

Highlights

Regional Inequality of the European ETS-2

Sigit Perdana, Marc Vielle

- The regressive nature of ETS-2 disproportionately affects lower-income households.
- Regions with fossil fuel reliance and limited low-carbon infrastructure face high burdens.
- Regions from Bulgaria, Hungary, and Poland are the most exposed regions.
- Vulnerable regions need direct subsidies and renewable energy incentives.
- Long-term solutions include energy-efficient housing and better public transport.

Regional Inequality of the European ETS-2

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Abstract

This groundbreaking study exposes the unequal burden of the EU's second Emissions Trading System (ETS-2) on households across 1,160 European regions, transforming how we understand the intersection of climate policy and social equity. By integrating household survey data, economic modeling, and spatial mapping, it reveals the stark implications of a projected carbon price of € 100 per ton of CO₂ by 2030 on heating and transportation costs. The findings show that ETS-2 risks deepening socioeconomic divides—especially for low-income, rural households with larger families—amplifying already existing vulnerabilities. Most alarmingly, regions with lower GDP per capita, particularly in Central and Eastern Europe, are hit hardest. This study not only reaffirms the regressive nature of carbon pricing mechanisms but also delivers a wake-up call for policymakers: without regionally targeted and socially just mitigation measures, ETS-2 could widen inequality across Europe. The insights offered here are essential for shaping a climate transition that is not only green, but also fair.

Keywords: ETS-2, Fit for 55, Energy expenditure, Regional heterogeneity, Equity, European climate policy

1. Introduction

The European Union Emissions Trading System-2 (EU ETS-2) is a new carbon pricing mechanism designed to cover emissions from buildings and

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road transport sectors, complementing the existing EU ETS (European Commission, 2021b). Set to become fully operational in 2027, the EU ETS-2 will operate on a 'cap-and-trade' principle, targeting upstream emissions. It aims to reduce emissions in these sectors by 42% by 2030 compared to 2005 levels, by full auction of allowances. To ensure price stability, a mechanism has been incorporated to release additional allowances if prices exceed € 45 per ton of CO₂ during the first three years of operation (Edenhofer et al., 2021; Eden et al., 2023).

The implementation of EU ETS-2, however, has raised significant concerns about its potential to exacerbate economic inequality. Critics argue that the system could disproportionately burden low-income households, which are more dependent on fossil fuels for heating and transport (van den Bergh et al., 2024). These concerns lie on a fundamental consideration in climate policies due to its multifaceted relationship with climate change (Feindt et al., 2021), following a broad consensus that energy policies impact sectors, household groups, and geographical regions differently. A poorly designed climate policy can exacerbate existing inequalities, while a well-designed that address both climate change and inequality can foster more equitable societies and increase public support for climate action.

Add to this, the energy transition has the potential to exacerbate regional inequalities (Keuchel and Lohrmann, 2024) and intensify resistance to European policies and infrastructure development (Rodríguez-Pose and Bartalucci, 2024). With the introduction of a new carbon price under the EU ETS-2, which will apply to household heating and transportation expenditures, there is a heightened risk of disproportionately impacting lower-income households and economically disadvantaged regions (Antosiewicz et al., 2022). Understanding the distributional effects of ETS-2 is therefore crucial to ensuring that the policy achieves its climate objectives while mitigating social and regional disparities. A comprehensive analysis of these effects is essential for inclusive planning processes (Hanna Lempinen and Korpikoski, 2025) including the design of compensatory mechanisms to enhance public acceptance of this critical transition toward a low-carbon economy (Muth et al., 2024). In this context, the implementation of the EU ETS-2 requires a rigorous assessment of its implications for inequality.

This paper examines the impact of the new ETS-2 price on household expenditures through a detailed distributional analysis, mapping 1,160 regions across Europe. This approach addresses a significant gap in existing research, which predominantly focuses on inequalities between countries or

among different household types (e.g., Emmerling et al. (2024)), without accounting for regional disparities. The objective is to provide a comprehensive understanding of how household size, composition, and regional characteristics shape the overall effects of ETS-2 on energy consumption and related costs. Specifically, the analysis examines the impact of the ETS-2 price on household spending for heating and transportation, incorporating both household-level and regional heterogeneity. By complementing recent studies that assess the distributional effects of ETS-2 based on income deciles or quintiles at the Member State level (e.g., Görlach et al. (2022); Held et al. (2022)), this study scrutinizes the regions most affected due to regional inequalities.

The structure of the paper is as follows: Section 2 provides an overview of the current EU ETS-2 proposal and reviews existing studies on its impacts, highlighting research gaps that inform the analytical scope and research question. Section 3 describes the methodology employed, followed by Section 4, which presents the analysis and results. Finally, Section 5 offers the conclusions of the study.

2. New Architecture of EU ETS-2 and Current Impact Analysis

2.1. From Concept to Action: The Role of ETS-2 in Achieving 2030 Goals

As part of the Fit for 55 package (European Commission, 2021a), the EU introduced a new ETS for buildings and road transport (ETS-2), aimed at reducing emissions in these sectors starting in 2027. This initiative complements existing measures within the Fit for 55 framework, which seeks to cut EU greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels (Agora Energiewende and Ecologic Institute, 2021). Other key elements include strengthening the existing ETS, raising renewable energy targets to 40%, enhancing energy efficiency, introducing a Carbon Border Adjustment Mechanism (CBAM), banning new internal combustion engine cars by 2035, and establishing SCF to mitigate the social impacts of ETS-2.

As it is designed to complement the existing ETS by covering CO₂ emissions that are not included by the existing ETS (Leenders et al., 2024), the CO₂ emissions that are included in ETS-2 come from buildings (primarily heating), road transport, and some additional sectors that include mainly small industries. The ETS-2 will cover emissions upstream (Braungardt et al., 2024), meaning that the obligation to surrender allowances will fall on the fuel suppliers rather than end-consumers. Allowances will initially

be primarily freely allocated, but will transition to full auction. To mitigate excessive price increases, additional allowances may be released from the market stability reserve if prices exceed € 45 during this period. The ETS-2 cap targets a 42% emissions reduction by 2030 compared to 2005 levels. To address the social impacts associated with this policy, the SCF has been established, financed through ETS-2 revenues. Member States can utilize this fund to support energy efficiency improvements, building renovations, the adoption of clean heating systems, the integration of renewable energy, and the promotion of zero-emission mobility. Additionally, the fund may provide direct income support to vulnerable groups, if necessary.

2.2. The ETS-2: Current Analysis

Initial works analysing ETS-2 have focused on the broader Fit for 55 package, emphasizing the costs associated with increasing abatement efforts (Boitier et al., 2023), rather than explicitly assessing the specific impacts of the EU ETS-2. A notable recent study by Chateau et al. (2023) provided a comprehensive analysis using the OECD’s ENV-Linkages model as part of the Fit for 55 framework, yet it only offers a general overview of the EU’s climate targets and does not delve into the detailed impacts of EU ETS-2. Crucially, there is no estimation of the EU ETS-2 price and, therefore, omits an analysis of its economic implications. The study merely reports that 5% of the abatement target under EU ETS-2 could be achieved, estimating a carbon price should be lower than the current EU ETS market price (projected at € 178 in 2030).

Other initial studies, however, offer valuable insights relevant to the broader scope of EU climate policy, including the planned expansion to the ETS-2. The EU’s introduction of the ETS-2 aims to address the challenge of reducing carbon emissions in the buildings and transport by imposing a carbon price on these sectors. The impact of carbon pricing will primarily fall on consumers (Funke et al., 2024), and it could disproportionately affect vulnerable households, particularly those with lower incomes (Ohlendorf et al., 2020) or higher energy dependencies (Semet, 2024).

The EU ETS-2 price mechanism will function similarly to a fuel tax due to its upstream implementation on fuel suppliers, who are expected to pass the costs to consumers through higher fuel prices (Abrell et al., 2024). This system will apply uniformly across the EU, increasing prices for various fuels used in buildings and transport. Like a fuel tax, it will create a financial

incentive for consumers to reduce fuel consumption or switch to cleaner alternatives, while also generating revenue for climate action and social measures. The key difference is that ETS-2 specifically targets CO₂ emissions, but its effect on consumers and the market will closely resemble that of a traditional fuel tax.

A key consideration is the regressive nature of these fuel taxes and their uneven impact across income groups (Rodríguez-Pose and Bartalucci, 2023; Fratesi, 2025). Jacobs et al. (2022) highlights that the current fuel tax regime disproportionately affects low-income households, particularly through petrol taxes, whereas diesel taxes exhibit a progressive effect. Using Germany as a case study, the research demonstrates that fuel taxes represent a larger proportion of disposable income for low-income households compared to wealthier ones. Similarly, Sterner (2012) and Linden et al. (2024) confirm that fuel taxes are generally regressive in high-income countries, though their effects vary significantly across socio-economic groups. These findings emphasize the need to understand such impacts to develop measures that mitigate adverse effects on vulnerable households.

