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Working Paper Unveiling the Energy Price Tag – Assessing the Degree of Regressivity of Household Energy Expenditures Among European Countries

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Unveiling the Energy Price Tag – Assessing the Degree of Regressivity of Household Energy Expenditures Among European Countries

Abstract

Policies to address climate change and the energy transition are increasingly gaining ground. However, a large body of research has mainly focused on the efficiency aspect of different instruments rather than their unintended side-effects. Only recently, both policymakers as well as researchers have started to emphasise equity aspects of these policies, since the acceptability of different measures also hinges upon the redistributional implications.

This paper contributes to the growing body of research on energy expenditure in-equality in advanced economies by quantifying the regressivity of energy expenditures across 19 European Union countries for the years 2010, 2015, and 2020. We reveal a consistent pattern of regressive energy expenditures across all countries and time periods, with significant variability in the degree and regressivity observed. Our analysis highlights the importance of a nuanced approach to assessing energy expenditure inequality and tailoring suitable energy and climate policies, as countries with the highest or lowest shares of disposable income spent on energy do not necessarily align with those exhibiting the most pronounced regressivity. Tailored policy instruments are essential, particularly when addressing the needs of specific groups, such as low-income households dependent on fossil-based heating systems. However, if broader population segments are affected, more complex solutions may be necessary.

We also examine the contributions of various socio-demographic factors to explaining energy expenditures inequality, finding that certain characteristics, such as house-hold size or socioeconomic status, contribute to a more even distribution of energy expenditures in the population. These insights suggest that policies aimed at reducing energy expenditure inequality may extend beyond income-based transfers to address the specific needs of different socio-demographic groups.

JEL-Codes: D310, H230, Q480.

Keywords: energy policy, energy expenditures, regressivity.

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1 Introduction

In the current landscape, addressing climate change while simultaneously catering to the security of energy supply stands out as crucial priorities for policymakers globally. Postpandemic and in the wake of geopolitical events like the Russian invasion, the intricate dance between demand and supply forces in energy markets has resulted in substantial price hikes. The equity dimension of these soaring energy prices takes center stage in the realms of climate change research and the ongoing transition of modern energy systems towards renewable sources. Particularly noteworthy is the intersection of policies aimed at mitigating negative environmental impacts, such as carbon pricing, with the potential to escalate the costs of energy sources. This dynamic often triggers unintended consequences on individual welfare, casting a shadow on the acceptability of such policies.

These developments impact households differently, contingent on their income and other socio-demographic characteristics. Numerous studies on climate change mitigation and the shift to renewable energy underscore the equity concerns of such policies (Hassett et al., 2009; Konsiky and Carley, 2021). However, we still need to better understand the magnitude of the possible regressive impact as it is an unintended side effect of policies aiming at reducing carbon emissions. The equity implications have also been acknowledged by policymakers who, in the design of new policy packages such as the EU For 55 package, underscore the importance of a socially fair transition since low-income individuals, who rely on affordable energy, may be disproportionately affected by climate policy measures that lead to escalating energy prices.

In this paper we provide a detailed analysis of the degree of regressivity of household energy expenditures. Whereas previous studies emphasised in particular the burden faced by the poorest households and hence the topic of energy poverty, we assert that energy expenditures affect households *along* the income distribution calling for a scrutinization of these effects across different income groups. We compute specific energy expenditure inequality indices, that reflect the degree of regressivity of energy expenditures, leveraging data sourced from the European Household Budget Survey (EHBS). The EHBS offers a wealth of information on energy-related housing expenditures, income, household appliances, and various socio-demographic characteristics for the years 2010, 2015, and 2020. The repeated cross-sectional data makes it possible to capture the development of regressivity over the last decade, during which the climate policy mix has evolved.

We quantify several dimensions of the regressive nature of energy expenditure using new measures or customize existing measures from other fields to our literature strand. To start with, we calculate the average shares of income households spend on energy by income quintile. In a second step, we assess the rate at which these shares decrease along the income distribution. This shows whether the burden decreases overproportionally from the lowest to the highest income households, compared to a system where the shares decline in a linear fashion. Third, we construct energy expenditure concentration curves — akin to income Lorenz curves — that illustrate the cumulative proportion of energy expenditures against the cumulative proportion of the sample. We then proceed to calculate indices that capture the magnitude of regressivity of energy expenditures by comparing the relative concentration of energy expenditures with that of disposable income. The surveys' detailed information enables us to compute these inequality measures for different categories of energy

expenditures, such as those related to mobility or housing. In addition, we decompose the energy expenditure concentration indices aiming to discern the specific contributions of specific household socio-demographic characteristics to the overall inequality in energy spending.

Our findings unveil a pattern of regressive energy expenditures across all analyzed countries, albeit with significant heterogeneities. First, there are significant disparities in the portions of income allocated to energy expenses not only across countries but also among different income brackets. The most notable gap in expenditure proportions between the top and bottom income quintiles occurred in Croatia in 2020, with a substantial difference of 19 percentage points, while Luxembourg exhibited the smallest difference at 4.7 percentage points. The descriptive evidence suggests that these large discrepancies can be partly explained by the types of heating systems that are more prevalent among poorer households (i.e. coal) since these are often also associated with higher costs. This implies that public policies aimed at supporting low income households can be specifically targeted for instance at facilitating and supporting the replacement of fossil based and expensive heating systems with more environmentally friendly heating systems which are also cheaper in terms of their variable recurring fuel costs.

When considering the rate at which the share of energy expenditures decreases with higher income, for instance in 2020, countries such as Greece or the Netherlands stand out with the highest values in absolute terms, implying that the burden decreases overproportionally from the lowest to the highest incomes compared to a system where the shares would decrease linearly. In contrast, Croatia and Bulgaria even feature positive but small values indicating a lower degree of convexity or a proportional decrease of energy expenditure shares along the income distributions. In general, this degree of convexity of energy expenditure shares can help us determine whether only the specific segment of low-income households is disproportionately affected or, if the impact extends to a broader group including the middle class. Policy instruments can then be tailored based on these insights.

Significant variations in the magnitude of regressivity as measured by the Kakwani index are also identified among the countries under scrutiny. The Kakwani index has been employed in the public economics literature to measure the progressivity of income tax systems. Using this metric, we show that for instance in 2020, Luxembourg stands out with the most regressive total household energy expenditures. In contrast, Bulgaria exhibits a substantially lower degree of regressivity.

Furthermore, we conduct a decomposition of the concentration index for energy expenditures, aiming to discern the specific contributions of specific household socio-demographic characteristics to the overall inequality in energy spending. Our findings indicate that the equivalent income emerges as the primary factor influencing energy expenditure inequality. However, its contribution also varies to a large extent elucidating only 50% of the concentration index in Bulgaria but as much as 85% in Spain for instance. Perhaps surprising, a number of socio-demographic characteristics, in particular household size, but also the age of the household head or socio-economic status have a negative effect on the concentration of energy expenditures thus contributing to a more equal distribution of these among households in some economies. This may have important consequences for the policy instruments that can be employed to address these issues. Hence, a more differentiated policy mix beyond purely income based transfers may be appropriate. With respect to the effects of the more recent energy price hikes, our simulations reveal that the burden on the first and highest income quintiles increases by on average 2.7 and 2 percentage points respectively. The concentration indices slightly increase implying, on the one hand, a slightly more unequal distribution of energy expenditures, however, on the other hand, also a closer alignment to the income inequality as measured by the Gini coefficient. This in turn results in a lower regressivity. Nevertheless, these results should be interpreted with caution since they may simply reflect a more pronounced reaction of poorer households to energy price hikes. Thus, the reduction in regressivity does not necessarily stem from a more equitable policy design, but rather from poorer lower income households strongly reducing their energy consumption and thus potentially foregoing essential energy services such as heating or lighting.

The remainder of this paper is structured as follows: Section 2 reviews the related literature, Section 3 provides an overview of the data, Section 4 explains the employed methods and corresponding results, and Section 5 concludes.

2 Literature

The empirical literature on the distributional impact of climate policies, energy poverty, and the energy transition provides valuable insights into the regressive nature of such measures, particularly in the context of the United States. Studies such as Burtraw et al. (2009), Hassett et al. (2009), and Fullerton et al. (2011) present evidence highlighting the regressive effects of US climate policy. The more recent work of Konisky & Carley (2021) looks into the lessons to learn from the Green New Deal about the importance of equity in the US climate policy. Examining electricity prices, Borenstein (2012) demonstrates that utilities adopt non-marginal increasing block prices and inefficiently low access fees to protect low-income customers while Levinson & Silva (2022) find that energy utilities concerned about inequality charge lower-than-efficient fixed costs and higher-than-efficient volumetric charges.

