity prices, such as fossil fuel prices, natural gas prices, household electricity demand, level of market liberalization, HICP index or Purchasing power index. Linked to this objective the following research questions arises: "How do supporting factors such as government subsidies, market liberalization, and fossil fuel price affect the final electricity costs?" "To what extent do structural factors, such as taxes influence the final price paid by consumers?"

• Analyze the impact and evaluate the effect of each type of renewable energy on final electricity prices, drawing conclusions to promote the most cost-effective use of renewables across Europe. Then the last research question is established: "Are certain types of renewable energy (wind, solar, hydro) more effective than others in reducing household electricity costs?"

To answer these questions, and following the justification presented in Chapter 3, this work relies on a robust methodological framework combining a dataset (built manually from Eurostat, IEA, and national sources) with statistical steps (Chapter 4), including the application of natural logarithms to most quantitative variables. This transformation improves linearity and interpretability (in terms of elasticities), and minimizes heteroscedasticity, as discussed in Chapter 5.4.

In order with the first objective, the relationship between the overall share of renewable energy (Share_RES) and household electricity prices suggests that merely increasing the penetration of renewables in the energy mix does not automatically translate into lower prices for consumers, in fact there is a positive relation between them, so that if the share of RES in electricity mix grows by 1%, then the price of electricity increases by 0,4% (aprox), which aligns with the results obtained by Cech and Janda (aprox 0,2% increase in electricity prices), as explained in Chapter 2.1. This finding supports previous literature, which emphasizes that the integration of renewable energy sources (RES) into the electricity grid entails substantial additional costs, particularly related to infrastructure, intermittency management, and regulatory support mechanisms (see Chapter 2). While RES may reduce marginal generation costs in theory, these benefits can be offset by integration challenges and the need for complementary investments. Anyhow the growth in the final price is small, so that this result shows that European investments in renewable energy technology is probably at the end of the amortization era.

According to the third objective, when the analysis disaggregates RES by technology, a clearer picture emerges. Wind energy shares show a positive and statistically significant association with electricity prices. A 1% increase in eolic share is associated with a 0.47% increase in electricity prices, which is a very similar relation to the one between the total share of renewable energy sources used to generate the electricity and electricity price, holding all else constant. A 1% increase in hydro share is associated with an around -0,2% decrease in electricity prices. These results indicate that the cost dynamics of renewables are not uniform across technologies. Newer or more variable sources like solar and wind may entail higher short-term integration costs compared to more established renewables like hydro.

There are several potential explanations for these results. First, intermittent technologies such as wind and solar require balancing capacity, backup generation, and grid flexibility investments, which can raise system costs and ultimately be passed on to consumers. Second, the development of these technologies has historically relied on generous subsidy schemes, especially in the earlier years of deployment, which may still be reflected in electricity bills.

Third, countries with high shares of wind and solar might have implemented these technologies in markets with already high electricity costs or with less efficient support frameworks.

Altogether, these findings suggest that the impact of renewable energy on household electricity prices is conditional on the type of technology deployed, the maturity of the system, and the regulatory and market design context. Wind and hydropower are the most widely used sources of electricity in Europe for domestic consumption. Their impact on price is the greatest, compared to solar. In 40 out of 96 total observations, wind power was used more than either of the other two, and in 43 out of 96 observations, hydropower was the most widely used of the three. This shows that solar power is the least used for this purpose, at least in Europe, and as explained in Chapter 3.3, eolic energy is the main source of RE used to generate electricity for household consumption from renewable sources with a 45% as shown in figure 12 (Eurostat, 2024f).

While renewables are essential for decarbonization and long-term sustainability, their short- to medium-term effects on prices are complex and can involve upward pressures, particularly when integration is not completely cost-optimized.

According to the second objective, the effect of supporting variables and other socioeconomic variables will be studied as they also show important and intuitive effects. Firstly, structural variables such as taxes exhibit a very strong and highly significant coefficient (3.5-4), confirming their central role in price formation. This corroborates the logic used in Chapter 5.2 to isolate taxes from the electricity price to study their influence in some regressions and exclude the taxes from other regressions, because as taxes have a very strong positive relation with the final price, the regressions would be completely explained by them instead of analyzing other control variables and their effects.

Secondly, when analyzing supporting variables, different conclusions can be made. Government subsidies display a positive coefficient (0.0928) with p-values around 0.0003, suggesting that public financial does not support RES adoption and environmental care, but this las regression (Regression 9) is only explaining a 5,4% of the dependent variable, so the results obtained on this last regression are not taken into account.

¿Why did this happen in this last regression?

To answer this question, the next control variable (heating oil prices) will be analyzed, the very low R^2 Within (0.054) obtained suggests that, despite including three individually significant variables (government subsidies, heating oil price, and electricity taxes) the model does not capture the full temporal variation in electricity prices within countries. This result highlights the limitation of relying on a narrow set of explanatory variables when analyzing household electricity prices. Notably, although heating oil prices are significant and negative, its indirect role in the electricity system means it contributes little to explaining within-country changes. Furthermore, the exclusion of other factors, which are known to be explanatory like electricity consumption, inflation, and renewable energy shares, which are present in other regressions, likely contributes to the model's low explanatory power.

Unlike natural gas, which is a key marginal fuel in electricity generation, heating oil is primarily used for industrial heating in some European countries, not residential heating, so the use of this fuel does not greatly influence the price of electricity, since people do not use this type of fossil fuel at home, they would first use natural gas than heating oil for domestic heating.

Additionally, heating oil prices are closely tied to global oil markets, and their fluctuations may reflect broader macroeconomic or supply-side dynamics that are not directly linked to the electricity sector.

On the other hand, the price of natural gas (log_gas_price), a key marginal fuel in many European countries (Chapter 2.1), increases the pressure on electricity prices with a coefficient around 0.5 and high significance ($p < 0.001$). This confirms the known transmission mechanism between fossil fuel markets and electricity pricing.

