The Inequality Cost of Energy: A Distributional Framework for Household Energy Burdens in the European Union

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Abstract

Household energy costs can be highly regressive. However, existing indicators provide limited information about how strongly these costs reshape the overall income distribution or how unevenly energy burdens are distributed across households. We develop two complementary, threshold-free measures of these dimensions. First, the energy-cost Gini gap measures the change in income inequality after deducting household energy expenditure from disposable income. Second, the Gini index of the household energy burden measures inequality in the share of household income devoted to energy expenditure. Combining the two measures yields a four-quadrant typology of (i) broad vulnerability, (ii) compound vulnerability, (iii) concentrated vulnerability, and (iv) low distributional pressure. We apply the framework to the European Household Budget Survey. In 2020, deducting energy expenditure increases the income Gini by between 0.6 and 3.1 percentage points, with the largest effects concentrated in Central and Eastern Europe. The Gini index of the household energy burden ranges from 0.33 in Slovakia to 0.5 in Finland, returning markedly different country rankings. The two measures are only weakly correlated, showing that the aggregate inequality effect of energy costs and the concentration of high energy burdens capture distinct dimensions of vulnerability. These differences imply that uniform approaches to compensating households for higher energy costs risk systematically mistargeting support across member states. Finally, the framework complements household-level energy-poverty indicators by providing a country-level distributional diagnostic suitable for cross-country and cross-time comparison.

Keywords: energy poverty; inequality; Gini coefficient; household budget survey; Social Climate Fund; ETS2

JEL classification: D31, D63, Q41, Q48, I32

1. Introduction

Unavoidable costs absorb different shares of household resources. Therefore, inequality in the resources remaining for other needs may differ substantially from inequality in disposable income. This logic is well established for taxes, transfers, and housing costs (Dustmann et al., 2022; Reynolds & Smolensky, 1977). Household energy expenditure raises two related distributional questions: (i) how much more unequal do household resources become once the cost of meeting energy needs is taken into account, and (ii) how unevenly is that energy burden distributed across households?

A distributional literature approaches these questions by examining how costs and resources are distributed across the population as a whole. Public finance analysis routinely compares inequality before and after taxes, transfers, or other deductions. For example, Linden et al. (2024) use a pre- and post-deduction Gini framework to assess the distributional effects of a hypothetical carbon tax across six EU countries. The same logic can be applied to actual energy expenditure by comparing the income distribution before and after deducting household energy costs. Gini and related measures of concentration have been used to describe inequality in energy consumption and energy footprints. Jacobson et al. (2005) analyse inequality in electricity consumption, while Oswald et al. (2020) examine embodied energy footprints. Ackermann & Radulescu (2026) use Household Budget Survey data for 19 EU countries to calculate the income Gini, the concentration index of residential energy expenditure and the Kakwani progressivity index. They show that energy expenditure is regressive across member states. Their analysis establishes how energy spending is distributed relative to income rank, but it does not ask how much deducting actual energy expenditure changes the income Gini coefficient, nor how dispersed expenditure-to-income burdens are across households. This literature provides established tools for analysing distributional effects and inequality in energy use, but has not brought together the effect of energy expenditure on income inequality with the distribution of household energy burdens. Yet household energy expenditure is not only a distributional issue. Because energy is required to meet basic needs, heavy burdens can also lead to material deprivation.

The energy-poverty literature approaches the problem from this household-vulnerability perspective, focusing primarily on identifying households that cannot secure adequate energy services without facing excessive financial strain. Early measures used normative expenditure thresholds, most prominently the ten per cent rule developed in the UK context (Herrero, 2017; Romero et al., 2018). Subsequent frameworks broadened the diagnosis through expenditure-based indicators such as 2M and M/2, consensual indicators such as inability to keep the home adequately warm and arrears on utility bills, and multidimensional national approaches (Castaño-Rosa et al., 2019; Gouveia et al., 2019; Kyprianou et al., 2019; Sokołowski et al., 2020). The revised Energy Efficiency Directive (EU/2023/1791) further established an EU-wide legal definition of energy poverty. These approaches provide essential information about who experiences high or inadequate energy burdens and in what form. Residual-income approaches, most notably those of Hills (2012), also explicitly consider the resources households retain after meeting energy costs.

Their purpose, however, is generally for household classification rather than for characterising the income distribution as a whole. Threshold-based indicators identify households that meet particular expenditure or deprivation criteria, and different indicators consequently capture different populations and can yield different country rankings (Croon et al., 2023; Menyhért, 2024). Increasingly multidimensional frameworks developed by the European Commission, the

Energy Poverty Advisory Hub and national institutions address this problem by combining indicators and contextual information (Directorate-General for Energy (European Commission) et al., 2025). The energy-poverty literature identifies vulnerability well, but does not generally characterise its distribution across the population as a whole. Therefore, the literature still does not directly answer either of our distributional questions in whole-distribution terms: (i) how much energy expenditure changes overall income inequality, and (ii) how unequal energy burdens are across the population independently of any poverty threshold.

We answer the two questions using complementary, threshold-free measures. For the first question, of how much energy expenditure changes the distribution of household resources, we propose the energy-cost Gini gap, defined as the difference between the Gini coefficient of equivalised disposable income after deducting residential energy expenditure and the Gini coefficient before deduction. For the second, *i.e.* how unevenly energy burdens are distributed, we calculate the Gini index of the household energy burden, where the burden is the ratio of residential energy expenditure to household income. The first measure captures the aggregate distributional effect of energy costs; the second captures the dispersion of exposure across households.

Combining the two measures produces a four-part typology. Countries with a relatively large energy-cost Gini gap but a low burden Gini exhibit broad vulnerability, whereas those with a high burden Gini but a small aggregate inequality effect exhibit concentrated vulnerability. Compound vulnerability combines high values on both dimensions, while low distributional pressure combines relatively low values on both. The distinction is relevant for policy because similar aggregate effects can conceal very different distributions of household exposure: broad vulnerability may favour more encompassing support, concentrated vulnerability more targeted structural interventions, and compound vulnerability a combination of the two.