The contribution by Vona (2021) offers an overview of the literature on the distributional effects of environmental policies, including those related to energy. Overall, these papers consistently identify regressive effects on income.

In the context of EU countries, Menyhert et al. (2022) provide a preliminary assessment of the potential social consequences of increasing energy and consumer prices. While their focus encompasses all living cost increases and purchasing power losses, our study narrows in on housing and fuel-related energy expenditures, employing the Kakwani index defined as the difference between the energy expenditure concentration and Gini index to assess the degree of regressivity.

Energy poverty, closely linked to energy inequality, has also been scrutinized by various researchers, including Drescher & Janzen (2021), Wu et al. (2017), and Halkos & Gkampoura (2021). For example, Drescher & Janzen (2021) use German SOEP data to reveal that, in 2019, 17% of households spent more than 10% of their income on domestic energy, with 4.5% to 14% experiencing persistent energy poverty. Wu et al. (2017) demonstrate a nearly 50% increase in energy poverty in the United States from 1990 to 2015, while Bouzarovski & Tirado Herrero (2017) and Halkos & Gkampoura (2021) emphasize the role of electricity

prices in driving energy poverty in Europe.

We enhance the existing literature by providing a comprehensive overview across a number of European countries and attempting to draw a differentiated picture that emphasises multiple dimensions that are needed to assess the inequality of energy expenditures.

Looking at the literature using inequality indices in energy related research, we find that previous studies commonly employ Gini coefficients to illustrate energy expenditure inequality among households, with Jacobson et al. (2005) and Oswald et al. (2020) providing examples for various countries. However, we argue that the Kakwani index is better suited for analyzing energy expenditure inequality, particularly in the context of advanced economies. This is the case, since computing a Gini type index, just offers information on the cumulative share of energy expenditures across the population, which is meaningful in the analysis of energy access, however it does not relate this to the distribution of income. The Kakwani index though, captures this latter aspect as well. The index, initially designed to assess the progressivity of tax payments, has found applications in health economics to analyze the distribution of health expenditures, as evidenced by studies such as A. Wagstaff & van Doorslaer (1994), E. v. D. Wagstaff A. & P.Paci (1989), A. W. Kakwani N. & van Doorslaer (1997), and E. v. D. Wagstaff A. & Watanabe (2003). Huang (2022) employs the Kakwani index to illustrate electricity expenditure inequality in Taiwan, marking a notable exception in the literature's use of this index for assessing energy expenditure inequality. Recent papers by Borenstein & Davis (2024) and Borenstein & Davis (2016), though not explicitly calculating the Kakwani index, assess the distributional effects of energy tax credits and find that the bottom three income quintiles have received about 10% of all credits, while the top quintile has received about 60%. Their method is quite similar to ours, insofar they plot income concentration curves against concentration curves for federal income tax credits, however they do not compute any indices of regressivity and focus on tax benefits in the United States while we consider the distribution of overall household energy expenditures in different European Union countries.

Our study thus contributes to this growing body of literature by augmenting the dimensions according to which energy expenditure inequality should be assessed and shows the different aspects of regressivity that should be considered for a sensible design of climate and energy policies.

3 Data and energy expenditure projection

We utilize data from the European Household Budget Survey (EHBS), provided by Eurostat, containing comprehensive details about individuals in households, household income, and expenditures. Our analysis focuses on sample surveys conducted in 2010, 2015, and 2020, encompassing between 275'259 and 208'519 observations.¹ This is a comprehensive data set that makes it possible to examine the distribution of energy expenditure and its regressivity

¹From this extensive pool, 361'181 observations were meticulously selected for analysis. The exclusion criteria were primarily based on the presence of missing values in crucial categories, such as income and energy expenditures, as well as the geographical context of the respective country. Furthermore, to ensure the reliability and representativeness of our findings, we systematically eliminate observations that did not fall within the range of a household's share of income spent on energy between 0 and 1.

and also to draw international comparisons. Nevertheless, we note that the consideration of regressivity on energy expenditure and income is not applicable in certain cases, as certain household types such as students or retirees obviously have lower incomes, but this does not imply worse living conditions. Studies by Poterba (1989) and Hassett et al. (2009) have shown that the impact of gasoline and fuel taxes are more evenly distributed among households when looking at lifetime income.

To ensure comparability across households, we compute equivalised values for the disposable income. Disposable income is defined as gross income minus expenditures on mandatory social security, taxes, basic health insurance premiums, and regular transfer payments to other households. Equivalised income is obtained by dividing the disposable income by the number of equivalent adults in the household, adhering to the OECD equivalence scale. This scale assigns a weight of 1 for the first adult, 0.5 for each additional household member aged 14 and above, and 0.3 for each additional household member under 14. The EHBS dataset also provides pertinent information on housing-related energy expenditures, encompassing electricity, gas, district heating, and fuel categories such as diesel and gasoline.²

Given that the EHBS only provides data up to 2020, we undertake simulations to gauge the ramifications of recent escalations in energy prices on energy expenditures. This illustrates the potential repercussions on energy inequality and the regressive effects of such price hikes. With these calculations we try to simulate today's situation, for which no accurate data is available. As the survey data is published with a time delay after the survey, we can at least estimate the direction in which energy expenditure and its distribution has developed. Although Europe overall is in the midst of the energy transition, recent energy price developments affected to a different extent single countries. The impact of surging energy prices depends on the respective country's energy mix or geopolitical interdependencies. For instance, countries such as Germany that feature a high share of natural gas in total energy consumption, are more strongly affected by rising natural gas prices. Furthermore, since the country also imported most of its natural gas via pipelines from Russia, it is more significantly affected by natural gas shortages and the associated energy price increases compared for instance to Spain, which imports its natural gas mainly as LNG from suppliers other than Russia (Holz et al., 2022).

To assess the effects of these price increases on the distribution of energy expenditures, we need to rely on a number of assumptions, since the necessary data for the years after 2022 is not available yet. In particular, we need to infer the quantity of energy demanded by energy source and household income quintile for 2023 (Q_{23}). We thus proceed in the following way. As a first step, we project energy expenditures (exp_{23}) by income quintile for different energy categories (gas, electricity, district heating, solid and liquefied fuel, hydrocarbon, gasoline and diesel) as a function of price elasticities of energy demand (η), the price of the respective energy category in 2020 (P_{20}) and 2023 (P_{23}), as well as the amount consumed in 2020 (Q_{20}). Hence, since $\eta = \frac{\frac{Q_{23}-Q_{20}}{\frac{P_{23}-P_{20}}{P_{23}-P_{20}}}$

$$\exp_{23} = P_{23} \times Q_{23} = P_{23} \times (\eta \times \frac{P_{23} - P_{20}}{P_{20}} \times Q_{20} + Q_{20})$$
(1)

We collect information on the prices for the various energy carriers as well as the price

²We follow the same methodology to compute equivalised energy expenditures.

elasticities of energy demand from different sources. Country specific electricity and gas prices for residential customers are provided by Eurostat (2023).³ Country-specific gasoline, diesel and heating oil prices, are retrieved from the International Energy Agency (2023).⁴⁵ ⁶ Since the HBS aggregates diesel and gasoline expenditures into only one fuel category, we approximate fuel prices by the weighted average of diesel and gasoline prices. The weights are proportional to the share of registered cars with the respective engine type in each country. ⁷⁸ The prices for solid fuels and liquified hydrocarbons are approximated with UK prices provided by the Office for National Statistics (2023). The heat price index is retrieved from the German Federal Statistical Office (Destatis) (2020,2022). These latter energy prices only vary over time but not by country. Second, income for 2023 is calculated employing country-specific labor indices from the OECD. Information on these price developments is provided in Table A1 in the Appendix.