Notably, variables reflecting market liberalization such as number of retailers, market share of the main supplier, or switching rate, did not show significant coefficients in most regressions. This could suggest that liberalization has not yet translated into more competitive prices at the household level, or that structural issues remain, this empirical outcome suggests that, despite formal steps toward liberalization in the electricity sector, its impact has not yet materialized in terms of reduced household electricity prices. New results do not align with the ones obtained by Da Silva and Cerqueira in 2017 (Chapter 2.2) which explained that there was a negative relation between the level of market liberalization and electricity prices.

In theory, liberalized markets are expected to promote competition, which should, in turn, exert downward pressure on consumer prices. A greater number of retailers implies increased competition, and a lower market share of the main supplier reflects less market concentration; and higher switching rates indicate active consumer behavior in seeking better deals. If liberalization were functioning effectively, we would expect these variables to have a significant negative correlation with electricity prices.

However, the lack of statistical significance of market competition variables (market share of main electricity retailer, number of retailers and switching rate) in this study may indicate several structural or behavioral issues that reduce the effectiveness of market liberalization. First, liberalization may be incomplete or limited in practice, even if it is legally established. Regulatory, administrative, or infrastructural barriers may persist, restricting true market competition. Second, consumer inertia plays a critical role. Many households may not switch providers due to lack of awareness, mistrust, or perceived complexity, reducing the intended competitive pressure. Third, legacy market structures may continue to favor a reduced number of companies in each country, thereby maintaining effective market concentration despite the existence of multiple suppliers on paper.

Regarding macroeconomic index such as PPP and HICP, different conclusions have been made. The Purchasing Power Parity (log_PPP) variable does not show any statistically significant relationship with household electricity prices in any of the regressions, which aligns with the results obtained by Da Silva and Cerqueira in 2017, that assured that there was not an existent relation between the GDP (which also measures the purchase capacity of society) and electricity prices. This suggests as explained before that differences in income or purchasing power across countries do not directly influence electricity prices, possibly because national regulatory frameworks and market dynamics play a more dominant role in price setting than consumers' income levels. On the other hand, the Harmonised Index of Consumer Prices (log_HICP), which serves as a proxy for inflation, shows a negative and statistically significant coefficient in some regressions (–0.1885 with a p-value of 0.0026 in regression 8). This result is counterintuitive at first, as one might expect electricity prices to rise with general inflation. However, it could indicate that countries with higher inflation may have implemented stronger price controls or subsidies to shield households from energy cost increases, thus weakening the direct link between inflation and electricity pricing, then the support from government to household does have an indirect relation with the electricity price because even though it did not show a direct relation in the linear regressions we can see that the government intervention in isolating the price of electricity to avoid the impact on family consumption has probably been the main reason why, despite inflation in recent years, the inflation on the price of energy has nevertheless remained very low. According to Bruegel (2024), European countries allocated hundreds of billions of euros between 2021 and 2023 to protect consumers from rising energy prices.

In methodological terms, the analysis shows the benefit of segmenting the regression model into multiple specifications to mitigate multicollinearity, as described in detail in Chapter 5.4. The VIF scores (Appendix) reinforce that variable combinations were well chosen. R-squared values are high (with within R^2 above 0.7 in several regressions), indicating that the models explain a substantial part of the variance in electricity prices.

In conclusion, this research offers strong evidence that the relationship between renewable energy and household electricity prices is complex and technology specific. Hydro contributes to reducing prices, while wind may still impose cost burdens in the short term. Policymakers should be aware that the energy transition requires not only technological advancement but also efficient regulatory and fiscal instruments to shield households from short-term price shocks. Ensuring affordability while decarbonizing the energy mix remains a fundamental challenge for the coming decades.

This study contributes to the academic discussion by offering empirical, country-level, panel-based evidence on electricity price drivers in the context of renewable energy expansion. It also proposes a common methodology that can be "easily" used and a transparent treatment of logarithmic variables to improve regression strength and interpretation. Including time dummies on external shocks (war in Ukraine, COVID-19 crisis) has helped to control events that were common to all European countries isolating then from other variables.

As for future work there are many different topics that need to be covered to improve the current situation of RES technologies that are used to generate not only electricity at household level, but on other levels as well.

First it would be interesting to understand why hydraulic technologies are more efficient than Eolic ones when reducing the final household prices of electricity. One explanation for the lower cost associated with hydropower compared to wind energy lies in the maturity and efficiency of the technology. Many hydropower plants in Europe were built decades ago and are now fully amortized, with minimal operating costs and high reliability. In contrast, wind power, despite being cleaner, has higher integration costs due to its intermittent nature and the need for grid adaptation or backup solutions. Additionally, hydropower offers dispatchable electricity and plays a stabilizing role in the energy mix, which can help reduce price volatility for consumers.

The electricity markets in Europe have suffered significant structural changes since 2022, particularly in response to recent global events such as the war in Ukraine, post-pandemic recovery policies, and the ongoing energy crisis. Including data from 2023 and future years would allow for a more complete understanding of how these exogenous shocks have reshaped electricity price dynamics and interacted with the energy transition.

Specifically, the Russian invasion of Ukraine in early 2022 led to unprecedented volatility in natural gas markets, as explained in the Chapter 3.1, exposing the vulnerability of European countries to fossil fuel dependency. This event triggered a rapid shift in energy policy across the EU, including the accelerated rollout of renewables, new subsidy schemes, emergency interventions in wholesale markets, and efforts to decouple gas prices from electricity prices. By extending the panel data to cover these developments, future research could assess whether the relationship between renewable energy penetration and household electricity prices has changed under new geopolitical and economic conditions.

CHAPTER 7. DECLARATION OF GENERATIVE AI TOOL USE

I, Claudia Muñoz Pombo, a GITI+ADE student at the Comillas University, hereby declare that, upon presenting my bachelor's degree, entitled "Exploring the Effect of Renewable Energy Adoption on Household Electricity Prices in Europe", have used the Generative Artificial Intelligence tool ChatGPT or other similar GAI code tools only in the context of the following activities:

1. Critique: To find counterarguments to a specific thesis I intend to defend.
2. References: Used in conjunction with other tools, such as Science, to identify preliminary references that I then cross-check and validate.
3. Code Interpreter: To perform preliminary data analysis.
4. Literary and Language Style Corrector: To improve the linguistic and stylistic quality of the text.
5. Synthesizer and Disseminator of Difficult Books: To summarize and understand complex literature.