Addressing the distributional effects of carbon taxes is essential, as implementing such measures without addressing their regressive nature risks exacerbating social and economic inequalities (Wallenko and Bachner, 2025). Vona (2023) emphasizes the complexity of distributional impacts in climate policies, underscoring the importance of approaches that account for household characteristics and consumption patterns. Similarly, Amores et al. (2023) highlight that the redistributive effects of energy taxation are closely tied to household expenditure allocation, particularly for energy-related expenses. The challenge lies in designing socially equitable carbon pricing mechanisms, as poorly implemented policies could exacerbate energy and transport poverty if not accompanied by robust compensatory measures (Feindt et al., 2021).

The ETS-2 introduces a carbon price on emissions from direct fuel combustion, including fossil fuel heating in buildings, aiming to incentivize the transition to cleaner heating systems. However, carbon pricing could lead to substantial increases in energy bills, potentially exceeding the levels seen during the 2022 energy crisis if decarbonization efforts fall short and prices escalate (Keliauskaite et al., 2025).

2.3. Distributional Impacts of European Carbon Taxation

Several assessment reports have analyzed the distributional effects of ETS-2, consistently highlighting its regressive nature in the context of carbon pricing. A recent report by the German Federal Ministry for Economic Affairs and Climate Action (Eden et al., 2023) estimates the distributional impacts of ETS-2, emphasizing its disproportionate effect on low-income households due to rising energy costs. The report advocates for targeted support through the SCF and increased stakeholder engagement to address energy and transport poverty. Similarly, an assessment by the German Government Council (Held et al., 2022) identifies criteria for equitable carbon pricing, emphasizing the need for a holistic policy mix, fair cost distribution among EU member states, and further refinement of the SCF to mitigate regressive impacts on vulnerable groups.

Recent study by Rüb (2024) provides a comparative analysis of a carbon tax on transport and heating fuels across seven EU countries (Germany, France, Spain, Poland, Finland, Hungary, and Ireland), using Eurostat’s Household Budget Survey (HBS) data and advanced inequality measures. The study finds that implementing a carbon tax without revenue recycling consistently exacerbates inequality, though the extent varies across countries. These findings align with reports from the Institute for European Environmental Policy (Gore et al., 2022) and the Institute for Sustainable Development and International Relations (Berghmans, 2022), which explore the interaction between ETS-2 and Energy Taxation Directive (ETD) reforms. Their analyses suggest that while reducing electricity taxes may benefit low-income households, increased fossil fuel taxes could disproportionately burden rural and middle-income households, highlighting the necessity of robust redistribution measures.

Further supporting this perspective, Stenning et al. (2021) from Cambridge University demonstrate that revenue recycling—through tax reductions, lump-sum transfers, or investments in low-carbon technologies—can mitigate adverse effects on GDP and employment while facilitating a just transition for households and industries. Similarly, Frondel and Schubert (2021) and Vandyck et al. (2022) emphasize the importance of compensatory measures in alleviating the regressive impacts of carbon pricing and balancing economic efficiency with social equity. Together, these studies underscore the critical role of redistribution mechanisms in ensuring that carbon pricing policies under ETS-2 are both economically viable and socially equitable.

Despite the valuable insights provided by these studies, significant research gaps remain. Key among these are the sectoral and geographical variations in ETS-2 impacts, as well as the effects on diverse household compositions, particularly in energy-poor regions. While Rüb (2024) highlights that the distributional effects of a carbon tax vary across countries due to differences in energy consumption patterns and economic conditions, the analysis is limited to a select group of countries rather than offering a broader regional assessment of ETS-2’s impact on household expenditures across Europe.

To inform equitable policy design, comprehensive and longitudinal studies are needed (Douenne and Fabre, 2022; Sarmiento et al., 2024). In particular, more detailed analyses should examine the differentiated effects of ETS-2 on household expenditures related to heating versus transportation across EU regions. Although the German assessment report (Eden et al., 2023) briefly addresses this issue, it lacks the depth necessary for a broader, more nuanced understanding.

Furthermore, an EU-wide analysis addressing geographical variations is essential. Although some studies highlight disparities between urban and rural households, in-depth research is needed on the impact of ETS-2 on different household compositions (e.g., single-parent families) beyond income categories such as quintiles or deciles. Similarly, while energy poverty has been acknowledged in existing literature, further analysis is required to assess how ETS-2 affects energy-poor households across various EU regions. A cross-country comparative analysis of ETS-2’s impacts across all EU member states would be invaluable for crafting policies that ensure fairness and equity in the transition to a low-carbon economy.

3. Data and Methodology

To provide a deeper understanding of how household size, composition, and regional characteristics influence the overall impact of ETS-2 on energy consumption and related costs, this paper employs a comprehensive methodology integrating household survey data, econometric estimates, and geographic information systems (GIS).

First, based on a review of existing literature, including Günther et al. (2024) and Rüb (2024), the analysis assumes an ETS-2 carbon price of € 100 per ton of CO₂ by 2030. This value represents the average within a projected range of € 71 to € 261 per ton, depending on the stringency of complementary energy efficiency policies, often used as a reference point to evaluate

the economic implications of carbon pricing and its effectiveness in achieving emission reduction targets while considering social equity. Strong policies are expected to lower the carbon price, while less stringency could result in significantly higher costs.

Second, data from the International Energy Agency (IEA)¹ on household energy prices are utilized to estimate the expected price increases for heating and transport fuels across the 27 EU Member States. These price estimates are integrated into a European Household Budget Survey (HBS),² which segments households into 60 categories based on three dimensions: income quintiles, urban versus rural locations, and family composition.

The survey categorizes households database into five income groups and defines urban areas as those with a population density of at least 500 inhabitants per square kilometer. Additionally, it classifies households into six types based on family composition. For each of these 60 household types, the anticipated increases in heating and transport costs due to the ETS-2 carbon price are calculated. These expenditure increases are then analyzed through econometric estimations to examine how various household characteristics shape the distributional impacts, offering a detailed assessment of the financial burden imposed by ETS-2 across different household types in Europe.

To further enhance the analysis, the results of econometric modeling are combined with a GIS-based spatial analysis at the NUTS-3 level, using data from the Eurostat database. This integration allows for the mapping of ETS-2 impacts across 1,160 European regions, identifying areas most affected by increased heating and transport costs. The analysis incorporates several indicators, including the percentage increase in household expenditures and an exposure index that highlights regions most vulnerable to these impacts. This methodology, which integrates household survey data, econometric estimates, and GIS to assess the regional impacts of ETS-2 on household expenditures, provides a valuable approach for identifying spatial disparities. By incorporating these analytical tools, it addresses the need for a more comprehensive assessment of climate policies within a broader socioeconomic context, as highlighted in Mikropoulos et al. (2025).

¹<https://www.iea.org/data-and-statistics/data-tools/end-use-prices-data-explorer?tab=Yearly+prices>

²<https://ec.europa.eu/eurostat/web/household-budget-surveys/database>

Figure 1 below provides an overview of this methodological framework, illustrating the step-by-step process used to evaluate the distributional effects of ETS-2. This approach ensures a nuanced understanding of the economic implications, accounting for disparities in income, location, and family structure across Europe.