Third, we use estimates for price elasticities of energy demand for different income groups from the relevant literature. The assumed values and the respective literature sources are summarised in the table below.⁹ As a plausibility check, we compare these values with the values estimated in the meta-analysis of Labandeira et al. (2017). The authors provide short- and long-run price elasticities of energy demand by energy type, albeit not according to income category. Still, the estimates we employ are within the range of these values. These price elasticities are also trustworthy in the context of the recent price spike. Peersman & Wauters (2022) report an average price elasticity of -0.22 using survey evidence on reported spending in hypothetical energy price shock scenarios. Since we did not find suitable estimates of the price elasticities of solid fuel, liquid fuel or liquefied hydrocarbon, we approximate the values by the price elasticities of natural gas. We argue that the energy carriers mentioned and natural gas are used in a similar manner to heat living space.

Energy	η	η	η	η	η	Split	Reference
Gas	-0.24				-0.14	income (45% / 55%)	Auffhammer & Rubin (2018)
Fuel	-0.63	-0.47	-0.37	-0.29	-0.21	expenditure quintiles	Wadud et al. (2009)
RDH*	-0.607		-0.598		-0.232	income quarters $(1/4, 2/4, 1/4)$	Trotta et al. (2022)
Electricity	-0.166	-0.103	-0.074	-0.063	-0.081	income quintiles	Feger et al. (2022)

Table 1: Energy price elasticities (η) for different source of energy

*Residential district heating

It is important to recognize that there can be significant variation in the extent to which individuals are exposed to energy price increases, both across as well as within countries. We

 $^{^{3}}$ For 2020 these prices are computed as the mean of the six-months average and for 2023 they are approximated by the price information available for the first 6 months of 2022.

⁴We compute the annual prices by averaging the information on the monthly prices noting that for 2023, the monthly information is available until February.

⁵For Finland, Malta and Cyprus the EU average gas price information is used because the information is missing on the national level.

⁶Slovakian oil price information is missing and we thus use the EU average prices in this case.

⁷This information is provided by the European Automobile Manufacturers' Association (ACEA).

⁸The missing values for Bulgaria and Malta are substituted with the EU average.

⁹The elasticities are assigned based on the income quintiles specific to each country.

recognize that we make a number of simplifying assumptions, however, these simulations can provide a first approximation of the expected effects since the true data is not available yet. We are also aware that the price elasticity of energy demand from high-income households is higher than that of lower-income households in the long term, as they have investment opportunities and are less likely to be tenants. They are therefore more likely to invest in energy-efficient housing. However, as our simulations only make sense in the short term because the next survey data will follow soon, the short-term price elasticities are more accurate. Our approximation of households' reactions to increased energy prices performs better for countries that faced no or little variation in energy prices for households. For instance, when examining heat price indices, the approximation is less precise, because the price of heat greatly differs depending on the type of energy source used. For example, district heating prices based on waste heat from data centers will vary less compared to natural gas prices. Lastly, we observe no cross-country price variation for solid fuel, liquified hydrocarbon and district heat, as we have no country specific information. However, a large part of the HBS sample does not provide specific information on expenditures on these energy sources either. Therefore, the bias for subsequent use of the calculated projections that we create by using a single, European wide price index is negligible.

The downside of this approach for calculating the projected energy expenditures for 2023 is its mechanical nature. To be more specific, we cannot quantify the actual adjustment of household energy consumption following a marked price increase for the following reason. The interpretation of price elasticities is based on marginal price changes. Therefore, lowincome households are expected to be more price sensitive compared to higher-income groups. Furthermore, according to eq. (1), simply plugging in the corresponding values may result in negative energy consumption for some income groups and energy sources (especially gas) in some countries (i.e. Hungary) in 2023. This can happen if the price change, multiplied by the respective price elasticity, is below -1. Since this is not realistic, we assume a minimum baseline gas consumption of 360 kWh per household annually for those households already utilizing gas in 2020. This figure aligns with the minimum electricity consumption deemed necessary for survival by the World Bank. Since there isn't a direct equivalent for this minimum gas consumption, we approximate it using electricity consumption. However, this approximation may be conservative, as developed countries typically have higher minimum consumption levels than those defined by the World Bank for developing nations and the distribution of gas consumption exceeds that of electricity. Thus, assuming a subsistence level of energy consumption (in particular gas) beyond which energy consumption cannot be reduced, may imply that higher income-groups may appear to be more elastic.

4 Methods & Results

In this section, we examine multiple dimensions of the regressivity of energy expenditure. We employ four distinct analytical approaches. First, we assess the variation in the proportion of income allocated to energy consumption across the highest and lowest income groups, followed by an analysis of the rate at which this proportion declines with rising income. To evaluate overall energy expenditure regressivity, we apply the concepts of the Concentration and Kakwani indices, which we further decompose by various socio-demographic variables in the final stage of our analysis.

4.1 Regressivity of energy expenditures - energy expenditure as a share of income

In the following we provide an overview of the energy expenditure inequality and the extent of the regressivity of energy expenditures in European Union countries. Furthermore, we calibrate the effect of higher energy prices on these. The following table presents the minimum and maximum values for energy expenditures as a share of equivalised disposable household income across the analysed economies for 2020 and 2023, stratified by the lowest and highest income quintiles.

Table 2: Highest and lowest shares of income spent on household energy expenditures for income quintiles 1 and 5 in 2020 and 2023

Year	Income quintile	Max	Min
2020	1	Croatia (30.1%)	Luxembourg (7.5%)
2020	5	Bulgaria (12.4%)	Luxembourg (2.8%)
2023	1	Greece (34.4%)	Luxembourg (8.3%)
2023	5	Greece (14.8%)	Luxembourg (3.9%)

Notes: The thresholds for calculating the quintiles in 2020 are 29,581, 38,996, 48,525, 64,856 for Luxembourg, 2,287, 2,949, 3,906, 5,267 for Bulgaria and 3,639, 5,301, 6,999, 9,554 for Croatia.

Among the poorest households in the 19 analyzed European countries 10 , Croatian households stand out with the largest share of energy expenditures in equivalent income, nearly three times higher compared to the poorest households in Belgium. Conversely, concerning the richest households in the respective countries, Bulgaria records the highest expenditure share, more than three times greater than in Denmark. In practical terms, Croatian low income households, with an equivalised monthly household income $\langle = 3, 639 \rangle$ Euro allocate one out of every three Euros of their disposable income towards energy-related expenditures. The most significant contrast in expenditure shares between the highest and lowest income quintiles is observed in Croatia in 2020, with a substantial 19 percentage points difference, while Belgium exhibits the smallest difference at 4.7 percentage points (see Figure 1 below). This difference in the burden between the first and fifth income quintile can be interpreted as a first proxy of regressivity, similar to comparing the average tax burden for different income brackets in the context of measuring tax progressivity. However, this is only a first approximation and requires a more nuanced scrutinization as explained further below.

Figures 1 and 2 depict the shares of total energy expenditures in equivalent income for the first and fifth income quintile for 2020 and 2023 respectively, ranked by the difference between Q1 - Q5. As the graphs illustrate, in most economies considered, the burden on households increases across the income groups in 2023 compared to 2020. Perhaps surprising, our simulations show that in some cases, household energy expenditures as a share of income may even decrease. This is the case for our projections for Hungary, Lithuania, Malta and

¹⁰Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Denmark, Estonia, France, Germany, Greece, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Slovakia, and Slovenia

Slovakia. This situation may arise first, if the expected change in income exceeds the effect of higher electricity prices and hence the induced reduction in energy consumption. Second, Hungary, Lithuania, and Malta experienced very pronounced gas price increases which, merely following eq.(1) would mechanically imply negative values for energy consumption in 2023. Since this is not realistic, we assume a certain minimum threshold energy consumption level, below which energy consumption cannot be further reduced. This subsistence level, which we calibrate to 360 kWh per year following World Bank sources may however turn out to be too conservative. Furthermore, if we assume low-income households to be more price sensitive, the increase in the shares of income spent on energy may turn out higher at the top of the income distribution. Thus, even if the overall regressivity may decline, poorer households may de facto be worse off, because they have to adjust to the price surges even more. The simulations for 2023 show that, on the one hand, Greece features the highest absolute shares both for the poorest as well as for the richest households with 34.4% and 14.8% respectively. It is also the country with the highest increases in these shares compared to 2020. On the other hand, Luxembourg and Malta feature the lowest absolute values for 2023, and Malta also experienced the least changes compared to 2020. Even though the actual shares may differ from our projections, our simulations indicate that higher energy prices, imply a decrease in the regressivity of the shares of energy expenditures across the income distribution. However, this may also reflect a more pronounced reduction in energy consumption among low-income groups.