I affirm that all information and content presented in this work are the product of my own research and individual effort, except where otherwise indicated and appropriate credit has been given (I have included appropriate references in the final project and have explicitly stated why ChatGPT or other similar tools were used). I am aware of the academic and ethical implications of submitting non-original work and accept the consequences of any violation of this statement.

Date: 21/07/2025

Firm:

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CHAPTER 9. APPENDICES

```
import pandas as pd
import statsmodels.api as sm
from statsmodels.regression.linear_model import OLS
import numpy as np
from scipy.stats import chi2

df = pd.read_excel("Test de Hausmann.xlsx", sheet_name="HOJA FINAL PARA R",
skiprows=2)
df.columns = [
    "Index", "Country", "Year", "Price_heating_oil", "Electricity_consumed",
    "Share_RES_in_electricity",                      "Electricity_price_excl_tax",
"Electricity_price_incl_tax",
    "HICP", "Natural_gas_price", "PPP", "Num_electricity_retailers",
    "Market_share_largest_supplier",                "Electricity_switching_rates",
"Household_subsidies"
]

df = df.dropna(subset=["Country", "Year"])
cols_to_numeric = df.columns.difference(["Country", "Year"])
df[cols_to_numeric] = df[cols_to_numeric].apply(pd.to_numeric, errors='coerce')
df["Year"] = df["Year"].astype(int)

df_panel = df.set_index(["Country", "Year"])
y = df_panel["Electricity_price_incl_tax"]
X = df_panel[[
    "Share_RES_in_electricity",      "Natural_gas_price",      "PPP",      "HICP",
"Household_subsidies"
]]
X = sm.add_constant(X)
panel_data = pd.concat([y, X], axis=1).dropna()
y_clean = panel_data["Electricity_price_incl_tax"]
X_clean = panel_data.drop(columns="Electricity_price_incl_tax")

dummies      =      pd.get_dummies(panel_data.index.get_level_values("Country"),
drop_first=True)
X_fe = pd.concat([X_clean.reset_index(drop=True), dummies.reset_index(drop=True)],
axis=1)
model_fe = OLS(y_clean.values, X_fe).fit()

model_re = OLS(y_clean.values, X_clean).fit()
b_fe = model_fe.params[:len(X_clean.columns)]
b_re = model_re.params
v_fe = model_fe.cov_params().iloc[:len(X_clean.columns), :len(X_clean.columns)]
v_re = model_re.cov_params()
b_diff = b_fe - b_re
v_diff = v_fe - v_re
```

```
stat = np.dot(np.dot(b_diff.T, np.linalg.inv(v_diff)), b_diff)
df_h = len(b_diff)
p_value = 1 - chi2.cdf(stat, df_h)

print(f"Hausman test statistic: {stat:.4f}")
print(f"P-value: {p_value:.4g}")

if p_value < 0.05:
    print("Se recomienda usar efectos fijos.")
else:
    print("Se recomienda usar efectos aleatorios.")
```

```
CÓDIGO REGRESIONES
from linearmodels.panel import PanelOLS
import pandas as pd

df = pd.read_excel("Libro2_modificado.xlsx", skiprows=3)

df.columns = [
    "Country", "Year", "log_Heating_Oil_Price", "log_Electricity_Consumption",
    "log_HICP", "log_Gas_Price", "log_PPP",
    "log_Num_Retailers", "log_Gov_Subsidies", "Switching_Rate",
"Market_Share_Main_Supplier",
    "Share_RES", "Share_Solar", "Share_Hydro", "Share_Eolic", "Taxes"
]

log_prices_incl_taxes = [
    -1.308592853, -2.320749064, -1.717580071, -1.266202881, -1.201974802,
    -2.047167981, -1.340938659, -1.807279281, -1.470545914, -1.630661549,
    -2.034850658, -1.535722875, -2.024196067, -1.616966179, -2.293625352,
    -1.991430664, -1.52924137, -1.890475442, -1.545055654, -1.93171143,
    -1.775492497, -1.757937921, -1.729912066, -1.600973834, -1.205974807,
    -2.215490386, -1.669718843, -1.06479074, -1.128865332, -1.640412717,
    -1.212677245, -1.622523152, -1.267267655, -1.598497972, -2.030270498,
    -1.443923474, -1.912572089, -1.614953093, -2.299589584, -1.901797574,
    -1.476219069, -1.848964943, -1.527857925, -1.831332244, -1.765507098,
    -1.817692851, -1.692819521, -1.345536369, -0.800955133, -2.165435255,
    -1.571660548, -0.532560116, -1.091537375, -1.328025453, -0.961549638,
    -0.786140047, -1.093624747, -1.512311202, -1.911218909, -1.010326724,
    -1.415105443, -1.588655373, -2.22192719, -1.140372223, -1.439695138,
    -1.830084584, -1.504177402, -1.07557959, -1.631683521, -1.669187917,
    -1.396748819, -1.294627173, -0.973390324, -2.126952524, -1.15486523,
    -1.034511363, -0.91130319, -1.452861605, -0.778705069, -1.465770563,
    -1.449447176, -1.350541191, -1.910543005, -1.094520671, -1.503727458,
    -1.246532419, -2.178599113, -1.324634981, -1.207311706, -1.531551374,
    -1.470110847, -1.655481851, -1.554476354, -1.638351923, -1.425867136,
    -1.522801606
]

df["log_Electricity_Price_Incl_Tax"] = log_prices_incl_taxes

for col in df.columns[1:]:
    df[col] = pd.to_numeric(df[col], errors='coerce')


df["Year_2020"] = 0
df["Year_2021"] = (df["Year"] == 2021).astype(int)
df["Year_2022"] = (df["Year"] == 2022).astype(int)


df_panel = df.set_index(["Country", "Year"])

regression_matrix = [
    [0, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0],
    [0, 1, 0, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 0],
```

```
    [0, 1, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0, 0, 1],
    [0, 1, 1, 1, 0, 1, 0, 1, 0, 0, 0, 1, 0, 0],
    [0, 1, 0, 1, 0, 1, 1, 1, 0, 0, 0, 0, 1, 0],
    [0, 1, 0, 1, 0, 1, 0, 1, 1, 0, 0, 0, 0, 1],
    [0, 1, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 0, 0],
    [0, 1, 0, 0, 0, 1, 1, 0, 0, 0, 1, 0, 1, 0],
    [1, 0, 0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 1]
]

variables = ['log_Heating_Oil_Price', 'log_Gas_Price',
'log_Electricity_Consumption',
             'Share_RES', 'log_PPP', 'log_HICP', 'log_Gov_Subsidies',
             'Market_Share_Main_Supplier', 'log_Num_Retailers', 'Switching_Rate',
             'Taxes', 'Share_Solar', 'Share_Hydro', 'Share_Eolic']

year_dummies = ["Year_2021", "Year_2022"]

for i, row in enumerate(regression_matrix):
    selected_vars = [var for var, use in zip(variables, row) if use == 1]
    selected_vars += year_dummies


    data = df_panel[["log_Electricity_Price_Incl_Tax"] + selected_vars].dropna()


    y = data["log_Electricity_Price_Incl_Tax"]
    X = data[selected_vars]

    model = PanelOLS(y, X, drop_absorbed=True)
    result = model.fit(cov_type="clustered", cluster_entity=True)

    print(f"\n===== Regresión {i+1} =====")
    print(result.summary)
    print("R² Within: ", result.rsquared_within)
    print("R² Between:", result.rsquared_between)
    print("R² Overall:", result.rsquared_overall)

RESULTADOS REGRESIONES
===== Regresión 1 =====
                                PanelOLS Estimation Summary
==================================================================================
===========
Dep. Variable:     log_Electricity_Price_Incl_Tax   R-squared:
0.9747
Estimator:                               PanelOLS   R-squared (Between):
0.9796
No. Observations:                              96   R-squared (Within):
0.6766
Date:                            Wed, Jul 23 2025   R-squared (Overall):
0.9747
Time:                                    22:01:02   Log-likelihood