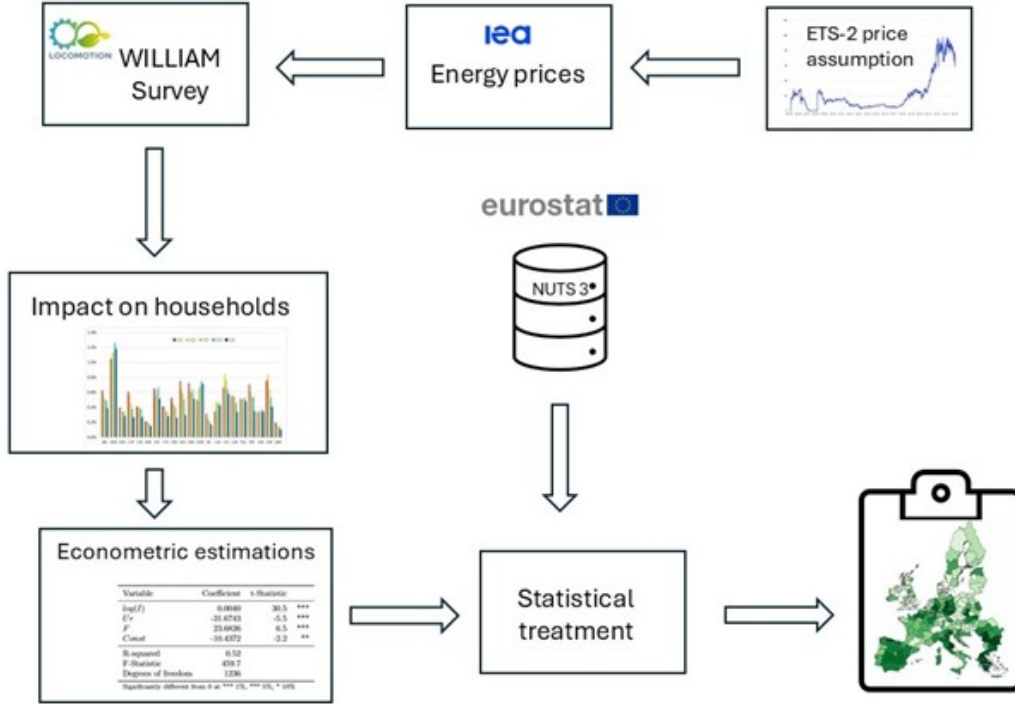


Figure 1: Methodological overview

4. Results and Analysis

4.1. Impact of an ETS-2 price on Households Energy Prices

Using data from the IEA and Eurostat databases, consumer prices for automobile diesel, motor gasoline, natural gas, heating oil, and coal were computed for the year 2023 for each European country. With an ETS-2 carbon price of € 100 per ton of CO₂ and factoring in the CO₂ content of each fossil fuel, the resulting price increases for heating and transport fuels were calculated. The analysis accounts for the level of dieselization in each

country (i.e., the share of diesel cars in the total passenger car fleet) and the proportion of coal in solid fuel consumption, which also includes wood.

Table 1 presents these price increases. For petroleum fuels, the increases are relatively comparable, ranging from 12.3% to 19.1% for transport fuels and 13.5% to 29.3% for heating oil. However, the projected increases in natural gas prices show significant variation, reflecting differences in countries' access to gas supplies and their tax structures. For instance, gas prices are projected to rise by 60.5% in Hungary and 44.9% in Croatia, while the increases in Sweden and Finland are much lower, at 9.5%.

Coal used for heating is (Heating Solid) limited in most European countries, accounting for an average of just 2.5% of household energy consumption in the EU (Gajdzik et al., 2023). However, its share is considerably higher in certain countries, such as Poland (24.6%), Ireland (11.6%), the Czech Republic (8.9%), and Bulgaria (4.2%), resulting in correspondingly higher increases in solid fuel prices in these regions.

These calculated price increases were integrated into a household budget survey, enabling the estimation of the additional spending on heating and transport for households across different countries. This approach provides a detailed assessment of the financial burden that ETS-2 could impose on household energy expenditures.

4.2. Impact on Households Expenditures

In integrating the change in energy price to the HBS, the WILLIAM European Household Database (Tomás et al., 2021) is utilized for the analysis. This database is developed within the Horizon 2020 European project LOCOMOTION³ that enables the classification of 60 distinct household types across each European Member States from the EU HBS by integrating three key dimensions. First, it categorizes households into five income groups: the first quintile (Q1), second quintile (Q2), third quintile (Q3), fourth quintile (Q4), and fifth quintile (Q5). Second, the database differentiates between urban and rural households, with urban areas defined as those having at least 500 inhabitants per square kilometer. Lastly, it distinguishes between six household types: single adults without children (S1), single adults with children (S2), couples without children (C1), couples with children (C2), other types of households without children (O1), and other types of households

³see: <https://www.locomotion-h2020.eu/>

Table 1: Fossil fuel price increase for households with an ETS-2 price equal to 100 €

	Heating Solid	Heating Gas	Heating Oil	Transport Fuel
Austria (AUT)	0.2%	12.3%	20.6%	15.3%
Belgium (BEL)	1.7%	18.8%	26.4%	14.3%
Bulgaria (BGR)	3.0%	25.5%	23.9%	18.2%
Croatia (HRV)	0.1%	44.9%	29.3%	16.3%
Cyprus (CYP)	0.0%	18.6%	23.3%	16.2%
Czech Republic (CZE)	21.3%	15.5%	24.1%	15.8%
Denmark (DNK)	0.0%	14.1%	13.5%	12.2%
Estonia (EST)	0.1%	21.5%	21.9%	14.6%
Finland (FIN)	0.1%	9.5%	17.4%	12.3%
France (FRA)	0.1%	17.4%	19.7%	13.8%
Germany (DEU)	1.4%	15.1%	24.1%	13.4%
Greece (GRC)	0.1%	18.6%	19.6%	12.6%
Hungary (HUN)	4.9%	60.5%	15.4%	15.2%
Ireland (IRL)	27.1%	13.5%	24.4%	14.8%
Italy (ITA)	0.0%	16.2%	16.1%	13.4%
Latvia (LVA)	0.1%	17.0%	21.9%	15.4%
Lithuania (LTU)	2.0%	11.7%	26.0%	16.6%
Luxembourg (LUX)	0.5%	13.9%	26.6%	16.1%
Malta (MTL)	0.0%	18.6%	25.7%	19.1%
Netherlands (NLD)	0.0%	11.5%	26.4%	12.7%
Poland (POL)	31.4%	27.8%	20.4%	16.9%
Portugal (PRT)	0.0%	14.5%	15.7%	15.1%
Romania (ROU)	0.4%	36.5%	18.5%	17.4%
Slovak Republic (SVK)	8.1%	16.4%	24.1%	14.9%
Slovenia (SVN)	0.0%	19.9%	22.6%	15.1%
Spain (ESP)	0.7%	18.6%	23.7%	15.6%
Sweden (SWE)	0.0%	9.5%	22.2%	13.3%

with children (O2).

The database does not include data for six European countries: Austria and the Netherlands are missing due to a lack of data, while Italy, Romania, Slovenia, and Malta are incomplete. The data, which is from the year 2015, is expressed in US\$₂₀₁₅ and includes final consumption expenditure by households, categorized by consumption purpose according to the Classification of Individual Consumption According to Purpose (COICOP). Additionally, it provides information on household size, income receipts, and savings, with a detailed list of variables available in Appendix A.

From this database, expenditures on heating fuels (solid fuels, gas, liquid fuels) and transport fuels are extracted for the 60 household types. Disposable income data is also incorporated. Figures 2 and 3 illustrate the percentage increase in expenditure relative to disposable income across income quintiles. The impacts vary significantly across Member States. In particular, the carbon price on heating is highly regressive, though there are notable exceptions in countries like Denmark, Estonia, Finland, Slovakia, and Sweden. Similarly, the impact on transport expenditure is also regressive, with exceptions in Bulgaria, Estonia, Hungary, Latvia, Poland, and Slovakia. The orders of magnitude observed are comparable to those cited in the WWF impact studies (WWF, 2022), although variations in country hierarchies may arise due to differences in assumptions and data sources, making direct comparisons inconclusive. Additional figures scrutinizing other dimensions (location, family composition) are provided in Appendix B.

4.3. Regression Analysis of Expenditure Increases

A regression analysis is conducted to provide a comprehensive understanding of how household size, composition, and regional characteristics influence the overall effects of ETS-2 on energy consumption and related expenditures, specifically for heating and transport. The analysis utilizes a dataset comprising 1,260 distinct household types, representing 60 household categories across 21 countries. Key explanatory variables include family composition (e.g., single, single with children, couple), urban or rural location, disposable income, heating degree days (applicable only for heating), and country-specific intercepts (Table 2). These variables enable a detailed evaluation of the variation in energy expenditure increases across different households and regions, shedding light on the distributional impacts of the ETS-2.