We apply the framework to the Eurostat Household Budget Survey for 2015 and 2020 across up to 23 EU member states. Four findings stand out. First, residential energy expenditure increases the income Gini in every country examined, by between 0.6 and 3.1 percentage points in 2020, with the largest effects concentrated in Central and Eastern Europe. Second, the Gini burden ranges from 0.33 in Slovakia to 0.50 in Finland, producing markedly different country rankings. The two measures are only weakly correlated in 2020, confirming that the aggregate inequality effect of energy expenditure and the dispersion of household burdens capture distinct dimensions of vulnerability. Third, the fuel-carrier decomposition shows substantial cross-country differences in which energy sources account for the distributional effect. Fourth, the share of the carrier-attributed Gini gap associated with fuels covered by the EU Emissions Trading System for buildings and road transport (ETS2) ranges from 2 per cent in Denmark to 85 per cent in the Netherlands.

These differences matter for the implementation of ETS2 and the Social Climate Fund (SCF). Member states differ not only in the magnitude of energy-related inequality but also in how household burdens are distributed and in the fuels through which that inequality arises. A common set of headline indicators can therefore conceal materially different distributional structures. Our measures are not intended to replace Eurostat energy-poverty indicators or national multidimensional frameworks, which remain essential for identifying vulnerable households and determining eligibility for support. Rather, they add a country-level distributional perspective: the energy-cost Gini gap shows how strongly energy expenditure widens the income distribution, the burden Gini shows how unevenly that burden is distributed, and the carrier decomposition shows how closely the resulting pattern overlaps with fuels directly covered by ETS2.

The remainder of the paper is organised as follows. Section 2 describes the data. Section 3 defines the distributional measures and decomposition methods. Section 4 presents the main results, including the cross-country distribution of the two Gini measures, the vulnerability typology, the fuel-carrier decomposition and the ETS2 coverage share. Section 5 discusses the policy implications, with particular attention to the Social Climate Fund. Section 6 concludes.

2. Data

2.1. The Eurostat Household Budget Survey

We use the 2015 and 2020 waves of the Eurostat Household Budget Survey (HBS), the main harmonised source of microdata on household expenditure in the European Union. The scientific-use files provide household-level information on net monetary income and expenditure under a common COICOP classification, together with survey weights for population-representative estimates within countries.

The 2015 wave was collected mainly between 2014 and 2016, and the 2020 wave between 2019 and 2021. The latter, therefore, overlaps with the COVID-19 pandemic; comparisons between the two waves are treated as descriptive.

Our main variables are equivalised disposable income and residential energy expenditure. Income is based on net monetary household income and equivalised using the modified OECD scale. Residential energy expenditure comprises electricity, gas, liquid fuels, solid fuels and heat energy. Variable construction, sample restrictions and the treatment of the pandemic-period wave are detailed in the appendices.

2.2. Country coverage

The analysis covers 23 EU member states in 2015, 19 in 2020, and 17 observed in both waves. Coverage differs because some scientific-use files lack the information needed to construct comparable measures of income and energy expenditure.

Cyprus, France and Malta are excluded from 2020 because their released files reproduce 2015 observations with monetary values rescaled using HICP coefficients rather than newly collected household data. Czechia and Italy are excluded, where the harmonised net monetary income variable used in the analysis is unavailable. Portugal and Romania are excluded from 2020 because residential energy expenditure is not reported at the required sub-category level. Sweden is absent from the 2020 sample because its scientific-use file was not available in our data release. Norway is available in 2020 but is excluded from the main analysis because the policy focus is the EU and the Social Climate Fund; it is reported separately as an EEA comparator.

The 2015 sample contains 233,812 household observations. The corresponding 2020 files contain 252,326 observations before excluding Norway. Full country coverage and descriptive statistics are reported in Appendix Table A1.

2.3. Descriptive patterns

Household energy expenditure differs markedly across the countries in the sample. Mean energy expenditure ranges from less than 3 per cent of disposable income in Luxembourg in 2020 to around 14 per cent in several Central and Eastern European countries in 2015. Income differences are similarly large: mean equivalised disposable income ranges from approximately €5,000 in the lowest-income countries to more than €40,000 in Luxembourg.

These differences provide the background for the distributional analysis that follows. Countries differ not only in the average resources households devote to energy, but also in where those costs fall across the income distribution. Appendix Table A2 reports the complete country-year summary statistics.

3. Measurement framework

We measure two distinct features of household energy exposure: the extent to which energy expenditure widens the income distribution, and the inequality of energy burdens across households. We then decompose the first measure by energy carrier.

3.1. Energy-cost Gini gap

For household i, let Y_i denote disposable monetary income, E_i residential energy expenditure, and s_i the modified OECD equivalence scale. Equivalised disposable income is

$$y_i = \frac{Y_i}{s_i} (1)$$

and equivalised income after energy expenditure is

$$y_i^E = \frac{Y_i - E_i}{s_i} \quad (2)$$

We define the energy-cost Gini gap as

$$\Delta G_E = G(y^E) - G(y) \ (3)$$

A positive value means that deducting household energy expenditure increases income inequality. The measure, therefore, captures the distributional effect of energy costs in a single statistic. We report the percentage-point gap in the Gini coefficient.

The construction follows the same pre-/post-deduction logic used to measure the redistributive effect of taxes and transfers (Causa & Hermansen, 2020) and differences between income before and after housing costs (Jenkins, 2024). Here, the deduction is observed in residential energy expenditure.

All Gini coefficients are calculated using survey weights. Confidence intervals for the Gini gap are obtained via bootstrap resampling that preserves the HBS survey structure; we use 300 replications and report 95th percentile intervals. The weighted Gini estimator and inference procedure are described in Appendix X.

3.2. Distribution of household energy burdens

The Gini gap measures how energy expenditure changes the income distribution. It does not show how unevenly energy costs are distributed relative to household resources.

We define the household energy burden as

$$b_i = \frac{E_i}{Y_i} (4)$$

We summarise its distribution using two statistics. The weighted mean burden,

$$\bar{b} = \frac{\sum_i w_i b_i}{\sum_i w_i} (5)$$

captures the average level of household exposure. The Gini index of the household energy burden,

$G_b = G(b)$ (6)

captures the dispersion of that exposure across households.

The distinction is important. Two countries can have similar average energy burdens but very different distributions of those burdens. More importantly for our framework, a country can have a large energy-cost Gini gap without having a particularly unequal burden distribution, and vice versa. The two measures, therefore, capture different dimensions of vulnerability.

For the burden measures, we restrict the sample to households with positive reported energy expenditure and $b_i \leq 1$. Zero energy expenditure is rare in the HBS and is likely to reflect reporting or imputation issues. Burdens above one generally arise from very low or temporarily negative reported incomes, particularly among self-employed households. Results under alternative restrictions are reported in Appendix X.