In addition, figures A1, A2, and A3 illustrate these aforementioned shares across the income distribution for various countries for the years 2020 an 2023 for different energy sources. At first glance, fuel expenditures seem to be less regressive. However, this may simply reflect the fact that car ownership is more common among higher income households, and hence households at the bottom of the income distribution do not incur any fuel costs at all and are thus also less exposed to rising gasoline or diesel prices.

Figure 1: Shares of total energy expenditures in equivalent income for the first and fifth income quintile in 2020



Source: Own illustration based on data from Eurostat.

Figure 2: Shares of total energy expenditures in equivalent income for the first and fifth income quintile in 2023



Source: Own illustration based on data from Eurostat.

One possible explanation for these marked differences, can be the influence of heating type. In columns 2-6 of Table A5 we present the differences in the shares of various heating

systems between the first income quintile (Q1) and the fifth income quintile (Q5). For instance in Croatia, the country with the largest difference in the share of energy expenditure burden between the richest and the poorest households, the share of coal heating is almost 5 percentage points higher in Q1 than in Q5 in 2020, whereas in Belgium, one of the countries with the lowest difference in the burden, heating systems of all types are very evenly distributed among income groups. Furthermore, we compute the average cost associated with each heating type for each country in 2020. This is presented in columns 7-11 of Table A5. Thus, Croatian households using coal heating in 2020 face an average expenditure share of 23.4%, which is the highest among all heating types. Hence, this descriptive evidence suggests that low-income households are more likely to employ heating systems that command higher expenditure shares.

While these descriptive statistics provide a snapshot of the disparity in energy expenditure shares among households, a more nuanced examination of inequality and especially the regressivity of energy expenditures requires additional indices.

4.2 Regressivity of energy expenditures - Assessing the degree of convexity

The regressivity of energy expenditures can be assessed in multiple ways. First, as shown above, it may be reflected by the difference in the share of income spent on energy between the lowest and the highest income households. The larger the difference, the higher the regressive impact of energy expenditures. Second, often overlooked, is the rate at which this share decreases along the income distribution from the lowest to the highest incomes. If this share decreases disproportionately, the degree of regressivity is higher compared to a system where the share decreases linearly. The intuition is comparable to the analysis of tax progressivity, where a progressive (regressive) tax system is characterized by average tax rates that increase (decrease) with income. Furthermore, if the rate at which the average tax rate increases (decreases) is increasing (decreasing), the tax structure is even more progressive (regressive).

Hence, we compute a novel measure that captures the degree of convexity of energy expenditures, by assessing the rate at which average energy expenditure rates decrease with higher income. Let us denote by $e_{ijt} = \frac{exp_{ijt}}{x_{ijt}}$ the energy expenditure rate of household *i* in country *j* in year *t* defined as this household's energy expenditures exp_{ijt} divided by its income x_{ijt} . If $\frac{\partial e_{ijt}}{\partial x_{ijt}} < 0$ the system is regressive. The degree of convexity is however best understood by looking at Figure 3. It illustrates positive (black) and negative (grey) deviations between the actual observed energy expenditure burdens and a linear decreasing trend. The degree of convexity is then obtained by aggregating these positive and negative deviations over the income of households observed in each survey. As a specific example, Figure 4 depicts the shares of income spent on energy by different income groups ordered from lowest to highest income for Greece and the year 2020.¹¹. We first group observations per year and country into 500 bins of equal size. Second, we calculate the average share of income spent on energy within each bin. Third, we add these individual deviations and normalize

¹¹We choose for illustration purposes Greece since it features the highest absolute value for the degree of convexity in 2020. See Table A6 in the Appendix.

them by the number of groups. The red dashed line shows a hypothetical distribution of these shares, where we assume that the shares decrease linearly from the lowest to the highest income group. The observed shares deviate however from this assumption. The actual shares lie in most cases substantially below the dashed line. Thus, in reality, the energy expenditure rate decreases overproportionally.

Our measure of energy expenditure regressivity reflects the degree of convexity of energy expenditure shares. This figure reflects the average deviation of the actual income shares spent on energy from a system with linearly decreasing shares. More negative values thus represent a higher degree of convexity and an overproportionally decreasing burden of energy expenditures with higher income. Table A6 presents the results for all analysed European countries. In contrast to the analysis presented in the previous section, Croatia and Bulgaria even feature positive but small figures for the degree of convexity, thus implying a roughly proportionally decline in the burden of energy expenditures along the income distribution. In 2020, Greece stands out with the largest degree of convexity, followed by the Netherlands and Luxembourg. Furthermore, our projected energy expenditures for 2023, imply an increased degree of convexity in 11 countries and a decreased degree of convexity in 8 countries in 2023 compared to 2020.



Figure 3: Curvature of energy expenditures

Notes: Blue line assumes energy expenditure shares decrease linearly with income. *Source:* Own illustration.

Figure 4: Actual vs. linearly decreasing shares of energy expenditures in income for Greece in 2020



Notes: Red dashed line assumes energy expenditure shares decrease linearly with income. *Source:* Own illustration based on data from Eurostat.

4.3 Regressivity of energy expenditures - Concentration and Kakwani index

In this section we apply metrics originating in public economics to assess the progressivity of tax systems. In general, there is a lack of consensus on how to measure the progressivity of tax systems. However, the literature distinguishes between approaches that are based on tax liability progression and approaches based on the distribution of tax liability. The former employs the elasticity of tax liability at a given income level and exploits information on average versus marginal tax rates (Musgrave & Thin, 1948). Thus, it can only provide a picture of progressivity at a given point in the income distribution. The latter approach measures tax progressivity in terms of tax liability shares relative to income shares across the income distribution. Thus, it accounts for both the income distribution as well as the income tax schedule in one measure. The two measures commonly applied are the so-called Kakwani index (N. C. Kakwani, 1977) and the Suits index (Suits, 1977). Both measure the extent to which the tax system deviates from proportionality. They differ from the former approaches also insofar they yield a summary statistic whereas the former vary with the tax base. The decision which method to apply depends on the main issue one is interested in as well as the available data. If the researcher is interested in the impact of taxes on the income distribution, the Musgrave & Thin (1948) approach is adequate since it relates the before and after Gini coefficients. In contrast, if we are interested in how the percentage distribution of taxes compares to the percentage distribution of income, the latter approaches should be applied. The question is how these methods can be translated for our setting.

In the context of this paper, we are mainly interested in the distribution of the burden of household energy expenditures across income quintiles as opposed to how these may themselves affect the income distribution. Hence, the Kakwani index is the suitable approach. Thus, in the following we turn to drawing concentration curves for energy expenditures and income similar to Borenstein & Davis (2024) and Borenstein & Davis (2016). In a scenario of complete equality in energy consumption across households, the energy Lorenz curve would align as a diagonal from (0,0) to (1,1). The energy concentration index for each country j = 1, ..., J and year t = 2010, 2015, 2020, 2023, denoted by C_{jt} , is defined as

$$C_{jt} = \frac{2}{n \cdot \mu_{jt}} \sum_{i=1}^{n} exp_{ijt} R_{ijt} - 1$$
(2)

where exp_{ijt} denotes the specific type of energy expenditure (i.e. electricity, heating, mobility) in the respective country j in year t, $\mu_{jt} = \frac{1}{n} \sum_{i=1}^{n} exp_{ijt}$ mean energy expenditures in the respective country and year, and R_{ijt} the relative rank of the *i*-th household in the income distribution of the respective economy. C_{it} ranges between -1 and 1 and is defined as twice the area between the concentration curve and the diagonal. The further the concentration curve lies from the diagonal, the more unequally energy expenditures are distributed across income groups. When the diagonal and the concentration curve overlap $C_{it} = 0$. It is negative (positive) when the concentration curve lies above (below) the diagonal. If it is positive, it means that energy consumption expenditures are concentrated predominantly among high-income households. The concentration index can be actually interpreted as a Gini coefficient applied to energy expenditures. Hence, it is a measure of *relative* inequality, meaning that a doubling of everyone's energy expenditures leaves the index unchanged. The following figure displays as an example the income Lorenz curve and the concentration curve for overall household energy expenditures for Bulgaria and the year 2020 since it displays the lowest degree of regressivity in terms of the Kakwani index. On the y-axis households are ordered by income while on the x-axis we see the cumulative expenditure or income up to the corresponding income percentile on the y-axis. Figure 5 illustrates that total energy expenditures are less concentrated than income in Bulgaria.