-3.6713
Cov. Estimator:                         Clustered
```

```
                                                    F-statistic:
578.20
Entities:                                     24    P-value
0.0000
Avg Obs:                                  4.0000    Distribution:
F(6,90)
Min Obs:                                  4.0000
Max Obs:                                  4.0000    F-statistic (robust):
297.94
                                                    P-value
0.0000
Time periods:                                  4    Distribution:
F(6,90)
Avg Obs:                                  24.000
Min Obs:                                  24.000
Max Obs:                                  24.000

                                      Parameter Estimates
==================================================================================
==============
                             Parameter  Std. Err.     T-stat    P-value    Lower
CI    Upper CI
----------------------------------------------------------------------------------
--------------
log_Gas_Price                   0.5665     0.0686     8.2517     0.0000
0.4301      0.7029
log_Electricity_Consumption    -0.0209     0.0203    -1.0278     0.3068     -
0.0612      0.0195
Share_RES                       0.0040     0.0021     1.9452     0.0549  -8.542e-
05      0.0081
Share_Solar                    -0.0009     0.0011    -0.8202     0.4143     -
0.0031      0.0013
Year_2021                      -0.0176     0.0200    -0.8779     0.3824     -
0.0574      0.0222
Year_2022                      -0.0326     0.0463    -0.7045     0.4830     -
0.1245      0.0593
==================================================================================
==============


R² Within:  0.67660547046392
R² Between: 0.9795750505123362
R² Overall: 0.9747135686393582

===== Regresión 2 =====
                            PanelOLS Estimation Summary
==================================================================================
===========
Dep. Variable:     log_Electricity_Price_Incl_Tax   R-squared:
0.9772
Estimator:                               PanelOLS   R-squared (Between):
0.9817
```

```
No. Observations:                      96   R-squared (Within):
0.7004
Date:                    Wed, Jul 23 2025   R-squared (Overall):
0.9772
Time:                            22:01:02   Log-likelihood
1.3581
Cov. Estimator:                 Clustered
                                            F-statistic:
472.07
Entities:                              24   P-value
0.0000
Avg Obs:                           4.0000   Distribution:
F(8,88)
Min Obs:                           4.0000
Max Obs:                           4.0000   F-statistic (robust):
200.43
                                            P-value
0.0000
Time periods:                           4   Distribution:
F(8,88)
Avg Obs:                           24.000
Min Obs:                           24.000
Max Obs:                           24.000

                             Parameter Estimates
================================================================================
====
                   Parameter  Std. Err.     T-stat    P-value    Lower CI
Upper CI
--------------------------------------------------------------------------------
----
log_Gas_Price         0.5097     0.0848     6.0090     0.0000      0.3411
0.6782
Share_RES             0.0026     0.0024     1.1050     0.2722     -0.0021
0.0073
log_PPP              -0.0345     0.0403    -0.8556     0.3946     -0.1145
0.0456
log_Num_Retailers     0.0163     0.0376     0.4327     0.6663     -0.0585
0.0910
Switching_Rate        0.0063     0.0167     0.3788     0.7057     -0.0268
0.0394
Share_Hydro          -0.0028     0.0017    -1.6712     0.0982     -0.0061
0.0005
Year_2021            -0.0193     0.0200    -0.9654     0.3370     -0.0590
0.0204
Year_2022            -0.0130     0.0500    -0.2602     0.7953     -0.1125
0.0864
================================================================================
====


R² Within:  0.7004316399943227
R² Between: 0.9817429262817335
```

```
R² Overall: 0.9772289756774127

===== Regresión 3 =====
                          PanelOLS Estimation Summary
================================================================================
===========
Dep. Variable:     log_Electricity_Price_Incl_Tax   R-squared:
0.9788
Estimator:                               PanelOLS   R-squared (Between):
0.9843
No. Observations:                              96   R-squared (Within):
0.6356
Date:                           Wed, Jul 23 2025   R-squared (Overall):
0.9788
Time:                                   22:01:02   Log-likelihood
4.6775
Cov. Estimator:                        Clustered
                                                   F-statistic:
690.90
Entities:                                      24   P-value
0.0000
Avg Obs:                                   4.0000   Distribution:
F(6,90)
Min Obs:                                   4.0000
Max Obs:                                   4.0000   F-statistic (robust):
286.06
                                                   P-value
0.0000
Time periods:                                   4   Distribution:
F(6,90)
Avg Obs:                                   24.000
Min Obs:                                   24.000
Max Obs:                                   24.000

                             Parameter Estimates
================================================================================
====
                   Parameter  Std. Err.     T-stat    P-value    Lower CI
Upper CI
--------------------------------------------------------------------------------
----
log_Gas_Price         0.6789     0.0562     12.087     0.0000      0.5673
0.7904
log_Gov_Subsidies     0.0214     0.0177     1.2097     0.2296     -0.0137
0.0565
Switching_Rate       -0.0234     0.0123    -1.9041     0.0601     -0.0477
0.0010
Share_Eolic           0.0047     0.0017     2.7487     0.0072      0.0013
0.0081
Year_2021            -0.0110     0.0315    -0.3509     0.7265     -0.0736
0.0515
Year_2022            -0.0845     0.0455    -1.8558     0.0668     -0.1750
0.0060
```

```
================================================================================
====


R² Within:  0.6356426500728276
R² Between: 0.9843457906210508
R² Overall: 0.9787504632071408

===== Regresión 4 =====
                          PanelOLS Estimation Summary
================================================================================
===========
Dep. Variable:     log_Electricity_Price_Incl_Tax   R-squared:
0.9753
Estimator:                               PanelOLS   R-squared (Between):
0.9799
No. Observations:                              96   R-squared (Within):
0.6883
Date:                           Wed, Jul 23 2025   R-squared (Overall):
0.9753
Time:                                   22:01:02   Log-likelihood
-2.6140
Cov. Estimator:                        Clustered
                                                    F-statistic:
433.70