3.3. Decomposition by energy carrier

Residential energy expenditure consists of five carriers: electricity, gas, liquid fuels, solid fuels, and district heat. Their distributional effects can differ because their expenditure shares and their incidence across the income distribution differ.

Let E_{ik} denote household i's expenditure on carrier k, with

$E_i = \sum_k E_{ik}$ (7)

For each carrier, we define a single-carrier Gini gap as

$\Delta G_k = G\left(\frac{Y_i - E_{ik}}{s_i}\right) - G\left(\frac{Y_i}{s_i}\right)$ (8)

This measures how much inequality would change if expenditure on that carrier alone were deducted from household income. A positive value indicates that the carrier is distributed regressively: its deduction increases income inequality.

Because the Gini coefficient is sensitive to reranking, the five carrier-specific gaps do not add exactly to the total energy-cost Gini gap. We write

$\Delta G_E = \sum_k \Delta G_k + R$ (9)

where R captures the residual arising from cross-carrier reranking. Empirically, this residual is negligible in our sample, below 0.003 percentage points for every country-year, so the carrier-specific gaps provide a close additive approximation to the total. We report the residual alongside the decomposition.

To understand why a carrier has a large or small distributional effect, we further separate its contribution into two components: its expenditure share and its distribution across the income ranking. The resulting decomposition distinguishes carriers that matter because households spend heavily on them from carriers that matter because their costs fall disproportionately on lower-income households. The formal derivation is provided in Appendix X.

Finally, we use the carrier decomposition to measure exposure to ETS2. Gas, liquid fuels and solid fuels are directly covered by the new emissions trading system for buildings and road transport. We define the ETS2 coverage share as

$S_{\text{ETS2}} = \frac{\Delta G_{\text{gas}} + \Delta G_{\text{liquid}} + \Delta G_{\text{solid}}}{\sum_k \Delta G_k}$ (10)

The measure gives the share of the approximately additive energy-cost Gini gap attributable to carriers directly covered by ETS2. A high value means that the carriers responsible for a large part of the country's existing energy-related inequality fall within the ETS2 perimeter.

The coverage share should not be interpreted as the causal effect of ETS2 on inequality. That effect will depend on carbon price pass-through, behavioural responses, and compensation through the Social Climate Fund. The measure captures exposure only: the extent to which existing energy-related inequality is associated with fuels that ETS2 will price.

4. Results

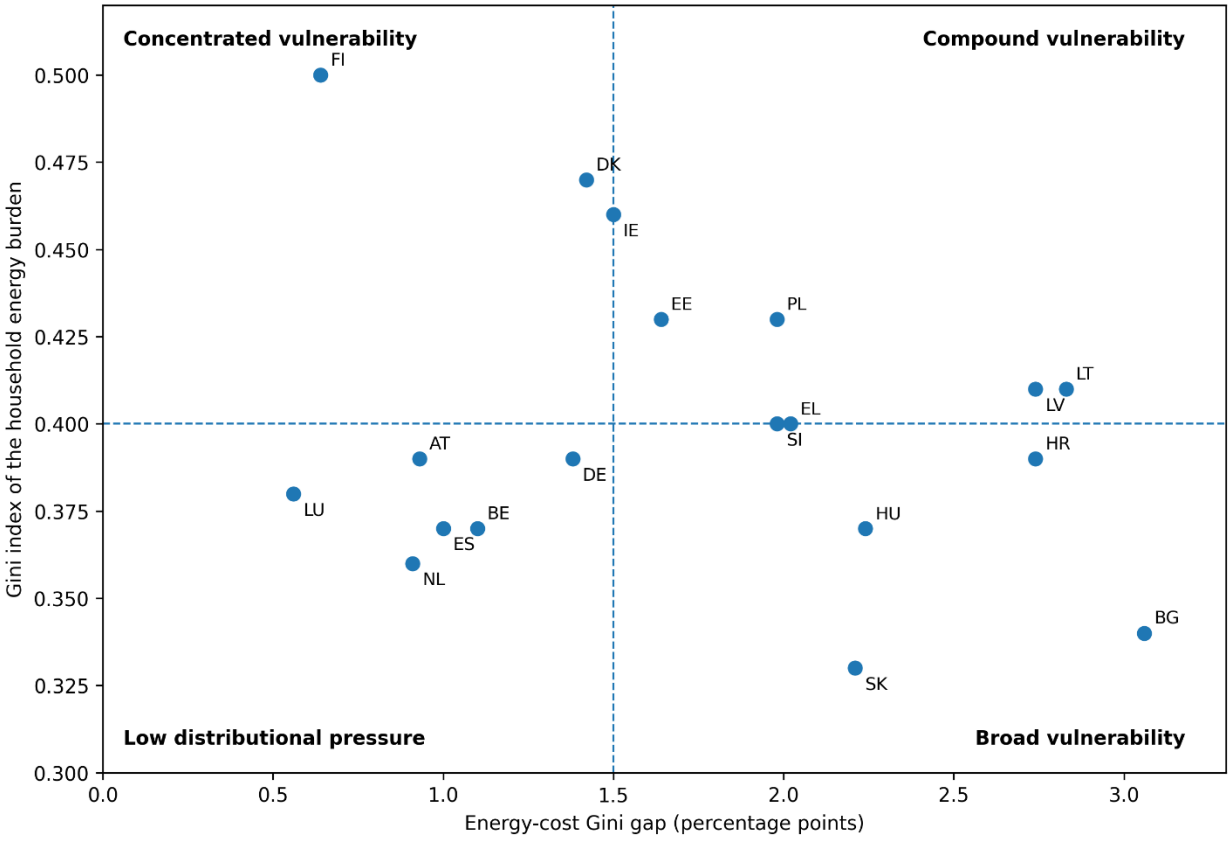
We organise the results in three subsections. Section 4.1 presents the energy-cost Gini gap and the Gini index of the household energy burden jointly, and uses their combination to construct the four-part typology. Section 4.2 decomposes the energy-cost Gini gap by fuel carrier. Section 4.3 examines exposure to ETS2 by reporting both the absolute contribution of ETS2-covered fuels to the Gini gap and their share of the carrier-attributed total.

4.1. The distributional structure of household energy costs

Household energy expenditure increases income inequality in every country in the 2020 sample, but the magnitude varies substantially across the EU. The energy-cost Gini gap ranges from 0.6 percentage points in Luxembourg to 3.1 points in Bulgaria, with a median of 1.5 points. The largest gaps are concentrated in Central and Eastern Europe: Bulgaria is followed by Lithuania (2.8 pp), Croatia and Latvia (2.7 pp), Hungary and Slovakia (2.2 pp), and Poland (2.0 pp). Greece also reaches 2.0 points. At the other end of the distribution, Luxembourg and Finland record gaps of around 0.6 points, while Austria and the Netherlands remain below 1 point.