Figure 5: Lorenz Curve and Concentration Curve for Energy Expenditures in Bulgaria 2020



Source: Own illustration based on data from Eurostat.

To facilitate a numerical comparison instead of relying on energy expenditure concentration curves, we employ Kakwani indices. Developed by N. C. Kakwani (1977) as a measure of tax progression, the Kakwani index is originally defined as the difference between the concentration index of tax payments and the Gini income coefficient. In a similar manner, we can employ it to compute the degree of regressivity of energy expenditures. Hence, the Kakwani index for energy expenditures in country j and year t is defined as:

$$K_{jt} = C_{jt} - G_{jt} \tag{3}$$

where G_i , the Gini index, is defined as:

$$G_{jt} = \frac{\sum_{i=1}^{n} \sum_{l=1}^{n} |x_{ijt} - x_l|}{2n\bar{x_{it}}}$$
(4)

with n the number of households in country j, x_{ijt} the disposable income of the *i*th household, and $\bar{x_{jt}}$ denoting the mean income in the respective year. By definition, $-2 \leq K_{jt} \leq 1$. If the concentration curve of energy expenditures lies above the income Lorenz curve (as in Figure 5 above), $K_{jt} < 0$ which means that the cumulative share of energy expenditure exceeds the cumulative share of income and thus implies regressive energy expenditures. The opposite is true for positive values of K_{jt} .

The dataset enables us to distinguish between various categories of energy expenditures such as expenditures on mobility which encompass spending on gasoline and diesel or electricity expenditures. The household energy category includes spending on gas, district heating, and electricity. Our analysis consistently reveals the regressive nature of energy expenditures across all countries studied, with a median value of the Kakwani index for total household energy expenditures of -0.15 in 2020. The degree of regressivity exhibits a slight increase over the 2010-2020 period, mirrored by the lower values of the Kakwani index. Figure 6 depicts the median values of the Kakwani index for 2010 and 2020 across different types of energy expenditure categories. The graph illustrates that housing-related energy expenditures (including expenditures on electricity and heating) feature the most pronounced regressivity. As mentioned above, mobility related expenditures seem to be the least regressive but probably simply as a result of the poorest households not owning a car and hence not incurring any fuel costs.

Figure 6: Median Kakwani Index of European Union States in 2010 and 2020 for different energy expenditures



Source: Own illustration based on data from Eurostat.

Figure 7 illustrates the distribution of the three distinct indices (energy concentration, Kakwani and Gini index) for all countries in the year 2020. The concentration index is positive for all countries and years, suggesting the existence of energy expenditure inequality. However, it is noteworthy that income inequality, measured by the Gini index, is considerably higher than that of energy expenditures, resulting in negative values of the Kakwani index for all countries and years. Hence, this corresponds to the illustrative example of Bulgaria depicted in Figure 5, where the Lorenz curve lies below the energy expenditure curve, and both lie below the 45 degree line.

We observe only a minor increase in the Kakwani index for total energy expenditure projected for 2023 compared to 2020 (see Figure 8 and Table A2 in the Appendix). This may reflect the heightened responsiveness of low-income households to the upsurge in energy prices. Hence, while higher energy prices do lead to larger fractions of income spent on energy, the overall regressivity may even decrease. Nevertheless, we should bear in mind that this rather reflects the more pronounced reaction of low income households to energy price hikes who thus forego essential energy consumption.



Figure 7: Distribution of Concentration, Gini and Kakwani Index in 2020

Source: Own illustration based on data from Eurostat.

Figure 8: Development of Kakwani indices in various European Union countries



Source: Own illustration based on data from Eurostat.

4.4 Regressivity of energy expenditures - Socio-demograhic factors contribution to energy expenditure concentration

In a next step we delve deeper into understanding the magnitude of the contribution of distinct socio-demographic factors to energy expenditure inequality. Thus, we decompose the energy concentration index into potential determinants to assess the relative contribution of these various components to explaining energy expenditure inequality. Following Wagstaff, van Doorslaer and Watanabe (2003) and Huang (2022) we regress our variable of interest exp_{ijt} on a number of controls:

$$exp_{ijt} = \alpha + \sum_{k} \beta_{kjt} x_{kijt} + \epsilon_{ijt}$$
(5)

 β_{kjt} thereby represent the respective coefficients and ϵ_{ijt} the error term. We use the following control variables: equivalent income, number of income earners, household size, and dummy indicators accounting for socio-economic status and household type.¹² Hence, the

¹²The indicator variables for the different household type categories (1-6) capture the composition of the household, such as one-, two- or three-person household with or without children. The indicator variables for socio-economic status (1-6) represent manual worker and non manual workers in the private and public sector respectively, as well as self-employed or unemployed individuals. Additionally, we use indicator variables of the age of the household head (above 65, between 64 and 24 and below 24), the number of income earners (0-4, where 4 is for households with more than three income earners), and the household size (1-7, where 7 stands for all households with more than 6 household members).

concentration index C_{jt} can be expressed as:

$$C_{jt} = \sum_{k} \frac{\beta_{kjt} \bar{x}_{kjt}}{\mu_{jt}} C_{kjt} + \frac{GC_{\epsilon jt}}{\mu_{jt}}$$
(6)

$$GC_{\epsilon jt} = \frac{2}{n} \sum_{i=1}^{n} \epsilon_{ijt} R_{ijt}$$
⁽⁷⁾

 μ_{jt} thereby represent average energy expenditures in country j in year t, \bar{x}_{kjt} the mean of the variable considered and C_{kjt} the concentration index of the respective variable in country j. $GC_{\epsilon jt}$ is a generalized concentration index for the residual. Hence, the energy concentration index can be decomposed into a deterministic component $\sum_k \frac{\beta_{kjt} \bar{x}_{kjt}}{\mu_{jt}} C_{kjt}$ defined as the weighted sum of the concentration indices of the regressors and a residual component representing the inequality in energy expenditures that cannot be explained by systematic variations in the regressors. The weight of the respective concentration indices C_{kjt} is given by the elasticity of energy expenditures with respect to the respective regressor $\frac{\beta_{kjt} \bar{x}_{kjt}}{\mu_{jt}}$.

Table 3 displays the outcomes of the decomposition analysis conducted for 15^{13} European Union countries in the year 2020. According to equation (6), the impact of each element on the disparity in energy expenses is ascertained by multiplying the concentration index with the elasticity of the respective determinant. The concentration index for each determinant (i.e income, household size, etc.) illustrates how the determinant is distributed among different income groups, thereby indicating the level of inequality. The contribution of the deterministic component ranges between 0.03 (Belgium) to 0.21 in Bulgaria. On the whole, the incorporated controls account for 75% to 98% of the overall concentration index.

¹³We include here only 15 out of 19 countries, due to missing information on some variables in the Czech Republic, Slovenia and Malta. Furthermore we drop Luxembourg as it represents an outlier due to specific demographic characteristics.

Country	CI	Cumulative Contribution $\sum_k \frac{\beta_k \bar{x}_k}{\mu} C_k$	Fraction (in %)	Residual
AT	0.09	0.09	91	0.01
BE	0.03	0.03	93	0.00
BG	0.21	0.18	85	0.03
CY	0.15	0.11	75	0.04
DE	0.13	0.11	84	0.02
DK	0.10	0.10	98	0.00
EE	0.12	0.11	90	0.01
EL	0.12	0.11	88	0.01
ES	0.09	0.08	92	0.01
FR	0.15	0.12	82	0.03
HR	0.17	0.16	94	0.01
HU	0.17	0.15	85	0.03
LT	0.15	0.13	89	0.02
LV	0.22	0.18	82	0.04
SK	0.09	0.08	90	0.01

Table 3: Concentration indices, cumulative contribution of explanatory variables and explained fraction

Source: From the dataset encompassing 19 European Union countries, we exclude the Czech Republic, Slovenia, and Malta due to missing information on relevant covariates. We also Luxembourg because it is an outlier due to the specific nature of the demographic characteristics.

Table 4 displays the results of the regression introduced in eq. (5) for Bulgaria and Spain (the two countries with the lowest and highest absolute values of the Kakwani index) and the year 2020 as illustrative examples. All coefficients should be interpreted with the reference category being the indicator variable with the lowest numerical value, except for equivalent income, which is a numeric variable measured at the level scale. The largest values for the elasticities in absolute terms are recorded for equivalent income, the age of the household head and different household types. In Table 5 we also present the fraction of inequality in energy expenditures explained by different components. Thus, in our illustrative example for Bulgaria and Spain, equivalent income explains only 50% in Bulgaria but even up to 85% of the energy expenditure concentration index in Spain. Covariates such as education, number of income earners or socio-economic status account for smaller fractions of the overall energy expenditure inequality. In contrast, some covariates such as the age of the household head (Bulgaria) or the household size (Spain) even contribute to a decrease in the concentration of energy expenditures.