Entities:                                      24   P-value
0.0000
Avg Obs:                                   4.0000   Distribution:
F(8,88)
Min Obs:                                   4.0000
Max Obs:                                   4.0000   F-statistic (robust):
191.67
                                                    P-value
0.0000
Time periods:                                   4   Distribution:
F(8,88)
Avg Obs:                                   24.000
Min Obs:                                   24.000
Max Obs:                                   24.000

                              Parameter Estimates
================================================================================
==============
                             Parameter  Std. Err.     T-stat    P-value    Lower
CI    Upper CI
--------------------------------------------------------------------------------
--------------
log_Gas_Price                   0.5124     0.0884     5.7944     0.0000
0.3367      0.6882
log_Electricity_Consumption     0.0053     0.0317     0.1667     0.8680     -
0.0578      0.0683
Share_RES                       0.0041     0.0022     1.8496     0.0677     -
0.0003      0.0085
```

```
log_HICP                          -0.0887      0.0925     -0.9580      0.3407      -
0.2726       0.0952
Market_Share_Main_Supplier  -1.438e-05      0.0020     -0.0071      0.9943      -
0.0040       0.0040
Share_Solar                       -0.0008      0.0014     -0.5595      0.5772      -
0.0036       0.0020
Year_2021                         -0.0219      0.0191     -1.1472      0.2544      -
0.0598       0.0160
Year_2022                         -0.0023      0.0535     -0.0434      0.9655      -
0.1085       0.1039
=================================================================================
==============



R² Within:  0.6882684292438906
R² Between: 0.9799447026164325
R² Overall: 0.9752644343348716

===== Regresión 5 =====
                                PanelOLS Estimation Summary
=================================================================================
===========
Dep. Variable:      log_Electricity_Price_Incl_Tax   R-squared:
0.9787
Estimator:                              PanelOLS   R-squared (Between):
0.9837
No. Observations:                             96   R-squared (Within):
0.6719
Date:                           Wed, Jul 23 2025   R-squared (Overall):
0.9787
Time:                                   22:01:02   Log-likelihood
4.4568
Cov. Estimator:                        Clustered
                                                   F-statistic:
504.28
Entities:                                     24   P-value
0.0000
Avg Obs:                                  4.0000   Distribution:
F(8,88)
Min Obs:                                  4.0000
Max Obs:                                  4.0000   F-statistic (robust):
235.23
                                                   P-value
0.0000
Time periods:                                  4   Distribution:
F(8,88)
Avg Obs:                                  24.000
Min Obs:                                  24.000
Max Obs:                                  24.000

                                   Parameter Estimates
=================================================================================
=============
```

```
                            Parameter  Std. Err.     T-stat    P-value    Lower
CI    Upper CI
--------------------------------------------------------------------------------
-------------
log_Gas_Price                  0.4641     0.0907     5.1197     0.0000
0.2840      0.6443
Share_RES                      0.0024     0.0024     1.0321     0.3049     -
0.0022      0.0071
log_HICP                      -0.1417     0.0784    -1.8069     0.0742     -
0.2976      0.0142
log_Gov_Subsidies              0.0425     0.0296     1.4343     0.1550     -
0.0164      0.1013
Market_Share_Main_Supplier  5.477e-05     0.0021     0.0264     0.9790     -
0.0041      0.0042
Share_Hydro                   -0.0026     0.0015    -1.7309     0.0870     -
0.0057      0.0004
Year_2021                     -0.0078     0.0258    -0.3013     0.7639     -
0.0590      0.0435
Year_2022                      0.0165     0.0528     0.3127     0.7552     -
0.0884      0.1214
================================================================================
=============


R² Within:  0.6719202264607034
R² Between: 0.9836546687155102
R² Overall: 0.9786525449380588

===== Regresión 6 =====
                                PanelOLS Estimation Summary
================================================================================
===========
Dep. Variable:     log_Electricity_Price_Incl_Tax   R-squared:
0.9807
Estimator:                               PanelOLS   R-squared (Between):
0.9856
No. Observations:                              96   R-squared (Within):
0.6810
Date:                            Wed, Jul 23 2025   R-squared (Overall):
0.9807
Time:                                    22:01:03   Log-likelihood
9.3393
Cov. Estimator:                         Clustered
                                                    F-statistic:
559.46
Entities:                                      24   P-value
0.0000
Avg Obs:                                   4.0000   Distribution:
F(8,88)
Min Obs:                                   4.0000
Max Obs:                                   4.0000   F-statistic (robust):
496.43
```

```
                                                                    P-value
0.0000
Time periods:                                              4    Distribution:
F(8,88)
Avg Obs:                                              24.000
Min Obs:                                              24.000
Max Obs:                                              24.000

                                     Parameter Estimates
================================================================================
=============
                            Parameter  Std. Err.     T-stat    P-value    Lower
CI    Upper CI
--------------------------------------------------------------------------------
-------------
log_Gas_Price                  0.4817     0.0701     6.8758     0.0000
0.3425      0.6210
Share_RES                      0.0028     0.0018     1.5408     0.1270     -
0.0008      0.0064
log_HICP                      -0.1511     0.0603    -2.5052     0.0141     -
0.2710     -0.0312
Market_Share_Main_Supplier    -0.0009     0.0019    -0.4879     0.6268     -
0.0046      0.0028
log_Num_Retailers              0.0375     0.0307     1.2206     0.2255     -
0.0236      0.0986
Share_Eolic                    0.0046     0.0015     3.0179     0.0033
0.0016      0.0076
Year_2021                     -0.0302     0.0189    -1.5943     0.1145     -
0.0678      0.0074
Year_2022                      0.0152     0.0494     0.3073     0.7594     -
0.0830      0.1134
================================================================================
=============


R² Within:  0.6810076307250538
R² Between: 0.9856047718327507