The Gini index of the household energy burden produces a markedly different ranking. Finland has the highest Gini burden in the 2020 sample (0.50), despite having one of the smallest energy-cost Gini gaps. Denmark (0.47) and Ireland (0.46) similarly combine relatively dispersed household burdens with moderate aggregate inequality effects. Bulgaria and Slovakia show the opposite pattern: energy expenditure substantially widens the income distribution, but household energy burdens are comparatively less dispersed (Figure 1). The cross-country correlation is weak, indicating that the two statistics capture distinct dimensions of exposure.

Figure 1. Energy-cost Gini gap and inequality of household energy burdens, EU member states, 2020



Notes: The horizontal axis reports the energy-cost Gini gap, defined as the difference between the Gini coefficient of equivalised income before and after deducting residential energy expenditure, expressed in percentage points. The vertical axis reports the Gini coefficient of the household energy burden ratio. Dashed lines indicate the classification thresholds of 1.5 percentage points and 0.40, approximately the respective sample medians. Country labels use ISO-2 codes.

Source: Authors' calculations based on Eurostat Household Budget Survey microdata, 2020.

The joint distribution identifies four configurations. Broad vulnerability combines a large inequality effect with relatively low dispersion of household burdens. Bulgaria, Croatia, Hungary and Slovakia fall into this group. Here, energy costs reduce household resources across a relatively broad part of the population rather than being concentrated mainly among a small group of extreme cases.

Compound vulnerability combines a large energy-cost Gini gap with a high burden Gini. Lithuania, Latvia, Greece, Poland, Slovenia, Estonia and Ireland fall into this quadrant. These countries face both a sizeable aggregate distributional effect and substantial heterogeneity in household exposure.

Concentrated vulnerability describes countries where the aggregate inequality effect is smaller, but household burdens are highly dispersed. Finland and Denmark fall into this group. Energy expenditure has a relatively limited effect on the overall income distribution, but some households face burdens substantially above those experienced by the rest of the population.

Finally, low distributional pressure characterises Germany, Belgium, Spain, Austria, the Netherlands and Luxembourg, where both measures lie below the respective thresholds.

These categories describe the distribution of observed energy expenditure, not the prevalence of energy poverty. Spain illustrates the distinction. It performs poorly on several consensual energy-poverty indicators, including the inability to keep the home adequately warm and utility bill arrears, yet falls into the low-distributional-pressure quadrant in our framework. The two findings are not contradictory. Energy-poverty indicators identify households experiencing inadequate energy services or difficulty paying bills; our measures capture how strongly actual energy expenditure widens the income distribution and how unevenly that expenditure is distributed relative to household income. They therefore describe different, complementary dimensions of vulnerability.

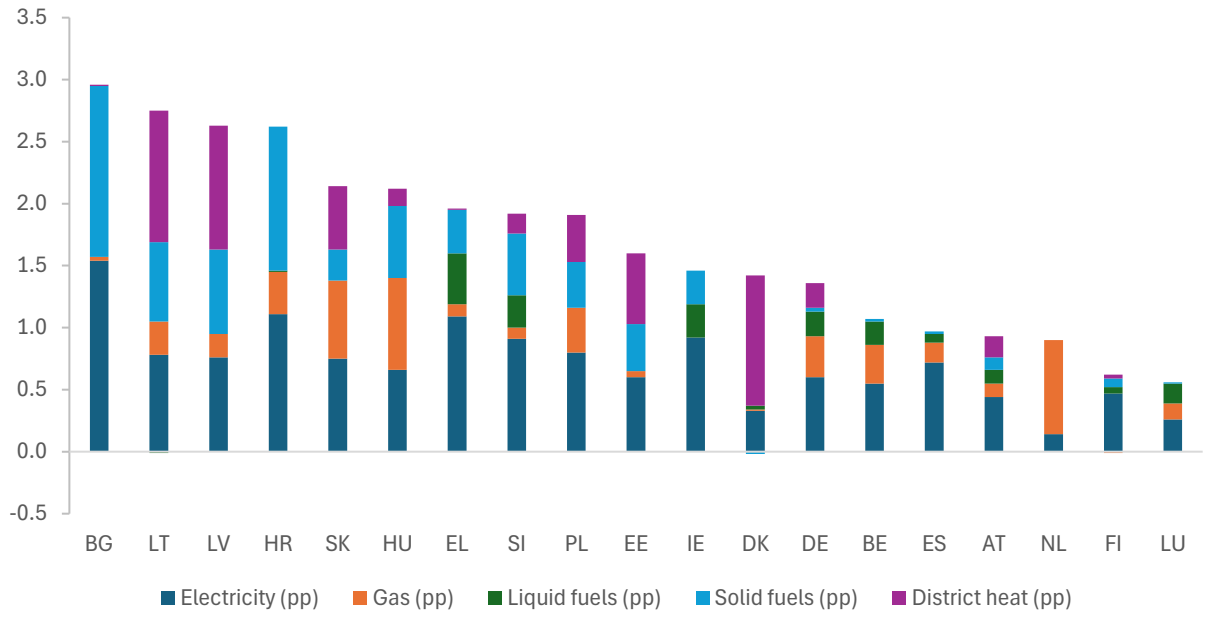
The 2015 results show a broadly similar geographical pattern. Energy-cost Gini gaps are again the largest in Central and Eastern Europe, while the burden Gini produces a different country ranking. Full country results for both waves and changes between 2015 and 2020 are reported in Appendix B.

4.2. Fuel-carrier decomposition

The aggregate effect of energy expenditure masks substantial differences between energy carriers. Figure 2 decomposes the energy-cost Gini gap into electricity, gas, liquid fuels, solid fuels and district heat.

Electricity contributes positively to the gap in every country in the 2020 sample, but the composition of the total effect varies considerably. Solid fuels account for almost half of the gap in Bulgaria and Croatia. District heat is particularly important in Lithuania, Latvia, Estonia and Denmark, while gas dominates in the Netherlands. Liquid fuels make a sizeable contribution mainly in Greece.