Country		B	ulgaria		S	Spain		
Variable	Coefficient	SE	Elasticity $\frac{\beta_{kj}\bar{x}_{kj}}{\mu_j}$	CI	Coefficient	SE	Elasticity $\frac{\beta_{kj}\bar{x}_{kj}}{\mu_j}$	CI
Education2	123.15	72.28	0.02	-0.45	130.51*	56.20	0.01	-0.24
Education3	139.86*	69.10	0.07	-0.04	142.39*	58.61	0.01	-0.12
Education6	156.17*	72.27	0.04	0.36	233.11**	57.26	0.05	0.22
Equivalent income	0.10**	0.01	0.37	0.28	0.04**	0.00	0.26	0.29
Age HH head >64	231.14	259.79	0.09	0.19	528.99	374.78	0.14	0.01
Age HH head >65	291.50	261.53	0.15	-0.15	441.10	377.10	0.06	-0.02
HH type 2	385.30**	32.20	0.13	0.08	859.96**	44.62	0.11	0.10
HH type 3	483.39**	176.37	0.04	0.23	1302.00**	155.09	0.06	0.01
HH type 4	333.38**	107.27	0.01	-0.05	649.86**	99.94	0.01	-0.39
HH type 5	519.80**	172.96	0.06	0.21	1188.69**	150.06	0.13	-0.02
HH type 6	556.33**	189.78	0.03	-0.04	1281.55**	168.31	0.03	-0.19
HH size 3	250.56	165.16	0.03	0.23	282.66*	139.08	0.03	0.00
HH size 4	459.82**	170.55	0.04	0.20	783.98**	145.67	0.06	-0.05
HH size 5	586.67**	188.45	0.01	-0.08	1055.92**	160.04	0.02	-0.19
HH size 6	1071.60**	216.48	0.01	-0.29	929.91**	211.14	0.00	-0.38
HH size 7	611.00**	236.23	0.00	-0.37	1360.76**	267.49	0.00	-0.62
1 income earner	28.60	44.75	0.01	0.12	-29.08	61.29	0.00	-0.06
2 income earner	244.76**	66.27	0.06	0.31	113.58	78.99	0.02	0.10
3 income earner	408.30**	103.24	0.02	0.26	242.54*	117.59	0.00	-0.01
4 income earner	437.44**	135.60	0.01	-0.09	352.06*	167.48	0.00	-0.02
Socio.economic status 2	38.54	45.73	0.00	0.57	-37.17	43.45	0.00	0.35
Socio.economic status 3	184.35**	57.00	0.01	0.26	298.93*	50.66	0.01	0.00
Socio.economic status 4	-234.19**	56.65	-0.01	-0.43	-473.22**	68.29	-0.01	-0.67
Socio.economic status 5	10.17	51.92	0.00	-0.20	-11.54	67.97	0.00	0.00
Socio.economic status 6	-47.06	74.53	0.00	-0.25	-262.23**	78.73	-0.01	-0.33

Table 4: Coefficients, elasticity and the corresponding concentration indices for Bulgaria and Spain 2020

Notes: 1% significance level (**), 5% significance level (**). We use 2,938 observations from Bulgaria and 18,379 from Spain in the year 2020. The dummy variables "socio-economic status" and "HH type" indicate the socio-economic and demographic composition of the household. The following categories apply: one adult (1), two adults (2), more than two adults (3), one adult with children (4), two adults with children (5), more than two adults with children (6). Manual worker (1), non-manual worker (2), self-employed worker or farmer (3), unemployed (4), retired (5), other inactive (6). The reference category is manual worker and omitted from the present listing. The reference category for all indicators is represented by the lowest value of the indicator. For example households with no income earner is the reference category. The variable household size 1 does not appear in the table as it is multicollinear to HH type 1 and hence household size 2 is the reference category.

Table 5:	$\operatorname{Contribution}$	of different	socio-demographic	variables to	explaining the	ne concentra-
tion inde	X					

Country	Bulgaria		Spain	
Variable	Contribution	%	Contribution	%
Concentration index	0.21	100	0.09	100
Education	0.01	3	0.01	7
Equivalent income	0.10	50	0.07	85
Age HH head	0.00	-2	0.00	0
HH type	0.03	15	0.00	-1
HH size	0.01	5	-0.01	-10
# income earner	0.02	11	0.00	2
Socio-economic status	0.01	4	0.01	9
Residual	0.03	15	0.01	8

Figure 9 illustrates the relative contributions of different socio-economic variables to explaining the concentration index for various European Union states in 2020. Equivalent income stands out as the main contributor to the concentration index, albeit its contribution varies to a large extent between countries. Hence, in Latvia the contribution amounts to only 33% whereas it is even as high as 113% in Belgium. As depicted in the graph, in some countries, a number of socio-demographic factors even feature a negative contribution to the concentration index. This is especially the case for household size (in particular in Belgium and Spain) and socio-economic status (in Slovakia and Denmark). Accordingly, these variables counteract the effect of the other variables and hence cushion the effect on the inequality of household energy expenditures. This feature can for instance be explained in the following way. A larger household size induces a higher energy consumption but, at the same time, bigger households are more common at the lower end of the income distribution. Hence, this implies that the energy Lorenz curve is shifted upwards toward the diagonal and thus energy expenditures are more equally distributed across income.

Figure 9: Relative contribution of different socio-demographic variables to explaining the concentration index for various European Union states in 2020



Source: Own illustration based on data from Eurostat.

The concentration indices of energy expenditures slightly changed between 2010 and 2020. Table 6 presents the changes in concentration index for 13 European Union countries. The highest increase in the concentration index is observed in Hungary, at 0.068, while the largest decrease is noted in Greece, at 0.063. In 9 out of 13 countries, the concentration index decreased, implying less concentrated energy expenditures and hence more equally distributed energy expenditures. At the same time, during the aforementioned time period the Gini coefficient remained almost unchanged. Hence, the two effects imply an increase in the Kakwani index in 8 out of 13 countries. Thus, in Belgium, Bulgaria, Cyprus, Estonia,

Greece, Spain Lithuania and Slovakia the regressivity slightly decreased whereas it slightly increased in Germany, France, Hungary and Latvia. Table A1 in the Appendix presents summary statistics of the Kakwani index for 2010, 2015, 2020 and 2023. Our projections for 2023 reveal that the Kakwani index slightly increased between 2020 and 2023. This implies that, even though energy prices increased considerably, assuming a higher price sensitivity of lower income households, their expenditures as a share of income increased relatively less compared to those of richer households, contributing to a reduction of regressivity.

Table 6: Overview of changes in the inequality of energy expenditures and the regressivity in 13 European Union countries from 2010 to 2020

Country	ΔCI	$\Delta \mathbf{KI}$
BE	-0.057	0.015
BG	-0.019	0.037
CY	-0.027	0.036
DE	0.001	-0.010
EE	-0.045	0.050
EL	-0.063	0.027
ES	-0.017	0.007
FR	0.032	-0.044
HR	-0.006	-0.000
HU	0.068	-0.068
LT	-0.055	0.051
LV	0.048	-0.040
SK	-0.026	0.012

Notes: We further exclude Austria and Denmark due to missing information in 2010.

5 Conclusion

This paper contributes to the growing body of research on energy expenditure inequality in advanced economies by quantifying the regressivity of energy expenditures across European Union countries along various dimensions. In the context of the targeted reductions in greenhouse gas emissions and the necessary transformation of energy systems, this consideration is of paramount importance. Policy instruments such as CO_2 prices or subsidies aimed at enhancing energy efficiency in buildings, promoting the adoption of solar panels, and supporting the expansion of electromobility will have a major impact on household energy expenditures. At the same time, households considerably differ in terms of sociodemographic characteristics, budget constraints or living conditions (e.g., tenants versus homeowners). Thus, these instruments and hence energy prices do not have a uniform effect in the population. A comprehensive assessment of total household energy expenditure is thus called for. We analyze cross-sectional survey data from 19 European countries for the years 2010, 2015, and 2020, revealing a consistent pattern of regressive energy expenditures across all countries and years examined. However, there is significant variability in the degree of convexity and regressivity among the studied countries.