R² Overall: 0.9807171739431562

===== Regresión 7 =====
                                PanelOLS Estimation Summary
================================================================================
===========
Dep. Variable:      log_Electricity_Price_Incl_Tax    R-squared:
0.9832
Estimator:                                PanelOLS    R-squared (Between):
0.9865
No. Observations:                               96    R-squared (Within):
0.7811
Date:                             Wed, Jul 23 2025    R-squared (Overall):
0.9832
Time:                                     22:01:03    Log-likelihood
15.835
```

```
Cov. Estimator:                         Clustered
                                                    F-statistic:
742.19
Entities:                                      24   P-value
0.0000
Avg Obs:                                   4.0000   Distribution:
F(7,89)
Min Obs:                                   4.0000
Max Obs:                                   4.0000   F-statistic (robust):
559.74
                                                    P-value
0.0000
Time periods:                                   4   Distribution:
F(7,89)
Avg Obs:                                   24.000
Min Obs:                                   24.000
Max Obs:                                   24.000

                                      Parameter Estimates
=================================================================================
==============
                             Parameter  Std. Err.     T-stat    P-value    Lower
CI    Upper CI
---------------------------------------------------------------------------------
--------------
log_Gas_Price                   0.5107     0.0529     9.6618     0.0000
0.4057      0.6157
log_Electricity_Consumption    -0.0464     0.0173    -2.6814     0.0087     -
0.0808     -0.0120
Share_RES                       0.0005     0.0020     0.2653     0.7914     -
0.0034      0.0044
Taxes                           3.6696     0.8404     4.3665     0.0000
1.9997      5.3395
Share_Solar                  6.537e-06     0.0010     0.0065     0.9948     -
0.0020      0.0020
Year_2021                      -0.0463     0.0172    -2.6857     0.0086     -
0.0805     -0.0120
Year_2022                      -0.0367     0.0395    -0.9287     0.3555     -
0.1152      0.0418
=================================================================================
==============


R² Within:  0.7810886540635231
R² Between: 0.9864530027385101
R² Overall: 0.9831577047145968

===== Regresión 8 =====
                                PanelOLS Estimation Summary
=================================================================================
===========
Dep. Variable:      log_Electricity_Price_Incl_Tax   R-squared:
0.9858
```

```
Estimator:                              PanelOLS   R-squared (Between):
0.9890
No. Observations:                             96   R-squared (Within):
0.7876
Date:                           Wed, Jul 23 2025   R-squared (Overall):
0.9858
Time:                                   22:01:03   Log-likelihood
23.863
Cov. Estimator:                        Clustered
                                                   F-statistic:
879.63
Entities:                                     24   P-value
0.0000
Avg Obs:                                  4.0000   Distribution:
F(7,89)
Min Obs:                                  4.0000
Max Obs:                                  4.0000   F-statistic (robust):
446.32
                                                   P-value
0.0000
Time periods:                                  4   Distribution:
F(7,89)
Avg Obs:                                  24.000
Min Obs:                                  24.000
Max Obs:                                  24.000

                                 Parameter Estimates
================================================================================
====
                   Parameter  Std. Err.     T-stat    P-value    Lower CI
Upper CI
--------------------------------------------------------------------------------
----
log_Gas_Price          0.3999     0.0643     6.2237     0.0000     0.2722
0.5276
log_HICP              -0.1885     0.0608    -3.0984     0.0026    -0.3094     -
0.0676
log_Gov_Subsidies      0.0304     0.0231     1.3171     0.1912    -0.0154
0.0762
Taxes                  3.3701     0.5877     5.7341     0.0000     2.2023
4.5379
Share_Hydro           -0.0017     0.0013    -1.3273     0.1878    -0.0043
0.0009
Year_2021             -0.0444     0.0195    -2.2826     0.0248    -0.0831     -
0.0058
Year_2022              0.0240     0.0465     0.5170     0.6065    -0.0683
0.1163
================================================================================
====


R² Within:  0.7875540837491988
R² Between: 0.9889839447117263
```

```
R² Overall: 0.9857517798931023

===== Regresión 9 =====
                          PanelOLS Estimation Summary
================================================================================
===========
Dep. Variable:     log_Electricity_Price_Incl_Tax   R-squared:
0.9721
Estimator:                               PanelOLS   R-squared (Between):
0.9871
No. Observations:                              96   R-squared (Within):
0.0540
Date:                          Wed, Jul 23 2025   R-squared (Overall):
0.9721
Time:                                  22:01:03   Log-likelihood
-8.3613
Cov. Estimator:                       Clustered
                                                    F-statistic:
522.98
Entities:                                      24   P-value
0.0000
Avg Obs:                                   4.0000   Distribution:
F(6,90)
Min Obs:                                   4.0000
Max Obs:                                   4.0000   F-statistic (robust):
594.73
                                                    P-value
0.0000
Time periods:                                   4   Distribution:
F(6,90)
Avg Obs:                                   24.000
Min Obs:                                   24.000
Max Obs:                                   24.000

                             Parameter Estimates
================================================================================
========
                       Parameter  Std. Err.     T-stat    P-value    Lower CI
Upper CI
--------------------------------------------------------------------------------
--------
log_Heating_Oil_Price    -0.3787     0.0291    -13.026     0.0000     -0.4364
-0.3209
log_Gov_Subsidies         0.0928     0.0246     3.7717     0.0003      0.0439
0.1416
Taxes                     4.3067     0.8522     5.0535     0.0000      2.6136
5.9998
Share_Eolic               0.0021     0.0018     1.1681     0.2459     -0.0015
0.0057
Year_2021                -0.0235     0.0276    -0.8503     0.3974     -0.0784
0.0314
Year_2022                 0.3187     0.0505     6.3064     0.0000      0.2183
0.4191
```

```
================================================================================
========