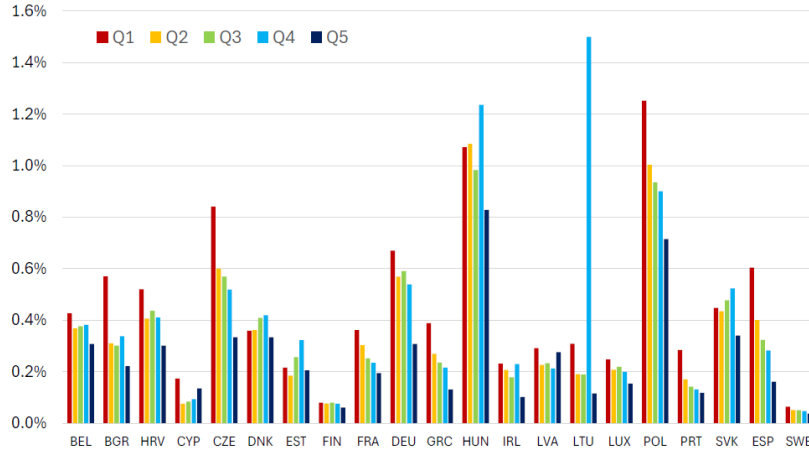


Figure 2: Increase of heating expenditure in % of disposable income per quintile and country

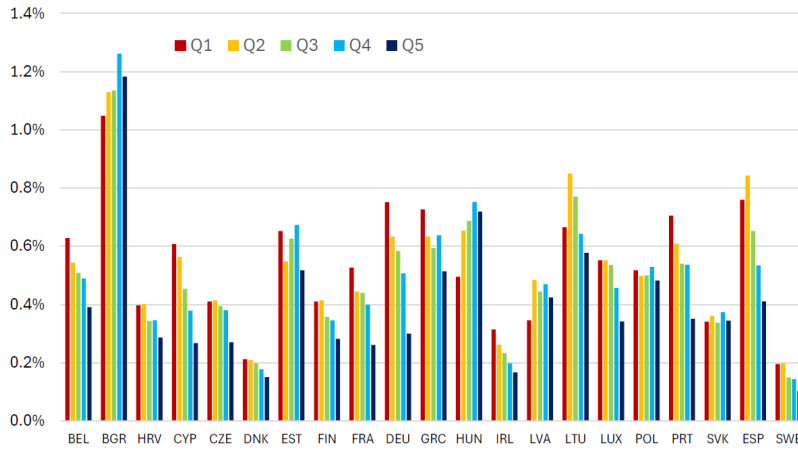


Figure 3: Increase of transport expenditure in % of disposable income per quintile and country

4.3.1. Regression Results: Transport Expenditure

Table 3 presents the regression results for the relationship between household composition and regional characteristics and their impact on transport expenditures. The analysis reveals that larger households experience a greater increase in transport costs, while households in rural areas bear higher transportation costs compared to their urban counterparts. These findings align with previous studies, such as Wadud et al. (2009), who re-

Table 2: Data used in the regressions

Variable	Description	Source	Unit
E_H	Heating fuel expenditure increase	WILIAM database	US \$ converted in € 2015
E_T	Transport fuel expenditure increase	WILIAM database	US \$ converted in € 2015
I	Disposable income	WILIAM database	US \$ converted in € 2015
U_r	Type of area	WILIAM database	Urban=1, Rural=0
F	Family composition	WILIAM database	†
HDD	Heating degree days (year 2015)	Eurostat	degree
F_j	Country specific effects		1 if the household lives in this country

†: Single=1; Single with children=1.5; Couple=2; Couple with children=2.5; Other=3; Other with children=3.5

ported higher fuel consumption among rural households in the United States, and Berry (2019), who observed similar patterns in France. The econometric estimation demonstrates strong validity, with an R^2 value of 0.82, and all coefficients are statistically significant with expected signs, reinforcing the robustness of the results. A more recent study of Keuchel and Lohrmann (2024) also highlights these regional disparities, noting that households in rural areas are more affected by rising fuel prices compared to those in urban centers.

The inclusion of country fixed effects significantly enhances the model’s explanatory power by accounting for unobserved, time-invariant country-specific factors. This approach minimizes the bias of the omitted variables by controlling for characteristics unique to each country, thus isolating the variation within the country of the variables under analysis. The estimated coefficients reflect the average effect of the independent variables on the dependent variable within countries, rather than across countries. By capturing the distinct economic, social, and environmental contexts of each country, the fixed effects framework enables a more precise assessment of how household composition and regional characteristics shape energy expenditures.

The high coefficient value for fixed effects in explaining transport costs suggests a greater unobserved, time-invariant heterogeneity across countries in transport-related expenditures. This indicates that country-specific factors, such as geography, infrastructure, or long-standing policies, exert a stronger influence on transport costs. Additionally, the variation in transport costs between countries, not captured by the observed variables, is more pronounced.

A similar regression analysis is then conducted on the increase in transport energy expenditure resulting from a 1% rise in oil prices (denoted as $\overline{E_T}$),

Table 3: Regression on transport expenditure E_T with country-specific effects

Variable	Coefficient	t-Statistic
I	0.0077	21.8***
I^2	-3.45618E-08	-12.0***
Ur	-31.0937	-9.7***
F	16.7753	6.7***
ESP	191.1672	18.2***
SVK	129.6248	11.6***
PRT	150.6891	14.0***
POL	169.5824	14.9***
LUX	355.8678	33.8***
LTU	191.7235	17.1***
LVA	147.8394	12.9***
IRL	52.9735	5.2***
HUN	198.4989	16.7***
GRC	163.3045	15.4***
DEU	184.0693	17.9***
FRA	127.0759	12.4***
FIN	108.9093	10.6***
EST	189.1115	16.6***
DNK	25.7105	2.5**
CZE	139.1676	12.2***
CYP	96.6883	9.3***
HRV	136.9857	11.9***
BGR	242.9977	19.3***
BEL	200.7175	19.5***
$Const$	-219.1779	-20.2***
R-squared	0.82	
F-Statistic	238.3	
Degrees of freedom	1235	

Significantly different from 0 at *** 1%, *** 5%, * 10%

excluding country-specific effects among the explanatory variables. This estimation is designed to address gaps in the household budget survey for countries such as Austria, the Netherlands, Italy, Romania, Slovenia, and Malta. The results, shown in Table 4, demonstrate that while the estimation quality is lower than in the previous model, with an R^2 value of 0.59, it remains sufficiently robust for analytical purposes. Additionally, the coefficients maintain their expected signs, underscoring the reliability of the model for application to the excluded countries.

Table 4: Regression on transport expenditure $\overline{E_T}$ without country-specific effects for one percent price increase

Variable	Coefficient	t-Statistic
I	0.00036	15.5***
I^2	-9.13374E-10	-3.9***
Ur	-2.1098	-6.6***
F	1.5009	7.2***
$Const$	-2.4412	-4.2***
R-squared	0.59	
F-Statistic	454.82	
Degrees of freedom	1255	

Significantly different from 0 at *** 1%, *** 5%, * 10%

4.3.2. Regression Results: Heating Expenditure

A distinct regression analysis is conducted for heating expenditures by normalizing energy expenditure based on heating degree days (HDD) and subsequently applying a logarithmic transformation to this variable. The explanatory variables also include the logarithm of disposable income to account for its influence on heating costs. The results, presented in Table 5, reveal an R^2 value of 0.7, indicating a strong explanatory power for the model. All variables included in the estimation are statistically significant and exhibit the expected signs, effectively explain variations in heating costs across household types and regions.

The analysis reveals a positive and statistically significant relationship between disposable income and heating expenditures, indicating that higher-income households tend to incur greater energy costs, consistent with increased energy consumption among wealthier households. The negative coefficient for urban residence highlights that urban households generally face

lower heating costs compared to their rural counterparts, likely due to differences in housing characteristics and heating system efficiencies. This finding aligns with Mata et al. (2021), who observed lower heating demands among urban households.

Furthermore, the positive and significant association between family composition and heating expenditures underscores the influence of household size on energy demand, as larger households require more energy resources. This aligns with findings by Mata et al. (2021); Trotta et al. (2022), who demonstrated that variables reflecting dwelling size, such as floor area, number of bedrooms, or lot size, are positively correlated with energy demand, thereby explaining the impact of family size on heating costs in the estimation.

For countries excluded from the sample, the increase in energy expenditure resulting from a 1% rise in energy prices is estimated separately for each fossil fuel type, including solid fuels, natural gas, and heating oil. The corresponding estimates are presented in Tables 6, 7, and 8. While these estimates provide a basis for understanding expenditure changes, the quality of the model adjustments is notably lower, indicating reduced explanatory power compared to the primary sample.