A key aspect of our analysis is the argument that assessing inequality in the distribution of energy expenditure burdens among households requires a more nuanced approach than simply focusing on the proportion of income spent on energy, especially among the poorest households. Our findings demonstrate that the countries with the lowest or highest share of equivalent disposable income spent on energy — or those with the largest absolute difference between the shares of income spent on energy by households in the first and fifth income quintiles — do not necessarily correspond to those with the lowest or highest degree of regressivity This highlights the importance of a comprehensive examination of these dynamics.

The design of effective climate and energy policies requires consideration of multiple dimensions to ensure that heavily burdened households are not disproportionately strained, thereby fostering political support for climate initiatives. The Kakwani index offers valuable insights into overall regressivity, while variations in the proportion of income spent on energy highlight the differing burdens across income groups. Additionally, assessing the degree of convexity in energy expenditure shares can help determine whether a specific segment of low-income households is disproportionately affected, or if the impact extends to a broader group, including the middle class. Policy instruments should be tailored based on these insights. For instance, if a clearly identifiable group, such as low-income households relying on fossil-based heating systems, is affected, targeted policies promoting the adoption of more environmentally friendly heating systems with lower variable fuel costs could provide effective assistance. However, if a broader population is impacted, designing appropriate measures becomes more challenging, requiring alternative solutions. Despite these considerations, the primary objective of climate policies — to transition towards low-carbon production and consumption—must remain paramount.

The focus on Europe does not constrain the generalizability of our results. Many industrialized countries have already implemented stringent climate regulations, and their experiences offer valuable lessons for other regions. Beyond the EU, countries such as China, with its commitment to net-zero targets by 2060, and the United States, through initiatives like the Green New Deal, provide relevant contexts for comparison.

Our simulation of the effects of recent energy price hikes reveals a somewhat surprising outcome: Regressivity is lower in 2023 compared to 2020, given the parameters assumed in the simulation. This finding is largely due to the higher price sensitivity of lower-income households, which leads them to reduce energy consumption more significantly. However, this reduction in regressivity should be interpreted with caution, as it does not result from more equitable policy design but rather from households being forced to forgo essential energy consumption, such as cooking and heating.

Ultimately, we examine the contribution of various socio-demographic variables to the overall concentration index of energy expenditures. Interestingly, some socio-demographic factors, such as household size or socio-economic status, have a negative contribution to the concentration index in certain countries, thereby contributing to a more equitable distribution of energy expenditures across the population. This finding is significant because it underscores that distinct policies addressing the unequal distribution of the energy expenditure burden among households may be warranted beyond income-based transfers. Fur-

ther research should delve deeper into these channels. While this study primarily examines the distributional effects of increased energy prices, existing literature also explores the distributional impacts of state subsidies for climate-friendly technologies, such as solar panels(Lekavičius et al., 2020) or electric vehicles (Guo & Kontou, 2021) or weatherization Borenstein & Davis (2024). These subsidies often predominantly benefit higher-income households and will likely play a crucial role in the future distribution of energy expenditures, as households with electric vehicles and/or solar panels tend to experience lower energy costs, all else being equal. Therefore, more recent data in the literature may increasingly reflect the adoption of these technologies. Future research should thus focus on analyzing the impact of shifts in energy production, extending beyond carbon pricing policies.

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Appendix

Country In	ncome'20In	1come'22Gas	ioline'20 Die	sel'20C	0il'20 Gas	oline'23 Die	sel'23 C	il'23 G	as'23 G	as'20E	ec'23 El	ec'20H	eat'20 I	Heat'23 H	ydro'202E	[ydro'235	olid'20S	olid'23 F	uel'20 F	lel'23
Austria	108.59	116.95	1.24	1.20	0.69	1.69	1.84	1.39	0.08	0.02	0.21	0.14	96.50	120.50	121.30	143.10	127.30	161.00	1.22	1.77
$\operatorname{Belgium}$	109.37	120.90	1.46	1.47	0.53	1.83	1.85	1.06	0.06	0.02	0.38	0.18	96.50	120.50	121.30	143.10	127.30	161.00	1.47	1.83
Bulgaria	113.93	118.43	1.06	1.05	0.92	1.40	1.57	1.38	0.12	0.02	0.10	0.08	96.50	120.50	121.30	143.10	127.30	161.00	1.06	1.47
Croatia	113.93	118.43	1.37	1.32	0.57	1.53	1.73	1.12	0.08	0.03	0.12	0.10	96.50	120.50	121.30	143.10	127.30	161.00	1.35	1.64
Cyprus	113.93	118.43	1.23	1.27	0.78	1.48	1.69	1.23	0.08	0.02	0.26	0.13	96.50	120.50	121.30	143.10	127.30	161.00	1.24	1.53
Czechia	129.22	146.32	1.22	1.21	0.63	1.67	1.68	1.21	0.08	0.02	0.36	0.13	96.50	120.50	121.30	143.10	127.30	161.00	1.21	1.68
Denmark	111.59	117.54	1.65	1.39	1.35	2.12	1.94	2.00	0.13	0.02	0.36	0.09	96.50	120.50	121.30	143.10	127.30	161.00	1.57	2.07
$\operatorname{Estonia}$	128.09	150.54	1.43	1.25	0.82	1.87	1.87	1.38	0.13	0.02	0.21	0.09	96.50	120.50	121.30	143.10	127.30	161.00	1.36	1.87
Finland	106.00	111.35	1.61	1.43	0.91	2.08	2.21	1.70	0.08	0.02	0.19	0.12	96.50	120.50	121.30	143.10	127.30	161.00	1.56	2.11
France	111.3	114.56	1.55	1.44	0.87	2.02	2.00	1.44	0.07	0.03	0.17	0.13	96.50	120.50	121.30	143.10	127.30	161.00	1.48	2.01
Germany	112.07	111.96	1.47	1.27	0.60	1.94	1.94	1.27	0.05	0.02	0.23	0.14	96.50	120.50	121.30	143.10	127.30	161.00	1.40	1.94
Greece	113.93	118.43	1.68	1.40	1.02	2.03	1.90	1.32	0.15	0.02	0.46	0.13	96.50	120.50	121.30	143.10	127.30	161.00	1.65	2.02
Hungary	160.76	203.38	1.16	1.20	1.20	1.73	1.84	1.84	0.14	0.02	0.09	0.08	96.50	120.50	121.30	143.10	127.30	161.00	1.18	1.76
Ireland	111.70	119.80	1.47	1.37	0.63	1.72	1.82	1.18	0.08	0.03	0.38	0.21	96.50	120.50	121.30	143.10	127.30	161.00	1.41	1.78
Italy	103.88	106.72	1.63	1.50	1.30	1.98	2.00	1.73	0.11	0.02	0.32	0.14	96.50	120.50	121.30	143.10	127.30	161.00	1.57	1.99
Latvia	147.69	164.75	1.30	1.19	0.67	1.75	1.81	1.35	0.14	0.02	0.24	0.10	96.50	120.50	121.30	143.10	127.30	161.00	1.23	1.79
Lithuania	197.80	246.78	1.25	1.14	0.50	1.62	1.77	1.12	0.12	0.02	0.20	0.10	96.50	120.50	121.30	143.10	127.30	161.00	1.17	1.73
Luxembourg	99.29	107.07	1.23	1.11	0.50	1.66	1.71	1.09	0.11	0.03	0.17	0.15	96.50	120.50	121.30	143.10	127.30	161.00	1.16	1.69
Malta	113.93	118.43	1.56	1.42	1.14	1.44	1.29	1.08	0.08	0.02	0.12	0.12	96.50	120.50	121.30	143.10	127.30	161.00	1.50	1.37
Netherlands	112.66	118.63	1.78	1.41	1.12	1.96	1.86	2.04	0.06	0.02	0.32	0.14	96.50	120.50	121.30	143.10	127.30	161.00	1.73	1.94
Poland	133.35	163.56	1.14	1.15	0.71	1.52	1.72	1.40	0.10	0.03	0.10	0.09	96.50	120.50	121.30	143.10	127.30	161.00	1.14	1.61
$\operatorname{Portugal}$	118.73	133.92	1.59	1.42	1.19	1.81	1.70	1.71	0.10	0.02	0.20	0.11	96.50	120.50	121.30	143.10	127.30	161.00	1.48	1.74
$\operatorname{Romania}$	113.93	118.43	1.09	1.10	0.91	1.42	1.62	1.51	0.15	0.03	0.27	0.10	96.50	120.50	121.30	143.10	127.30	161.00	1.09	1.51
Slovakia	123.36	144.35	1.35	1.22	0.96	1.66	1.71	0.96	0.08	0.03	0.13	0.11	96.50	120.50	121.30	143.10	127.30	161.00	1.29	1.68
Slovenia	120.22	136.34	1.21	1.21	0.95	1.42	1.63	1.23	0.08	0.03	0.15	0.11	96.50	120.50	121.30	143.10	127.30	161.00	1.21	1.53
Spain	106.47	108.30	1.34	1.22	0.65	1.75	1.77	1.21	0.10	0.02	0.30	0.12	96.50	120.50	121.30	143.10	127.30	161.00	1.27	1.76
Sweden	110.50	116.97	1.54	1.57	1.07	1.90	2.26	1.48	0.14	0.03	0.25	0.12	96.50	120.50	121.30	143.10	127.30	161.00	1.55	2.04