R² Within:  0.05395968655864536
R² Between: 0.9870912597118472
R² Overall: 0.9721181319567016


CÓDIGO VIF

import pandas as pd
from linearmodels.panel import PanelOLS
from statsmodels.stats.outliers_influence import variance_inflation_factor
import statsmodels.api as sm

df = pd.read_excel("Libro2_modificado.xlsx", skiprows=3)

df.columns = [
    "Country", "Year", "log_Heating_Oil_Price", "log_Electricity_Consumption",
    "log_HICP", "log_Gas_Price", "log_PPP", "log_Num_Retailers",
    "log_Gov_Subsidies", "Switching_Rate", "Market_Share_Main_Supplier",
    "Share_RES", "Share_Solar", "Share_Hydro", "Share_Eolic", "Taxes"
]


log_prices_incl_taxes = [-1.308592853, -2.320749064, -1.717580071, -1.266202881,
-1.201974802,
    -2.047167981, -1.340938659, -1.807279281, -1.470545914, -1.630661549,
    -2.034850658, -1.535722875, -2.024196067, -1.616966179, -2.293625352,
    -1.991430664, -1.52924137, -1.890475442, -1.545055654, -1.93171143,
    -1.775492497, -1.757937921, -1.729912066, -1.600973834, -1.205974807,
    -2.215490386, -1.669718843, -1.06479074, -1.128865332, -1.640412717,
    -1.212677245, -1.622523152, -1.267267655, -1.598497972, -2.030270498,
    -1.443923474, -1.912572089, -1.614953093, -2.299589584, -1.901797574,
    -1.476219069, -1.848964943, -1.527857925, -1.831332244, -1.765507098,
    -1.817692851, -1.692819521, -1.345536369, -0.800955133, -2.165435255,
    -1.571660548, -0.532560116, -1.091537375, -1.328025453, -0.961549638,
    -0.786140047, -1.093624747, -1.512311202, -1.911218909, -1.010326724,
    -1.415105443, -1.588655373, -2.22192719, -1.140372223, -1.439695138,
    -1.830084584, -1.504177402, -1.07557959, -1.631683521, -1.669187917,
    -1.396748819, -1.294627173, -0.973390324, -2.126952524, -1.15486523,
    -1.034511363, -0.91130319, -1.452861605, -0.778705069, -1.465770563,
    -1.449447176, -1.350541191, -1.910543005, -1.094520671, -1.503727458,
    -1.246532419, -2.178599113, -1.324634981, -1.207311706, -1.531551374,
    -1.470110847, -1.655481851, -1.554476354, -1.638351923, -1.425867136,
    -1.522801606]
df["log_Electricity_Price_Incl_Tax"] = log_prices_incl_taxes


for col in df.columns[1:]:
    df[col] = pd.to_numeric(df[col], errors='coerce')
```

```
df["Year_2021"] = (df["Year"] == 2021).astype(int)
df["Year_2022"] = (df["Year"] == 2022).astype(int)

df_panel = df.set_index(["Country", "Year"])

regression_matrix = [
    [0, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0],
    [0, 1, 0, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 0],
    [0, 1, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0, 0, 1],
    [0, 1, 1, 1, 0, 1, 0, 1, 0, 0, 0, 1, 0, 0],
    [0, 1, 0, 1, 0, 1, 1, 1, 0, 0, 0, 0, 1, 0],
    [0, 1, 0, 1, 0, 1, 0, 1, 1, 0, 0, 0, 0, 1],
    [0, 1, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 0, 0],
    [0, 1, 0, 0, 0, 1, 1, 0, 0, 0, 1, 0, 1, 0],
    [1, 0, 0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 1]
]
year_dummies = ["Year_2021", "Year_2022"]

variables = ['log_Heating_Oil_Price', 'log_Gas_Price',
'log_Electricity_Consumption',
             'Share_RES', 'log_PPP', 'log_HICP', 'log_Gov_Subsidies',
             'Market_Share_Main_Supplier', 'log_Num_Retailers', 'Switching_Rate',
             'Taxes', 'Share_Solar', 'Share_Hydro', 'Share_Eolic']


for i, row in enumerate(regression_matrix):
    selected_vars = [v for v, u in zip(variables, row) if u == 1] + year_dummies
    data = df_panel[selected_vars].dropna().copy()
    data.index = pd.MultiIndex.from_tuples(data.index)
    X = sm.add_constant(data)

    vif_result = pd.DataFrame()
    vif_result["Variable"] = X.columns
    vif_result["VIF"] = [variance_inflation_factor(X.values, j) for j in
range(X.shape[1])]

    print(f"\n===== VIF - Regresión {i+1} =====")
    print(vif_result)

RESULTADOS VIF

===== VIF - Regresión 1 =====
                      Variable        VIF
1                log_Gas_Price   1.274563
2  log_Electricity_Consumption   1.139883
3                    Share_RES   1.074642
4                  Share_Solar   1.049984
5                    Year_2021   1.137114
6                    Year_2022   1.276103

===== VIF - Regresión 2 =====
            Variable          VIF
```

```
1       log_Gas_Price     2.313306
2           Share_RES     1.114888
3             log_PPP     1.576329
4   log_Num_Retailers     1.164231
5      Switching_Rate     1.670007
6         Share_Hydro     1.093099
7           Year_2021     1.148456
8           Year_2022     1.367094

===== VIF - Regresión 3 =====
             Variable         VIF
1       log_Gas_Price    1.833846
2   log_Gov_Subsidies    1.265563
3      Switching_Rate    1.611039
4         Share_Eolic    1.080874
5           Year_2021    1.152912
6           Year_2022    1.351704

===== VIF - Regresión 4 =====
                       Variable         VIF
1                 log_Gas_Price     1.588981
2   log_Electricity_Consumption     1.220432
3                     Share_RES     1.104482
4                      log_HICP     1.485269
5    Market_Share_Main_Supplier     1.437437
6                   Share_Solar     1.354719
7                     Year_2021     1.250849
8                     Year_2022     1.306177

===== VIF - Regresión 5 =====
                     Variable         VIF
1               log_Gas_Price     1.645245
2                   Share_RES     1.154737
3                    log_HICP     1.198044
4           log_Gov_Subsidies     1.269676
5  Market_Share_Main_Supplier     1.267815
6                 Share_Hydro     1.062534
7                   Year_2021     1.249554
8                   Year_2022     1.337231

===== VIF - Regresión 6 =====
                     Variable         VIF
1               log_Gas_Price     1.465387
2                   Share_RES     1.102511
3                    log_HICP     1.305315
4  Market_Share_Main_Supplier     1.374884
5           log_Num_Retailers     1.173664
6                 Share_Eolic     1.218069
7                   Year_2021     1.249382
8                   Year_2022     1.303280

===== VIF - Regresión 7 =====
                       Variable        VIF
```

```
1                 log_Gas_Price    1.372680
2  log_Electricity_Consumption    1.146284
3                     Share_RES    1.258065
4                         Taxes    1.317333
5                   Share_Solar    1.076183
6                     Year_2021    1.144137
7                     Year_2022    1.277496

===== VIF - Regresión 8 =====
            Variable          VIF
1      log_Gas_Price     1.486082
2           log_HICP     1.244600
3  log_Gov_Subsidies     1.232853
4              Taxes     1.283975
5        Share_Hydro     1.098732
6          Year_2021     1.244123
7          Year_2022     1.315031

===== VIF - Regresión 9 =====
                Variable          VIF
1  log_Heating_Oil_Price    1.422352
2      log_Gov_Subsidies    1.209443
3                  Taxes    1.251568
4            Share_Eolic    1.190422
5              Year_2021    1.165694
6              Year_2022    1.486142
```