Figure 2. Fuel-carrier decomposition of the energy-cost Gini gap, 2020



Notes: Bars report the contribution of electricity, gas, liquid fuels, solid fuels and district heat to the energy-cost Gini gap. Carrier contributions are calculated by deducting expenditure on each carrier separately from household income

and recomputing the Gini coefficient. Their sum closely approximates the total gap; the cross-carrier reranking residual is below 0.003 percentage points for every country. Countries are ordered by the total energy-cost Gini gap.

Source: Authors' calculations based on Eurostat Household Budget Survey microdata, 2020.

The importance of a carrier reflects both its share of household expenditure and its location in the income distribution. Solid fuels stand out: where they account for a non-negligible share of household expenditure, their contribution to inequality relative to their budget share is consistently high. Gas and electricity show greater cross-country variation, reflecting differences in heating systems and the socioeconomic composition of households that use each carrier.

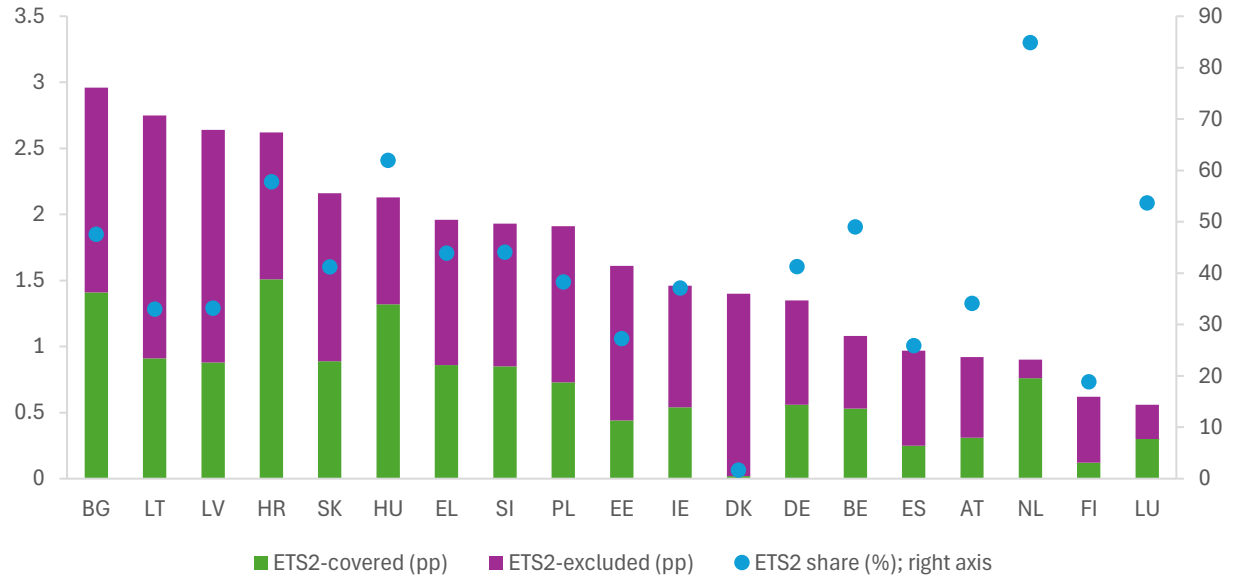
4.3. Exposure to ETS2

The carrier decomposition also shows how closely existing energy-related inequality overlaps with the fuels directly priced by ETS2. We summarise this overlap in two ways. The ETS2-exposed Gini contribution is the combined contribution of gas, liquid fuels and solid fuels to the energy-cost Gini gap. The ETS2 coverage share expresses this contribution as a proportion of the total carrier-attributed gap.

The distinction matters because a high coverage share does not necessarily imply a large distributional exposure to ETS2. A country may have a high share simply because its overall energy-cost Gini gap is small. Conversely, a country with a lower coverage share but a much larger overall gap may have a larger absolute inequality contribution associated with ETS2-covered fuels.

Figure 3 shows both dimensions. The total height of each bar represents the carrier-attributed energy-cost Gini gap, while the ETS2-covered component identifies the absolute contribution associated with gas, liquid fuels and solid fuels. The corresponding coverage share is reported for each country.

Figure 3. Share of the energy-cost Gini gap attributable to ETS2-covered fuels, 2020



Notes: The ETS2-covered component comprises contributions from gas, liquid fuels, and solid fuels. The non-ETS2 component comprises electricity and district heat. Electricity is covered upstream by ETS1 rather than ETS2; district heat is not directly included in ETS2, although its price may be affected through the fuels used in heat generation. Countries are ordered by the total energy-cost Gini gap.

Source: Authors' calculations based on Eurostat Household Budget Survey microdata, 2020

The results reveal substantial cross-country heterogeneity. The ETS2 coverage share ranges from 2 per cent in Denmark to 85 per cent in the Netherlands. In Denmark, almost all of the contribution to inequality comes from electricity and district heat, so the overlap between existing energy-related inequality and the fuels directly priced by ETS2 is minimal. In the Netherlands, by contrast, gas accounts for most of the energy-cost Gini gap.

Among countries with large overall Gini gaps, the degree of ETS2 exposure also varies considerably. Coverage is around one-third in Lithuania and Latvia and 27 per cent in Estonia, compared with 48 per cent in Bulgaria, 58 per cent in Croatia and 62 per cent in Hungary. The same overall distributional burden can therefore arise from very different combinations of fuels inside and outside the ETS2 perimeter.

These results should not be interpreted as estimates of the distributional effect of ETS2. The eventual effect of carbon pricing will depend on price pass-through, behavioural responses, fuel switching and compensation through the Social Climate Fund. The measures instead describe pre-existing exposure: the extent to which current energy-related inequality is associated with fuels that ETS2 will directly price.

5. Discussion

This section discusses the broader implications of the distributional patterns identified in the analysis. We first consider what the distinction between broad, concentrated and compound vulnerability implies for how household energy inequality should be interpreted and for the choice between temporary compensation and structural support. We then examine how these pre-existing patterns of vulnerability interact with the introduction of ETS2, focusing on the extent to which carbon pricing operates through energy carriers that already contribute to inequality in household resources.

5.1. Different structures of vulnerability and the choice of policy instruments

The energy-cost Gini gap and the Gini index of household energy burdens evaluate inequality in different spaces. The first asks how much meeting household energy costs changes the distribution of economic resources. The second asks how unequally the financial burden of energy is distributed across households. In this sense, the distinction reflects (Sen, 1992) broader observation that assessments of inequality depend on the space in which equality and inequality are evaluated. Similarity in disposable income does not imply similarity in resources remaining after essential expenditure, just as similarity in average energy costs does not imply similarity in the burdens households bear to secure energy services. The four-quadrant typology can therefore be read as identifying different forms of distributive vulnerability.