Table 5: Regression on heating expenditure ($\ln(E_H/HDD)$) with country-specific effects

Variable	Coefficient	t-Statistic
$\ln(I)$	0.9311	16.4***
Ur	-0.3087	-8.6***
F	0.1079	3.8***
ESP	3.0267	25.9***
SVK	2.5954	21.1***
PRT	2.5345	21.3***
POL	3.4725	27.4***
LUX	2.2641	19.5***
LTU	1.6222	13.0***
LVA	1.7506	13.7***
IRL	1.8880	16.5***
HUN	3.5564	21.8***
GRC	2.5646	21.8***
DEU	2.6833	23.3***
FRA	2.6129	22.8***
FIN	0.3703	3.2***
EST	1.5615	12.3***
DNK	2.2902	19.9***
CZE	2.8976	22.9***
CYP	2.2462	19.4***
HRV	2.8953	22.6***
BGR	2.1830	14.7***
BEL	2.5949	22.6***
$Const$	-15.5312	-26.7***
R-squared	0.70	
F-Statistic	1258	
Degrees of freedom	1255	

Significantly different from 0 at *** 1%, *** 5%, * 10%

Table 6: Regression on solid heating expenditure ($\ln(\overline{E_H}/HDD)$) without country-specific effects for one percent price increase

Variable	Coefficient	t-Statistic
$\ln(I)$	0.3097	7.1***
Ur	-0.9469	-18.1***
F	0.1807	5.3***
$Const$	-11.2238	-26.7***
R-squared	0.26	
F-Statistic	148.6	
Degrees of freedom	1256	
Significantly different from 0 at *** 1%, *** 5%, * 10%		

Table 7: Regression on gas heating expenditure ($\ln(\overline{E_H}/HDD)$) without country-specific effects for one percent price increase

Variable	Coefficient	t-Statistic
$\ln(I)$	0.2042	1.19*
Ur	-0.0202	-0.10*
F	1.2733	9.46***
$Const$	-12.4749	-7.60***
R-squared	0.09	
F-Statistic	41.7	
Degrees of freedom	1256	
Significantly different from 0 at *** 1%, *** 5%, * 10%		

Table 8: Regression on oil heating expenditure ($\ln(\overline{E_H}/HDD)$) without country-specific effects for one percent price increase

Variable	Coefficient	t-Statistic
$\ln(I)$	6.0694	15.1***
Ur	-2.6579	-5.5***
F	-1.0900	-3.5***
$Const$	-72.1479	-18.2***
R-squared	0.16	
F-Statistic	85.39	
Degrees of freedom	1256	
Significantly different from 0 at *** 1%, *** 5%, * 10%		

4.4. Impact at Regional Level: Spatial Disaggregation and Mapping

The regional impact of an ETS-2 price on heating and transport energy expenditures is analyzed and mapped to provide a comprehensive understanding of its spatial distribution. This analysis integrates econometric modeling results with a GIS-based spatial framework at the NUTS-3 level, utilizing data from the Eurostat database. The integration enables the mapping of ETS-2 impacts across 1,160 European regions, highlighting areas most affected by increased energy costs.

Exogenous variables used in the regressions are extracted from Eurostat at the NUTS-3 level, requiring extensive efforts to consolidate various data sources, address missing values for certain regions, and harmonize regional definitions in light of changes to names and boundaries. Spatial disaggregation to the NUTS-3 level is performed using methods outlined in Table 9. For regions in countries not represented in the household budget survey, econometric estimates of the impact of a 1% energy price increase are applied, with adjustments based on the price increases detailed in Table 1.

Table 9: NUTS-3 variables

Variable	Source	Name
HDD	Eurostat	Heating degree days by NUTS-3 region - Averaged years 2019-2023
Ur	Eurostat	Urban-rural typology (1=predominantly urban, 0=predominantly rural, 0.5=intermediate)
F	Eurostat	Family composition Computed from CENSUS 2011 round on families by type, size and NUTS-3 region
I	Eurostat	Disposable income Computed from disposable income at NUTS-2 level (I_j) and GDP per capita at NUTS-2 (GDP_j) and NUTS-3 level (GDP_i) for year 2015 $I_i = I_j \cdot \frac{GDP_i}{GDP_j}$ with $i \in j$

The average regional increase in energy expenditures due to heating is €125, while transport-related expenditures average €185. Both categories exhibit maximum increases of approximately €500. The distributions of these increases across regions are visualized in Figures 4 and 5, which provide histograms illustrating the variability in heating and transport costs among regions.

Further regional mapping reveals a somewhat scattered distribution of the impacts across regions. Central European regions, particularly in Germany and Austria, experience higher increases in transport expenditures, as

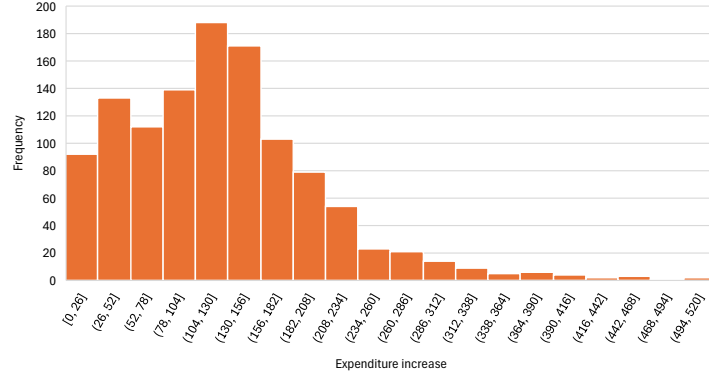


Figure 4: Histogram of heating expenditure increase in € by region

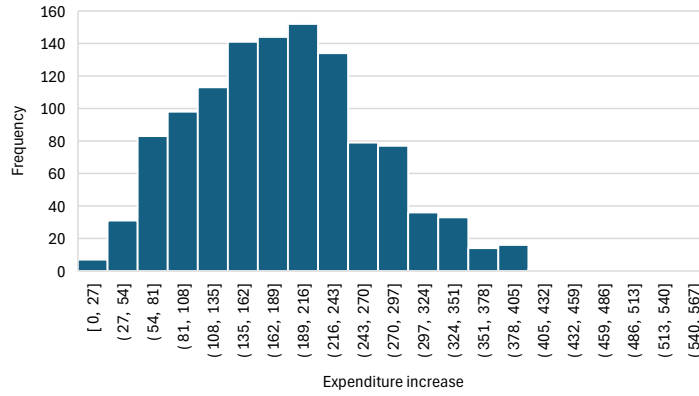


Figure 5: Histogram of transport expenditure increase in € by region

shown in Figure 6. In contrast, regions in Eastern Europe, such as Poland and Slovenia, exhibit more substantial increases in heating expenditures, as depicted in Figure 7, underscoring the geographical disparities in energy cost impacts driven by the ETS-2 price.

Regions in Central EU such as in Germany and Austria are likely to face

higher increases in transport costs under the implementation of the EU ETS-2 due to several factors. These countries have extensive road networks and significant reliance on road transport for goods and people heighten their susceptibility to increased fuel costs (Rodrigue, 2020). Germany's existing national carbon pricing system for heat and road transportation may also lead to transitional price adjustments under ETS-2 (Glaser, 2014), exacerbating short-term cost impacts. Furthermore, the strong industrial sectors in both countries, which depend heavily on transportation, render them more vulnerable to higher transport costs compared to less industrialized regions (Faber et al., 2014).

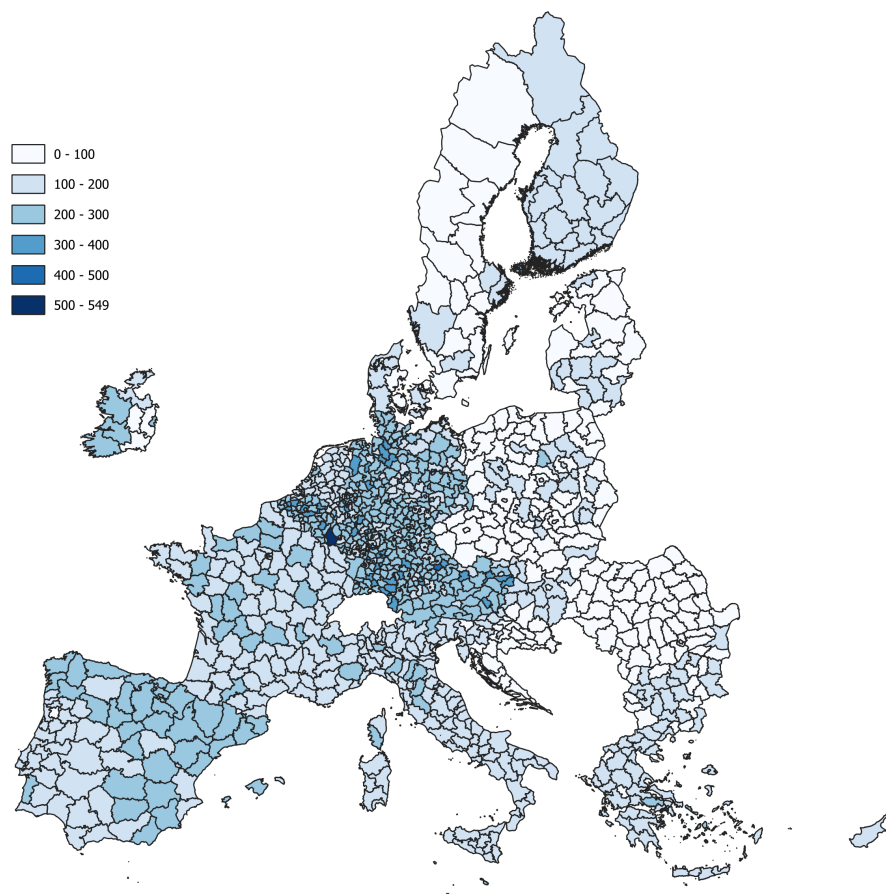


Figure 6: Increase of transport expenditure in € by regions

On the other hand, regions in Poland and Slovenia are likely to experi-

ence higher increases in heating costs due to their heavily reliance on fossil fuels for heating, particularly coal in Poland, making them more vulnerable to carbon pricing (Verma et al., 2023). Additionally, their underdeveloped low-carbon infrastructure, including limited adoption of near-zero emissions buildings and renewable energy systems, hampers their ability to transition away from carbon-intensive heating methods (Peszko et al., 2020). Slovenia's current carbon tax of € 17 per tonne, significantly lower than the anticipated ETS-2 prices, indicates a larger price jump upon implementation. Furthermore, the absence of stringent national climate policies may lead to a steeper adjustment for these regions as ETS-2 takes effect.