Variables	Regresión 1	Regresión 2	Regresión 3	Regresión 4	Regresión 5	Regresión 6	Regresión 7	Regresión 8	Regresión 9
log_Gas_Price	0.5665 (0.0000***)	0.5097 (0.0000***)	0.6789 (0.0000***)	0.5124 (0.0000***)	0.4641 (0.0000)	0.4817 (0.0000***)	0.5107 (0.0000***)	0.3999 (0.0000***)	
log_Electricity_Consumption	-0.0209 (0.3068)			0.0053 (0.8680)			(-0.0464) (0.0087***)		
Share_RES	0.0040 (0.0549*)	0.0026 (0.2722)		0.0041 (0.0677*)	0.0024 (0.3049)	0.0028 (0.1270)	0.0005 (0.7914)		
Share_Solar	-0.0009 (0.4143)			-0.0008 (0.5772)			0.0000065 (0.9948)		
log_PPP		-0.0345 (0.3946)							
log_Num_Retailers		0.0163 (0.6663)				0.0375 (0.2255)			
Switching_Rate	0.0063 (0.7057)	0.0063 (0.7057)	(-0.0234) (0.0601*)						
Share_Hydro					(-0.0026) (0.0870*)			-0.0017 (0.1878)	
log_Gov_Subsidies			0.0214 (0.2296)		0.0425 (0.1550)			0.0304 (0.1912)	0.0928 (0.0003***)
Share_Eolic			0.0047 (0.0072***)			0.0046 (0.0033***)			0.0021 (0.2459)
log_HICP				-0.0887 (0.3407)	(-0.1417) (0.0742*)	(-0.1511) (0.0141**)		(-0.1885) (0.0026***)	
Market_Share_Main_Supplier				-0.00001 (0.9943)		-0.0009 (0.6268)			
Taxes							3.6696 (0.0000***)	3.3701 (0.0000***)	4.3067 (0.0000***)
log_Heating_Oil_Price									(-0.3787) (0.0000***)
R2_Within	0,6766	0,7004	0,6356	0,6883	0,6719	0,681	0,7811	0,7876	0,054
Observations	96	96	96	96	96	96	96	96	96
Note: Standard errors are clustered at country level. Statistical significance is represented by pvalue as follows p<0.01***, p<0.05**, p<0.1*									