Then, the scope of temporary compensation may need to be wider than a conventional energy-poverty threshold would suggest. Around the introduction of ETS2, income support can protect households against an immediate deterioration in disposable resources, while investments in building efficiency and heating systems can reduce underlying costs across a broader segment of the housing stock. Eligibility rules that are too narrow may otherwise leave households exposed even when they do not meet established energy-poverty thresholds.

Concentrated vulnerability presents a different issue. Here, the overall effect of energy expenditure on income inequality is relatively limited, but burden ratios differ substantially between households. This is consistent with vulnerability approaches to energy poverty, which emphasise that the difficulty of securing adequate energy services is shaped by combinations of household resources, dwelling efficiency, heating technology, tenure, and energy needs rather than income alone (Bouzarovski, 2014). The relevant inequality can therefore arise between households with similar incomes but very different housing conditions or technological constraints.

A capabilities interpretation makes this distinction particularly clear (Day et al., 2016). The same monetary resources can translate into very different effective living conditions. A household in an inefficient dwelling or dependent on an expensive heating technology may need to spend considerably more than another household to obtain the same level of warmth. Observed expenditure consequently reflects both economic resources and the circumstances under which households convert those resources into energy services.

For policy, concentrated vulnerability strengthens the case for interventions that can identify these circumstances. Rather than compensating a broad population for higher expenditure, support can place greater weight on the households, dwellings and heating systems responsible for the upper tail of the burden distribution. Renovation, heating-system replacement and other structural measures are particularly relevant because they change the conditions that generate high burdens rather than compensating households after those burdens have arisen.

Compound vulnerability combines both problems. Energy expenditure substantially worsens the overall distribution of household resources, and burden ratios are also highly dispersed. This creates the strongest case for combining temporary income support with structural intervention . The distinction is partly temporal. Transfers can operate immediately, whereas renovation and heating-system replacement take time to implement and generate savings (Croon et al., 2024). The policy problem is therefore not simply whether to compensate households or invest in structural change, but how to sequence the two so that households are protected while their capacity to adapt is being increased.

The typology should nevertheless not be interpreted as a complete assessment of energy justice. Energy-justice scholarship distinguishes the distribution of costs and benefits from questions of recognition and participation in decision-making (Jenkins, 2019). The indicators developed here deliberately address the distributive dimension. They cannot determine whether particular social groups are adequately recognised, whether households have meaningful influence over policy choices, or whether a particular distribution should ultimately be regarded as fair. Nor should the four quadrants be interpreted as mechanical prescriptions. They operate at the national level, while vulnerability varies within countries across regions, settlement types, dwelling quality, tenure and heating technologies. Their purpose is to identify the distributional structure that Social Climate Plans should investigate further. The policy mix then depends on the mechanisms producing that structure and on the administrative capacity to reach the relevant households.

5.2. Carbon pricing, inherited energy systems and the scope of compensation

The fuel decomposition adds another dimension to this distinction. ETS2 changes the price of fossil energy within housing and energy systems that already differ substantially across and within countries. Whether a household heats with gas, coal, liquid fuels, electricity, or district heat reflects current consumption choices, the dwelling it occupies, available infrastructure, previous

investment decisions, and the technologies embedded in the building. Household exposure to carbon pricing is therefore partly shaped by circumstances that precede ETS2.

This interpretation is consistent with the view of domestic energy deprivation as a product of socio-technical pathways through which households obtain energy services (Sareen et al., 2020). It also means that households differ in their ability to respond to it. Some can reduce fossil fuel consumption, finance renovations, or replace their heating technology relatively easily. Others face capital constraints, tenancy arrangements, building characteristics or infrastructural conditions that substantially restrict substitution. The same price signal can therefore confront households with very different sets of feasible responses.

The ETS2 coverage is an indicator of alignment and does not substitute for an estimate of the future distributional effect of carbon pricing. Therefore, carbon pricing can intersect with existing inequality. A household may already face a high energy burden because it occupies an inefficient dwelling or is locked into a particular heating system (Belaïd, 2018). ETS2 can then increase the price associated with that pre-existing configuration. The resulting distributional challenge is therefore whether households should be compensated for a new carbon price, and whether inherited differences in housing and technology limit their ability to adjust to it.

The distinction between temporary compensation and structural investment follows directly. Transfers alter the distribution of purchasing power after the price increase has occurred. Renovation and heating-system investments alter the conditions that determine households' future exposure to that price. The two instruments therefore perform different functions: one protects current household resources, while the other changes the amount or type of energy households need to purchase in the future. This is also consistent with the broader carbon-pricing literature, which shows that the use of carbon-pricing revenues is integral to both the distributional design and the public acceptability of carbon-pricing systems (Klenert et al., 2018).

This does not imply that structural investment is intrinsically preferable to transfers. A household cannot immediately respond to a carbon price simply because renovation would eventually reduce its energy demand. Investments require time, financing, administrative capacity and often coordination with landlords, housing associations or other owners. Temporary transfers can therefore protect households during a period in which the underlying source of exposure cannot yet be changed (Antosiewicz & Sokołowski, 2025). In countries with substantial ETS2 exposure, the relevant policy problem is consequently one of both protection during adjustment and long-run decarbonisation.

The distinction between the ETS2-covered and uncovered components of the Gini gap also clarifies the institutional role of the Social Climate Fund. A large ETS2-exposed component indicates that the new carbon-pricing system operates through energy carriers already contributing substantially to inequality in household resources (Tamasiga et al., 2024). In such cases, compensatory and structural measures financed through the SCF are closely connected to the distributional exposure associated with the instrument that motivates the Fund.

A large uncovered component identifies a different problem. Substantial energy-related inequality may arise from electricity, district heat, or other expenditures outside the direct ETS2 perimeter. Such vulnerability remains important for energy and social policy, but it is not generated by the fuels directly priced under ETS2. It therefore cannot, by itself, justify a larger SCF allocation without extending the Fund’s logic beyond its current mandate. The decomposition consequently

helps separate the broader objective of reducing energy inequality from the narrower task of managing the social consequences associated with ETS2.