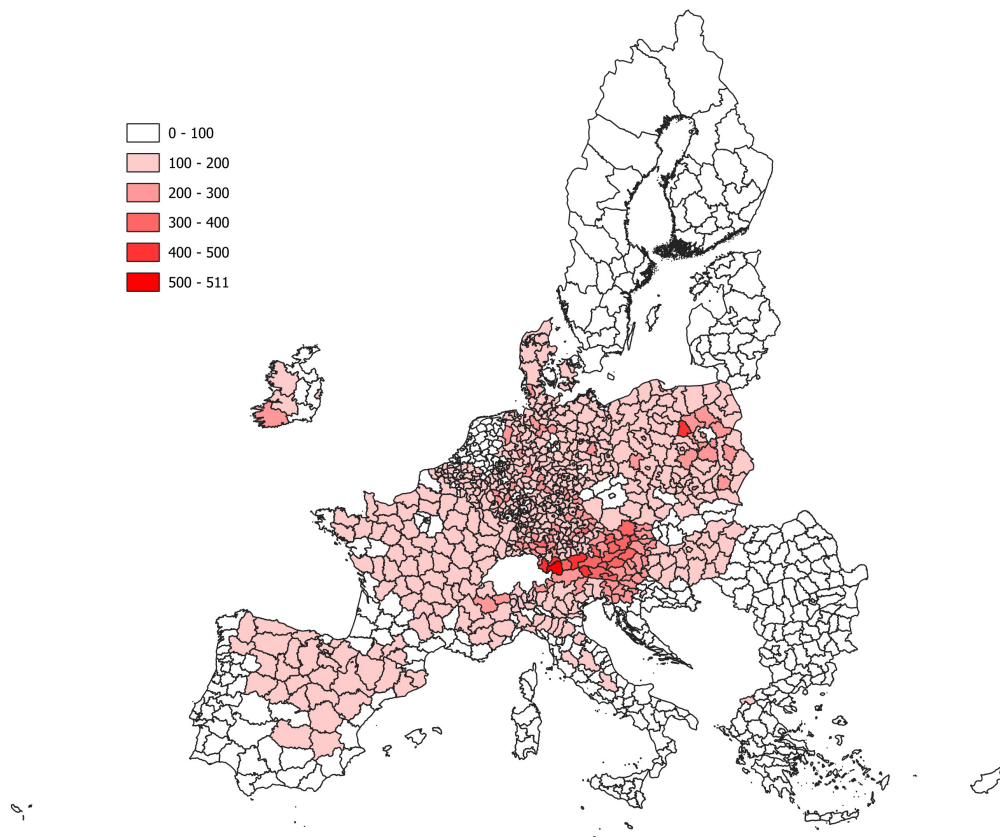


Figure 7: Increase of heating expenditure in € by regions

An exposure index was calculated for each region by considering disposable income, where total expenditure increases for transport and heating

were divided by disposable income and normalized to values between 0 (not exposed) and 1 (fully exposed). The resulting index, mapped in Figure 8, reveals significant regional disparities, with Poland, Bulgaria, Hungary, and Slovenia showing notably higher levels of exposure, highlighting substantial inequalities across regions.

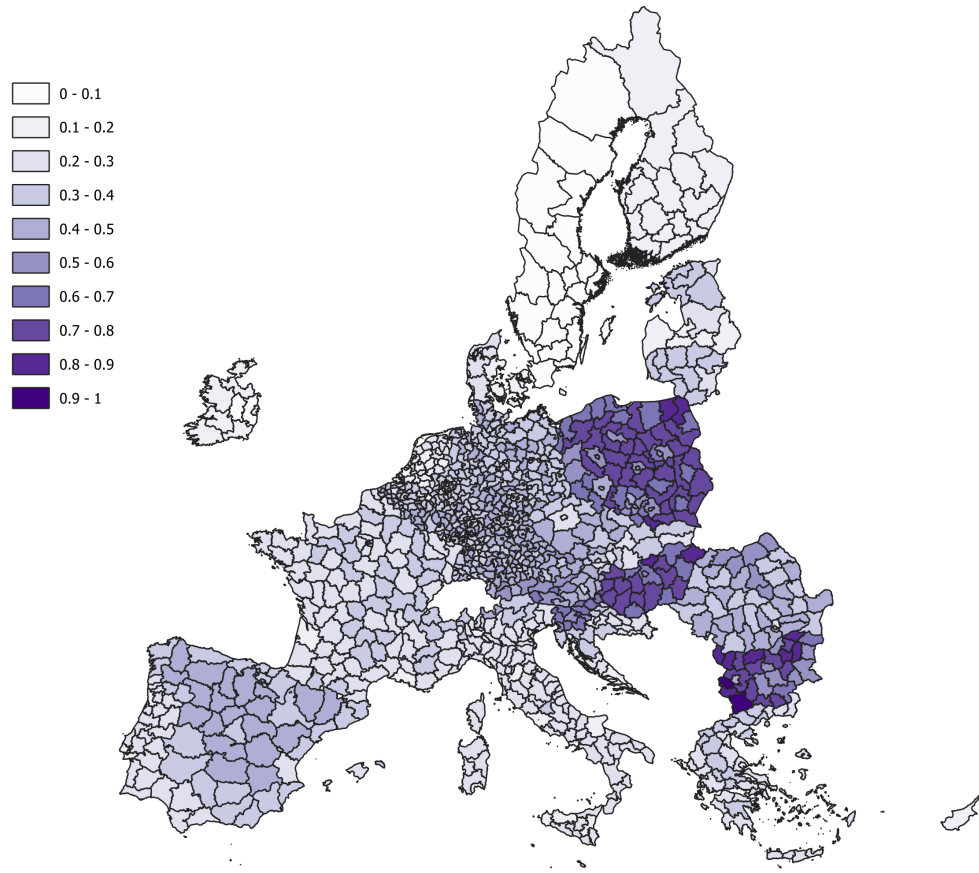


Figure 8: Exposed regions

The higher exposure indexes observed in certain regions can be attributed to several factors. Lower average disposable incomes in these countries, compared to Western European counterparts, amplify the relative impact of increased transport and heating costs. Additionally, the higher emissions intensity of these regions, driven by colder winters and less efficient building stock, results in greater vulnerability to carbon pricing. Furthermore, some recent

reports indicate that without social welfare redistribution mechanisms, fossil gas heating prices in some Eastern European countries could rise by up to 37%, exacerbating the financial burden on households in these areas (WWF, 2022).

Likewise, Figure 9 shows the correlation between the exposure index and per capita income across various regions. It clearly reveals an indication that the regions most vulnerable to risk are predominantly among the economically disadvantaged areas within the European Union, characterized by a per capita income of less than 20,000 €.