Table A1: Energy price developments by country

Kakwani Total	2010	2015	2020	2023
Min	-0.24	-0.24	-0.26	-0.21
Mean	-0.15	-0.14	-0.16	-0.13
Median	-0.15	-0.15	-0.16	-0.13
Max	-0.03	-0.06	-0.07	-0.01
Kakwani Household	2010	2015	2020	2023
Min	-0.28	-0.28	-0.27	-0.22
Mean	-0.20	-0.19	-0.20	-0.16
Median	-0.20	-0.19	-0.20	-0.17
Max	-0.10	-0.10	-0.17	-0.06
Kakwani Electricity	2010	2015	2020	2023
Min	-0.29	-0.29	-0.28	-0.28
Mean	-0.21	-0.20	-0.20	-0.18
Median	-0.23	-0.20	-0.20	-0.19
Max	-0.12	-0.10	-0.16	-0.11
Kakwani Fuel	2010	2015	2020	2023
Min	-0.24	-0.21	-0.24	-0.23
Mean	-0.05	-0.06	-0.07	-0.07
Median	-0.04	-0.08	-0.08	-0.08
Max	0.21	0.20	0.15	0.16

Table A2: Summary Statistics Kakwani Index

CI Total	2010	2015	2020	2023
Min	0.08	0.04	0.02	0.06
Mean	0.15	0.14	0.13	0.15
Median	0.17	0.14	0.13	0.14
Max	0.24	0.23	0.22	0.25
CI Household	2010	2015	2020	2023
Min	0.04	0.02	0.01	0.06
Mean	0.10	0.09	0.08	0.12
Median	0.10	0.09	0.07	0.12
Max	0.17	0.16	0.15	0.20
CI Electricity	2010	2015	2020	2023
Min	0.03	-0.00	-0.00	0.00
Mean	0.09	0.09	0.08	0.10
Median	0.09	0.08	0.09	0.10
Max	0.15	0.16	0.16	0.18
CI Fuel	2010	2015	2020	2023
Min	0.09	0.07	0.04	0.05
Mean	0.25	0.23	0.21	0.21
Median	0.27	0.21	0.20	0.21
Max	0.52	0.50	0.44	0.45

 Table A3: Summary Statistics Concentration Index

Table A4: Summary Statistics Gini Index

Gini	2010	2015	2020	2023
Min	0.22	0.22	0.22	0.22
Mean	0.30	0.29	0.28	0.28
Median	0.31	0.28	0.28	0.28
Max	0.36	0.37	0.35	0.34

Oil	0.098	0.091	0.104	0.110	0.130	0.078	0.109	0.151	0.110	0.108	0.184		0.214	0.068	0.154	0.202		0.166	0.169	,
Heat	0.070		0.145		0.087	0.080	0.098	0.155		0.075	0.120	0.111	0.141		0.150	0.096		0.120	0.121	
Gas	0.070	0.065	0.145	0.125	0.090	0.051	0.081	0.127	0.089	0.088	0.156	0.142	0.118	0.045	0.140	0.102	0.068	0.130	0.164	
Electric	0.056	0.059	0.129	0.122	0.069	0.050	0.071	0.118	0.084	0.069	0.098	0.084	0.107	0.037	0.111	0.074		0.128	0.089	
Coal	0.086	0.084	0.220	0.132	0.106	0.084	0.131	0.167	0.112	0.086	0.234	0.182	0.157	0.044	0.165	0.095		0.157	0.168	 :
\triangle Share Electric	0.007	0.022	0.063	-0.089	-0.030	-0.040	-0.057	0.124	0.271	-0.101	0.013	-0.022	-0.024	0.060	-0.022	-0.076	0.000	0.051	-0.018	
\triangle Share Oil	-0.044	0.005	-0.002	-0.259	0.029	-00.00	0.000	-0.206	-0.033	-0.034	-0.025	0.000	0.001	0.077	-0.010	-0.001	0.000	-0.097	-0.003	
\triangle Share Heat	0.083	0.000	-0.184	0.000	0.118	0.195	-0.079	-0.008	0.000	-0.001	-0.102	-0.011	-0.098	0.000	-0.158	0.001	0.000	-0.002	-0.019	-
\triangle Share Gas	-0.053	-0.033	-0.028	0.401	-0.105	-0.135	-0.027	-0.046	-0.248	0.193	-0.362	0.009	-0.127	-0.111	-0.073	0.075	0.000	-0.119	-0.162	
\triangle Share Coal	0.007	0.006	0.150	-0.053	-0.011	-0.012	0.163	0.136	0.011	-0.057	0.476	0.024	0.248	-0.026	0.263	0.001	0.000	0.168	0.201	
country	AT	BE	BG	CY	DE	DK	EE	EL	ES	FR	HR	HU	LT	LU	LV	MT	NL	SI	SK	

Table A5: Difference in heating system between Q1 and Q5 and average share of income spent on energy by heating system

Note: The first six columns present the difference in the share of households using a specific heating system between the first and fifth income quintiles. The last five columns depict the average share of

income allocated to energy expenditures by heating system.

country	2010	2015	2020	2023
BE	-0.179	-0.120	-0.083	-0.108
BG	-0.098	-0.108	0.002	0.003
CY	-0.125	-0.023	-0.023	-0.019
CZ	-0.103	0.062		
DE	-0.076	-0.062	-0.122	-0.124
DK	-0.126	-0.061	-0.025	-0.026
EE	-0.136	-0.188	-0.044	-0.046
EL	-0.179	-0.229	-0.232	-0.147
ES	-0.098	-0.073	-0.057	-0.080
FI	-0.081	-0.114		
FR	-0.125	-0.143	-0.143	-0.046
HR	-0.099	0.008	0.053	0.181
HU	-0.080	-0.179	-0.162	-0.189
IE	-0.201	-0.165		
LT	-0.117	-0.094	-0.044	-0.050
LV	-0.099	-0.075	-0.101	-0.074
MT	-0.111	-0.131	-0.131	-0.125
PL	-0.098	-0.043		
PT	-0.074	-0.147		
RO	0.003	-0.001		
SE	0.038	0.037		
SI	-0.183	-0.110	-0.127	-0.112
SK	0.108	-0.061	-0.113	-0.105
UK	-0.094			
LU		-0.131	-0.202	-0.068
NL		-0.217	-0.210	-0.202
AT			-0.058	-0.067

Table A6: Degree of convexity

Note: This table presents the degree of convexity of energy expenditure shares along the income distribution following the calculations described in section 3.3.



Figure A1: Share of income spent on different energy sources for Germany, France, and Spain (left column is in 2010, right column is in 2023)

Source: Own calculation based on data from the European Household Budget Survey provided by Eurostat and price elasticity estimates for energy of various recent studies.



Figure A2: Share of income spent on different energy sources for Austria, Denmark, and Belgium (left column is in 2010, right column is in 2023)

Source: Own calculation based on data from the European Household Budget Survey provided by Eurostat and price elasticity estimates for energy of various recent studies.



Figure A3: Share of income spent on different energy sources for Greece, Croatia, and Hungary (left column is in 2010, right column is in 2023)

Source: Own calculation based on data from the European Household Budget Survey provided by Eurostat and price elasticity estimates for energy of various recent studies.