For SCF design, the coverage share alone is therefore insufficient. The relevant exposure depends jointly on the magnitude of the overall energy-cost Gini gap and the part attributable to ETS2-covered fuels. The ETS2-exposed Gini contribution captures this absolute component. A country with a high coverage share but a small overall Gini gap does not necessarily face greater distributional exposure than a country in which ETS2 covers a smaller proportion of a much larger inequality effect. Both the relative alignment and the absolute magnitude of existing vulnerability matter when deciding how strongly Social Climate Plans should emphasise compensation, structural investment and complementary national policies.

6. Conclusion

The Social Climate Fund establishes an unprecedented EU mechanism to address the social consequences of carbon pricing in buildings and road transport. Yet its implementation requires information that existing energy-poverty indicators were not designed to provide: how strongly household energy expenditure widens the income distribution, whether high burdens are broadly shared or concentrated among particular households, and how closely these distributional patterns overlap with the fuels priced by ETS2.

This paper develops two complementary measures for answering these questions. The energy-cost Gini gap measures the increase in income inequality after deducting residential energy expenditure. The Gini index of the household energy burden measures how unevenly expenditure-to-income ratios are distributed across households. These allow measurement of the ETS2 coverage share, which is the proportion of the carrier-attributed inequality effect attributable to fuels directly covered by ETS2. None requires households to be classified above or below an energy-poverty threshold.

Applied to the Eurostat Household Budget Survey, the energy-cost Gini gap ranges from 0.6 percentage points in Luxembourg to 3.1 points in Bulgaria in 2020. The largest effects are concentrated in Central and Eastern Europe. The burden Gini produces a markedly different country ranking, showing that the aggregate inequality effect of energy expenditure and the concentration of household burdens are distinct dimensions of vulnerability. Their joint distribution identifies four configurations—broad vulnerability, compound vulnerability, concentrated vulnerability, and low distributional pressure—with different implications for the balance between temporary income support and structural investment.

The carrier decomposition adds a further dimension. Solid fuels contribute a particularly large share of inequality relative to their expenditure share, while the composition of the overall effect differs sharply across countries. The share attributable to ETS2-covered fuels ranges from 2 per cent in Denmark to 85 per cent in the Netherlands. ETS2 therefore intersects with very different pre-existing patterns of energy-related inequality across member states. The coverage share does not predict the distributional effects of carbon pricing; rather, it measures how closely the fuels affected by ETS2 align with those currently associated with energy-related inequality.

The analysis has several limitations. The 2020 HBS overlaps with the COVID-19 pandemic and should not be interpreted as a normal-period equilibrium. More fundamentally, the framework is static: it measures the distribution of observed expenditure and does not model price pass-through, behavioural responses or investment induced by carbon pricing. Observed expenditure may also

understate need where households ration energy, while monetary income does not capture self-provided energy such as collected biomass. The measures should therefore be interpreted as distributional summaries of observed household budgets, not estimates of the welfare cost of inadequate energy services.

Two extensions are particularly natural. First, the same framework can be applied to transport fuels, allowing the residential and road-transport components of ETS2 exposure to be assessed within a common distributional framework. Second, repeated HBS waves can show how the Gini gap, burden distribution, and carrier composition evolve as incomes rise, buildings are renovated, and heating is electrified. This is particularly important for the Social Climate Fund, whose implementation extends to 2032, while household energy systems are changing rapidly.

The broader contribution is methodological. Energy-poverty measurement has developed increasingly sophisticated tools for identifying who is vulnerable and how severely. The measures proposed here address a different question: how does household energy expenditure affect the distribution of economic resources as a whole? The energy-cost Gini gap and burden Gini provide threshold-free, comparable summaries of the scale and structure of that effect. They do not replace existing energy-poverty indicators. They add a distributional perspective that those indicators lack by design.

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Appendix A. Data and estimation details

A1. Variables

The analysis uses four sets of variables from the Eurostat Household Budget Survey (HBS) household files.

Income. Household disposable income is measured using net monetary income (EUR_HH095), defined as monetary income from all sources net of income taxes and social contributions. The measure excludes income in kind and imputed rent.

Equivalence scale. Household income is equivalised using the modified OECD scale (HB062), which assigns a weight of 1.0 to the first adult, 0.5 to each additional person aged 14 or over, and 0.3 to each child under 14.

Residential energy expenditure. Total residential energy expenditure is the sum of five COICOP categories: electricity (EUR_HE0451), gas (EUR_HE0452), liquid fuels (EUR_HE0453), solid fuels (EUR_HE0454), and heat energy, including district heating (EUR_HE0455). Transport fuels are excluded because the analysis is restricted to residential energy expenditure.

Survey weights. All statistics use the household survey weight HA10.

A2. Analytical samples

We require positive net monetary income, a valid equivalence scale and a positive non-missing survey weight. Households are also required to have positive income after residential energy expenditure is deducted. Observations with missing information needed to construct the relevant measure are excluded.

For the household-energy-burden statistics, we additionally require positive recorded residential energy expenditure. Because households with non-positive post-energy income are excluded, the resulting burden ratio lies below one.

The 2015 analytical sample contains 23 EU member states: Belgium, Bulgaria, Cyprus, Czechia, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Croatia, Hungary, Ireland, Lithuania, Luxembourg, Latvia, the Netherlands, Poland, Portugal, Romania, Slovakia and Sweden.

The 2020 analytical sample contains 19 member states: Austria, Belgium, Bulgaria, Germany, Denmark, Estonia, Greece, Spain, Finland, Croatia, Hungary, Ireland, Lithuania, Luxembourg, Latvia, the Netherlands, Poland, Slovenia and Slovakia. Country-level availability and exclusions are discussed in Section 2.2.

Seventeen countries are observed in both waves and form the balanced sample used for the 2015–2020 comparison: Belgium, Bulgaria, Germany, Denmark, Estonia, Greece, Spain, Finland, Croatia, Hungary, Ireland, Lithuania, Luxembourg, Latvia, the Netherlands, Poland and Slovakia.

A3. Distributional measures and inference

Let Y_i denote net monetary household income, E_i residential energy expenditure, s_i the modified OECD equivalence scale and w_i the survey weight. Equivalised disposable income and equivalised income after energy expenditure are

$$y_i = \frac{Y_i}{s_i}$$

and

$$y_i^E = \frac{Y_i - E_i}{s_i}.$$

For a variable x_i, with weighted mean

$$\mu_x = \frac{\sum_i w_i\, x_i}{\sum_i w_i},$$

we calculate the weighted Gini coefficient as

$$G(x) = \frac{\sum_i \sum_j w_i w_j \left| x_i - x_j \right|}{2\mu_x (\sum_i w_i)^2}.$$

The energy-cost Gini gap is

$$\Delta G_E = G(y^E) - G(y).$$

Positive values indicate that deducting residential energy expenditure increases measured income inequality. Results are reported in Gini percentage points.