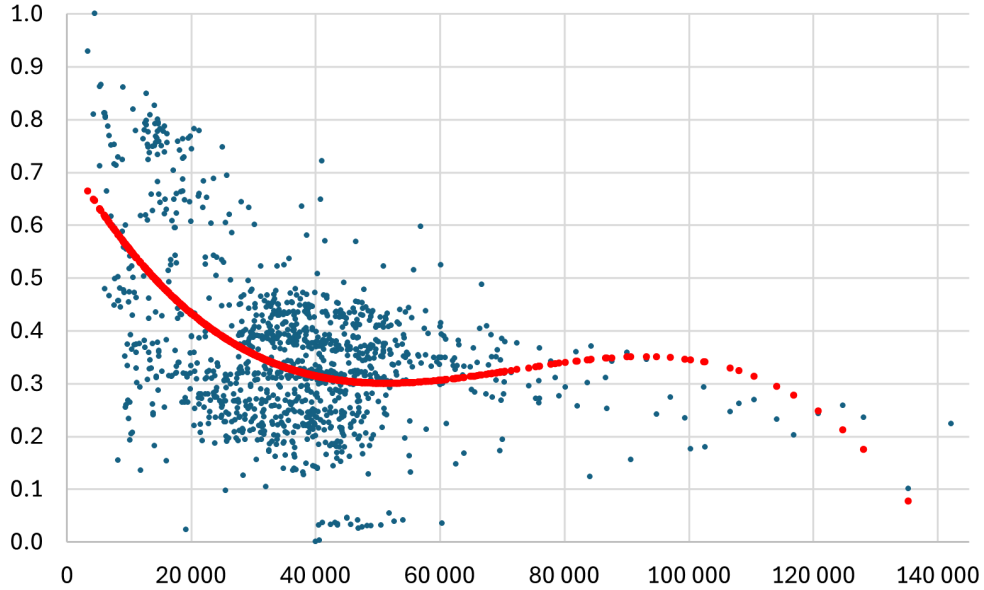


Figure 9: Relationship between exposed region and income per capita in € - blue point: computed exposure index - red point: estimated exposure index with a polynomial equation of degree 3 using OLS

As presented in Table 10, the regions with the highest 10% exposure are concentrated in Bulgaria, Hungary, Poland, and Slovenia. Additionally, several NUTS-3 regions in Austria, Germany, Romania, and Spain are significantly represented within the top 20%. Overall, a total of 348 regions fall within the top 30% of the highest exposure index. Notably, no regions from France, Greece, Portugal, or the Netherlands are included in this category.

Table 10: Top exposed regions by country

	Top 10%	Top 20%	Top 30%	Number of regions
Austria 	6	19	26	35
Belgium 	0	5	12	44
Bulgaria 	22	27	28	28
Croatia 	0	0	0	21
Cyprus 	0	0	0	1
Czech Republic 	0	1	6	14
Denmark 	0	0	0	11
Estonia 	0	0	0	5
Finland 	0	0	0	19
France 	0	0	0	96
Germany 	0	42	125	400
Greece 	0	0	0	52
Hungary 	19	20	20	20
Ireland 	0	0	0	8
Italy 	0	1	1	107
Latvia 	0	0	0	5
Lithuania 	0	0	0	10
Luxembourg 	0	0	0	1
Malta 	0	0	0	2
Netherlands 	0	0	0	40
Poland 	57	73	73	73
Portugal 	0	0	0	26
Romania 	2	22	25	42
Slovakia 	0	0	0	8
Slovenia 	10	12	12	12
Spain 	0	10	20	59
Sweden 	0	0	0	21
EU27 	116	232	348	1160

5. Conclusion and Policy Implications

The analysis of the EU’s Emissions Trading System 2 (ETS-2) presented in this study highlights significant distributional implications across households and regions within Europe. The research underscores the regressive nature of the ETS-2 price mechanism, revealing that lower-income households, particularly those in rural areas or regions with a greater dependence on fossil fuels for heating and transportation, bear a disproportionate share of the financial burden. These impacts are further exacerbated in economically disadvantaged regions, such as those in Central and Eastern Europe, where vulnerabilities are amplified by lower GDP per capita and limited access to energy-efficient infrastructure.

Through a comprehensive methodological approach that integrates household survey data, econometric analysis, and GIS-based spatial mapping, the study identifies significant heterogeneities in expenditure increases due to the ETS-2. The findings indicate that regions with high coal reliance, such as Poland, and those with limited low-carbon infrastructure face the highest heating cost burdens, while urban-rural disparities contribute to variations in transport-related expenditures. These results reinforce the critical need for regionally sensitive policy interventions to ensure the equitable distribution of climate transition costs.

Result findings emphasize the potential role of the Social Climate Fund (SCF) to mitigate the adverse impacts of the ETS-2. While the SCF offers a mechanism to support vulnerable households through direct income transfers and investments in energy efficiency, its current design may require further refinement to address the nuanced regional and socioeconomic disparities effectively. To tackle the spatial inequalities, it is important to strategically utilize the SCF. Policymakers should prioritize funding for energy efficiency improvements and the transition to renewable energy sources in the most affected regions, and must consider targeted measures, such as scaling support based on regional vulnerabilities and accelerating investments in renewable energy and public transportation, to enhance the SCF’s efficacy and promote fairness in the transition to a low-carbon economy (Jüngling et al., 2025).

Policy interventions must prioritize addressing the unique challenges faced by the most exposed regions, such as Poland, Bulgaria, Hungary, and Slovenia, where low disposable incomes exacerbate the impacts of ETS-2. Targeted financial assistance programs should be designed to offset increased heating and transportation costs for households in these regions. Direct subsidies

for energy bills, along with vouchers or rebates for renewable energy systems, can provide immediate relief while encouraging the adoption of cleaner energy sources.

Investments in infrastructure are equally critical to reducing long-term vulnerabilities in these regions. Policymakers should prioritize the development of energy-efficient housing and public transportation networks tailored to regional needs. Initiatives such as retrofitting buildings for energy efficiency, expanding access to district heating systems, and subsidizing the transition to electric vehicles can significantly reduce the carbon intensity of these regions while alleviating the economic burden on their populations.

Capacity-building programs should complement these measures by fostering local expertise and employment opportunities in the renewable energy sector. By supporting workforce development and technological innovation in low-carbon industries, governments can ensure that the transition to a sustainable economy creates equitable economic opportunities, particularly in regions most affected by the ETS-2. Such efforts can enhance resilience, promote social inclusion, and secure public buy-in for the EU's broader climate objectives.

In conclusion, while the ETS-2 represents a critical step toward achieving the EU's climate objectives under the Fit for 55 framework, its implementation must be accompanied by robust compensatory measures and inclusive policymaking to avoid exacerbating social and regional inequalities. Future research should focus on longitudinal analyses and cross-country comparisons to refine the understanding of ETS-2's impacts and guide the development of policies that balance environmental imperatives with social equity. By addressing these challenges, the EU can foster greater public acceptance and support for its ambitious climate transition goals.

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Appendix A. List of Variables in the Wiliam European Household Database

Table A.11: List of variables

Code	Name
Country	Country
q_income	Income quintiles
v_income	Income ventiles
urb_rur	Population density level
type.household	Type of household
hh_weights	Households
n_pers	Population
n_esOECD	Equivalent household size (modified OECD scale, 1994)
n_children	Children
n_adult	Adults
n_retiree	Retirees
m_age	Average age of household members
n_rooms	Number of rooms available to the household
car	Households with car
P3	Final consumption expenditure
CP011	Food
CP012	Non-alcoholic beverages
CP021_22_23	Alcoholic beverages; tobacco; and narcotics
CP031	Clothing
CP032	Footwear
CP041_42	Actual rentals for housing; imputed rentals for housing
CP043_44	Maintenance and repair of the dwelling; water supply and miscellaneous services relating to the dwelling
CP045	Electricity, gas and other fuels
CP0451	Electricity
CP0452	Gas
CP0453	Liquid fuels
CP0454	Solid fuels
CP0455	Heat energy
CP051	Furniture and furnishings, carpets and other floor coverings
CP052	Household textiles
CP053	Household appliances
CP054	Glassware, tableware and household utensils
CP055	Tools and equipment for house and garden
CP056	Goods and services for routine household maintenance
CP061	Medical products, appliances and equipment
CP062_63	Out-patient services; hospital services
CP071	Purchase of vehicles
CP072	Operation of personal transport equipment
CP0721	Spare parts and accessories
CP0722	Fuels and lubricants
CP0723	Maintenance and repair of personal transport equipment
CP0724	Other services in respect of personal transport equipment
CP073	Transport services
CP0731	Passenger transport by railway
CP0732	Passenger transport by road
CP0733	Passenger transport by air
CP0734	Passenger transport by sea and inland waterway
CP0735	Combined passenger transport
CP0736	Other purchased transport services
CP081_82_83	Postal services; telephone and telefax equipment; telephone and telefax services
CP091	Audio-visual, photographic and information processing equipment
CP092	Other major durables for recreation and culture
CP093	Other recreational items and equipment, gardens and pets
CP094_95_96	Recreational and cultural services; newspapers, books and stationery; package holidays
CP101_102_103_104_105	Education
CP111	Catering services
CP112	Accommodation services
CP121_122_123_124_125_126_127	Personal care; prostitution; personal effects n.e.c.; social protection; insurance; financial services n.e.c.; other services n.e.c.
D11_B3G	Gross wages and salaries and gross mixed income
D12_D61	Social security contributions
B2G	Gross operating surplus
D4_received	Property income received
D4_paid	Property income paid
D51_D59	Taxes
D62	Social benefits other than social transfers in kind
D7_rec	Other current transfers received
D7_paid	Other current transfers paid
D8	Adjustment for the change in pension entitlements
P51C	Consumption of fixed capital
B6G	Disposable income, gross
B6N	Disposable income, net
B8G	Saving, gross
B8N	Saving, net
B8G	Saving, gross
B8N	Saving, net
NF_ASS	Non-financial assets
F_ASS	Financial assets
LIAB	Liabilities
NW	Net wealth

Appendix B. Additional figures

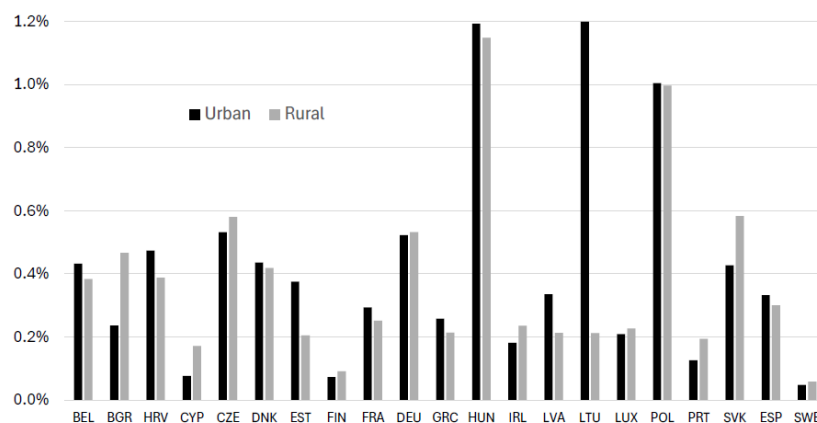


Figure B.10: Increase of heating expenditure in % of disposable income per location of household (rural and urban) and country

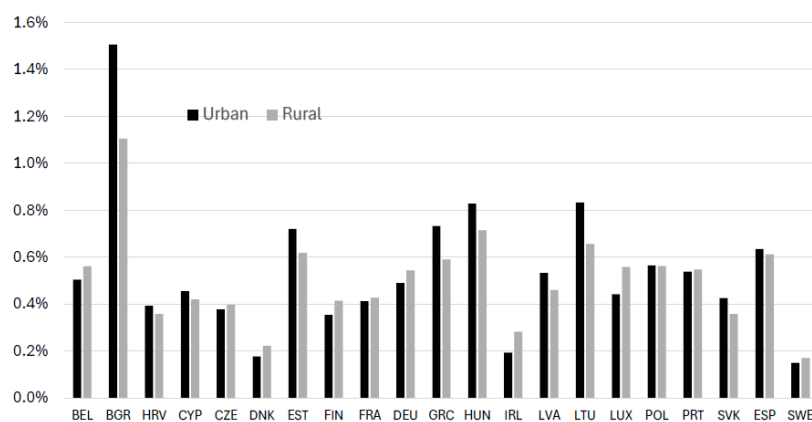


Figure B.11: Increase of transport expenditure in % of disposable income per location of household (rural and urban) and country

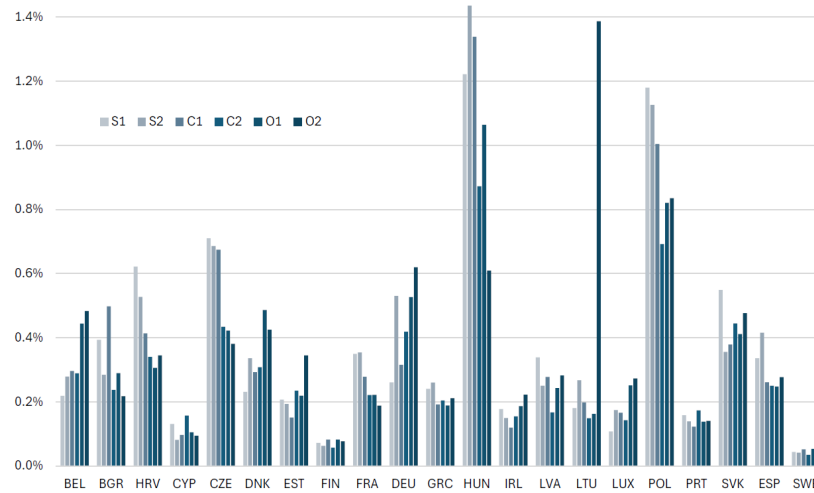


Figure B.12: Increase of heating expenditure in % of disposable income per family composition and country

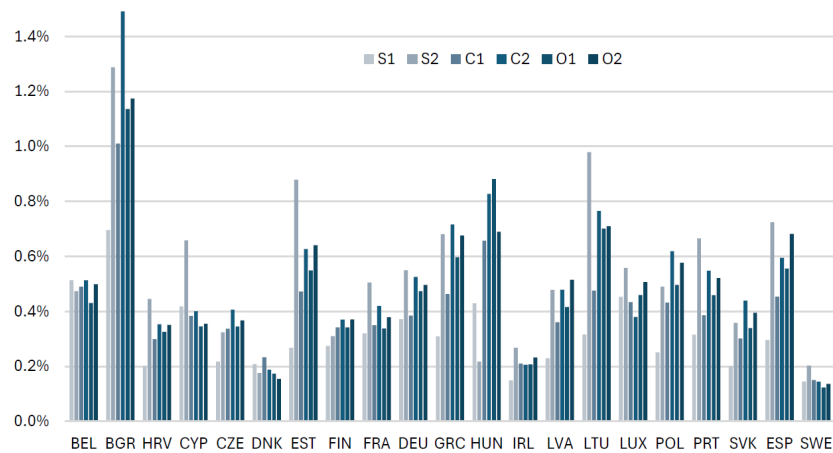


Figure B.13: Increase of transport expenditure in % of disposable income per family composition and country

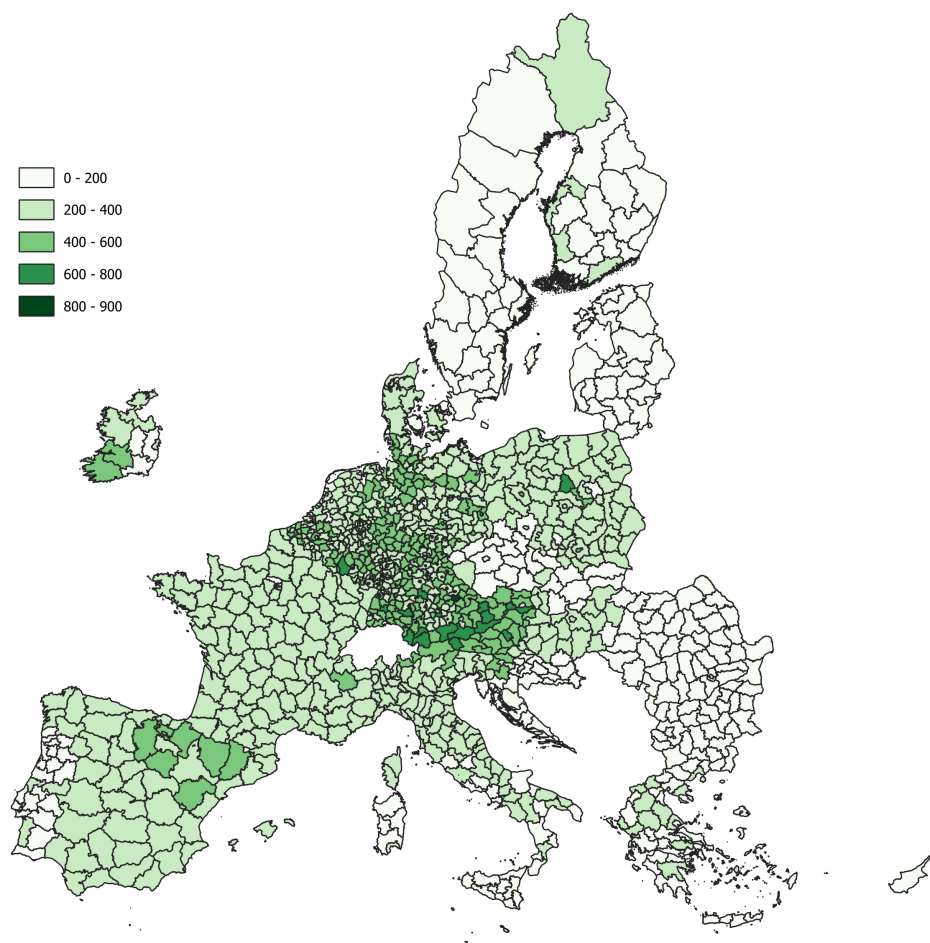


Figure B.14: Increase of energy expenditure in € by regions