The household energy burden is defined as

$$b_i = \frac{E_i}{Y_i}.$$

Its weighted mean is

$$\bar{b} = \frac{\sum_i w_i\, b_i}{\sum_i w_i},$$

and the Gini index of the household energy burden is

$$G_b = G(b).$$

The two measures capture different features of the distribution. ΔG_E describes the change in the income distribution after energy expenditure is deducted, whereas G_b describes dispersion in expenditure-to-income ratios across households.

Confidence intervals for the energy-cost Gini gap are obtained using 300 non-parametric bootstrap replications within each country-year sample. Survey weights are retained in each replication. The reported 95 per cent intervals correspond to the 2.5th and 97.5th percentiles of the bootstrap distribution.

A4. Fuel-carrier decomposition and ETS2 exposure

Residential energy expenditure is decomposed into five carriers,

$$E_i = \sum_k E_{ik},$$

where k denotes electricity, gas, liquid fuels, solid fuels or district heat.

For each carrier, we calculate a single-carrier Gini contribution,

$$\Delta G_k = G\left(\frac{Y_i - E_{ik}}{s_i}\right) - G\left(\frac{Y_i}{s_i}\right).$$

Because deducting several expenditure components can change household rankings, the individual carrier contributions are not exactly additive:

$$\Delta G_E = \sum_k \Delta\, G_k + R,$$

where R is a reranking residual. Empirically, the residual is below 0.003 Gini percentage points in every country-year observation.

For ETS2, we define the ETS2-exposed Gini contribution as

$$\Delta G_{\text{ETS2}} = \Delta G_{\text{gas}} + \Delta G_{\text{liquid}} + \Delta G_{\text{solid}},$$

and the contribution associated with carriers outside ETS2 as

$$\Delta G_{\text{non-ETS2}} = \Delta G_{\text{electricity}} + \Delta G_{\text{district heat}}.$$

The ETS2 coverage share is

$$S_{\text{ETS2}} = \frac{\Delta G_{\text{ETS2}}}{\sum_k \Delta\, G_k}.$$

The measure describes the correspondence between the current distributional contribution of residential energy expenditure and the fuels that ETS2 directly covers. It is not an estimate of the eventual distributional effect of carbon pricing.

A5. Descriptive statistics

Table A1 reports the analytical sample size and the principal income and expenditure variables by country and year. Mean equivalised income varies substantially across the sample, as does the share of household income devoted to residential energy. The mean energy share ranges from 2.9 per cent in Luxembourg in 2020 to approximately 14 per cent in Romania in 2015.

Table A1. Descriptive statistics by country and year

Table 1. Summary statistics by country and year.

Country	Year	Households (N)	Mean equiv. income (EUR)	Mean energy expend. (EUR)	Mean energy share (%)	Mean equiv. scale	Median equiv. income (EUR)
BE	2015	6,128	23,249	1,917	6.5	1.6	20,933
BG	2015	2,959	3,207	582	13.2	1.6	2,852
CY	2015	2,874	16,033	1,169	5.2	1.8	13,259
CZ	2015	2,927	8,161	1,108	10.4	1.5	7476
DE	2015	52,282	22,794	1,385	5.4	1.5	19,528
DK	2015	2,202	37,227	2,987	7.1	1.5	32,420
EE	2015	3,391	8,069	912	9.9	1.6	6,480
EL	2015	6,001	10,000	1,216	10.1	1.7	8,400

ES	2015	21,931	13,770	1,116	6.3	1.7	12,000
FI	2015	3,664	26,014	1,284	3.8	1.5	23,271
FR	2015	16,680	24,112	1,331	4.8	1.5	20,539
HR	2015	2,020	6,076	1,121	13.4	1.9	5,278
HU	2015	7,143	5,449	949	13.7	1.6	4,762
IE	2015	6,809	26,895	2,003	6.0	1.8	23,243
LT	2015	3,439	4,948	819	13.9	1.5	4,154
LU	2015	3,165	40,360	2,201	4.3	1.6	34,742
LV	2015	3,841	5,496	875	12.9	1.6	4,570
NL	2015	14,372	24,539	1,600	5.8	1.5	21,476
PL	2015	36,584	6,201	987	11.2	1.8	5,349
PT	2015	11,346	10,857	1,247	9.8	1.7	8,418
RO	2015	30,461	2,996	597	14.0	1.8	2,637
SE	2015	2,858	27,186	1,197	3.3	1.5	25,007
SK	2015	4,780	7,907	1,461	12.1	1.9	7,259
AT	2020	7,135	29,468	1,591	4.6	1.5	26,827
BE	2020	6,094	24,092	1,600	5.3	1.6	22,246
BG	2020	2,948	4,115	664	13.0	1.5	3,508
DE	2020	51,528	25,635	1,781	6.2	1.4	22,345
DK	2020	2,228	39,055	2,675	6.2	1.5	34,436
EE	2020	5,016	11,624	841	6.5	1.5	9,857
EL	2020	6,156	10,568	1,274	10.0	1.7	9,600
ES	2020	19,032	16,132	1,157	5.5	1.7	14,388
FI	2020	3,135	27,552	1,373	4.0	1.4	24,045
HR	2020	1,801	7,302	1,146	11.9	1.8	6,523
HU	2020	5,417	7,315	950	10.5	1.6	6,514

IE	2020	1,729	32,770	2,412	6.0	1.8	28,794
LT	2020	4,330	8,425	976	11.5	1.4	6,882
LU	2020	1,409	48,718	1,686	2.9	1.6	43,733
LV	2020	2,640	7,490	923	11.5	1.6	6,131
NL	2020	10,354	28,363	1,540	4.8	1.5	25,214
PL	2020	32,432	8,002	927	8.8	1.8	7,083
SI	2020	3,530	13,738	1,511	8.8	1.7	12,494
SK	2020	4,629	9,931	1,485	10.1	1.9	9,309

Notes: (N) denotes the number of household records in the analytical sample. Means are calculated using household survey weights. Equivalised income is based on EUR_HH095 and the modified OECD equivalence scale. Residential energy expenditure is the sum of EUR_HE0451–EUR_HE0455.

Source: Authors' calculations based on Eurostat HBS 2015 and 2020.